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# Epidemiology of Neurocysticercosis in Mexico: From a Public Health Problem to Its Control

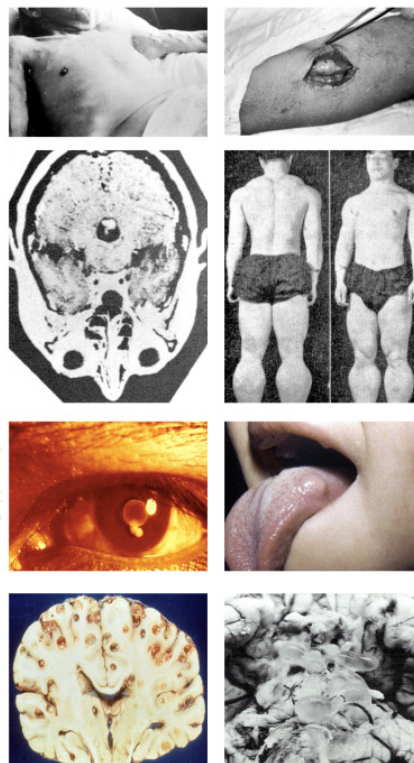
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<http://dx.doi.org/10.5772/53839>

## 1. Introduction

Cysticercosis is a parasitic disease of humans caused by the establishment of the larval stage of the cestode *Taenia solium* in several organs (Figure 1).

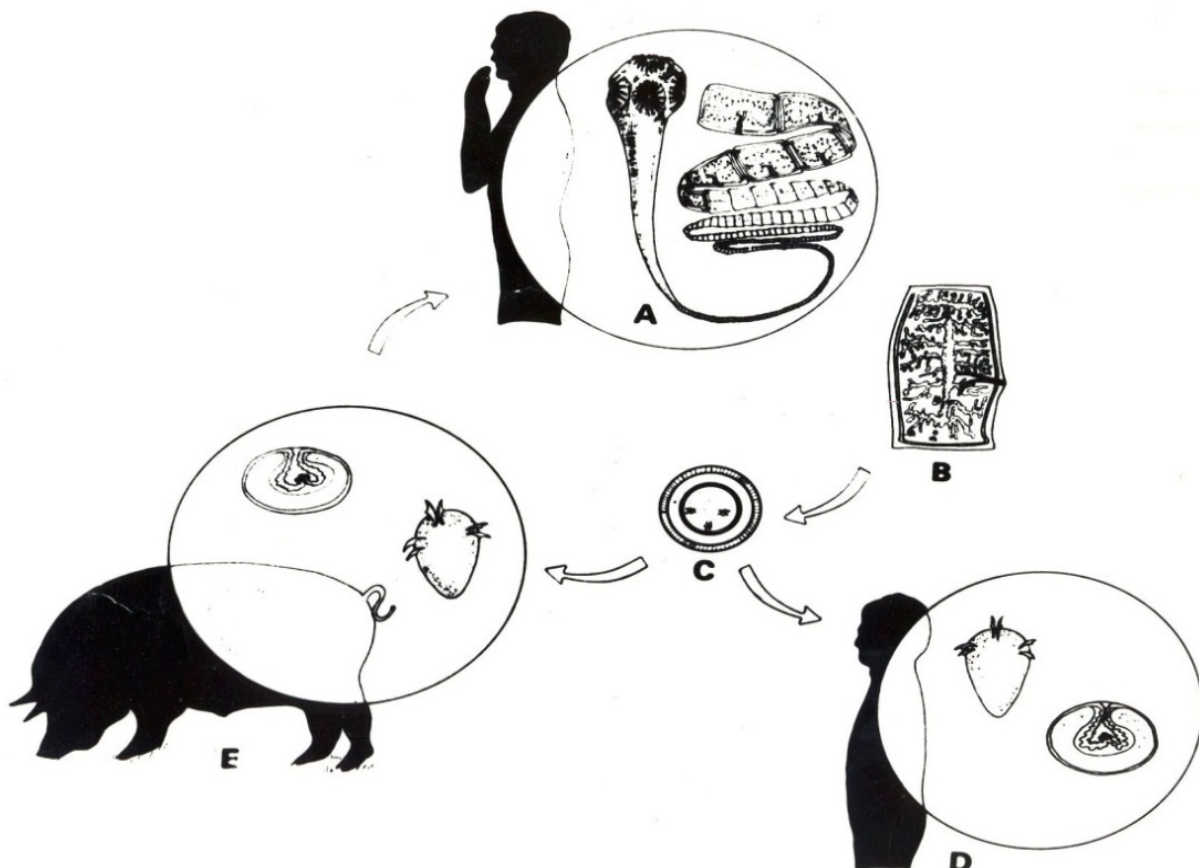


**Figure 1.** Images of cysticerci lodged in different locations. From top (left) to the bottom (right): disseminated subcutaneous cysticercosis, confirmed by biopsy, lingual cysticercosis, intramuscular (pseudohypertrophy), intraocular (anterior chamber), intraventricular (IV ventricle), multiple locations of cellulosa type and subarachnoid (racemose) neurocysticercosis.

The main clinical presentation is neurocysticercosis (NCC); it is due to the establishment of cysticerci in the Central Nervous System, where, depending on the specific location, can cause different symptoms, the main being epilepsy and hydrocephalus. Cysticercosis is a disease associated to poverty, lack of health education, inadequate hygienic habits and insufficient sanitary infrastructure; therefore it is common in underdeveloped countries. The life cycle of the parasite includes the human being, which is the only definitive host and, thus, lodges the adult tapeworm, which measures 1-4 meters long and is formed by a scolex, a neck and a long chain of proglottids that, as they are farther away from the neck, they develop into sexual maturity and, afterwards, gravidity.

