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Review

Cysticercosis/Taeniasis in Asia and the Pacific

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ABSTRACT

Three taeniid tapeworms infect humans in Asia and the Pacific: *Taenia solim*, *Taenia saginata*, and *Taenia asiatica*. Although there is continuing debate about the definition of a new species, phylogenetic analyses of these parasites have provided multiple lines of evidence that *T. asiatica* is an independent species and the sister species of *T. saginata*. Here we review briefly the morphology, pathology, molecular biology, distribution and control options of taeniasis/cysticercosis in Asia and the Pacific and comment on the potential role which dogs may play in the transmission of *T. solium*. Special attention is focused on Indonesia: taeniasis caused by *T. asiatica* in North Sumatra, taeniasis/cysticercosis of *T. solium* and taeniasis of *T. saginata* in Bali, and taeniasis/cysticercosis of *T. solium* in Papua (formerly Irian Jaya). Issues relating to the spread of taeniasis/cysticercosis caused by *T. solium* in Papua New Guinea are highlighted, since serological evidence suggests that cysticercosis occurs among the local residents. The use of modern techniques for detection of taeniasis in humans and cysticercosis in humans, pigs and dogs, with the possible adoption of new control measures will provide a better understanding of the epidemiology of taeniasis/cysticercosis in Asia and the Pacific and lead to improved control of zoonotic and simultaneously meat-borne disease transmission. Key Words: *Taenia solium*—*T. saginata*—*T. asiatica*—Cysticercosis—Taeniasis—Asia and the Pacific—Indonesia—Papua New Guinea—Emerging and re-emerging zoonotic disease—Immunodiagnosis—Molecular diagnosis—Vaccine. Vector-Borne Zoonotic Dis. 4, 95–107.

INTRODUCTION

INFECTIONS IN HUMANS with the adult tapeworms of *Taenia* spp. (taeniasis) and in humans and animals with the metacestode stages of these parasites (cysticercosis) are recognized to occur in countries in the Asia-Pacific region (Ito 1992, Simanjuntak et al. 1997, Rajshekhar et al. 2003). However, their epidemiology in Asia has not been the subject of substantial scientific investigation. Relatively recently our understanding of this disease complex has improved following the recognition that, in addition to the pork tapeworm, *Taenia solium* and the beef tapeworm, *Taenia saginata*, a third *Taenia* species infects humans in Asia. Several decades ago it was recognized that taeniid cestodes expelled from local people in some areas of Asia appeared to be *T. saginata* (so called Asian *Taenia*), although the persons harboring the parasites ate pork but not beef (Kosin et al. 1972). The unique life cycle of Asian *Taenia* was demonstrated experimentally by Fan (1988) in Taiwan. In contrast to *T. saginata*, pigs act as

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the intermediate host where infective metacestodes develop in the liver. The metacestodes in pigs have only rudimentary or vestigial hooks, but adult tapeworms lack rostellar armature and in this regard are similar to *T. saginata*. Eom and Rim (1993) suggested this parasite to be a new species, *Taenia asiatica,* and provided the first full description with a justification for recognizing and naming the species. It is now clear that there are two sister species in Asia, *T. saginata* from beef and *T. asiatica* from viscera of pigs (reviewed by Fan 1988, Fan and Chung 1998, Eom and Rim 2001, Hoberg 2002, Pawlowski 2002, Ito et al. 2003a, 2003b). According to the criteria for the speciation of discrete biological entities, *T. asiatica* is expected to be an independent species and is the sister species of *T. saginata* (Hoberg 2002).

This brief review considers the present situation concerning human *Taenia* infections in Asia and the Pacific with special emphasis on the epidemiology of infections in Indonesia and Papua New Guinea (PNG). Advances in technology for diagnosis and cysticercosis control are also discussed.

Taenia species infecting humans in Asia and the Pacific

It is clear that human taeniasis and cysticercosis are present in Asia and the Asian-Pacific region. *T. solium* occurs in the majority of Asian countries, including China, India, Indonesia, Thailand, Laos, Cambodia, Nepal, Philippines, Myanmar, Vietnam, and Korea (reviewed by Singh et al. 2002), where local people consume pork. In PNG, serological studies have suggested that *T. solium* infections can be associated with the movement of Papuan refugees (Fritzsche et al. 1990, Wandra et al. 2003).

Pork is a staple part of the diet in China, especially in rural villages and *T. solium* cysticercosis is a serious public health issue in this country (Singh et al. 2002, Ito et al. 2003b). In southeast Asia, including the southern part of China and northern part of Vietnam, it is common for rural people to live in houses where pigs, dogs, and other animals are housed under the floors. Indeed, the Chinese character meaning "house" shows pigs kept under the roof (under the floor) and reflects the traditional way of life. Such a situation predisposes these communities to transmission of *T. solium* from human to pigs.

