Parasites & Vectors

# The epidemiology of porcine *Taenia solium* cysticercosis in communities of the Central Highlands in Vietnam

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## Abstract

**Background:** *Taenia solium* cysticercosis, recognized as a neglected tropical disease by the WHO, is distributed mostly in developing countries of Latin America, sub-Saharan Africa and Asia. Pigs and humans act as intermediate hosts, acquiring *T. solium* cysticerci (larval stage) in their tissue, through the ingestion of *T. solium* eggs shed in the faeces of humans infected with adult tapeworms. The disease has a negative impact on rural economies due to losses in productivity arising from human disease, pork carcass condemnations and loss of market access. The aim of this study was to estimate the prevalence of *T. solium* cysticercosis in pigs in Dak Lak Province in the Central Highlands of Vietnam and to identify household level characteristics associated with *T. solium* porcine cysticercosis.
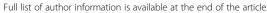
**Methods:** This was a cross-sectional study of household pigs in three districts of Dak Lak Province. A total of 408 households in six villages in three districts were visited between June and October 2015. A questionnaire was administered to the head of each household, and within each household, serum samples were collected from three pigs. Serum samples were analyzed using the recombinant T24H antigen in enzyme-linked immunoelectrotransfer blot assay and lentil lectin purified glycoprotein in EITB assay. A Bayesian, mixed-effects logistic regression model was developed to identify management factors associated with the probability of a household having at least one cysticercosis-positive pig.

**Results:** The prevalence of porcine *T. solium* cysticercosis in this study was low at 0.94 [95% confidence interval (CI) 0.51–1.68] cases per 100 pigs at risk, in agreement with other studies conducted throughout Vietnam. Scavenging of food and coprophagy were associated with *T. solium* cysticercosis [odds ratios 1.98 (95% CrI: 0.55–4.74) and 2.57 (95% CrI: 1.22–4.66), respectively].

**Conclusions:** This study proves that the seroprevalence of porcine cysticercosis in Dak Lak Province was as low as that of other studies conducted throughout Vietnam. Scavenging of food and coprophagy are modifiable factors, providing the opportunity to decrease the prevalence of porcine cysticercosis further in the province.

**Keywords:** *Taenia solium*, Porcine cysticercosis, Epidemiology, Vietnam

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## Background

*Taenia solium* cysticercosis is recognized as a neglected tropical disease by the WHO [1]. It is distributed mostly in developing countries of Latin America, sub-Saharan Africa and Asia [2]. Pigs and humans act as intermediate hosts, acquiring *T. solium* cysticerci (larval stage) in their tissue, through the ingestion of *T. solium* eggs shed in the faeces of humans infected with adult tapeworms. Consumption of raw and/or undercooked pork with active *T. solium* cysticerci may result in *T. solium* taeniasis in humans. The presence of porcine cysticercosis impacts negatively on an economy due to costs arising from carcass condemnation and negative impacts on market access and trade of pork.

Although Vietnam is located in a region endemic for *T. solium* [3], the data on porcine cysticercosis are limited. In addition, it is not clear whether porcine cysticercosis is endemic in the country. During 1994 to 2005, the highest reported prevalence of porcine cysticercosis in Vietnam among four carcass-based studies was less than 1% [4]. These estimates were, for the most part, based on studies conducted in commercial slaughterhouses, and therefore do not reflect the prevalence of cysticercosis in pig populations in rural communities that are not processed in commercial slaughterhouses [5]. Of the relatively small number of studies that have quantified the prevalence of porcine cysticercosis in the country, most were conducted prior to 2003 with a focus on the north of Vietnam [4]. To the best of our knowledge, the only study of porcine cysticercosis in the south of Vietnam was carried out in 1994 [6].

Dak Lak Province is located in the Central Highlands in the south of Vietnam. A recent study in the communities of the province demonstrated an apparent prevalence of 1.2% *T. solium* taeniasis [7]. In most communities in the province, pigs are free-roaming and outdoor defaecation is common [8]. These characteristics are conducive for infection and transmission of *T. solium* cysticercosis to pigs. The aim of this study was to estimate the prevalence of cysticercosis in pigs in Dak Lak and to identify household level characteristics associated with *T. solium* porcine cysticercosis.