Each gravid proglottid contains around 60,000 microscopic eggs; these segments are periodically released with feces. When outdoor defecation or improper latrines are found, pigs ingest feces; if contaminated with tapeworm eggs or proglottids, the embryos transform into the larval stage or cysticercus in the musculature and the central nervous system.

If humans eat insufficiently cooked or raw pork that is contaminated with cysticerci, the scolex evaginates, and with its double row of hooks and four suckers in the rostellum, anchors to the intestinal mucosa and, after a few months, a new gravid tapeworm initiates the life cycle (Figure 2) [1].



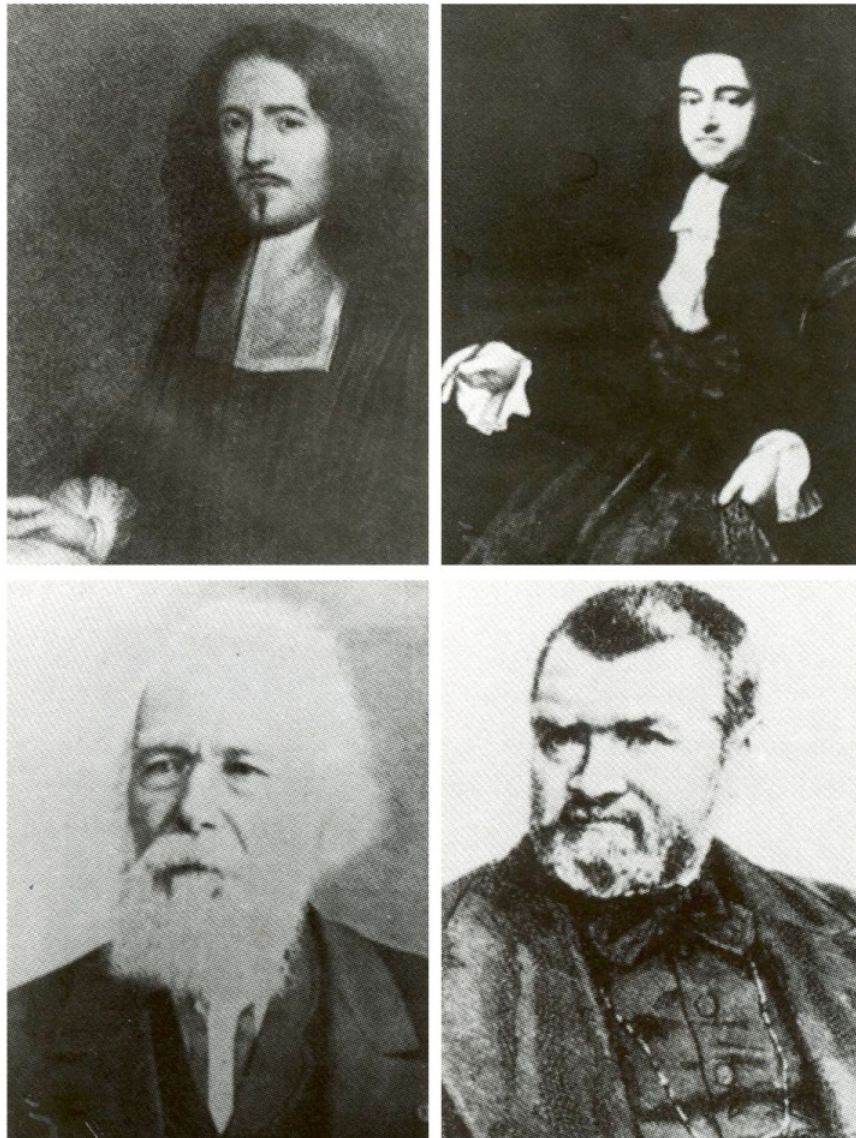
**Figure 2.** Life cycle of *T. solium*. A- Adult in the small intestine. B- gravid proglottid. C- infective egg containing an oncosphere. D- Human cysticercosis. E- Porcine cysticercosis an hexacanth oncosphere and an invaginated cysticercus are drawn.

Cysticercosis has been known since ancient times; it was detected in an Egyptian mummy by paleoparasitologists [2]. In a popular Greek theater play "The Knights" by Aristophanes, the slave Demosthenes says "We will set his mouth open with a wooden stick as the cooks do with pigs; we will tear out his tongue, and, looking down his gaping throat, will see whether his inside has any pimples" [3]. Egyptian and Greek cultures also distinguished tapeworms, but the relation between both developmental stages was not known. Probably Egyptians had *Taenia saginata* because they did not eat pork meat; Hipocrates, Aristoteles y Teofrastus called the worms "flatworms" while the Romans, Celsus, Galenus and Pliny the elder, called them "lumbricus latus" that meant "wideworm". At the beginning of the Christian era, some Arab authors such as Serapio, considered that each proglottid was a different worm and were named "cucurbitinum" not only because of their resemblance to pumpkin seeds, but also because these seeds were used to release tapeworms, and, interestingly, are still in use nowadays [4].