The situation with regard to taeniasis in humans in Asia should be re-evaluated based on features such as mitochondrial DNA (mtDNA) sequences that are able to differentiate *T. saginata* and *T. asiatica* (Zarlenga et al. 1991, Bowles and McManus 1994, Eom and Rim 2001, Nakao et al. 2002, Yamasaki et al. 2002, 2004). It is therefore necessary to engage in new and broad-based surveys across this region. Analyses using mtDNA have revealed that *T. asiatica* is distributed in Taiwan, China, South Korea, Indonesia and Vietnam (Eom et al. 2002, Willingham et al. 2003, Yamasaki et al. 2004). It is likely that it also exists in Thailand (Fan et al. 1990), the Philippines (Fan et al. 1992, Bowles and McManus 1994), and Malaysia (Bowles and McManus 1994).

Biology of the three human Taenia *species*

The three human taeniid species and their development in intermediate host animals are summarized in Table 1 (Ito et al. 2001, 2003a, Pawlowski 2002). The critical difference between *T. asiatica* and *T. saginata* is the preferred intermediate host of each species. *T. asiatica* utilizes the pig whereas *T. saginata* predominantly infects cattle. The cysticercus of *T. asiatica* is typically small, being about 2 mm in diameter, and occurs predominantly in the liver of pigs while *T. saginata* cysticerci may develop up to 10 mm in diameter and occur predominantly in the musculature of cattle. Figure 1 shows mature cysticerci of *T. saginata* and *T. asiatica* that developed in severe combined immunodeficiency (*scid*) mice, particularly in non-obese diabetic *scid* (NOD/Shi-*scid*) mice (Ito et al. 2001). *In vitro* hatched oncospheres of all these human taeniid species can develop into fully mature cysticerci in NOD/Shi-*scid* mice (Ito et al. 1997, 2001, reviewed by Ito and Ito 1998, Ito et al. 2003a). The potential for such development of cysticerci in model hosts provides an opportunity to obtain large quantities of parasite material for research and diagnostic purposes, particularly into *T. asiatica*, which is relatively difficult to obtain.

Based on molecular phylogenetic analysis, it has been revealed that *T. asiatica* is closely re-

TABLE 1. *TAENIA* SPECIES INFECTING HUMANS IN THE ASIA-PACIFIC REGION

Species	*Definitive host*	*Principal intermediate host(s)*	*Size of metacestode (mm)*
Taenia solium[a]	Human	Pig (human)[b]	5–8 × 3–6 (5–8 × 3–6[c])
Taenia asiatica	Human	Pig	2 × 2 (7–10 × 4–6[c])
Taenia saginata	Human	Cattle	7–10 × 4–6 (7–10 × 4–6[c])

[a]The number of hooks of the metacestode of *T. solium* grown in NOD/Shi-*scid* mouse is highly variable from 0 to 32 (Margono et al. 2003).
[b]Although humans are commonly infected with the metacestodes, these infections are not involved in subsequent transmission of the parasite (Hoberg et al. 2001).
[c]The size of metacestodes grown in NOD/Shi-*scid* mouse 150 days after inoculation of *in vitro* hatched oncospheres (Ito et al. 2001; unpublished).

lated to *T. saginata* with some distinct but minor differences in DNA sequence (Zarlenga et al. 1991, Bowles and McManus 1994, Hoberg et al. 2000, Eom et al. 2002, Ito et al. 2002b). The debate on whether this porcine parasite should be classified as a new species (*T. asiatica*) or a subspecies (*T. saginata asiatica*) has been the topic of considerable debate over the past decade (Fan et al. 1995, reviewed by Ito et al. 2003a, 2003b, Ito and Craig 2003). However, the

