Control of *Taenia solium*

Armando E. Gonzalez a,*, H.H. García b, Robert H. Gilman c,
Victor C.W. Tsang d, Cisticercosis Working Group in Peru

a Facultad de Medicina Veterinaria, UNMSM. Apartado 03 5013, Lima, Peru
b Instituto Nacional de Ciencias Neurologicas, Jiron Ancash 1271, Barrios Altos, Lima, Peru
c Department of International Health, Bloomberg School of Public Health, Johns Hopkins University, 615 N Wolfe St, Room 3501, Baltimore, MD 21205, USA
d Centres for Disease Control, Bldg 23, Room 1003, 4770 Buford Hwy. ME, Atlanta, GA 30347, USA

**Abstract**

Control or eradication of *Taenia solium* cysticercosis has been achieved to date only in Europe and North America. Significant improvements in sanitary conditions and developing functional slaughterhouse control systems were primarily responsible for control in these regions. Conversely, in endemic areas of developing countries control is limited by economic and sanitary conditions: the life cycle of *T. solium* is sustained because pigs have access to infected faeces, and cysticercosis-infested pork is available for consumption. Interventionsal trials with massive human cestocidal chemotherapy, treatment of both human and porcine populations with antihelminthic drugs and/or immunotherapy and health education have shown improvements in specific settings but not yet proven to be sustainable in the long-term. In order to ensure sustainability, any given control strategy towards elimination/eradication of porcine cysticercosis should incorporate economic incentives.

© 2003 Elsevier Science B.V. All rights reserved.

**Keywords:** *Taenia solium*; Control strategies; Cysticercosis

1. Introduction

Cysticercosis is a common disease in pig raising areas of most of the world (Acha and Szyfres, 1986). The life cycle of *Taenia solium* includes the pig as the normal intermediate host, harbouring the larval vesicles or cysticerci, and the human as the definitive host, harbouring the adult form of the tapeworm (Nash and Neva, 1984). Humans can also serve as the intermediate host and develop the cystic form by accidental ingestion of the adult tapeworm eggs. Human cysticercosis causes a variety of neurological symptoms, most commonly seizures due to cysts in the brain (neurocysticercosis) (Garcia and Del Brutto, 2000).

*T. solium* is probably responsible for over 10% of acute care admissions to the neurological ward of countries where it is endemic (Garcia and Del Brutto, 2000). In individuals living in zones that are highly endemic for cysticercosis, 30% or more of late onset seizures are associated with serological evidence of infection (Garcia et al., 1999;...
González et al., 1999). In addition, it produces widespread livestock production losses to pig owners caused by the intermediate stage of cysticercosis infecting the pig. Although porcine cysticercosis produces no clinical symptoms, an infected carcass cost only one third of the price of a healthy one (CWGP, 1993). The rates of porcine infection are variable, but in endemic regions, over 30% of pigs may be infected (González et al., 1990).

2. Economic issues

Eradication strategies which have functioned in developed countries, are usually not suitable for most developing countries. Any disease eradication programme that considers the economic factor is more likely to be successful, sustainable and also result in the acceptance of health education campaigns (Gilman et al., 1999).

In the past, the World Health Organisation suggested that control programs would be successful if inspection of pig carcasses in slaughterhouses were rigorously enforced (Gemmell et al., 1983). Thus far, this strategy has failed in developing countries. Targeting slaughterhouses as the primary intervention fails to influence the animal husbandry practices which occur before the pigs are brought to market. Instituting a policy in which pigs that are detected to have cysticercosis are confiscated without payment to the pigs owner leads to the establishment of a clandestine market for pigs that may be infected with *T. solium*. In Peru, if porcine cysticercosis is detected, the pig is confiscated and no payment is given to the peasant. Consequently, 55% or pigs are illegally slaughtered and this figure is close to 100% in many rural areas (CWGP, 1993). Evidently, the policy of slaughterhouse inspection is effective only in non-endemic areas or when pigs came from commercial farms.