## Methods

### Study site and sampling

Fieldwork was conducted between June and October 2015 in Krong Nang, M'Drak and Buon Don districts in Dak Lak Province, Vietnam. These districts were chosen as the study sites based on their diverse geographical characteristics. The study sites have been described in detail elsewhere [7]. In brief, M'Drak is located in the east of Dak Lak Province with an average altitude of 400 m to 500 m and has a tropical monsoon climate typical of the Vietnam's Central Coast. Krong Nang is situated in the north of the province at an altitude of 800 m. Buon Don, situated to the west of the province with an average elevation of 330 m and has a hot and dry climate. The standard of living in this area of Vietnam is generally poor. Open defaecation using outdoor pit latrines is common practice and livestock access to these latrine areas is usually unrestricted. The practice of non-confinement of pigs and cattle is common with slaughter activities often carried out in backyards [4].

A sampling frame listing the name of all villages in the three study districts was obtained from Sub-Department of Animal Health office. Villages eligible for sampling comprised those with more than 1000 pigs, as recorded by the Sub-Department of Animal Health within the Ministry of Agriculture. All eligible villages within each of the three study districts were assigned a number and two numbers were chosen at random to select villages from each district for inclusion in the study. Within each selected village, a list of householder names was obtained from the respective village head person, and each householder name was then coded with a number (the number of households per village ranged from 200 to 300). A sheet of paper was drawn up into squares and each square numbered from 1 to 300. The squares were cut into pieces and placed face-down on a table. The village head was then asked to select between 100 and 140 squares. The number on each selected square identified each household to be sampled. All selected households were visited several days before sampling to obtain consent from participants. Within each district, blood samples were collected from pigs in each of the study households. At the time of each household visit pig owners were asked to complete a questionnaire on the number and type of pigs kept and details of demography, husbandry practices, and diet (Table 1). All questionnaires were conducted in local Vietnamese phraseology and their validity pre-tested on 30 pig owners in another community in Dak Lak Province before application to the field survey. In addition, interviewers were trained before administering the questionnaires. Pigs were selected at random by the member of research group for blood sampling. Pigs that were pregnant or ill, and pigs aged less than 2 months of age were excluded from sampling. At the time of each household visit 10 ml of blood was obtained from the cranial vena cava of each pig into plain blood collection tubes. The blood samples were allowed to clot at ambient temperature prior to centrifugation at 3200× *g* for 5 min to separate serum. Serum was dispensed into 1.5 ml aliquots and stored at -20 °C until use.

### Sample size estimation

The aim of this study was to estimate the prevalence of porcine *T. solium* cysticercosis in Dak Lak Province.

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**Table 1** Details of information about general and pig information

| Requesting information | Detail |
|---|---|
| General information | Address of house; number of people per household; presence and type and location of toilet; number of livestock per household; vegetables and crops management (source of water for irrigation, kind of manure for vegetables and crops); coordinate of household, pigsty, toilet and vegetable patch; elevation of household; number of dogs; location of defecation for dogs; efforts to disinfect dog's faeces; observation of *Taenia* proglottids in dog's faeces |
| Pig information | |
| Demography | Sex; age; breed; number of pigs |
| Husbandry management | The presence and location of pigsty; whether pig confined or free-roaming; roaming range of pigs; whether pigs eat human faeces; whether pigs have access to human defecation area |
| Diet management | Drinking water sources for pigs, kind of food for pigs (commercial or handmade bran, scavenging), feeding raw vegetables to pigs or not, vegetables washed before feeding pigs |

Based on a previous slaughterhouse based survey by Van De at al. [9], the prevalence of porcine cysticercosis was assumed to be 10%. Assuming 95% certainty that this estimate was within 5% of the actual population prevalence (i.e. cysticercosis prevalence ranged from 5% to 15%) and ignoring the possibility that cysticercosis positive pigs were clustered within households, we estimated that a total of 384 pigs were required to be sampled. We then assumed the average number of pigs eligible for random sampling per household was at least three and an intra-class correlation coefficient for *T. solium* cysticercosis of 0.07 [10] returning a design effect of 1.14. Our revised sample size, accounting for the likelihood that porcine cysticercosis clusters within households, was 384 × 1.14 = 438 for each of the three study districts.

