The pork tapeworm, a neglected but important foodborne parasite in and outside endemic areas: challenges of diagnosis and control

Pierre Dorny
Human taeniid tapeworms

Taenia solium  Taenia saginata  Taenia asiatica

A. Flisser et al. 2004, J. Parasitol. 90, 914-916
Taenia solium – life cycle

Porcine cysticercosis

Neurocysticercosis

Taeniasis
**Taenia solium - distribution**

Endemic in pig raising/pork consuming developing countries
**Taenia solium - importance**

- Neglected zoonotic disease that causes a considerable disease burden on poor rural pig-keeping communities in developing countries
- Commonest cause of *acquired epilepsy* in endemic countries
- 2.8 million DALYs
- The total number of people with NCC between 2.56–8.30 million

- Concern in non-endemic areas due to international travelling
- Economic burden potentially high due to condemning infected carcasses at meat inspection
~ 29% PWE in endemic countries with lesions of NCC

Also contributes to other neurologica disorders (% poorly known)
Disease burden (DALY) of food-borne parasites according to WHO regions
Major challenges in diagnosis and control

**DIAGNOSIS**

- **Diagnosis in humans** requires a combination of epidemiological, clinical, neuroimaging and serological tools: *cost and logistics*

- **Diagnosis in pigs** is based on meat inspection, which is unsensitive and often not performed in developing countries: *underdiagnosis*

- **Bed- or pen side diagnostic tests** are currently not available
Major challenges in diagnosis and control

**CONTROL**

Control is mainly based on meat inspection but should include health education, improved sanitation, improvement of pig breeding systems.

New intervention options have been developed for control or even elimination of the disease, but their potential has yet to be assessed in different settings.
Diagnosis in **humans**

- **Diagnosis of an intestinal tapeworm infection**
  - Parasitological diagnosis: microscopy, molecular confirmation
    - Proglottids in stool: ‘self diagnosis’
    - Eggs by coprological examination
    - Worm expelled following anthelmintic treatment
Diagnosis in **humans**

- **Diagnosis of an intestinal tapeworm infection**
  - Copro-antigen ELISA
    - Genus-specificity vs species-specificity
    - Not commercially available
  - Copro-PCR
    - Species-specific
    - Need for a molecular lab
  - Serological diagnosis (EITB-T): r33 recombinant Ag
    - Immunoblot for Ab detection for intestinal *T. solium* infection
    - Avoids handling faeces
    - Ab still measurable after treatment
Diagnosis in **humans**

- **Diagnosis of (neuro)cysticercosis**
  - complicated because histological demonstration of the parasites is not possible

  - modern neuroimaging techniques and development of immunological tests enhanced diagnostic accuracy

- diagnosis remains problematic as neuroimaging findings are rarely pathognomonic and immunodiagnostic tests vary in sensitivity and specificity
Diagnosis in **humans**

- **Diagnosis of (neuro)cysticercosis**
  - Parasitological diagnosis
  - Imaging
  - Serological diagnosis
    - Antibody detection methods
    - Antigen detection methods
Diagnosis in **humans**

**Diagnosis of (neuro)cysticercosis**

- Parasitological diagnosis
  - Autopsy or biopsy
  - Demonstration of scolex with the hooks or fragments of the bladder wall
Diagnosis in humans

Diagnosis of (neuro)cysticercosis

Imaging

- Diagnosis
- Location, number, degenerative state, inflammation, ...
- Clinical management
- Prognosis

- Computed tomography (CT-scan)
- Magnetic resonance imaging (MRI)

- Expensive
- Accessibility
- Interpretation
Diagnosis in humans

- Diagnosis of (neuro)cysticercosis
  - Serological diagnosis
    - Antibody detection methods
    - Antigen detection methods
Diagnosis in humans

Diagnosis of (neuro)cysticercosis

Serological diagnosis

Antibody detection methods

- ELISA or EITB formats
- Crude, purified or recombinant antigens
- Performance of ELISA poor, EITB better but expensive
- Abs indicate exposure rather than current infection
- Transient antibodies
- Serology cannot confirm location of cysts
Diagnosis in **humans**

**Diagnosis of (neuro)cysticercosis**

**Serological diagnosis**

**Antigen detection methods**

- ELISA format
- Monoclonal antibody-based capturing
- Ags indicate current infection
- Serology cannot confirm location of cysts
Revised diagnostic criteria for neurocysticercosis

O.H. Del Brutto, T.E. Nash, A.C. White Jr., V. Rajshekhar, P.P. Wilkins, G. Singh, C.M. Vasquez, P. Salgado, R.H. Gilman, H.H. Garcia

Table 1
Revised diagnostic criteria and degrees of diagnostic certainty for neurocysticercosis.