Peasants use the pig rearing activity for short-term savings (Fernández and Gutiérrez, 1986). They buy the pig during the harvest season or whenever they have an extra income. Pigs will protect peasants from inflation and will eventually produce a profit from growth and/or offspring. Furthermore, they optimise the profit of rearing pigs by keeping the investment and costs to a minimum. A pig is one of the few assets available to the farmer that can be quickly and easily converted into cash (Fernández and Gutiérrez, 1986). A pig can be fed at little cost by permitting it to range free in villages or on free farm land and in this way obtain a variety of foods to supplement its diet, including human and other animals faeces (Gilman et al., 1999). Corn or grains that would be otherwise allocated to feed pigs can then be used for other purposes. Permitting pigs to range freely also has a secondary economic advantage in that pigs are utilised as sanitarians to maintain villages free from garbage, small vermin and animal and human faeces (Gilman et al., 1999). Control strategies that fail to recognise this economic significance will be less successful in controlling *T. solium*.

People will require an economic incentive before they adopt different pig rearing practices. Whereas the seroprevalence in pigs is usually two to three times that in humans, in a rural community on the coast of Peru, pigs had lower seroprevalence than did the human population (Gilman et al., 1999), probably due to a reduction of transmission in the immediate past. The only modification required to achieve this reduction was the corralling or tethering of pigs. When asked about the reason for the change, peasants reported that the rice crop had been introduced to the area, and that the free-ranging pigs affected adjoining rice fields. Rice cropping was not only more profitable, but also provided by-products to feed to tied and corralled pigs (Gilman et al., 1999).

A similar phenomenon happens with development. Most developed countries controlled the parasite as a consequence of the development process. Improvements in environmental hygiene and meat inspection procedures were implemented mainly to ensure food safety and raise living standards. However, the point where people stop raising pigs and started buying pork from the market previously required that the opportunity cost of feeding and raising pigs became higher than buying pork at regulated markets. This prompted entrepreneurs to produce pork in corrals under controlled conditions. Porcine cysticercosis then
decreased because corralling indirectly prevented the animals from eating human faeces.

Finally, before leaving the issue of economics, it is important to address how a successful control program must take into account the financial incentives of the other party involved in the pig trade—the purchasing parties. Pigs are mostly sold alive to intermediary agents which in turn take them to the cities. If a pig is found infected the intermediary will still try to sell this meat. Sustainable programs must aim to decrease the supply of infected meat to consumers. Currently, diseased meat is sold clandestinely and disguised by mixing it with uninfected pork. To the purchasers diseased meat has the advantage of cheap price but the disadvantage of being illegal (CWGP, 1993). Control efforts need to purchase diseased meat at the market price and process it in a safe manner. This process would have several advantages including replacement of the clandestine market. Diseased meat could then be processed so all cysts are killed and then sold for sausage or other processed meats, albeit at reduced prices (Gilman et al., 1999).

3. Development and education

Efforts to educate villagers at schools, village meetings, and on an individual basis have been highly successful in terms of teaching villagers the parasite life cycle and the connection between infected pigs and themselves or others getting cysticercosis (Keilbach et al., 1989; Sarti et al., 1997). Villagers were able to describe how *T. solium* infection was transmitted, how it could be prevented. Knowledge, Attitude and Practice (KAP) studies can demonstrated that villagers understand the role of *T. solium* infection in pigs and the *T. solium* larvae’s relationship to neurocysticercosis or epilepsy (Sarti et al., 1997). However, the knowledge acquired does not appear to result in dramatic changes in risk behaviour.

It is worth emphasising that an understanding of the role economic incentives play in behavioural change at the local level is essential to the development of health education control components. The major driving force behind raising pigs is economic (Gonzalez, 1997). The health risk of transmitting and getting cysticercosis is not viewed as an immediate or real risk by villagers (Garcia and Del Brutto, 2000). Thus, even though knowledge is present, it does not influence actions as strongly as does the immediate economic benefit of maintaining pigs in a cheap but unhealthy manner (Gilman et al., 1999).

4. Treatment of human population

Other proposed strategies for control emphasise eliminating egg dissemination in the environment using mass human chemotherapy (Allan et al., 1997; Diaz Camacho et al., 1991; Sarti et al., 2000). This strategy is based on the assumption that if egg dispersion is stopped, then the disease transmission cycle will be broken. These measures were successfully used on other animal cestodes such as *Echinococcus granulosus*. Consequently, this approach was proposed and used as a model for controlling *T. solium* cysticercosis (Gemmell et al., 1983; Cruz et al., 1989). However, as pointed out by Lawson and Gemmell (1989), field trials and control programmes demonstrated that ovine echinococcosis (*E. granulosus*) and the cysticercosis (*Taenia hydatigena* and *Taenia ovis*) have different epidemiological stabilities and do not respond in the same way to control efforts. *T. hydatigena* is mainly found in endemic state and thus is readily transformed, by dog-dosing programmes, to an extinction status. In contrast, *T. solium* cysticercosis, which is usually in the hyper-endemic state, may only be transformed to the endemic state.

