



## Assessing the impact of a joint human-porcine intervention package for *Taenia solium* control: Results of a pilot study from northern Lao PDR



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### ABSTRACT

Following confirmation that a remote village of approximately 300 inhabitants in northern Lao PDR was hyperendemic for the Neglected Tropical Disease *Taenia solium*, a pilot human-porcine therapeutic control intervention was implemented between October 2013 and November 2014. Mass drug administration with a three day albendazole 400 mg protocol was offered to all eligible humans in October 2013 and March 2014. At these times, and again in October 2014, eligible village pigs received the anti-cysticercosis TSOL18 vaccination and an oral dose of oxfendazole anthelmintic at 30 mg/kg, both repeated one month later. Community and individual human taeniasis prevalences were estimated via copro-antigen ELISA of volunteered human faecal samples prior to October 2013, and again in January 2015, in order to examine the short term impact of the intervention.

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Pre and post intervention analysis demonstrated a 78.7% decrease in crude prevalence within the target area during this time, from 30.6% (95% C.I. 25.5–38.9%) to 6.5% (95% C.I. 3.4–9.5%). When results were adjusted for the sensitivity and specificity of the diagnostic assays, the intervention appeared to result in a significant ( $\chi^2 = 40.7$   $p < 0.0001$ ) reduction. A subset of 48 individuals followed throughout the study period demonstrated similar results to the community level findings, with crude pre and post intervention estimates of 22.9% (95% C.I. 10.8–35.0%) and 6.25% (95% C.I. 0–13.5%), respectively, which again suggests a significant (McNemar  $\chi^2 = 32.23$   $p < 0.0001$ ) reduction when the diagnostic parameters were accounted for.

This pilot study is the first of its kind to investigate *T. solium* control opportunities in Southeast Asia, demonstrating that treatment of both humans and pigs in a given target area with a recommended anthelmintic protocol can result in a significant decrease in human taeniasis levels over a relatively short period of time. Moreover, this study provides the first data on the impact of a combined human-porcine therapeutic intervention upon the adult parasite in the human host. This research contributes to the current requirement for evidence of successful *T. solium* control under various Neglected Tropical Disease policy narratives, although further research is required to assess the impact, feasibility and cost effectiveness of this approach on a broader scale.

### 1. Introduction

*Taenia solium* taeniasis-cysticercosis is a Neglected Tropical Disease (NTD) ranked first on the global scale of foodborne parasites of

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the Food and Agricultural Organisation of the United Nations (FAO) (FAO 2014), and is a significant cause of acquired epilepsy in developing countries (Ndimubanzi et al., 2010). The widespread disease is considered to be endemic in many parts of Latin America, Asia and Africa, with an increasing concern of case introduction in previously non-endemic countries through migration of human tapeworm carriers (Del Brutto, 2012; Gabriël et al., 2015). The growing advocacy regarding the socioeconomic impact of *T. solium* is evident by its recent prioritisation by key global health actors (Maurice, 2014; WHO, 2012, 2015a). Despite this, there remains a paucity of data currently available to the international community regarding the efficacy of current expert recommendations for control (Carabin and Traoré, 2014; WHO, 2015b).

*T. solium* follows a relatively complex transmission cycle perpetuated by poverty, free ranging pig systems, poor sanitation and the consumption of raw and undercooked pork. Humans act as both the definitive and accidental dead-end intermediate hosts of the parasite, capable of becoming infected with the adult and larval stages. Human taenia carriers harbour the adult tapeworm in the small intestine, with each tapeworm segment releasing thousands of eggs into the environment. Indiscriminate defecation, freely scavenging pigs and poor sanitation facilitate the ingestion of tapeworm eggs by pigs and humans, risking formation of the cystic larval stage in both. Cysts in the human central nervous system can result in Neurocysticercosis (NCC), manifesting clinically as epilepsy, chronic headaches, vertigo, visual disturbances and nausea amongst other symptoms (Del Brutto, 2012). Humans that ingest raw or undercooked cystic pork acquire the adult tapeworm, thus completing the life cycle.