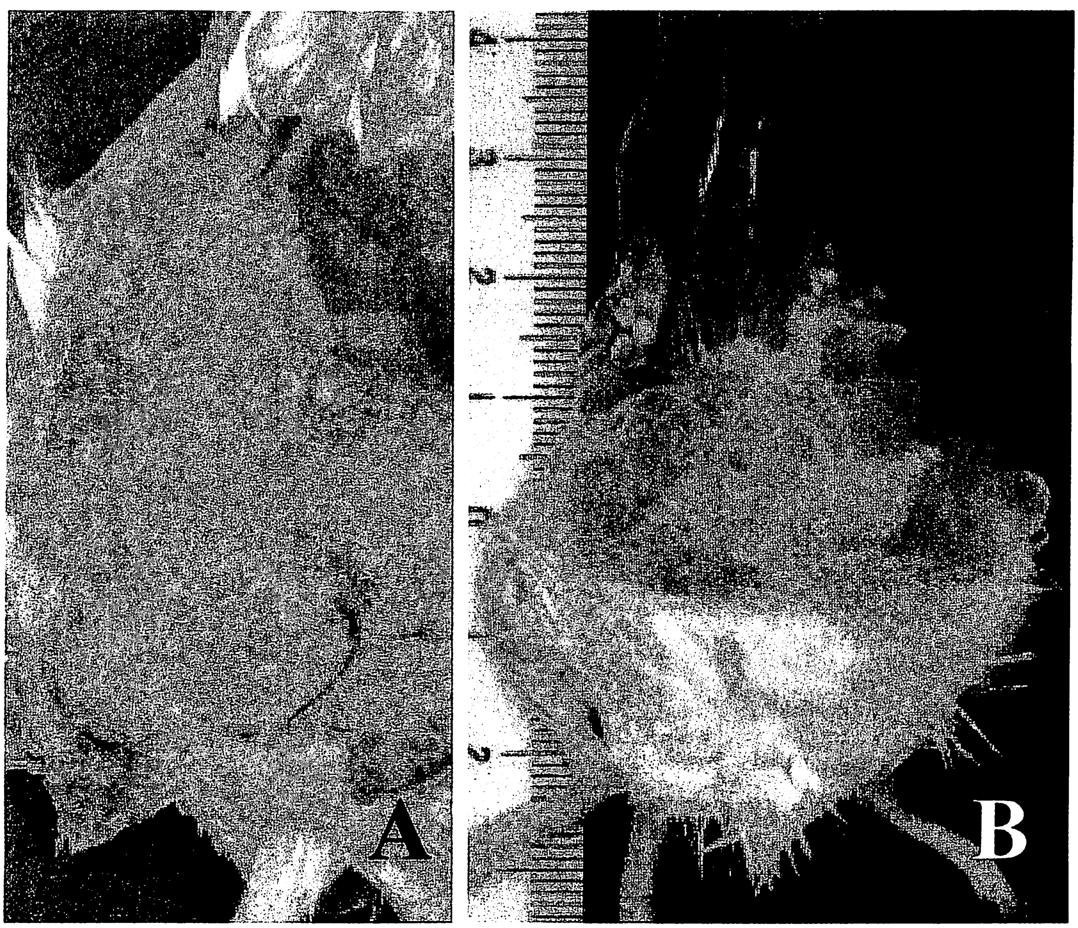

FIG. 1. Cysts of *Taenia saginata* (**A**) and *Taenia asiatica* (**B**) in NOD/Shi-*scid* mice 5 months after injection of *in vitro* hatched oncospheres.

extent of the evidence for *T. asiatica* being an independent species-level taxon is difficult to refute without any evidence of hybrids (Eom et al. 2002, Hoberg 2002). Available evidence suggests that *T. asiatica* does not cause cysticercosis in humans, as is also the situation with its sister-species, *T. saginata* (Ito et al. 2003a). The physiological basis for the differentiation between *T. saginata/T. asiatica* and *T. solium*, in this respect, remains unknown.

To date no evidence has been found to suggest the existence of genetic hybridization between *T. saginata* and *T. asiatica* in China where the two species occur sympatrically (Eom et al. 2002, Yamasaki et al. 2004), although the data available appear not to be sufficient as conclusive evidence. This may be expected to provide further evidence for assigning *T. asiatica* as a new species. However, as distinct from free-living animals and plants, parasites such as cestodes are often isolated as individuals within their human host with limited probability of simultaneous exposure to dual infections (Ito and Craig 2003, Ito et al. 2003a, 2003c, McCoy 2003, Meeûs et al. 2003). This is largely affected by traditional, cultural and religious factors. Therefore, as discussed previously (Ito et al. 2003b), it would be interesting to determine if these two species had the capacity to form hybrids if given the opportunity to co-exist in a single host. There is a report describing detection of out-cross of a related taeniid species, *Echinococcus multilocularis* (Nakao et al. 2003) and between sister species of *Schistosoma mansoni* and *S. rodhaini* (Morgan et al. 2003).