Furthermore, other crucial aspects are neglected in this mass treatment strategy. Human taeniasis, although critical to any control strategy, is difficult to treat, and re-infection may occur (Gilman et al., 1999). There is also a theoretical risk of a temporary increase in human cysticercosis infection during taeniasis treatment campaigns if disposal of stools is not carefully controlled (Gilman et al., 1999). A study performed in a community in Mexico found that swine cysticercosis prevalence increased from 6.6 to 11% 1 year after mass human chemotherapy (Keilbach et al., 1989).
5. Concurrent treatment of human and porcine populations

Strategies for the control of *T. solium* in humans would only be ineffective because transmission could subsequently occur from infected pigs. Therefore, eradication of *T. solium* from a disease-endemic area by application of human treatment alone would require consecutive interventions, for at least the average life span of the porcine reproductive stock. Furthermore, the interval between interventions should not exceed the pre-patent period, so that if new adult tapeworm infections occur, they would not have enough time to infect more pigs. This holds true also, if the porcine population alone is targeted by the intervention strategy. Such interventions would have to be made for the entire life span of the tapeworm, implying that the pig population has to be treated within the interval required for cyst maturation (Gonzalez, 1997).

Effective treatment of infected pigs is the next logical addition to mass or focused treatment of humans in control programmes (Gonzalez et al., 1997, 1995). Since humans can only become infected with the adult stages of this parasite when they eat contaminated pork, treatment of pigs prior to slaughter would block a key step in the transmission cycle of cysticercosis. Treating the pig population will not only control further infections of humans in control programmes (Gonzalez et al., 1996, 1997; Gonzalez et al., 2002). Work done by our group has demonstrated its efficacy against porcine cysticercosis in a single dose scheme, its superiority to praziquantel and albendazole, and other important characteristics: that it leaves pork with a very clean appearance although this process takes 2–3 months. Carcasses of pigs treated with 30 mg/kg of oxfendazole had a normal appearance, and were considered suitable for human consumption (Gonzalez et al., 1996, 1997, 1998).

We have also demonstrated in controlled and field experiments that oxfendazole-treated cysticercotic pigs can are protected from further infections for at least 3 months of protection to further challenges (Gonzalez et al., 2001). In field conditions, most pigs live around 9 months. Cysts take about 2 months to develop, so it is reasonable to assume that pigs will be infective only after 3–4 months of age. Therefore, if treated at 3–4 months of age, cured pigs are unlikely to be re-infected at least until 7 months of age, and it is very probable that this protection will extend for longer periods and thus cover the remaining lifetime of the pig. This means that oxfendazole is a potentially effective control agent because once treated, pigs are refractory to re-infection even in the event of ongoing exposure to the source of *T. solium* eggs. Obviously, other concomitant measures are still needed since seronegative pigs still remain susceptible to infection.

Oxfendazole (methyl [5-(phenylsulphinyl)-1H benzimidazole-2-yl] carbamate; Synanthic®) is a benzimidazole with anthelmintic properties against larval and adult gastrointestinal cestodes and nematodes in various animal species (Borgsteede, 1977; Corwin et al., 1979; Marriner et al., 1985). Work done by our group has demonstrated its value of the pigs it will lead to the remaining lifetime of the pig. Better market prices for treated pork and access to the formal marketing system will allow farmers to volunteer their pigs for chemotherapy. Better market prices for treated pork and access to the formal marketing system will allow strong incentives for farmers to treat their pigs, and community co-operation will be encouraged (Gonzalez, 1997). Mathematical models indicate that targeting both hosts would reduce the time required to eradication and thereby increase the likelihood of success (Gonzalez, 1997; Gonzalez et al., 2002).