Prior studies in Lao PDR have raised concerns about the prevalence and subsequent impact of *T. solium* in the country (Conlan et al., 2008; Okello et al., 2014; Tran et al., 2007) and the extent of disease in the Southeast Asian region more generally (Conlan et al., 2011; Dorny et al., 2004a; Willingham et al., 2010), reported to have one of the highest concentrations of free ranging pigs in the world (Willingham et al., 2010). The village intervention reported here builds on the results of a 2011 broad-based serological survey, where the highly sensitive and specific Enzyme-linked Immuno-electrotransfer Blot (EITB) strip diagnostic test (recombinant antigens rES33 and rT24, US Centers for Disease Control, Atlanta) revealed human *T. solium* seroprevalences of 46.7% (taeniasis) and 66.7% (cysticercosis) in this target village, compared to an average of 2.9% and 4.7% across the broader survey area (Okello et al., 2014). Subsequent investigation confirmed the village to have one of the highest reported prevalences of *T. solium* taeniasis in Southeast Asia to date (Okello et al., 2014).

After confirming the hyperendemic *T. solium* focus, researchers – driven by both an ethical responsibility to intervene and the call for validated *T. solium* control strategies by 2015 under the WHO NTD Roadmap (WHO, 2012) – returned to the village to undertake a multidisciplinary intervention consisting of social, economic and biomedical research in keeping with a One Health approach. Whilst models have suggested that both pigs and humans require treatment in order to quickly and sustainably impact on the parasite (Kyvsgaard et al., 2007), to date there is only a single field study that has tested this hypothesis in practice (Garcia et al., 2006), and none in Lao PDR or indeed the broader Southeast Asian context (WHO, 2015b).

## 2. Materials and methods

### 2.1. Characteristics of the study site

The study village is situated in the northernmost Lao PDR province of Phongsaly, in Mai District bordering Vietnam (Fig. 1).



Fig. 1. Village location.

Village access consists of a single dirt road of which usage is limited to the dry season that normally occurs from October to April each year. The isolated village consists of an average of 300 inhabitants from the Tai Dam ethnic group; an animistic population which regularly practises the consumption of raw pork as part of sacrificial ancestral ceremonies (Bardosh et al., 2014). Despite most households owning at least one *Moo Lat* (local breed) pig, low-input production systems predominate, resulting in high numbers of free ranging pigs. *T. solium* transmission is perpetuated by the easy access of these pigs to human faeces, given less than 20 percent of households have access to a latrine (Bardosh et al., 2014). The socioeconomic and sociocultural drivers of *T. solium* transmission in this community have been extensively discussed in a previous anthropological study by Bardosh et al. (2014). The authors believe the village dynamics observed here to be characteristic of the many small and often isolated communities of the highland areas of this region where *T. solium* has been previously reported (Conlan et al., 2008; Dorny et al., 2004a; Willingham et al., 2010), and as such provides a relevant case study for its control in the Southeast Asian context.

### 2.2. Study design

The overall goal of the study was to determine whether *T. solium* taeniasis could be controlled via anthelmintic interventions in both the human and porcine reservoirs, with control defined as the reduction in taeniasis prevalence, as measured by the coproantigen assay. Researchers hypothesised that by rapidly decreasing the number of human *T. solium* taeniasis carriers in this village in a relatively short period of time, the subsequent low levels could be sustained or further decreased through treating only the porcine host in the final round of the intervention. The ensuing biomedical intervention was designed with these objectives in mind, whilst simultaneously aiming to navigate the complex geographic and sociocultural characteristics of this village and its inhabitants. Aside from the biomedical intervention, concurrent anthropological research (Bardosh et al., 2014) and economic investigations (not reported here) were also undertaken during the two year period.