Techniques available for identification and diagnosis of taeniasis and cysticercosis caused by T. solium, T. saginata, *and* T. asiatica

The various techniques that are available for differentiation of the different species of *Taenia* in humans are summarized in Table 2 (Ito and Craig 2003). When proglottids are obtained from patients, preliminary differentiation of the parasite species can be made by observation of segment morphology. Where possible, it is also valuable to support morphological observations by analysis of mtDNA (Bowles and McManus 1994). Such DNA analysis, using PCR, can be undertaken using material obtained from proglottids, eggs or metacestode samples. In addition, the presence of taeniid DNA in fecal samples can be confirmed by copro-DNA analysis (González et al. 2000, Yamasaki et al. 2004) and a copro-antigen test can be used to detect taeniasis (Allan et al. 1990, 1996, 2003). Serological methods to detect specific antibodies in taeniasis (Wilkins et al. 1999, Nakao et al. unpublished) and cysticercosis (Tsang et al. 1989, Ito et al. 1998, Yang et al. 1998, Chung et al. 1999, Del Brutto et al. 2001) are also available for use with human serum samples as well as for animal intermediate hosts (Tsang et al. 1991, Ito et al. 1999, 2002a, Subahar et al. 2001, Sato et al. 2003). Alternatively, detection of circulating antigens is also available (Harrison et al. 1989, Brandt et al. 1992, Garcia et al. 2000, Nguekam et al. 2003, Ito and Craig 2004).

The situation with regard to the availability and type of serological assays for diagnosis of cysticercosis is changing. Currently, specific serology for *T. solium* cysticercosis is available from CDC, Atlanta (Tsang et al. 1989) and from Asahikawa Medical College (AMC) (Ito et al. 1998; reviewed by Ito and Craig 2003). The immunoblot developed at CDC utilizing a fraction of cysticercus glycoproteins has been recognized as the "gold standard" for serology of cysticercosis, however the same antigenic preparation was not effective when used in a simpler serological technique such as ELISA. More recently, glycoproteins purified using preparative isoelectric focusing at AMC have been found to contain very few contaminants and serological results in immunoblot and ELISA were very similar, allowing this preparation to be used for specific diagnosis of cysticercosis in ELISA (Ito et al. 1998, 1999, Sato et al. 2003). The biochemical and molecular characteristics of the diagnostic glycoproteins are being determined (Chung et al. 1999, 2002, Sako et al. 2000, Greene et al. 2000, Hancock et al. 2003) and it appears likely that defined recombinant antigens may eventually replace the glycoproteins derived from cysticerci that are currently being used (Hancock et al. 2004).

Little genetic variation has been detected among isolates of *T. asiatica* and considerably less than that observed for *T. saginata* (Yamasaki et al. unpublished). Molecular evidence

TABLE 2. IMMUNOLOGICAL AND MOLECULAR TECHNIQUES AVAILABLE FOR DIAGNOSIS/IDENTIFICATION OF TAENIASIS/CYSTICERCOSIS

Technique	*References*
Immunological techniques	
Detection of antibodies for cysticercosis in humans, pigs and dogs	Gottstein et al. 1986; Parkhouse and Harrison 1987; Tsang et al. 1989, 1991; Yang et al. 1998; Ito et al. 1998, 1999, 2002a; Chung et al. 1999; Sako et al. 2000; Wandra et al. 2000, 2003; Subahar et al. 2001; Del Brutto et al. 2001; Hancock et al. 2003; Sato et al. 2003
Detection of circulating antigens for cysticercosis in humans and pigs	Harrison et al. 1989; Brandt et al. 1992; Garcia et al. 2000; Nguekam et al. 2003
Serology for taeniasis in humans	Wilkins et al. 1999; Nakao et al. unpublished
Copro-antigen test for detection of taeniasis in humans	Allan et al. 1990, 1996, 2003
Molecular techniques	
DNA analysis for identification of taeniid species	Zarlenga et al. 1991; Bowles and McManus 1994; Eom and Rim 2001; Nakao et al. 2000, 2002; Yamasaki et al. 2002, 2004
Mitochondrial DNA analysis for identification of taeniid species and two genotypes of *T. solium* worldwide	Okamoto et al. 2001; Nakao et al. 2002; Yamasaki et al. 2002, 2004
Copro-DNA test	González et al. 2000, 2002a,b; Yamasaki et al. 2004

suggests that *T. solium* emerged several million years ago in Africa (Hoberg et al. 2001) and has differentiated into two genotypes: Asian and American/African (Okamoto et al. 2001) over a period of approximately one million years (Nakao et al. 2002; reviewed by Ito et al. 2002b, 2003b). While there are clear genetic differences between these two *T. solium* genotypes, no definitive evidence exists at this stage for there being other biological differences between Asian and American/African parasites.