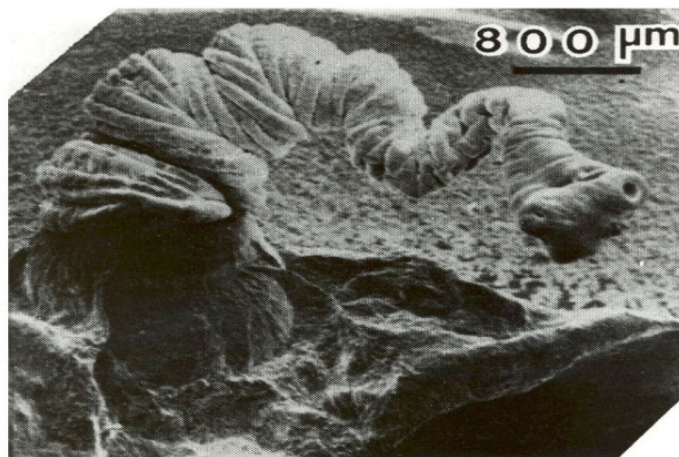
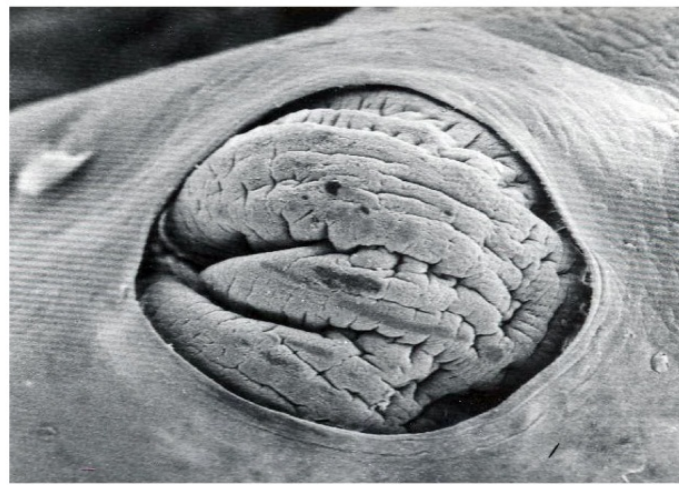
The species *T. solium* was described by Villanovani in 1585 and reflects the common finding of a solitary tapeworm, *T. solium* was differentiated from *T. saginata* and *Diphyllobothrium latum* by Tyson in 1683 who discovered and described the different types of heads or scolices of tapeworms; Redi published the following year illustrations of the scolex of dog and cat tapeworms. Van Beneden 170 years later stated that a tapeworm was an animal formed by multiple individuals and that cysticerci in pigs develop after ingesting *T. solium* segments. At that time Kuchenmeister, in spite of severe ethical criticisms, identified that humans are the hosts of the adult stage of *T. solium*. In two occasions (1854 and 1859) he fed death convicts with 63 and 40 cysticerci each, and found developing tapeworms in the small intestine after necropsy. Interestingly the number of tapeworms found was 10 and 20 respectively and, since the second prisoner ingested the bladder worms much before death than the first convict (four months vs 4 days) 11 worms had mature proglottids and the largest reached five feet (1.5 meters) in length. This finding further demonstrates that *T. solium* is not necessarily a solitary parasite. He stated that the sheer number of tapeworms produced ought to convince even the most skeptical that they were derived from the cysticerci that the convicts ingested. Nevertheless he recommended that the experiment of bladder worm feeding should be allowed to be repeated on criminals under death sentences and, in the case of subsequent pardon, the tapeworms could be easily expelled, calming anxious souls and serving science at the same time [4]. Figure 3 shows pictures of some of the scientists that made outstanding contributions to the understanding of the life cycle of *T. solium*: Malpighi, Tyson, van Beneden and Kuchenmeister. Not until last century the precise knowledge of the complete anatomy of a tapeworm, as well as its organization and individuality were defined, considering it a single animal.

Rumler was the first clinician that described a case of human cysticercosis in 1558 but considered it to be a tumor in the dura matter of a person with epilepsy. Panarolus, one hundred years later, reported similar cysts in the corpus callosum of the brain of an epileptic priest and Wharton found many cysticerci, that he considered to be glands in the adipose and muscle tissues of a soldier. The disease was not clearly identified as parasitic until

Malpighi in 1698 discovered the animal nature of these cysts and described their scolex. Goeze, not knowing this study, examined swine cysticerci and described their helminthic nature. The taxonomic classification of "*Cysticercus cellulosae*" was given by Zeder and Rudolph [4]. The use of a scientific name for this parasite was abolished when it was demonstrated that cysticerci are larval stages of *T. solium*. Therefore, when mentioning cysticerci it should only be stated "*cellulosae* type of *T. solium* cysticerci" or simply "*T. solium* cysticerci". Yoshino published detailed histological descriptions of the development of cysticerci, including the formation of the scolex and the size and appearance of its hooks, after he fed proglottids to pigs, released by him because he ingested cysticerci [5-8] and Rabiela demonstrated that there are intermediate forms between a cellulose and a recemose type cysticercus and that cysticerci evaginate through a pore. (Figure 4) [9, 10].



**Figure 3.** Photographs of M. Malpighi, E. Tyson, P.J van Beneden and F Kuchenmeister



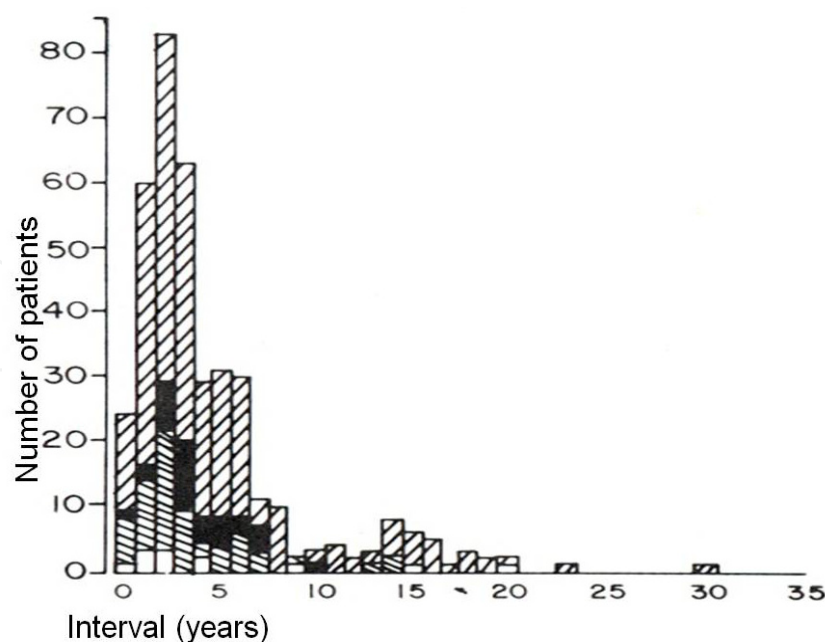
**Figure 4.** Micrographs of the evagination pore of a cysticercus and an evaginated cysticercus as well as a photograph of a bilobulated cysticercus; its appearance suggests the beginning of transformation from a cellulosae to a racemos type cysticercus. Kindly donated by Dr. Maria Teresa Rabiela (RIP)