### 2.3. Implementation of the therapeutic protocol in the human and porcine populations

The human intervention consisted of two rounds of community mass drug administration (MDA) with a three day albendazole 400 mg protocol (Eskazole<sup>®</sup>, GlaxoSmithKline) as described by Steinmann et al. (2011), aiming to rapidly decrease the levels of circulating taeniasis and halt the excretion of tapeworm eggs into the environment. This protocol was chosen over alternative taeniocidal options such as niclosamide or praziquantel for a number of reasons, including its acceptance by the Lao PDR Ministry of Health (praziquantel was not permitted), its reported efficacy on co-existing soil transmitted helminths (Steinmann et al., 2011) and its palatability/ease of administration, which helped improve compliance (Bardosh et al., 2014).

During each MDA round, local government medical personnel visited all households for three consecutive days in order to administer anthelmintic tablets to consenting eligible individuals according to the project's inclusion criteria: over six years of age, not pregnant or breastfeeding, not suffering from acute illness. This protocol enabled medical staff to assess patient health after the previous day's medication in order to effectively monitor and address any adverse reactions; medical staff also stayed overnight in the village for a further two days after the final treatment for this same reason. A detailed examination of the human MDA intervention is provided by Ash et al. (2015).

The porcine intervention consisted of intramuscular vaccination with the TSOL18 anti-cysticercosis vaccine (Lightowers, 2013) and oral oxfendazole (Oxfen LV<sup>®</sup>, Virbac) at 30 mg/kg (Moreno et al., 2012), followed by a repeat treatment one month later. This protocol assumed lifetime protection from *T. solium* (Lightowers, 2013), thus permanently removing the treated pigs' role as a human disease risk in this village. Intramuscular vaccination against Classical Swine Fever (CSF) – an important porcine production-limiting transboundary animal disease (TAD) in Southeast Asia – was added to the porcine intervention 'package' to improve community compliance and increase the productivity parameters of the smallholder pig enterprise, aligning with the livelihoods and trade mandate of the broader project.

The pig intervention took place at three separate intervals, with the first two rounds occurring alongside the two human MDAs in October 2013 and March 2014, and the third and final round occurring as a single activity in October 2014. Similar to the methodology used to undertake the human intervention (Ash et al., 2015), project veterinary staff established the number of eligible pigs per household each time, defined as: over 4 weeks of age, not pregnant or lactating, not previously treated by the project and not earmarked for sale or consumption within the following month, for reasons of oxfendazole withhold (Moreno et al., 2012). Owners provided both verbal consent and assistance identifying and restraining eligible pigs, with ear tags inserted to prevent re-treatment at subsequent interventions. All treated pigs were monitored by project veterinarians at each round, with sick pigs subsequently examined and treated if necessary. Owners were also advised not to sell or consume treated pigs for at least one month after oxfendazole treatment, to avoid the consumption of meat contaminated with oxfendazole residues within the seventeen day withhold period (Moreno et al., 2012).

### 2.4. Intervention monitoring

Given the poor specificity of available porcine cysticercosis serological diagnostics in the Asian context (Dorny et al., 2004b) and the challenges of post mortem fine dissection in this environment, a monitoring framework using human taeniasis cases as a sentinel of circulating *T. solium* was implemented. All human faecal sampling

was undertaken on a volunteer basis, with project staff using the rapport built up over the four year broader ACIAR project to encourage participation in the monitoring process. The monitoring was conducted over a period of two years between January 2013 and January 2015, with pre-intervention sampling occurring between January and October 2013 prior to the first round of MDA/porcine treatment, and post-intervention sampling in January 2015, almost 12 months after the administration of the second and final human MDA. On these occasions, human samples were identified by name, age and household number and subsequently coded for the purposes of record-keeping. The process for collection and storage of faecal samples was consistent with that described by Ash et al. (2015).