## Laboratory procedures

Pig serum samples were analyzed using the recombinant T24H antigen in enzyme-linked immunoelectrotransfer blot (rT24H-EITB) assay as described by Noh et al. [11] and lentil lectin purified glycoproteins in EITB (LLGP-EITB) assay as previously described by Tsang et al. [12] and Gonzalez et al. [13]. Both the LLGP-EITB and rT24H-EITB assay are immunoblot methods. The LLGP-EITB detects antibodies to one or more of seven lentil lectin purified glycoproteins (LLGPs), namely GP50, GP42, GP24, GP21, GP18, GP14 and GP13 which are present in the soluble fraction of an extract of *T. solium* cysticerci [11]. Reaction to any of these 7 glycoprotein antigens is considered positive. The rT24H-EITB assay detects antibodies against rT24H antigen derived from 24- and 42-kDa glycoproteins of the LLGPs [14].

To ascertain the analytical specificity of the rT24H antigen, we subjected 29 cysticercosis-negative USA pig sera, 12 necropsy-positive *T. solium*-positive Peruvian pig sera and 4 *T. hydatigena* necropsy-positive Vietnamese pig sera to the rT24H-EITB. All USA pig sera and Vietnamese *T. hydatigena* pig sera were negative for the rT24H-EITB, and all Peruvian *T. solium* positive pig sera

were positive on the rT24H-EITB. These preliminary results provided the basis of results show that under experimental conditions, the rT24H-EITB do not cross-react to pig sera with *T. hydatigena*.

Individual serum samples were screened in pools of four using the rT24H antigen in EITB assay format to detect the presence of antibodies against *T. solium* cysticerci. The rT24H antigen was utilized in the EITB assay as it offers the best overall diagnostic performance compared with other recombinant or synthetic antigens based on our preliminary data and previous human-based studies [15, 16]. Individual serum sample from each positive pools were then re-screened using rT24H-EITB and LLGP (native antigen of *T. solium* cysticerci) antigens. The LLGP-EITB has been used as the reference standard assay for serological diagnosis of *T. solium* cysticercosis in humans and pigs that has the specificity of 100% and sensitivity between 98–100% [12, 13]. Jayashi et al. [17] when validating the LLGP-EITB for naturally acquired porcine cysticercosis pointed out that the LLGP-EITB achieves optimal sensitivity of 78% (95% CI: 52–94%) and specificity of 76% (95% CI: 66–85%) when the assay reacts to ≥ 3 of 7 LLGP antigens. The diagnostic performance of LLGP-EITB for porcine *T. solium* cysticercosis was evaluated in Peruvian pigs, and the cross-reaction of the assay to *T. hydatigena* was not known [13]. An individual serum sample was considered positive for *T. solium* antibodies if it was positive to both rT24H and native LLGP antigens.

## Statistical analysis

Risk factors for porcine *T. solium* cysticercosis in the communities of Dak Lak Province were identified using logistic regression. In this study, the outcome of interest was a dichotomous variable where households where at least one pig was *T. solium* cysticercosis-positive were assigned a value of 1, and 0 otherwise. The association between each of a set of household-level candidate explanatory variables from the questionnaires and the outcome of interest were tested using unconditional odds

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ratios and the chi-square test. All explanatory variables associated with the outcome of being *T. solium* cysticercosis positive at an alpha level of < 0.20 using the chi-square test were selected for inclusion in the multivariable model.