The first report regarding NCC in Mexico, probably lost in the old Mexican literature, was published in 1901; the author, Dr. Ignacio Gómez-Izquierdo, described a patient from Cuba who died in a psychiatric asylum with diagnosis of alcoholism or tuberculosis. During necropsy multiple cysticerci were found. The author stated his doubts regarding the disease: "Diagnosis is almost impossible, because, with the exception of those cases in which

cysticerci are found in superficial tissues or in the eye, symptomatology by itself does not provide enough information in order to establish its diagnosis, and, if diagnosis could have been done with precision, would prognosis stop to be fatal? Are there medical or surgical treatments to successfully fight this disease? Our answer, sadly to say, is negative" [11]. The questions posed by Dr. Gómez-Izquierdo 110 years ago have illuminated the path of knowledge and reflect major advances in the last 30 years because NCC is diagnosed and treated with high efficiency and its fatality rate has dramatically diminished [12,13].

## 2. Epidemiology

Human cysticercosis was considered in the past to be less frequent than taeniosis due to the possibility of finding a tapeworm in feces, while muscle cysticerci mostly do not cause clinical signs and neurocysticercosis generally could not be identified due to its pleomorphic symptomatology [14,15]. Interest in NCC arose after Dixon and Lipscomb identified soldiers that acquired NCC when they were stationed in India [16]. This study is the only one that allowed identifying the duration of the disease and of the appearance of clinical manifestations, since it became clear when soldiers acquired NCC while stationed in India. Figure 5 shows a histogram of the time when soldiers presented the first convulsive crisis and/or subcutaneous nodules; as it can be seen in around 50% symptoms appeared two to four years after being in India, and cases were also identified as far as 30 years afterwards. MacArthur suggested that symptomatology was due to the death of parasites and suggested that the biological objective of cysticerci, while in the tissues of the intermediate host, is to remain silent in order to be able to continue their life cycle. He also suggested that parasite death could be associated to toxin release that increases irritation [17].



**Figure 5.** Histogram showing the interval in years in which signs and symptoms related to cysticercosis appeared in 450 soldiers after they returned from being stationed in India. Convulsive crisis (///), subcutaneous nodules (\\ \\), both (black) or other data (white), reproduced from [16].

Because human cysticercosis is a disease related to underdevelopment, it is present in countries that lack proper sanitary infrastructure and hygiene as well as insufficient health education [15,18,19]. An outstanding example is the emergence of neurocysticercosis in West New Guinea among the Ekari population, to whom the disease was unknown prior to the entrance of cysticercotic pigs as official gifts. Some 18-20% of the population acquired cysticercosis. The disease was detected by an epidemic of severe burns resulting from convulsions manifested while the people were sleeping around house fires; individuals also had subcutaneous nodules [20]. Between the 1940's and 1970's several reports of human necropsies performed in Latin America revealed the presence of cysticerci in the brain with different frequencies, so high that NCC is considered a public health problem in some countries [15,21,22]. As it can be seen in table 1, necropsies performed in Mexico reported an average of 2% of NCC. In addition, hospital-based reports provided data on the magnitude of cysticercosis in patients; the National Institute of Neurology and Neurosurgery reported a prevalence of 6% among its neurological patients [23]. This prompted the development and standardization of immunodiagnostic assays, and the detection of specific serum antibodies facilitated the shift to epidemiological information instead of that coming from autopsies, because these do not strictly represent the Mexican population since they were performed in people dying in public government hospitals, while seroepidemiological surveys are performed in open populations including both rural and urban settings [24].

Country	Years reported	%
Peru	1961-1974	5.9
Mexico	1947-1957	2.8
Brazil	1960-1979	2.4
Brazil	1965-1970	2.2
Mexico	1963-1974	2.2
Brazil	1992-1997	1.5
Mexico	1963-1973	1.5
Mexico	1953-1970	1.3
Peru	1961-1974	0.99
Colombia	1944-1964	0.78
Chile	1939-1966	0.70
Venezuela	1967	0.49
Ecuador	1947-1968	0.47
Costa Rica	1967	0.45
Colombia	1955-1970	0.40
El Salvador	1961	0.40
Chile	1947-1979	0.09
Honduras	1951-1966	0.02

**Table 1.** Frequency of neurocysticercosis in necropsies



For the first seroepidemiologic studies reported in Mexico, immunoelectrophoresis was used, initially in communities in the state of Chiapas: 1610 samples obtained from 9 communities, mostly rural, were analyzed. Interestingly, in spite of the low sensitivity of immunoelectrophoresis (50%), its high specificity (100% because practically no echinococcosis is found in Mexico) allowed to identify a clear correlation: communities with less than 4000 inhabitants had 1-8% seropositivity, while populations with more inhabitants (35,000 was the biggest) had 1% or less antibody frequency; indicating that the parasite was more prevalent in small, and thus less developed, towns [25]. Afterwards, using 20,000 samples from a national survey, a central area in Mexico, in which people had between 0.6 and 1% of anti-cysticercus antibodies, was identified; remarkably this geographic area, called "El Bajío", is the most important pig breeding area for national consumption of pork meat [26]. A few years later, in El Sotano, a small community in the state of Hidalgo, 6% of the 124 inhabitants had antibodies detected by ELISA, 25% of their pigs had cysticerci that were palpated in their tongues and 3% of the people had *Taenia* eggs. *Ascaris*, *Trichuris* and *Toxocara* eggs were found in soil samples but no *Taenia* eggs were identified in soil. The clustered distribution of infected pigs, tapeworm carriers and people with serologic or clinical evidence of cysticercosis suggested intra-household transmission. Furthermore, although the correlation of seropositivity and clinical history suggestive of NCC in individual residents was poor, there was an apparent spatial association between tapeworm carriers and persons with serologic or clinical histories associated to NCC [27]. This information was very interesting because it identified, for the first time ever, the main risk factor for NCC: the presence of a person infected with an adult tapeworm at home (which I consider my most important contribution to the control of NCC), instead of egg transmission through strawberries, lettuce, coriander and any other vegetable grown at floor level, eaten unpeeled, uncooked and probably unwashed, that could have been irrigated with sewage.