During the two year study period, the average village population of 300 inhabitants was distributed across 55 permanent households. From these, 50/55 (90.9%) households had at least one member that was (i) eligible for treatment at either MDA1 and/or MDA2 and (ii) supplied researchers with a faecal sample at the pre and/or post data collection events. Due to its higher sensitivity (Praet et al., 2013), copro-antigen ELISA – which identifies products released by adult *Taenia* species (Allan and Craig 2006) – was chosen over standard microscopy techniques as the primary method for detection of *Taenia* species in these samples. All copro-antigen positive samples – identified as having a mean OD value equal to or above the calculated cut-off value of 1.7 – underwent subsequent microscopy analysis to identify whether genetic material (eggs/proglottids) was present in the sample. PCR at the 12S rRNA locus (Trachsel et al., 2007) was then performed on all microscopy-positive samples to confirm the presence of *T. solium*, as opposed to human taeniids *T. asiatica* and *T. saginata* also found in the region (Conlan et al., 2008).

### 2.5. Statistical analysis

Data were entered into Microsoft Excel and statistical analysis was carried out using the 'R' environment for statistical computing (R Development Core Team, 2005). The function 'epi.conf' in the package 'EpiR' (Stevenson et al., 2013) was used to provide confidence intervals for all prevalence and incidence estimates, accounting for the potential intra-household clustered nature of the data and the finite nature of the population under study, which remained relatively stable at approximately 300 persons throughout the study period. An estimate was made of the intra-class correlation coefficient using the ICCbare function in package ICC (Wolak et al., 2012) and design effect then estimated as  $\text{design} = \text{ICC} * (n - 1) + 1$  where  $n$  = average samples per household. The copro-antigen ELISA used for human taeniasis detection has an estimated sensitivity of 84.5% (95% C.I. 61.9–98%) and specificity of 92% (95% C.I. 90–93.8%) (Praet et al., 2013). In order to incorporate these estimated parameters into the prevalence estimates, the 'epi.prev' function in package 'epiR' was used (Stevenson et al., 2013). Population impact was estimated with all participants in each sampling point used as the denominator (ie  $n = 121$ ;  $n = 138$ ), and individual level impact was estimated using only those participants who provided two sequential faecal samples as a denominator ( $n = 48$ ). Comparison between pre and post intervention prevalence levels was made using the 'chisq.test' function in 'epiR' at the village level and using the 'mcnemar.test' function for individual level data.

### 2.6. Ethics statement

Ethical approval for this study was granted by the Lao PDR Council of Medical Science National Ethics Committee for Health Research (NECHR), approval number 013/NECHR, and Australia's Commonwealth Scientific and Industrial Research Organisation

**Table 1**  
Number of pigs and humans treated at each intervention round.

Intervention	Pig N <sub>total</sub>	Pig N <sub>eligible</sub>	Pig N <sub>treated</sub>	Cumulative pig coverage (% of total pig population)	Human N <sub>total</sub>	Human N <sub>eligible</sub>	Human N <sub>treated</sub>
October 2013	293	167	144	49.1	298	222	190
March 2014	354	93	86	65.0	293	215	185
October 2014	445	238	184	93.0	N/A	N/A	N/A

(CSIRO) Animal, Food and Health Sciences Human Research Ethics Committee (CAFHS HREC), approval number 13/10. The study was registered with the Australia New Zealand Clinical Trials Registry (ANZCTR), trial number ACTRN12614001067662. Ethical approval for the use of the experimental TSOL18 porcine vaccine and concurrent oxfendazole administration at an off-label dosage of 30 mg/kg was approved by the Australian Animal Health Laboratory Animal Research Ethics Committee (AAHL AEC, approval number 1516) which adheres to the Australian and New Zealand Council for the Care of Animals in Research and Training (ANZCCART); Lao PDR does not currently have an animal ethics committee. All human participants underwent a comprehensive consultation process, providing informed consent via signature (or thumbprint in the case of illiteracy), with a parent or guardian providing consent for children under eighteen years of age. Owners gave oral informed consent for treatment of their pigs, also assisting project veterinary staff in their identification and restraint.