Distribution of the three human taeniid species in Indonesia

In Indonesia *T. solium* is known to occur in Bali and in Papua (Irian Jaya) (Sutisna et al. 1999, Wandra et al. 2000, 2003, Subahar et al. 2001, Ito et al. 2002a, Margono et al. 2003, reviewed by Simanjuntak et al. 1997, Singh et al. 2002) while *T. asiatica* exists in the Batak ethnic communities in Sumatra, especially in Samosir Island in Lake Toba, North Sumatra (Kosin et al. 1972). *T. saginata* also occurs in Bali (Simanjuntak et al. 1977, Sutisna et al. 1999). *T. solium* taeniasis in Bali and *T. asiatica* taeniasis in Samosir Island are now not easy to detect because local customs have changed and people are tending to eat well-cooked pork especially on Samosir Island; also pigs are increasingly being grown with no direct contact with human feces particularly in Bali. However, the prevalence of *T. saginata* taeniasis is increasing in Bali where uncooked beef is now more commonly eaten by local people as the economic situation in Bali has improved. In many Asian countries people often eat pork when their economic situation is poor but when it improves, many people move to eating beef. In Bali, although the majority of the local population is Hindu (non-strict Hindu), the eating of uncooked minced beef with vegetable and coconuts is increasing in popularity and replacing uncooked minced pork with fresh pig blood, known as "LAWAR." Following a field survey in December 2002 in Bali, 29 local people from 125 villagers were confirmed to have taeniid cestodes. A total of 32 tapeworms were expelled after antihelmintic treatment and confirmed to be *T. saginata* by morphology and mtDNA analysis (Wandra et al. unpublished).

Human cases of *T. solium* cysticercosis continue to occur in Bali, but it is very difficult to detect *T. solium* taeniasis in Bali nowadays. There is no definitive evidence for the presence of *T. asiatica* in Bali, although 146 of 638 pigs (22.9%) at a slaughter house in Bali in 1998 were found to have cysts in the liver (Sutisna et al. unpublished).

Taeniasis/cysticercosis of Taenia solium *in Papua (Irian Jaya)*

New Guinea Island is divided politically into two countries. The western part was governed by the Dutch but more recently has been incorporated into Indonesia (from 1969) and called Irian Jaya until becoming known since 2000 as Papua. The eastern part, PNG was previously governed by Australia and is now an independent country. *T. solium* is the only taeniid cestode found in humans in Papua. An increasing flow of refugees from Papua entering PNG has been raising concerns with the PNG government that these people may carry infectious diseases and *T. solium* particularly, into PNG (Fritzsche et al. 1990, McManus 1995, Flew 1999, Wandra et al. 2003, Thompson et al. 2003, Ito et al. 2003a). A report which investigated the distribution of *T. solium* taeniasis/ cysticercosis in Papua and PNG has been published recently (Wandra et al. 2003). *T. solium* cysticercosis has been confirmed from Paniai, Jayawijaya and Manokwari Districts in Papua. Table 3 summarizes the results of serological investigations carried out on samples from 96 local people in Jayawijaya District, Papua. As there was no hospital where computed tomography (CT) or magnetic resonance imaging (MRI) could be used to confirm cysticercosis infection in individuals, it was only possible to check for subcutaneous nodules, known locally as "Biji-Biji," and positive serology using an immunoassay with specific glycoprotein antigens (Ito et al. 1998, Wandra et al. 2003, Margono et al. 2003). As summarized in Table 3, it was clear that the majority of the local people with a history of epileptic seizures and subcutaneous nodules were serologically positive for cysticercosis. Figure 2 illustrates the results of cysticercosis ELISA carried out on samples from 96 local people from Jayawijaya District. Subcutaneous nodules, removed from some individuals were analyzed morphologically and by mtDNA analysis and were confirmed to be the *T. solium* Asian genotype (Wandra et al. 2003). It was concluded that more than 80% of local people over 18 years old who had history of epileptic seizures and subcutaneous nodules from Jayawijaya were confirmed as having cysticercosis based upon serological and mtDNA analysis (Table 3). Approximately 30% of asymptomatic healthy people were serologically identified as positive for cysticercosis although follow-up investigations with these people indicated that many did have detectable subcutaneous nodules. Clearly the simplest method which can give a good indication of cysticercosis in very remote areas is physical examination for detection of subcutaneous nodules (Wandra et al. 2003, Ito et al. 2003a).