A frequentist fixed-effects logistic regression model was developed in which the probability of a household having at least one cysticercosis-positive pig was parameterized as a function of the explanatory variables with significance of the chi-square test at $P < 0.20$, as described above. The significance of each explanatory variable in the model was tested using the chi-square test. Explanatory variables that were not statistically significant were removed from the model one at a time, beginning with the least significant, until the estimated regression coefficients for all the explanatory variables retained in the model were significant at an alpha level of < 0.05.

To account for the hierarchical structure of the data (households within villages) a village-level random effect term ($V_i$), was included in the model as shown in Equation 1. District was not a significant predictor of household level *T. solium* cysticercosis status at the alpha level of 0.05 and was therefore not considered further in the mixed-effects model.

$$\log \left[ \frac{pi}{1-pi} \right] = \beta_0 + \beta_1 x_{1i} + \cdots + \beta_m x_{mi} + V_i + \varepsilon_i \quad (1)$$

Due to the low prevalence of *T. solium* cysticercosis (12 of 1281 pigs were positive) regression coefficients for the mixed-effects logistic regression model were estimated using a Bayesian approach implemented in JAGS [18, 19]. Flat (uninformed) prior distributions were assumed for the intercept $\beta_0$ and each of the regression coefficients for the fixed effects $\beta_1 \cdots \beta_m$. The village-level random effect term ($V_i$) was parameterized as having a normal distribution with mean 0 and precision (inverse variance) $\tau$.

For each of the Bayesian regression analyses we ran the Markov chain Monte Carlo sampler for 40,000 iterations and discarded the first 1000 'burn-in' samples. Convergence was visually assessed by plotting cumulative path plots for each of the monitored parameters [20, 21] and quantified using the Raftery & Lewis convergence diagnostic [22, 23]. Parallel chains were run using diverse initial values to ensure that convergence was achieved to the same distribution [24]. Posterior sample sizes were determined by running sufficient iterations to ensure that the Monte Carlo standard error of the mean was at least one order of magnitude smaller than the posterior standard deviation for each parameter of interest.

The results of the final mixed-effects logistic regression model are reported in terms of adjusted odds ratios for each explanatory variable. Assuming a causal relationship between a given explanatory variable and porcine cysticercosis, an adjusted odds ratio [and its 95% credible interval (CrI)] of > 1 indicates that, after adjusting for other variables in the model, the explanatory variable increased the risk of a pig being cysticercosis positive. An adjusted odds ratio (and its 95% CrI) of < 1 indicates that exposure to the explanatory variable was protective, and an OR of 1 indicates that the variable was not associated with porcine cysticercosis risk.

Statistical analyses were performed using the packages *R2jags* [25] and *coda* [26] implemented in R version 3.3.0 [27].

## Results

### General description of study population

A total of 1324 pig serum samples were collected in Krong Nang, M'Drak and Buon Don districts in Dak Lak Province. Of these, 1281 samples were eligible for further examination as 43 samples were excluded from analysis due to hemolysis or missing questionnaire information. All 1281 serum samples were screened in pools of 4 using the rT24H-EITB assay, and 10 pool samples were identified as positive. Twelve single samples among the 10 positive pool samples were positive for *T. solium* antibodies using the rT24H-EITB assay and all 12 single samples were positive using LLGP-EITB. The prevalence of *T. solium* cysticercosis in pigs in the study districts was 0.94 (95% CI: 0.51–1.68) per 100 pigs at risk. The 12 positive pigs belonged to 11 households in the three study districts. Of 203 households visited in M'Drak district, 9 (4.43%, 95% CI: 2.17–0.85%) possessed *T. solium* seropositive pigs. Among 70 visited households in Krong Nang district, two (2.8%, 95% CI: 0.49–10.8%) possessed *T. solium* cysticercosis positive pigs, and no seropositive pigs were identified in 135 households in Buon Don District.

The hierarchical structure of the data in this study is shown in Table 2. The 1281 pigs were from 408 households and, within each household, an average of three pigs were sampled (minimum 1; maximum 24).