### 3. Results

As described by Ash et al. (2015), 190 and 185 people were treated in MDA rounds 1 and 2, respectively (Table 1), equivalent to over 85% of the total eligible population and consistent with WHO standards for acceptable MDA coverage (WHO, 2006). Whilst no extreme adverse reactions (EARs) occurred, mild reactions including headaches, vertigo, breathing difficulties and gastrointestinal discomfort were efficiently addressed by the medical teams, helping to improve confidence and compliance of the village residents with the broader intervention.

Each porcine intervention treated over 75% of the eligible village pig population, with a total of 414 village pigs receiving lifetime protection from *T. solium* cysticercosis during the intervention period (Table 1). No serious adverse reactions were noted, however around ten pigs were assessed by veterinarians throughout the intervention period due to owner reports of inappetence following therapeutic treatment, all of which spontaneously resolved without veterinary intervention. Largely as a result of pigs planned for sale or consumption within the month being defined as ‘ineligible’ under the inclusion criteria, owner compliance with the advised month-long withhold period was generally good, with only one farmer selling his pigs before the project team returned for booster treatment one month later.

Over the course of the study, 211 unique individuals provided faecal samples for copro-Ag ELISA analysis, 48 of whom provided samples at both the 2013 (pre intervention) & 2015 (post intervention) sampling points. Of the total 211 samples provided, 121 samples were analysed in 2013 (average of 2.42 samples per household) and 138 samples were analysed in 2015 (average of 2.76 samples per household), resulting in an average of 4.2 samples collected per household over the course of the study period.

#### 3.1. Community-level pre and post intervention prevalences

Prior to the intervention, copro-Ag ELISA detected 37 cases of taeniasis (37/121) across 26 households (Fig. 2); a crude prevalence of 30.6%. Accounting for the clustered nature of the data, and the

finite population of approximately 300 people, resulted in a 95% confidence interval of 25.5–38.9%. Further adjustment for the sensitivity and specificity of the diagnostic assay resulted in the true pre-intervention prevalence estimate of 29.5% (95% C.I. 19.7–40.9%). Of the 37 positive copro-antigen ELISA samples, microscopy analysis detected taeniid eggs in 10 samples, which were subsequently submitted to PCR and sequencing. Of these, 8 matched published sequences to *T. solium* [NCBI Accession numbers AB086256 and L49444], with the remaining 2 identifying as *T. saginata*.