<table>
<thead>
<tr>
<th>Diagnostic criteria</th>
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<tbody>
<tr>
<td><strong>Absolute criteria:</strong></td>
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<tr>
<td>- Histological demonstration of the parasite from biopsy of a brain or spinal cord lesion.</td>
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<tr>
<td>- Visualization of subretinal cysticercus.</td>
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<tr>
<td>- Conclusive demonstration of a scolex within a cystic lesion on neuroimaging studies.</td>
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<tr>
<td><strong>Neuroimaging criteria:</strong></td>
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<tr>
<td>- Major neuroimaging criteria:</td>
</tr>
<tr>
<td>- Cystic lesions without a discernible scolex.</td>
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<tr>
<td>- Enhancing lesions.</td>
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<tr>
<td>- Multilobulated cystic lesions in the subarachnoid space.</td>
</tr>
<tr>
<td>- Typical parenchymal brain calcifications.</td>
</tr>
<tr>
<td>- Confirmative neuroimaging criteria:</td>
</tr>
<tr>
<td>- Resolution of cystic lesions after cysticidal drug therapy.</td>
</tr>
<tr>
<td>- Spontaneous resolution of single small enhancing lesions.</td>
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<tr>
<td>- Migration of ventricular cysts documented on sequential neuroimaging studies.</td>
</tr>
<tr>
<td><strong>Clinical/exposure criteria:</strong></td>
</tr>
<tr>
<td>- Major clinical/exposure:</td>
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<tr>
<td>- Detection of specific anticysterceral antibodies or cysterceral antigens by well-standardized immunodiagnostic tests.</td>
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<tr>
<td>- Cysticercosis outside the central nervous system.</td>
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<tr>
<td>- Evidence of a household contact with <em>T. solium</em> infection.</td>
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<tr>
<td>- Clinical manifestations suggestive of neurocysticercosis.</td>
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<tr>
<td>- Individuals coming from or living in an area where cysticercosis is endemic.</td>
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<table>
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<th>Degrees of diagnostic certainty</th>
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<tr>
<td><strong>Definitive diagnosis:</strong></td>
</tr>
<tr>
<td>- One absolute criterion.</td>
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<tr>
<td>- Two major neuroimaging criteria plus any clinical/exposure criteria.</td>
</tr>
<tr>
<td>- One major and one confirmative neuroimaging criteria plus any clinical/-exposure criteria.</td>
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<tr>
<td>- One major neuroimaging criteria plus two clinical/exposure criteria (including at least one major clinical/exposure criterion), together with the exclusion of other pathologies producing similar neuroimaging findings.</td>
</tr>
<tr>
<td><strong>Probable diagnosis:</strong></td>
</tr>
<tr>
<td>- One major neuroimaging criteria plus any two clinical/exposure criteria.</td>
</tr>
<tr>
<td>- One minor neuroimaging criteria plus at least one major clinical/exposure criteria.</td>
</tr>
</tbody>
</table>

*Note: All criteria marked with an asterisk (*) are based on evidence from neuroimaging studies.*
Developing of a Point of Care Test

- For taeniasis and cysticercosis diagnosis
- Lateral flow
- Using recombinant antigens (T24 and s33)
- CDC Prototype
- Currently evaluated in Tanzania and Zambia
Diagnosis of porcine cysticercosis

- Veterinary public health: meat safety
  - Identifying infected pigs: elimination of infected animals from the food chain

- Epidemiological studies
  - Indicator of exposure (proxy for human exposure)

- Monitoring of control/intervention programs
  - Measuring effect of intervention (sentinels)
Diagnosis of porcine cysticercosis

- Tongue inspection
- Carcass inspection
- Full carcass dissection
- Partial carcass dissection
- Serological methods