In a study undertaken in order to determine markers of *T. solium* transmission and risk factors in an urban community, 1000 soldiers from a military camp in Mexico City and their families were studied. Serum samples were used to detect cysticercus antigens and antibodies and fecal specimens were examined for *Taenia* coproantigens (CpAgs) and eggs. Antibodies were detected in 12.2% of soldiers and 5.8% and 10% of relatives of positive and negative soldiers, respectively. Antigens in serum were detected in 2.8% of the soldiers and in 4.2% of the relatives of antibody-positive soldiers. CpAgs were found in 0.5% and *Taenia* eggs in 0.1% of soldiers but were not found in their families. Interestingly, 12% of the family members of positive soldiers had had a history of proglottid release, compared to only 3.7% of the family members of negative soldiers. Lastly, 86% of the family members of positive soldiers had eaten in street food stores, compared to only 62.5% of those of negative soldiers. Both risk factors identified were statistically significant, indicating again, that the main risk factor was an association with the presence of a tapeworm carrier at home confirming its importance for the transmission of *T. solium* [28]. Therefore, a clinical history of taeniosis in a family member, defined as elimination of proglottids in feces, should be taken into account by health personnel in order to be treated in spite of being asymptomatic, and to prevent other members of the family from becoming infected. Likewise, public health authorities should control street food vendors to reduce new cases of *T. solium* infections by

means of hygienic and sanitary measures. The results obtained support that the prevalence of human cysticercosis in Mexico was, as indicated by previous necropsy findings, around 2%, while the prevalence of antibodies was much higher, suggesting exposure to the parasite but not current infection. In another national survey, using indirect hemagglutination, a similar antibody prevalence was found (15% of the 11,611 homes analyzed), and 2.2% had two or more seropositive members, pointing to the presence of an intestinal tapeworm carrier [29].

Many epidemiological surveys were performed with ELISA in the 1980's, supported by direct detection of cysticerci in pigs' tongue and tapeworm eggs in human feces [27, 28, 30-34] and, in the 1990's, by western blot (WB) [27, 30, 35-41] using an enriched fraction of glycoproteins as antigen source [42] allowing the demonstration of the presence of all the components of the life cycle (Tables 2 and 3), [24]. Table 3 also shows that swine cysticercosis is higher in Peru, suggesting that Peruvian pigs have easier access to human feces. Furthermore, one survey was performed in two rural communities of Mexico in order to compare the performance of both assays; 2524 individuals were studied, 7.5% were positive by WB, 2.1% by ELISA and only 3.1% in both assays [43]. Reports of predictive values indicate that for screening purposes, WB would be the test of choice, and for diagnosis, performing WB and CT tests would yield the best results, although with clinical data suggestive of NCC even ELISA is useful to support diagnosis [24].

Community studied, state	Year	Number of samples	% pigs with tongue cysticerci	% people with eggs in feces	% people positive in ELISA
El Sótano, Hidalgo	1984	124	24	3.1	6
San Pedro Martir, DF	1985	928	0	0	0
El Salado, Sinaloa	1986	432	Present	1.2	12
Los Sauces, Guerrero	1987	440	6.6	3.0	2.3
La Curva, Sinaloa	1989	549	1.4	1.3	11

**Table 2.** Epidemiologic studies performed with ELISA for detection of people with anti-cysticercus antibodies

When data from table 1 are compared to those of tables 2 and 3, it is evident that the prevalence of anti-cysticercus antibodies in humans (2.3-24%) is much higher than the finding of the parasite in pathology studies (0.02-5.9%), indicating that antibodies reflect exposure and not necessary the presence of the parasite; its serologic confirmation can be obtained by detecting cysticercal antigens. One survey used monoclonal antibodies in a capture ELISA [44,45] in 900 inhabitants of the community of Cerritos, San Luis Potosí, 1% positive samples for antigens and 4.2% for antibodies were found, only one sample was positive in both tests. Interestingly, although antigen detection was lower, two of the three positive cases that accepted undergoing computed tomography (CT) had images compatible with cysticerci, while only two of the seven antibody positive individuals had CT images resembling cysticerci [46]. These data point to a higher correlation with the disease in open populations when parasite antigens are being searched than when antibodies are detected.

Another field study showed an association between the presence of antigens and that of late onset epilepsy, while antibodies were associated to the presence of subcutaneous nodules; furthermore specificity and positive predictive values for the antigen capture ELISA was high with samples of epileptic people [47]. It has also been demonstrated that this capture ELISA is useful to evaluate symptomatic patients, who can benefit with immediate treatment [48]. Similar studies have been implemented in the last decade in Asia and Africa.