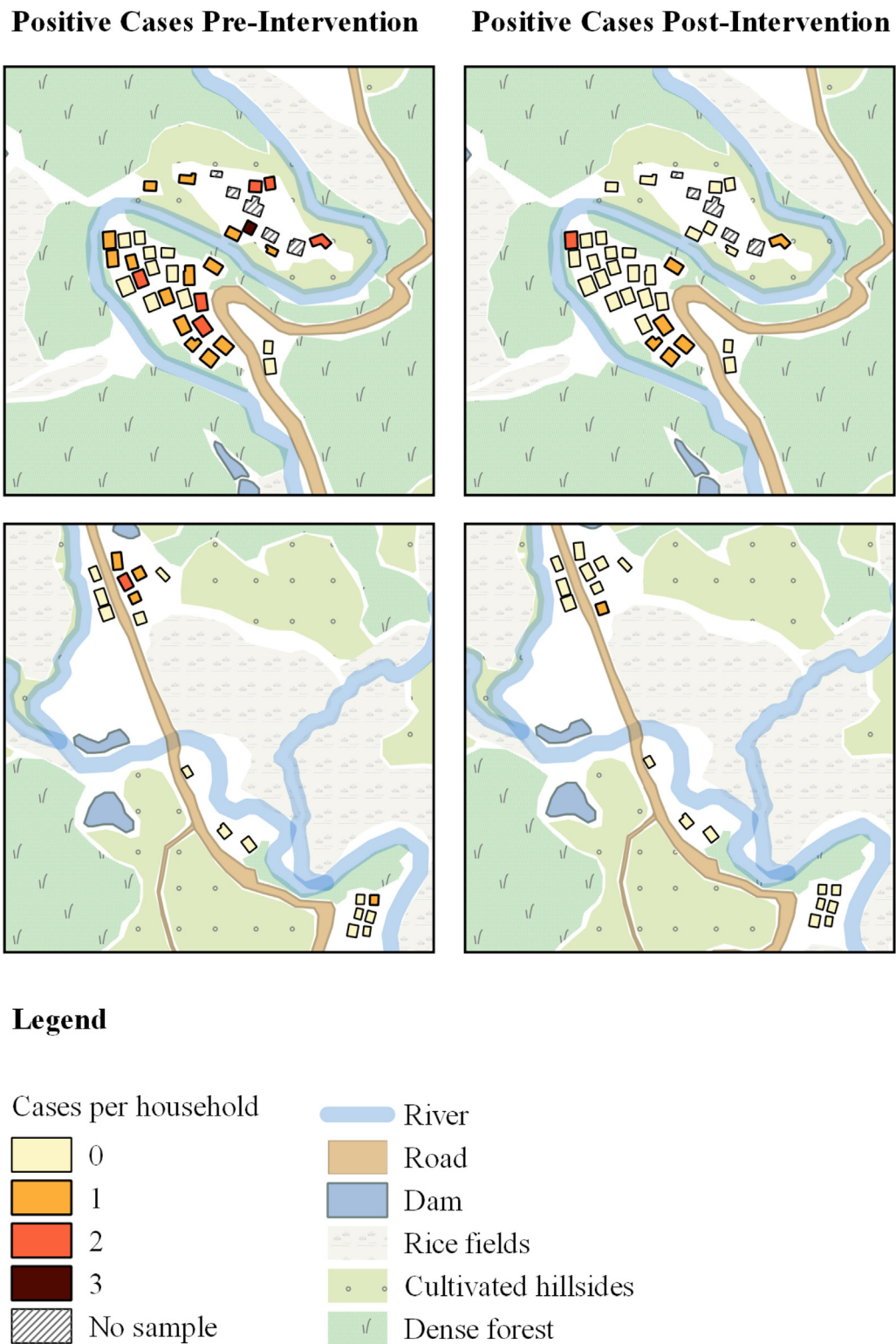
Post-intervention, copro-antigen ELISA on 138 samples volunteered in January 2015 detected 9/138 cases of taeniasis across 8 separate households (Fig. 2); a 78.7% reduction to 6.52% (95% C.I. 3.4–9.5%) accounting for clustering and a finite population. Adjusting for the diagnostic parameters, true village post-intervention prevalence was returned as 0% (95% C.I. 0–5.1%), resulting in a significant ( $\chi^2 = 40.7$   $p < 0.0001$ ) reduction of 100% from the estimated pre-intervention level. This result also demonstrated a significant ( $\chi^2 = 5.1$ ,  $p = 0.024$ ) reduction from March 2014, where copro-Ag ELISA monitoring estimated a human *Taenia* spp. prevalence of 12.5% (95% C.I. 3.6–27.4%) in the community after two rounds of MDA. Taeniid eggs were detected in only one of the post-intervention copro-antigen positive samples, determined as *T. solium* upon subsequent PCR and sequence analysis.

#### 3.2. Individual estimated prevalences

Of the 48 individuals from 31 households who provided faecal samples at both sampling points, 11 samples from 11 separate households were found to be positive by copro-Ag ELISA in 2013; a crude prevalence estimate of 22.9% (95% C.I. 10.8–35%), suggesting a true prevalence of 19.5% (95% C.I. 6.9–37.3%) when the diagnostic parameters were accounted for. In 2015, 3 samples from 3 separate households were positive by copro-Ag ELISA, a crude prevalence of 6.25% (95% C.I. 0–13.5%), suggesting a true prevalence of 0% (95% C.I. 0–11.5%) which was significantly lower than the pre-intervention prevalence (McNemar  $\chi^2 = 32.23$   $p < 0.0001$ ). None of the 11 taeniasis carriers identified in 2013 remained positive in 2015. The three new infections detected by copro-Ag ELISA at the second sampling suggest an incidence of 0.031 (95% C.I. 0.01–0.09) (3100 per 100,000 person-years). The Lao Ministry of Health ensured all new infections detected at the final sampling event in January 2015 were offered anthelmintic treatment with three doses of albendazole 400 mg.