*Taenia solium* cysticerci on a pig’s tongue

Se 8-21%, sp 80-100%

Pigs with cysts on tongue often go to illegal market, alternative circuit

Useful tool for rapid assessment of hot spots
Diagnosis of porcine cysticercosis

- Tongue inspection
- Carcass inspection
- Full carcass dissection
- Partial carcass dissection
- Serological methods

Many pigs slaughtered in rural areas are not inspected

se 22%, sp 100%
Diagnosis of porcine cysticercosis

- Tongue inspection
- Carcass inspection
- Full carcass dissection
- Partial carcass dissection
- Serological methods

Gold standard technique
- Experimental studies
- High cost and labour intensive
Diagnosis of porcine cysticercosis

- Tongue inspection
- Carcass inspection
- Full carcass dissection
- Partial carcass dissection
- Serological methods

- Dissection of only the tongue, masticatory muscles and heart
- 80% sensitivity
Diagnosis of **porcine cysticercosis**

- Tongue inspection
- Carcass inspection
- Full carcass dissection
- Partial carcass dissection
- Serological methods
Diagnosis of porcine cysticercosis

- Serological methods: immunodiagnosis
  - Tests developed in humans adapted for pig samples
    - Ab detection: sensitivity and **specificity** issues, exposure
    - Ag detection: **specificity** issue

- Benefits
  - Ante-mortem diagnosis
  - More sensitive than tongue palpation
Control

Control is mainly based on meat inspection but should include health education, improved sanitation, improvement of pig breeding systems.

New intervention options have been developed for control or even elimination of the disease, but their potential has yet to be assessed in different settings.
Strategies for intervention

- Control slaughter
- Meat inspection
- Cook meat
- Restrain pigs
- Improve sanitation
- Build and use latrines
- Mass taenidical treatment

Break the life cycle:
- Avoid pigs to have access to human faeces

**TAENIA SOLIUM LIFE CYCLE**
Strategies for Intervention

- Medical world: blaming veterinary sector
  - They should guarantee safe meat for consumers
Options for control

1. Meat inspection
2. Meat processing
3. Pig coralling
4. Sanitation
5. Mass human chemotherapy
6. Health education
1. Meat inspection

- Low sensitivity
- Pigs slaughtered in illegal slaughter places
2. Meat processing

Cysticerci killed by

- -20°C, 3 days
- Cooking

Freezing: feasibility at rural level minimal

Undercooking

- Barbecued meat
- Raw meat tradition
- Lack of firewood
3. Pig corralling

- Simplest way to prevent pigs to have contact with human faeces
- But, main reason for farmers in developing countries to raise pigs
  - No investment in feeding by allowing to roam free
  - Subsistence farming: pig is key cash income
  - Pigs keep village clean
4. Sanitation

- Building (and using!) latrines
- Hygiene
- Hand washing
5. Mass human chemotherapy

- Praziquantel or niclosamide single dose treatment for elimination of Taenia

- Decrease in prevalence of human taeniasis and porcine cysticercosis

- Transmission variables return to pre-intervention levels a few months after interruption of treatments

- Concerns about effects of PZQ on cysticercosis-infected individuals
6. Health education

- Awareness
- Posters, leaflets, information campaigns, TV, ...
- Schools

To be included in control programmes
Few studies have measured effects
LET'S BREAK THE PORK TAPEWORM CYCLE
with these 6 easy steps

1. Always use a toilet.
   Use a toilet to stop worm eggs infecting pigs and other people.

2. Wash your hands.
   Tape worm eggs are too small to see and spread easily. So wash your hands well with soap and clean water after using the toilet and before touching food.

3. Go to the clinic.
   If you think you have tapeworm go to the clinic and get treatment as soon as possible.

4. Stop pigs from roaming.
   Keep your pigs in a pen or feed to a stake, so that they can't eat human faeces containing tape worm eggs.

5. Check meat is safe.
   Check meat carefully to make sure there are no cysts. Meat with cysts should not be eaten or sold.

6. Cook meat well.
   It is better to be safe than sorry. Pork must be cooked thoroughly so that there is no pink meat and no blood running out. This will kill any tapeworm cysts and prevent infection.