Community studied, state	Year	Number of samples	% pigs with tongue cysticerci	% people with eggs in feces	% people positive in WB
Xoxocotla, México	1988	13227	4	0.3	11
Angahuan, México	1988	3065	6.5	0.5	5
Churusapa, Perú	1988	279	49	1	7
Maceda, Perú	1988	421	43	1	8
Haparquilla, Perú	1990	365	46	ND	13
Jocote, Guatemala	1991	1161	14	3	17
Quesada, Guatemala	1991	1204	4	1	10
Saylla, Perú	1990-3	501	36	3	24
San Pablo, Ecuador	1992	2723	ND	ND	10
Tegucigalpa, Honduras	1998	404	ND	0.6	16
Salama, Honduras	1999	480	ND	2.5	17
Cd. de México, México	1999	1000	ND	0.5	12

**Table 3.** Epidemiologic studies performed with western blot for detection of people with anti-cysticercus antibodies

### 3. Risk factors and intervention trials

It has been considered for a long time in Mexico that fruits, such as strawberries, and vegetables, such as lettuce, that are eaten unpeeled and uncooked and that grow at ground level, are the main sources of *Taenia* eggs that cause human NCC. But in a study carried out in the counties of Irapuato in the state of Guanajuato and Zamora, Michoacan, which are important locations for the production of strawberries, no *Taenia* eggs were identified in large amounts of homogenized strawberries collected throughout one year but low numbers of protozoan cysts and one *Ascaris* egg were found [49]. This indicated that, although there was contamination with human feces, strawberries did not carry tapeworm eggs. Also, the absence of *Taenia* eggs in domestic flies was demonstrated in the community of Tianquizolco, where over one thousand flies were caught in homes and assessed for their role in the transmission of *Taenia solium* [50]. On the other hand, multiple studies have demonstrated that the prevalence of tapeworm carriers is higher among household members of NCC patients than in the rest of the population [27,51, 52]. For transmission of NCC the importance of a tapeworm carrier in the household and not of egg ingestion in strawberries or of contaminated flies changes the concept of control, since it is much easier

and cheaper to treat tapeworm carriers than to modify sewage and irrigation in developing countries with huge territories.

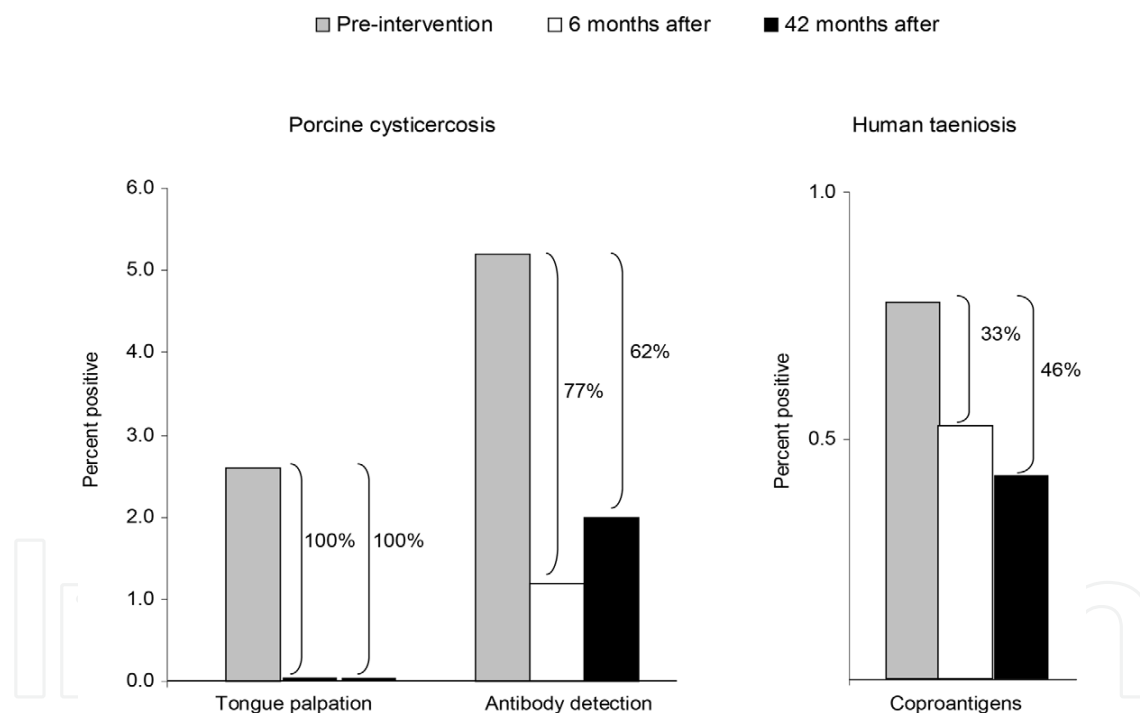
A clear association exists between the presence of taeniosis and the severity of NCC, therefore the perception that *T. solium* tapeworms are silent guests causing no harm to humans is erroneous, and tapeworm carriers should be regarded as potential sources of contagion to both themselves and to those living in their close environment [53]. Just how important is the presence of a tapeworm carrier was demonstrated by the case of 4 orthodox Jewish families from New York, in which 4 neurological cases and 7 seropositive people were along two years after. Although these families did not ingest pork meat, the maid who cooked for these families was from Mexico and she had an intestinal *T. solium* [54].

The information presented above clearly demonstrates a clustered distribution of persons with serological or clinical evidence of cysticercosis, infected pigs and tapeworm carriers, thus allowing to evaluate intervention measures: health education, self-detection of tapeworm carriers, mass treatment against human taeniosis and pigs vaccination. Regarding health education as a community-based intervention measure, a comprehensive study was undertaken in Chalcatzingo, Morelos with approximately 2000 inhabitants. An educational program was developed to identify the local knowledge of both diseases (taeniosis and cysticercosis) and of both parasites (the tapeworm and the cysticercus), in order to promote recognition of the parasites and knowledge of the transmission, and to improve hygienic behavior and sanitary conditions that foster transmission. This was performed by in-depth questionnaires developed by anthropologists. Based on the information obtained, an educational intervention was developed which included explanation of the life cycle, diseases, risk factors and control measures. For this purpose the anthropologists trained local leaders, selected among students, housewives, and teachers as well as the priest, to be in charge of promoting and providing health education, so that education remained in the community after the project ended. The effects of this educational intervention were evaluated by measuring changes in knowledge, attitudes and practices (Table 4) and prevalences of human taeniosis and swine cysticercosis before and after the campaign [56]. The prevalence in pigs at the start of the education intervention was 2.6% and 5.2% by tongue examination and western blot for antibody detection, respectively. Approximately one year after the intervention they were 0% and 1.2%, respectively, and remained so for almost 4 years. (Figure 6) [57].