## 4. Discussion

Evidence of successful *T. solium* control strategies is currently sparse (WHO, 2015b). Despite current expert recommendations supporting an approach combining human MDA with porcine anthelmintic treatment and vaccination (WHO, 2015a,b), and modelling suggesting this approach would have a rapid and sustained effect on *T. solium* (Kyvsgaard et al., 2007), only one published study has attempted to verify this hypothesis to date (Garcia et al., 2006). The findings reported here present the first known data on the impact of a combined human-pig intervention upon the adult *T. solium* parasite in the human host, and the first



**Fig. 2.** Positive households detected at pre and post intervention.

data on *T. solium* control in the southeast Asia region more generally, thus contributing to the current requirement for validated intervention packages by 2015 (WHO, 2012).

The joint human-porcine pilot study described here achieved a significant ( $\chi^2 = 40.7$   $p < 0.0001$ ) adjusted reduction of the village-level taeniasis infection to 0.0% (95% C.I. 0–5.1%) during the project

lifetime, consistent with findings in a subset of tracked individuals from the same village over the same period. Triangulation of the PCR results described here with previous diagnostic and anthropological research findings from the same village (Ash et al., 2015; Bardosh et al., 2014; Okello et al., 2014) concludes that *T. solium* is the dominant *Taenia* species in this population. Whilst the

hyperendemic situation described here is unusual compared to previously reported *T. solium* prevalences in Lao PDR (Okello et al., 2015), the aforementioned EITB study suggests similar ‘hotspots’ may exist in the country, necessitating the development of a methodology to identify these.

Modelling data suggests that in the absence of complementary strategies such as pig based interventions, taeniasis prevalence would soon return to pre-intervention levels after the cessation of human MDA (Kyvsgaard et al., 2007). The significant ( $\chi^2 = 5.1$ ,  $p = 0.024$ ) reduction in taeniasis prevalence detected via copro-antigen analysis in the ten months between March 2014 and January 2015 in the absence of human treatment suggests that the final porcine-only intervention may have contributed towards the continued reduction in parasite prevalence in man. We propose the data presented in this study provides an impetus for further studies to evaluate the hypothesis that an initial rapid reduction in parasite prevalence achieved by human MDA can be sustained through the addition of an intervention in the porcine species.

Despite the promising results of this intervention within the timescale of the study, there were several challenges to its design and implementation, with the first being the monitoring and evaluation of progress. Given the importance of pigs in this animistic community for ceremonial/sacrificial purposes (Bardosh et al., 2014), and the lack of adequate facilities in northern Lao PDR for large-scale fine-dissection of pigs, post-mortem analyses to identify cysts were not possible. This, in addition to the poor specificity of currently available porcine cysticercosis diagnostic assays in the Asian context (Dorny et al., 2004b), meant that circulating *T. solium* levels were measured via identification of human taeniasis carriers, which brought with it several challenges regarding compliance and the reliance on volunteer sample collection, as discussed by Ash et al. (2015). Moreover, given the cultural beliefs of this ethnic group regarding removal of blood from the human body (Bardosh et al., 2014), it was not possible to make any inference on the short term impact of the intervention on human cysticercosis levels via the currently available diagnostic assays (Deckers and Dorny, 2010). Given cases of neurocysticercosis are strongly suspected to be present in this community (Okello et al., 2014), longer term assessments of the impact of a human-porcine approach on human cysticercosis is required.