**Table 2** Structure of the data from 1281 study pigs from six villages in M'Drak, Buon Don and Krong Nang districts

| Level | Number | Number at the next highest level | |
|---|---|---|---|
| | | Mean | Range |
| Districts | 3 | – | – |
| Villages | 6 | 2 | 2 |
| Households | 408 | 68 | 21–135 |
| Pigs[a] | 1281 | 3 | 1–24 |

[a]A total of 1281 pigs recruited in this study. The mean no. of pigs per household was three (range 1–24)

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Of the 408 households, 266 (65%, 95% CI: 60–70%) used a pit latrine; however, most of these latrines were of temporary construction, which animals were able to access. A total of 35% (95% CI: 30–40%) of householders responded that their family members practiced outdoor defecation; children typically defaecated around the main household building while adults defaecated some distance from the main household building, within the confines of the household property. Seventy-six percent (95% CI: 72–80%) of households had a pigsty and 58% (95% CI: 53–63%) confined their pigs at all times. Free-roaming pigs habitually ranged around the village to seek food and to return to their litters located under stilt housing in the afternoon. Approximately 7% (95% CI: 5–10%) of households used water sourced from lakes, streams or ponds for their pigs. The remaining households used either rainwater or water from wells or pipes. Dogs were kept in 63% (95% CI: 59–68%) of the households that owned pigs (Table 3).

Among the 1281 pigs that were sampled, 41% (95% CI: 38–44%) were of local breed (Soc). A total of 27% (95% CI: 24–29%) of the sampled pigs were reported to regularly consume human faeces. A little over half of the pigs were routinely offered raw, unwashed vegetables (57%; 95% CI: 54–59%). Commercial and/or homemade bran was offered to 89% (95% CI: 86–91%) of pigs. The small proportion of pigs that were not supplied bran (11%, 95% CI: 9–12%) were scavenging for the most part (Table 4).

### Risk factors for porcine *T. solium* cysticercosis

Of the data recorded using the questionnaire, we identified two factors associated with a pig's likelihood of being *T. solium* cysticercosis positive: (i) frequent coprophagy of human faeces; and (ii) scavenging for food. Estimated regression coefficients for the mixed-effects logistic regression model provided in Table 5. After adjusting for the other explanatory variables in the model, the odds of a household where pigs routinely consumed human faeces being *T. solium* cysticercosis positive was 2.57 (95% CrI: 1.22–4.66) times that of a household where pigs did not consume human faeces. The odds ratio for a household where pigs routinely scavenged for food was 1.98 (95% CrI: 0.55–4.74).

### Discussion

In low-income rural communities of Vietnam, a substantial proportion of the human population practice open defaecation and uncooked pork and beef consumption is relatively common. Allowing pigs to roam freely is a common husbandry practice in the region [4, 5, 9, 28, 29]. Despite all relevant risk factors for cysticercosis being present in each of the communities in this study, the prevalence of *T. solium* cysticercosis was low at

**Table 3** General description of household data

| Characteristic | Frequency | Percentage (95% CI) |
|---|---|---|
| Number of households | 408 | – |
| District | | |
| M'Drak | 203 | 50 (45–55) |
| Buon Don | 135 | 33 (28–38) |
| Krong Nang | 70 | 17 (14–21) |
| Presence of pit latrine | | |
| Yes | 266 | 65 (60–70) |
| No | 142 | 35 (30–40) |
| Presence of pigsty | | |
| Yes | 311 | 76 (72–80) |
| No | 97 | 24 (20–28) |
| Are pigs permitted to roam freely? | | |
| Yes | 172 | 42 (37–47) |
| No | 236 | 58 (53–63) |
| Source of water for pigs | | |
| Pipe/well/rain water | 379 | 93 (90–95) |
| Lake/stream/pond | 29 | 7.0 (4.9–10) |
| Owning dogs | | |
| Yes | 259 | 63 (59–68) |
| No | 149 | 37 (32–41) |
| Household observing proglottids in dog faeces | | |
| Yes | 113 | 44 (37–50) |
| No | 146 | 56 (50–62) |
| Faeces of dogs treated | | |
| Yes | 3 | 1.1 (0.3–4.6) |
| No | 256 | 99 (96–99) |
| Site of dog defecation | | |
| Inside compound | 192 | 74 (68–79) |
| Outside compound | 67 | 26 (21–32) |