6. *T. solium* elimination and tapeworm reintroducción

Until the successful use of oxfendazole against porcine cysticercosis was described (Gonzalez et al., 1995) and later corroborated (Benitez, 2001), treatment of the porcine population was disregarded as impractical, because of costs and the need for multiple doses of treatment. Our group has also carried out intervention studies that
evaluated the effect of combined mass therapy targeting both human and porcine populations in the Peruvian highlands and in the Northern Coast of Peru (Garcia, 2002). In the former experiment, eight highly endemic villages located in the Mantaro valley were selected for the study. The selected population underwent a cysticercosis control program that included mass treatment of human and porcine populations. All pigs were treated twice with oxfendazole (single dose, 30 mg/kg) at the beginning of the experiment (month-0 and -4). Following baseline sampling (30 days after treating the pigs), the villagers in the treatment branch of the study received praziquantel in taenidical doses. The strategy was shown to be only partially successful. Benefits of the intervention as measured by incident cases of porcine cysticercosis remained statistically significant up to 16 months $(P = 0.04)$, although the magnitude of the improvement was much less than expected. The biotic potential of *T. solium* ultimately recovered to steady state baseline values. Sentinel pig trials corroborated that environmental contamination returned to baseline levels, 18 months after intervention. The study demonstrated that information regarding variables affecting the biotic potential, such as residual environmental contamination, average number of pigs infected by one tapeworm during a single day and time to tapeworm population renewal were important. Estimation of these variables were later used to calculate the number of interventions and the minimum treatment coverage required for a strategy using either common sense or mathematical approaches.

In the second trial in Tumbes, a control program was performed in eight villages in the Matapalo district, in the Peruvian–Ecuadorian border. The parasite was eliminated in two of the villages and was significantly decreased from the rest after two interventions in humans and four interventions in the porcine population. Interventions were scheduled every 3 months. However, the tapeworm was reintroduced in the villages and new porcine cysticercosis cases were detected after 6 months of the second human intervention. Movement of *T. solium* tapeworm carriers or infected swine have been also shown to have spread the disease from endemic to non-endemic areas causing either periodic localised outbreaks of cysticercosis or establishment of the parasite in new areas such as Irian Jaya, Indonesia (Margono et al., 2001; Subahar et al., 2001; Wandra et al., 2000).

7. Perspectives of control using vaccines

The potential of a vaccine for controlling porcine cysticercosis has been described in the past (Flisser and Lightowlers, 2001; Lightowlers, 1989, 1990, 1997, 1999; Lightowlers and Gauci, 2001; Lightowlers and Rickard, 1993; Rickard, 1991; Rickard and Williams, 1982; Sciutto et al., 2002) and some promising results were also published (Johnson et al., 1989; Molinari et al., 1997; Nascimento et al., 1995; Plancarte et al., 1999; Sciutto et al., 1990). A successful vaccine that has the potential of interrupting the cycle should decrease over time the number of infected pigs and people. Nevertheless, the potential use of a vaccine will depend on its availability and cost (Gilman et al., 1999). Porcine cysticercosis is a zoonoziz in which the clientele for a vaccine would be rural endemic villages. A high priced vaccine would undoubtedly be an impediment to the use of a vaccine strategy. The result might mirror the hog cholera vaccine, which is effective and prevents a frequently fatal disease of pigs but is limited in most rural villages due to cost and inadequate distribution.

Significant problems with porcine vaccination will need to be addressed prior to its use in the field. There is some evidence that pigs become infected with *T. solium* early in life. If this is true, immunisation must be performed at an early age. Pigs immunised at an early age may not be able to mount an effective protective immune response to a vaccine due to the immaturity of their immune system. Alternatively, vaccinating pigs later in life may not be effective: if pigs are infected early in life and then vaccinated, the ability of the vaccine to eliminate an already established infection is poor (Gilman et al., 1999). It has previously shown that immunisation of pigs after infection is not an effective means of combating porcine cysticercosis (Evans et al., 1997). Also in young pigs, if
maternal antibody is present it may inhibit an effective antibody response to *T. solium* vaccines for a sizeable length of time, according to duration of passive antibodies (Gonzalez et al., 1999).

8. Concluding remarks

From the vast array of potential interventions against *T. solium*, only economic development has proven effective to achieve sustained eradication. A practical, cost-effective combination of interventions needs to be defined from reliable data, including trials in diverse geographical regions to ensure its potential applicability in other zones. We strongly believe that besides being culturally acceptable, this combination of interventions needs to take advantage of the economical factors that drive domestic pig rearing.

References