The second challenge was the achievable coverage for both the human and pig populations. Despite covering over 85% of the eligible human population at each MDA, this only related to approximately 60% of the total village population (Table 1). Around a third of the village population at the time consisted of children under six years old; hence this group made up the majority of the ‘ineligible’ individuals under the inclusion criteria. The much smaller proportion of non-consenting individuals consisted of mainly school-age children who either refused to take the drugs or whose parents did not consent to their treatment for a number of reasons, as discussed by Bardosh et al. (2014) and Ash et al. (2015). Despite parent assurances that children less than 18 years of age were culturally forbidden to eat raw pork (Bardosh et al., 2014), copro-antigen and follow-up microscopy results confirmed *T. solium* positive cases in children as young as six years old, aligning with anthropological findings to suggest that children of all ages may partake in raw pork consumption from time to time (Bardosh et al., 2014). The consideration of an appropriate treatment regime for children as young as two years old may need to be considered in areas of parasite hyperendemicity, and researchers recommend future *T. solium* control programmes in all areas work alongside existing school deworming programmes to optimise participation in the 6–18 year age group.

The fact that around 40% of village inhabitants remained potential sources of infection at any one time highlighted the requirement to concurrently address the porcine population in this village. However large numbers of pigs were also ineligible at each

intervention round as a result of pregnancy, lactation, age or pending slaughter, resulting in similar coverage challenges; less than 50% of the total number of village pigs were treated in the first intervention (October 2013). However, as the intervention progressed, large numbers of ‘present but ineligible’ pigs were able to be ‘mopped-up’ in successive rounds, resulting in over 90% of the pig population being protected by the time the intervention period ended (Table 1). Given the propensity for the consumption of pigs less than six months old (Bardosh et al., 2014), researchers conceded that some new-born pigs may well have been consumed before they had a chance for treatment under a 6-monthly protocol; the incidence of new human infections of 0.031 (95% C.I. 0.01–0.09) – corresponding to three individuals who had all received at least one full course of the albendazole MDA protocol – indicates that infected pork is still being consumed by community members. Regardless of whether these new infections were from community pigs ineligible/unavailable for treatment, or from pigs consumed outside the study area, the issue of ‘porous borders’ remains central to any control strategy, particularly in areas that experience high human and pig migration rates.

Acknowledging the small study area, the results of this pilot study nevertheless show promise that the current expert recommendations of an intersectoral approach to *T. solium* control (WHO, 2015a,b) could be effective. The next step is to build on this knowledge through the development of community-based randomised trials which further estimate the impact and cost effectiveness of the approach and importantly, its impact on human cysticercosis (Carabin and Traoré, 2014). It is also important to concurrently investigate the options for the sustainable supply and delivery of affordable therapeutics, ensuring compliance with existing socioeconomic factors and cultural dynamics in the specific contexts examined. For example, conducting a detailed evaluation of the pig production enterprise in intervention areas, including trends or traditions around pig sales and consumption, could help ensure a vaccination/oxfendazole regime that optimises the prevention of viable porcine *T. solium* infections whilst simultaneously avoiding the likelihood of consumption of meat containing oxfendazole-derived residues. Furthermore, whilst CSF vaccine and albendazole tablets are commercially available in Lao PDR, ensuring their continued accessibility to isolated communities requires further systemic improvements in human and animal health service delivery more generally. Oxfendazole produced by MCI Santé Animale (Morocco) has recently been registered for use in pigs and is now commercially available in some countries, whilst TSOL18 is in the latter stages of the registration process and anticipated to become available as a commercial product by 2016.

## 5. Conclusion

This research provides some of the first empirical evidence to support current expert recommendations suggesting that *T. solium* control is possible through the implementation of anthelmintic treatment interventions in both the human and porcine populations of a given target area. Identifying innovative ways to integrate *T. solium* control into existing disease control frameworks – such as STH control programmes (Ash et al., 2015) or alongside concurrent initiatives for CSF control in co-endemic countries – could be advantageous in terms of resource outlay compared to addressing this disease as a single entity. The next priority is to further investigate the early promising results of this pilot study through trials on larger populations, with a view to improving the feasibility and sustainability if this approach through the development of context-specific human and/or porcine intervention protocols that maximise cost effectiveness.

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