0.94 (95% CI: 0.51–1.68) cases per 100 pigs at risk. A similar, low prevalence of cysticercosis has been observed not only in Dak Lak Province but in other regions of Vietnam [4, 6, 30]. In 1994 Huan, in a cross-sectional study of pigs submitted for slaughter from 12 provinces in the south of Vietnam, reported a prevalence of 0.90 (95% CI: 0.45–1.76) cases per 100 pigs at risk [6]. In three studies carried out in 10 provinces in the north of Vietnam between 1999 and 2003, the prevalence of cysticercosis ranged from 0 to 0.06 cases per 100 pigs at risk [31–33]. In the Province of Bac Ninh in the north of Vietnam, a known foci of *T. solium* in humans, carcass examination of 26 village pigs identified no cases of *T. solium* cysticercosis. Instead, 10 pigs were positive for *T. hydatigena* cysticerci [34]. These findings are in agreement with those of Conlan et al. [35], who reported a low

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**Table 4** General description of pig data

| Characteristic | Frequency | Percentage (95% CI) |
|---|---|---|
| Number of pigs | 1281 | – |
| Sex | | |
|   Male | 536 | 42 (39–45) |
|   Female | 745 | 58 (55–61) |
| Age (months) | | |
|   < 4 | 497 | 39 (36–42) |
|   4–12 | 665 | 52 (49–55) |
|   > 12 | 119 | 9.3 (7.8–11) |
| Breed | | |
|   Imported breed | 522 | 41 (38–44) |
|   Local breed (Soc) | 759 | 59 (56–62) |
| Allowed to roam freely | | |
|   Yes | 406 | 32 (29–34) |
|   No | 875 | 68 (66–71) |
| Human coprophagy | | |
|   Yes | 340 | 27 (24–29) |
|   No | 941 | 73 (71–76) |
| Main food | | |
|   Commercial/handmade bran | 1145 | 89 (86–91) |
|   Scavenging | 136 | 11 (9.0–12) |
| Provision of raw, unwashed vegetables[a] | | |
|   Yes | 723 | 57 (54–59) |
|   No | 555 | 43 (41–46) |

[a]Three cases was excluded from analysis

prevalence of *T. solium* cysticercosis of 0.8% in village pigs in Laos with a relatively high prevalence of *T. hydatigena* (22 cases per 100 pigs at risk) and a high prevalence of *T. solium* taeniasis. Conlan et al. [35] hypothesized that *T. hydatigena* is likely to cross-protect pigs from *T. solium* infection.

In Vietnam the prevalence of *T. hydatigena* cysticercosis in pigs has been reported to be high, ranging between 25–38% in the north and the prevalence has been strongly correlated with the presence of *T. hydatigena* infection in dogs [36]. In addition, most of the households that owned pigs in the three study districts also kept dogs and approximately one half of the households owning dogs reported that they had observed proglottids in their dog's faeces (Table 3). All of the 10 free-roaming village pigs that were backyard slaughtered had *T. hydatigena* cysticerci present in the mesentery, stomach, spleen, and liver (personal observation from fieldwork). It is our inference that the relatively high prevalence of *T. hydatigena* infection in dogs is likely to be a major source of *T. hydatigena* cysticercosis in pigs. If this is true a cautioned approach to cysticercosis control in pigs would be advised if *T. hydatigena* were to be targeted through pig confinement and canine deworming programs. Eliminating or reducing pig exposure to *T. hydatigena* would likely result in an increase in the observed prevalence of *T. solium* in non-compliant free-roaming pigs, providing an increased public health risk to the community.