In many areas of Papua, local people live with free-ranging pigs and dogs, and latrines are rarely used hence these animals have free access to human feces. Serological analysis of pigs from Jayawijaya District, Papua revealed approximately 70% to be seropositive (Subahar et al. 2001). Furthermore, 11.0% (7/64) of local dogs in Jayawijaya, Papua were found to be

TABLE 3. SEROLOGICAL ANALYSIS OF 96 LOCAL PEOPLE IN JAYAWIJAYA DISTRICT, PAPUA 1996 FOR DETECTION OF SPECIFIC ANTIBODY RESPONSES AGAINST THE GLYCOPROTEINS OF *TAENIA SOLIUM* CYSTICERCI

Groups	*No. of persons examined*	*ELISA (%[d])*
ES[a]	17	12 (70.6)
With SCN[b]	12	10 (83.3)
Without SCN	5	2 (40.0)
SCN	32	20 (62.5)
Subtotal	49	32 (65.3)
HP at risk[c]	47	14 (29.8)
Total	96	46 (47.9)

[a]With history of epileptic seizures.
[b]With subcutaneous nodules.
[c]Healthy people at risk.
[d]Percentage of no. of seropositive persons/no. of examined persons (Fig. 2).
Original data from Wandra et al. 2003.

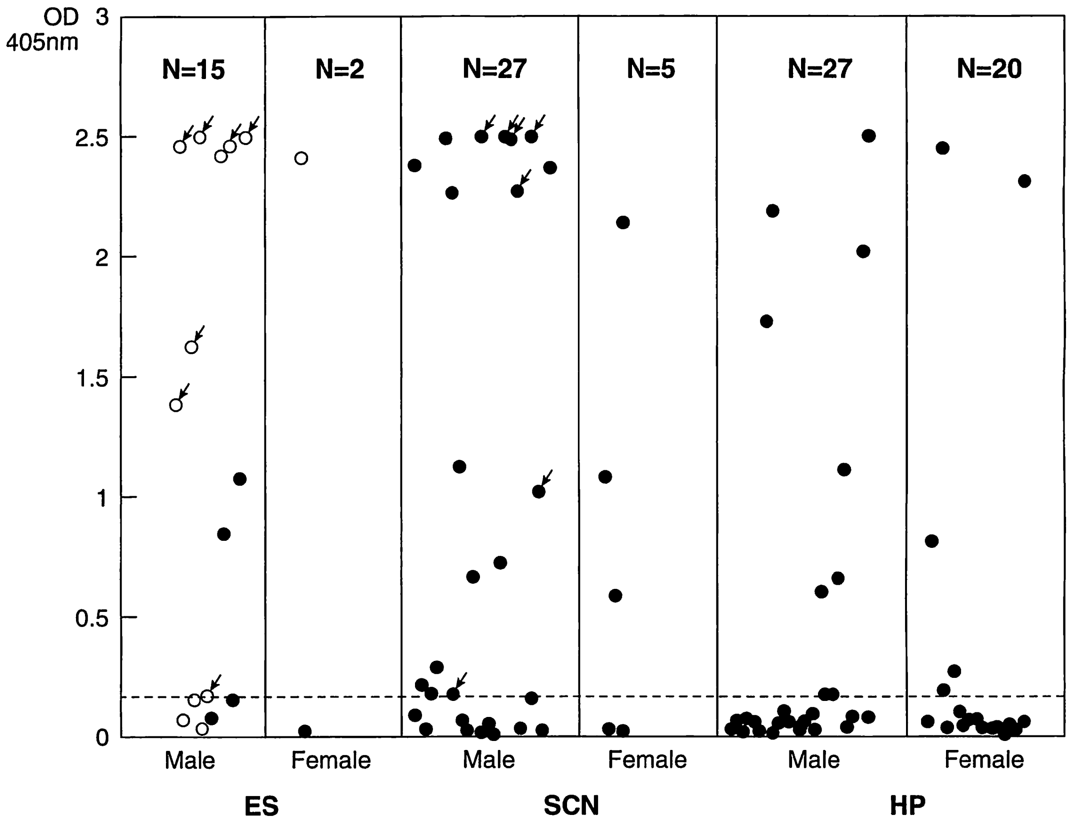

FIG. 2. ELISA results of 96 local people from Jayawijaya District in Papua, Indonesia 1996. ES, SCN, and HP groups represent individuals with a history of epileptic seizures, individuals with subcutaneous nodules and healthy individuals at risk, respectively (Table 3) (original data from Wandra et al. 2003). Open circles represent individuals with both ES and SCN. Arrows show 14 persons from whom subcutaneous nodules were resected and confirmed to be viable *T. solium* cysticerci by either morphological or mitochondrial DNA analysis. There was no difference in antibody responses in local people of cysticercosis with or without history of epilepsy.

positive in serological assays for cysticercosis and were subsequently confirmed to harbor viable *T. solium* cysticerci (Ito et al. 2002b).