THE PORK TAPEWORM CYCLE

Pigs get infected. Free-range pigs get infected by eating human faeces containing tapeworm eggs.

Swallowing tapeworm eggs is dangerous. Tapeworm eggs grow into cysts in the brain, eyes, muscles, paralysed, severe headaches, insanity and even death.

Patients get tapeworms when they eat the cysts in undercooked meat.

Thousands of tapeworm eggs come out with the faeces. Tapeworm segments can be seen in the faeces. They release thousands of eggs into the environment.

This child has a tapeworm growing inside him.
6. Health education

Educational tool:

The Vicious Worm
a cysticercosis advocacy information tool

https://theviciousworm.sites.ku.dk
Strategies for Intervention

Options for control

1. Meat inspection
2. Meat processing
3. Pig corralling
4. Sanitation
5. Mass human chemotherapy
6. Health education
7. Pig vaccination
8. Pig treatment
7. Pig vaccination

- TSOL18 vaccine: recombinant oncosphere antigen
  - Near to 100% efficacy in experimental conditions
  - First field trial in Cameroon: 100% reduction of infection

- Commercialisation?
7. Pig vaccination

- No protection after first injection
- Combination with Oxfendazole treatment at 2\textsuperscript{nd} vaccination
- Vaccinate all pigs in village every 3 to 4 months
- Are farmers willing to pay?
- To be validated in the field
8. Pig treatment

**Oxfendazole** 30 mg/kg single treatment

- 100% efficacy against cysticerci outside brain
- Commercially available (Paranthic 10%)
- 21 day withdrawal period for residues in meat
- Dead cysticerci remain visible for months after treatment
  - Still reduced price of carcass
Elimination of *Taenia solium* Transmission in Northern Peru


for the Cysticercosis Working Group in Peru†
Elimination of *Taenia solium* transmission in Peru

- Transmission of *T. solium* infection was interrupted on a regional scale in a highly endemic region in Peru
- Combination of strategies:
  - Mass drug administration humans + treatment and vaccination of pigs
- Questions:
  - Sustainability?
  - Monitoring?
  - Avoid reintroduction?
  - Applicability in other areas?
Control/elimination of *T. solium* transmission

**Many challenges remain**

- diagnostic difficulties
- differences in transmission patterns between regions requiring other approaches
- frequency and combination of interventions
- acceptability by communities
- integration of control methods in preventive health programmes
- cost/benefit of interventions
- national policies on subsidising and implementing control
Control/elimination of *T. solium* transmission

- Testing intervention tools in the field is time consuming and expensive.

- **Mathematical and computational models**
  - **CystiSim**: Agent-Based model for *Taenia solium* transmission and control

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cystiSim: Agent-Based Model for Taenia_solium Transmission and Control

The cystiSim package provides an agent-based model for Taenia solium transmission and control. cystiSim was developed within the framework of CYSTINET, the European Network on taeniosis/cysticercosis, COST ACTION TD1302.

Version: 0.1.0
Depends: R (≥ 3.3.0), ggplot2
Imports: magrittr, knitr, graphics, grDevices, stats, utils
Published: 2016-05-15
Author: Brecht Devleeschauwer [aut, cre], Uffe Christian Braae [aut]
Maintainer: Brecht Devleeschauwer <brechtvd at gmail.com>
BugReports: https://github.com/brechtdv/cystiSim/issues
License: GPL-2 | GPL-3 [expanded from: GPL (≥ 2)]
URL: https://github.com/brechtdv/cystiSim
NeedsCompilation: no
Materials: README NEWS
CRAN checks: cystiSim results

Downloads:

- Reference manual: cystiSim.pdf
- Package source: cystiSim_0.1.0.tar.gz
- Windows binaries: r-devel: cystiSim_0.1.0.zip, r-release: cystiSim_0.1.0.zip, r-oldrel: not available
- OS X Mavericks binaries: r-release: cystiSim_0.1.0.tgz, r-oldrel: not available
We are currently evaluating an elimination/control programme in a highly endemic region in Zambia
• Intensive programme: attempt to eliminate *T. solium* in 1.5 years
• MDA PZQ, TSOL18, Oxfendazole
• Challenge to keep local population motivated