Among the investigated households that owned pigs, a little under one-quarter did not have a pigsty and most of the pigs that were kept were of the local breed (Table 4). Local breeds are preferred due to their ability to thrive under harsh raising conditions and poor feeding [12]. Allowing pigs to free-roam for food was common practice (Table 3). The odds of a household where pigs routinely scavenged for food being seropositive for *T. solium* cysticercosis was 1.98 (95% CrI: 0.55–4.74) times greater than the odds of a household where pigs were fed commercial and/or homemade bran (Table 5). Similarly, the odds ratio for a household where pigs routinely consumed human faeces being seropositive was 2.57 (95% CrI: 1.22–4.66) times greater than the odds of a household where this

**Table 5** Risk factors associated with *T. solium* cysticercosis positive in pigs

| Explanatory variable | Number of pigs | | Regression coefficient (SD) | MC error | Adjusted OR (95% CrI) |
|---|---|---|---|---|---|
| | Positive | Total | | | |
| Intercept | 12 | 1281 | -5.9800 (1.5480) | 0.006 | – |
| Coprophagy of human faeces: | | | | | |
|   No | 3 | 941 | Reference | | |
|   Yes | 9 | 340 | 2.6600 (0.8470) | 0.004 | 2.57 (1.22–4.66) |
| Kind of food | | | | | |
|   Bran | 6 | 1145 | Reference | | |
|   Scavenging | 6 | 136 | 2.1400 (1.0320) | 0.003 | 1.98 (0.55–4.74)[a] |
| Random effects[b] | Estimate | SD | | | |
|   Village | 2.18 | 5.77 | | | |

[a]Interpretation: The odds of *T. solium* cysticercosis positive for pigs that scavenged food was 1.98 (95% credible interval 0.55–4.74) times that of pigs that did not scavenge for food
[b]Variance and standard deviation (SD) of the variance of the village-level random effect

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practice was not habitual. It is known that risk factors for transmission and circulation of porcine cysticercosis are numerous and may vary in different settings. We found that allowing pigs to free-roam and allowing pigs to routinely consume human faeces were associated with *T. solium* exposure, consistent with other studies [37–39]. Research on the epidemiological characteristics of porcine cysticercosis in Peru [40], Mozambique [41] and Mexico [42] found that older pigs were more likely to show evidence of exposure to *T. solium* compared to younger pigs, an association not identified in this study. Similarly, while studies from Zambia [43], Mexico [44], and Tanzania [45] showed that the prevalence of *T. solium* exposure was higher in male pigs compared with females, this association was not identified in this study. In this study, both of the risk factors identified are modifiable, which means that there exists an opportunity to decrease the prevalence of porcine cysticercosis even further. We propose that a combination of intervention measures including education and public awareness campaigns, strategies to reduce coprophagy among pigs and enhanced meat inspection (particularly backyard slaughtered stock) are likely to have the greatest impact on porcine cysticercosis risk with positive secondary effects on human health [46]. For this to be successful there is a need for commitment and support from local and/or central veterinary and medical health authorities.

## Conclusions
The prevalence of porcine *T. solium* cysticercosis in this study was low at 0.94 (95% CI: 0.51–1.68) cases per 100 pigs at risk, in agreement with other studies conducted throughout Vietnam. Scavenging of food and coprophagy were associated with *T. solium* cysticercosis risk. Both of these characteristics are modifiable providing the opportunity to decrease the prevalence of porcine cysticercosis even further.

### Abbreviations
EITB: enzyme-linked immunoelectrotransfer blot; LLGP: lentil lectin purified glycoprotein; rT24H: recombinant antigen T24H

### Availability of data and materials
All relevant data are included within this published article.

### Ethics approval and consent to participate
This study was reviewed and approved by the Animal Ethics and scientific committee, Tay Nguyen University (reference number 50.KCNTY), and conducted under the supervision of the local center for animal health, Dak Lak, Vietnam. Verbal consent was obtained to participate in the study. The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

### Consent for publication
Not applicable.

### Competing interests
The authors declare that they have no competing interests.

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