Occurrence of T. solium *taeniasis/cysticercosis in PNG*

Investigations into the presence and distribution of *T. solium* from PNG are preliminary. Approximately 600 human serum samples from PNG have been tested for cysticercosis (Wandra et al. 2003, Ito et al. 2003a, Ito et al. unpublished). Approximately 3% of them were found to be serologically positive for cysticercosis. One (29-year-old) woman whose spouse was a Papuan refugee showed an antibody response typical of cysticercosis and reported occasional headaches indicating possible neurocysticercosis. Other positive cases showed relatively weak responses and were possibly exposed to eggs of *T. solium.*

The first suspected cysticercosis case was reported from a Papuan refugee (Fritzsche et al. 1990) who was serologically positive for cysticercosis using an immunoblot method (Gottstein et al. 1986). The detection of cysticercosis in non-imported cases may be crucial to suggest that *T. solium* might have been established in PNG even prior to the arrival of Papuan refugees (McManus 1995, Flew 1999, Thompson et al. 2003). Therefore, field surveys in local people and pigs to detect cysticercosis, by serology and post-mortem observation of cysts in pigs are matters of priority in studies investigating the distribution of *T. solium* in PNG and East Timor and other neighbor areas where the majority is Christian and eat pork (Ito et al. 2003a).

Possible role for dogs in the transmission of T. solium *cysticercosis*

Pigs are the principal intermediate host for *T. solium,* however numerous other species have been described as suitable intermediate hosts. In addition to pigs and humans as intermediate hosts of *T. solium,* Abuladze (1964) cited as hosts a variety of species of boar, pig and monkey as well as the dog, rabbit, hare, camel and bear. Many of these observations have relied on diagnoses based on parasitological features of the cysticerci, particularly the size and morphology of the rostellar hooks, and possibly include some cases of misidentification. However, there are numerous independent reports identifying cysticerci of *T. solium* in the domestic dog (*Canis familiaris*) from a variety of geographical sites (see literature cited by Abuladze 1964). More recently, experimental confirmation of the ability of *T. solium* to cause viable infections with cysticerci in the muscles of dogs was provided by Fan et al. (1994) using *T. solium* eggs from proglottids obtained from a patient in Hainan Province, China. As has been mentioned earlier, serological and necropsy examination of dogs in the Jayawijaya region of Papua have confirmed many to be infected with viable cysticerci of *T. solium*. Not only is there a large dog population in Indonesia (recently the Indonesian Ministry of Agriculture estimated the country's dog population to be approximately $^1/_{16}$ of the human population), but the consumption of dog meat by humans occurs frequently in Sumatra, Sulawesi, the Flores Islands, Java and Papua. The eating of dog meat is traditional and common in many other Asian countries, including Thailand, Vietnam, China, and Korea (see Hou 1983, Dissamarn and Indrakamhang 1985, Cui and Wang 2001). Furthermore, the eating of dog meat is known to occur in many non-Asian countries, including many parts of Africa, Latin America, and some European countries. Hence, the transmission of *T. solium* between dogs and humans could occur if the people were to eat undercooked meat from dogs infected with *T. solium* cysticerci. While this possibility has been recognized since the earliest descriptions of the presence of the larval parasite in dogs, the significance of this potential mode of transmission of *T. solium* to humans has not, to our knowledge, been the subject of specific investigation. This could be an important, previously underrecognized factor in understanding the epidemiology of *T. solium* transmission and may need to be given particular consideration in relation to future efforts to better understand the epidemiology of *T. solium* cysticercosis and taeniasis, particularly in Asia.

Potential strategies for control of cysticercosis in Asia

In the same way that improvements in sanitary conditions and public education which occurred over the past century in Europe have had a major impact of the transmission of taeniasis/cysticercosis, similar improvements in the standard of public hygiene and education are likely to reduce the impact of neurocysticercosis in Asian countries. Industrialization and intensification of pig-rearing practices could also be expected to lead to decreased potential for exposure of pigs to human feces and hence decreased transmission of *T. solium.* However, such changes are generally associated with increases in general living standards, and, for those communities in developing countries in which neurocysticercosis is a significant cause of human morbidity and mortality, other disease control measures are required in order to achieve disease control in the foreseeable future.

Effective anthelmintics are available to eliminate the adult tapeworm from *Taenia* carriers. However, while ever there exists a substantial reservoir of the parasites in pigs which can cause new cases of taeniasis, the potential remains for continued disease transmission. Theoretically, control could be obtained by sustained diagnosis and treatment of *Taenia* carriers, or by treatment of the whole population with anthelmintics sufficiently regularly so as to prevent the occurrence of any gravid tapeworms within the population. For *T. solium,* this would require treatment approximately every 3 months. It may be necessary to persist with such treatments while any infected pigs remain as a source of new infections in humans. Some success has been achieved in controlling *T. solium* through anthelmintic treatment of

Taenia carriers, public education, or both (Sarti et al. 2000); however, no examples exist where such measures have led to the sustainable control of the parasite. The difficulty with such an approach in the developing world is in the cost and hence sustainability of the control measures for a sufficient length of time.