Apparently an economic factor facilitated the success, since people learned that by having pigs restrained in certain areas without access to human feces or garbage they would not acquire the disease and thus could be sold at a higher price. In Coapeche, Veracruz, where swine cysticercosis was ascertained by western blot, none of the 53 pigs studied had antibodies or cysticerci. Latrines were present in 91% of houses and pigs were kept in restrained areas, demonstrating that adequate basic sanitary conditions and pig breeding practices are effective and practical to control *T. solium* in rural communities [58]. High standards of meat inspection and proper disposal of infected pig carcasses will also aid in preventing infected pigs from entering the food chain.

Effect detected by the anthropologic questionnaire	Before intervention	After intervention	At 6 months	At 42 months
Chalcatzingo (Health education)	%	%	%	%
Free roming pigs	29	9	6	4
Pigs that ingest feces	31	16	14	0
Outdoors fecalism	49	47	44	21
Atotonilco (Cestocidal treatment)	%	%	%	%
Free roming pigs	18	16	40	3
Pigs that ingest feces	20	22	15	3
Outdoors fecalism	50	45	45	39
Tetelilla (Both interventions)	%	%	%	%
Free roming pigs	48	32	17	14
Pigs that ingest feces	40	38	30	17
Outdoors fecalism	78	70	60	52

**Table 4.** Main effects of the intervention as per the anthropologic questionnaire



**Figure 6.** Effect of health education provided to the community of Chalcatzingo, Morelos, Mexico. Evaluation of porcine cysticercosis was measured by tongue palpation and serum antibodies detected by Western blot, while that of human taeniosis was measured by coproantigen detection. Assessment was performed before intervention ( $n = 1,404$  for humans and 194 for pigs), 6 months later ( $n = 792$  for humans and 165 for pigs), and 42 months later in 1996 ( $n = 605$  for humans and 334 for pigs). Reproduced from [57].

Self-identification of tapeworm carriers as a community based intervention, alternative to health education, was evaluated in the municipality of Irapuato, Guanajuato. Clinical and animal health care practitioners and schoolteachers were trained in the life cycle, risk factors

and control measures related to infection with *Taenia solium*. Over 120 small glass bottles, each containing a few tapeworm segments fixed in formaldehyde and an instructional guide were distributed among all clinical practitioners (physicians and nurses) working in health centers. The guide contained 10 key points on how to ask questions about tapeworm infections. The small bottles were shown during questionnaire administration to all people that attended the clinic for any medical reason in order to determine if they had seen such parasites in their feces or their family. Information on taeniosis and cysticercosis was also provided to the general population via different media. Seven tapeworm carriers were recorded in the official epidemiology surveillance system the year previous to the study, interestingly, the year after the study, 41 tapeworm carriers (37 *T. saginata*; 4 *T. solium*) were recorded. Thus six times more tapeworm carriers were notified after the study. All four persons with *T. solium* were treated, thereby eliminating the parasite and subsequently preventing new cases of human and swine cysticercosis that might have arisen [59]. This study demonstrates that self-detection is a feasible tool for control of *T. solium*.

The use of mass treatment with praziquantel to eliminate tapeworms from human carriers as a community-based intervention measure was evaluated in two studies. In a small community (559 inhabitants) in La Curva, Sinaloa, over 70% of the population over 5 years of age was treated with a 10 mg/kg dose. One year later, no infections with *Taenia* sp. eggs were found and no pigs with cysticercosis were detected. Seropositivity using ELISA was 11% before treatment and 7% afterwards, in the 30-39 year age group, antibody detection decreased from 30% to 7% suggesting that elimination of tapeworms reduces the possibility of contact with infective eggs. Interestingly, in the geographic section of the community where 3 of the 4 tapeworm carriers were found and treated, seropositivity was reduced from 19% to 2%, indicating that serum antibodies to *Taenia* antigens are short-lived and diminish, as contact with the parasite is lost [34]. In the second study performed in Atotonilco (3007 inhabitants), 87% of the community received a single dose of 5 mg/kg following a recommendation from WHO [60]. The prevalence of taeniosis was reduced by 53% after 6 months and by 56% after 42 months, as measured by CpAg ELISA or egg detection; late onset general seizures decreased by 70%. Anti-cysticercus antibodies in the human population were reduced by 75% after 42 months and antibodies in pigs also showed a significant reduction (55%) after 6 months [61]. In conclusion, the impact of mass chemotherapy against taeniosis to control cysticercosis in the short and long term was successfully demonstrated. Experience with praziquantel however suggested that it should not be given at doses lower than 10mg/kg. This population-based cestocidal treatment eliminated tapeworm carriers but generated symptomatology in a previously asymptomatic neurological case [62]. This observation highlights the importance of weighing targeted treatment, instead of mass drug administration, which can be used since potential tapeworm carriers are identified by direct questioning or by detection of parasite antigens or eggs, as well as by association with late onset epilepsy.