The recent discovery of a single anthelmintic treatment that can eliminate viable cysticerci from pigs provides an important potential new control measure to assist with *T. solium* control (Gonzáles et al. 1996, 2001). A regime whereby all pigs were treated before slaughter would remove the source of *T. solium* taeniasis in humans. While this measure has the potential to play a valuable role in control of *T. solium*, it remains to be seen whether it is adopted widely for parasite control or whether the organizational structure required to administer it effectively, especially where informal slaughter occurs, will limit this as a control measure.

Recent research results point to the development of a potentially powerful new control measure for *T. solium* based on prevention of parasite transmission through pigs by application of a vaccine. Several research groups are active in the area, and early results look very promising. Two DNA based vaccines have been described as inducing protection against challenge infection in pigs with *T. solium* (Cai et al. 2001, Wang et al. 2003). Using a different approach, Huerta et al. (2001) have undertaken a field trial in pigs using synthetic peptides. The sequences of these peptides were based on the amino acid sequences of antigens discovered in the mouse model parasite *Taenia crassiceps*. Pigs vaccinated with the peptides showed a reduction in the number of animals having very high levels of infection. A vaccine which was capable of achieving this effect on a reliable basis could have an impact on the probability of transmission of the parasite to humans and, indirectly, reducing the incidence of both human taeniasis and neurocysticercosis.

An alternative approach which is being taken to vaccine development is through the application of recombinant oncosphere antigens. This approach has been successful in developing practical vaccines that reliably provide >95% protection against cysticercosis in sheep due to *Taenia ovis* and cattle due to *T. saginata*. These data have been reviewed recently elsewhere (Lightowlers et al. 2003). More recently, a similar approach has been adopted towards the development of a practical vaccine against *T. solium* infection in pigs. Oncosphere antigens have been cloned, characterized, and expressed, being the homologues of the 45W antigen (Gauci et al. 2001) and the 18K antigen (Gauci et al. 1998). Two independent trials have been completed in Mexico using these proteins (TSOL18 and TSOL45) as vaccines against experimental challenge infection with *T. solium* in pigs. In both trials, the TSOL18 antigen induced complete or near complete protection against the development of cysticerci following the challenge infection (Flisser et al. unpublished). Much further development work is required before this vaccine could be recommended for practical application and these studies have begun. Adoption of pig vaccination would be likely to be facilitated if the vaccine were able to be produced in an edible form. A number of aspects of *T. solium* taeniasis/cysticercosis suggest that this parasite may be eradicable (Schantz et al. 1993), and a case can be made for an effective control or eradication strategy based on treatment of *Taenia* carriers with anthelmintic while at the same time preventing pigs from acting as a source of new infections by application of an effective vaccine (Lightowlers et al. 1999).

One important consideration for control of *T. solium* transmission which may have particular relevance for Asia is the potential involvement of dogs as intermediate hosts for transmission of the parasite to humans. There is an urgent need for scientific investigation of the extent to which this mode of potential transmission of *T. solium* contributes to the epidemiology of the disease.

The medical consequences of infection with *T. saginata* or *T. asiatica* are substantially less than they are for *T. solium* and hence the urgency for adoption of disease control measures for these parasites are likely to be determined on economic grounds. As mentioned above, a vaccine has been developed which is very effective in preventing *T. saginata* infection in cattle. Given the close relationship between *T. saginata* and *T. asiatica*, the same vaccine may be effective also if used against *T. asiatica* infection in pigs.

CONCLUSION

T. solium, *T. saginata* and *T. asiatica* are all distributed in Asia. So far all *T. solium* specimens examined/tested from Asian countries are of the Asian genotype (Nakao et al. 2002). From a medical or public health point of view, *T. solium* cysticercosis has a very serious impact. A greater international focus is being placed on the health significance of neurocysticercosis. Recently, a proposal was presented for neurocysticercosis to become an internationally reportable disease (Roman et al. 2000) and in 2003 the World Health Assembly declared *T. solium* to be an important target parasite of public health significance worldwide and that it is an eradicable parasitic disease worldwide. The Japanese Government (Ministry of Education) has recommended the establishment of a medical/research network for the control of taeniid cestode zoonoses in Asia and Pacific regions from 2003 for three years. The main purpose of this new project would be to promote transfer of technology for taeniasis/cysticercosis and echinococcosis through collaborative projects. Grants for training at AMC will be available from this fund. Medical, public health, and veterinary staffs who have the responsibilities associated with control of cysticercosis and are interested in such training are invited to contact the senior author.

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