Another alternative for the control of cysticercosis is vaccination, especially because pigs are the only intermediate hosts that participate in the maintenance of the parasite in the environment. Based on the high protection obtained with recombinant antigens identified in *T. ovis* and *T. saginata* [63, 64], recombinant vaccines against *T. solium* were elaborated. For

this cDNA from a genomic library from a *T. solium* tapeworm was prepared and with probes from *T. ovis* 18k and 45k antigens, the homologue recombinant DNAs were identified and cloned in *E. coli*. The oncosphere recombinant antigens were purified and used to vaccinate pigs in two independent trials performed in different institutions under controlled conditions. The first one was in 2000 and the second one in 2002. Each pig received 200ug of recombinant antigen TSOL18 or TSOL45 or the carrier, Glutathione S Transferase (GST) as a control group, with 1mg Quil A as adjuvant, intramuscularly each 15 days, in two occasions in the first experiment and thrice in the second one. For challenge, gravid proglottids were separated from a tapeworm recovered from a carrier. Proglottids were minced; eggs were obtained by sieving, washed, counted and used to challenge pigs 3 weeks after the 2nd or 3rd immunization, respectively. Each pig received orally 40,000 eggs in the first experiment, and 9,000 in the second one. Necropsies were performed 3-4 months after challenge infection, carcass musculature was sliced with hand-held knives or scalpels, and the number and viability of cysticerci were determined. Table 5 shows the results of both vaccination trials. Protection was calculated as the percent reduction in the mean number of cysticerci in each group in comparison with the mean number of cysticerci in the control group; as it can be seen, in both experiments TSOL18 give practically full protection. TSOL45 gave a high value of protection in the second experiment but no protection was detected in the first one [65].

Number of cysticerci in experiment 1 (infected with 40,000 eggs per pig)		X	Protection (%)
GST	167, 206, 234, 262, 415	257	
TSOL18	0, 0, 0, 0, 0	0	100
Number of cysticerci in experiment 2 (infected with 9,000 eggs per pig)		X	Protection (%)
GST or PBS	6, 10, 11, 13, 17, 26, 28, 40, 59, 64, 100,127	42	
TSOL18	0, 0, 0, 0, 1	0.2	99.5

**Table 5.** Number of cysticerci found in individual pigs

The humoral immune response of all pigs was evaluated against the cysticercal enriched glycoprotein antigen used for the diagnosis of human cysticercosis [42] specific diagnostic bands were obtained in all control pigs but not in immunized pigs that did not developed cysticerci. The immune response was also evaluated against the vaccinating antigen by ELISA; specific, complement-fixing antibodies against the recombinant antigens increased after challenge and thereafter decreased; Furthermore, these and oncosphere antigens from other taeniid cestodes, contain a protein sequence motif suggesting a tertiary structure similar to the fibronectin type III domain [66]. Vaccination results show that pigs became protected from acquiring cysticercosis in experimental conditions, therefore they were evaluated in field trials in Peru [67] and Cameroon [68]; similar high levels of protection were obtained.

## 4. Conclusion

Many epidemiological studies have shown a correlation between human cysticercosis, taeniosis and epilepsy and between seropositive people, infected pigs and disposal of feces and have identified community, behavioural and environmental practices that must be modified to prevent continued transmission of cysticercosis and taeniosis.

Table 6 summarizes those that the author considers the most relevant. Most importantly, these studies have shown that the main risk factor is the presence of a *Taenia* carrier in the immediate environment. A proposal to declare neurocysticercosis an international reportable disease has been published [69].

This proposal, if taken in account, could be helpful in the control of cysticercosis, since, if cases of cysticercosis and of taeniosis are reported in all countries, it will provide accurate quantification of the incidence and prevalence of neurocysticercosis at regional level, thus permitting the rational use of resources in eradication campaigns. Although NCC is endemic in several countries of Latin America, Sub-Saharan Africa and Asia [69], due to migration there are many patients with NCC that attend hospitals in several cities of the USA and, even more important is the fact that tapeworm carriers have been identified in USA and even in Muslim countries, therefore now cysticercosis is considered an emerging infectious disease in USA and in some of its states it is now a reportable disease. [19,70,71]. It should be noted that approximately 200 million people cross the Mexico-USA border each year, multiplying the opportunities of acquiring and transporting adult *T. solium* [72].

### Personal measures

- After defecating check feces in search of a tapeworm
- If you have a tapeworm ask for treatment
- Wash hands after defecating
- Wash hands before eating and cooking
- Do not eat contaminated pork meat

### Hygienic measures

- Avoid having outdoor fecalism
- If outdoor fecalism is necessary, cover, bury or burn the feces
- Cook sufficiently pork meat to kill possible parasites
- Freeze pork meat at least 5 days before cooking
- Wash properly fruit and vegetables

### Pig breeding measures

- Avoid free roaming pigs
- Keep pigs in corrals
- Feed pigs with tortillas, bread and food leftovers
- Avoid access of pigs to letrines, feces and garbage
- Do not use pigpens as toilets
- Do not sell or buy pork meat with cysticerci

**Table 6.** Preventive measures against cysticercosis



The efforts and advancements described above, and others, drove Mexico onto a new stage regarding NCC: it is not anymore a public health problem. This parasitic disease was recognized as a public health problem when necropsy cases, published between 1947 and 1970, reported high frequencies of NCC. A recent publication [57] indicates that this disease has been controlled; the idea is supported by the dramatic decrease in the frequency of human NCC and human taeniosis obtained from the National Information System for Epidemiological Surveillance of the Ministry of Health in Mexico. The decrease was probably due to three reasons: 1) the abundant literature published by the Mexican scientific and medical communities working on cysticercosis; 2) the establishment of a National Program for the Control of *Taenia solium* since 1994; 3) the living conditions in Mexico have improved greatly in social, economy and health sectors.

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### Acknowledgement

This chapter is dedicated to all the students and collaborators that I have had along 40 years in cysticercosis research. Gustavo Barradas, Unidad de Informatica y Telecomunicaciones, Facultad de Medicina, UNAM, provided technical support in the preparation of the manuscript.

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