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Nilam Wavhal
Ph.D Scholar, Department of Veterinary Public Health & Epidemiology, Guru Angad Dev Veterinary Animal Sciences University, Ludhiana, Punjab, India

Nitin Wakchaure
Faculty, Department of Dairy Economics & Business Management, Guru Angad Dev Veterinary Animal Sciences University, Ludhiana, Punjab, India

Deepali Kalambhe
Ph.D Scholar, Department of Veterinary Public Health & Epidemiology, Guru Angad Dev Veterinary Animal Sciences University, Ludhiana, Punjab, India

Corresponding Author:
Nilam Wavhal
Ph.D Scholar, Department of Veterinary Public Health & Epidemiology, Guru Angad Dev Veterinary Animal Sciences University, Ludhiana, Punjab, India

Unmasking the silent threat: Cysticercosis and neurocysticercosis: Mini review

Nilam Wavhal, Nitin Wakchaure and Deepali Kalambhe

Abstract
Cysticercosis, a disease caused by the metacestodes of *Taenia solium* and it carries significant economic and public health implications, resulting in morbidity and mortality in many developing countries in Asia, Africa, and Latin America [1]. NCC is one of the most common parasitic diseases damaging the central nervous system (CNS) and serves as a "biological marker" reflecting a community's social and economic development. In numerous endemic communities, NCC is responsible for epilepsy in approximately 1% of the population [2]. An epidemiological shift can be attributed to factors like the intensified trade of animal products, increased global meat and live animal trade, and extensive migration of agricultural and other workers within and between countries, including domestic employees and international tourists [3, 4]. A significant challenge in managing cysticercosis is the limited awareness of the disease among individuals living in endemic regions.

Keywords: NCC, cysticercosis, *T. solium*, Taeniasis

1. Introduction
Taenia solium, *Taenia saginata*, and *Taenia saginata asiatica* are medically significant tapeworms. In their larval stages, they form '*Cysticercus cellulosae*' in suids, such as domestic pigs and wild boars (Sus scrofa), 'Cysticercus bovis' in cattle, and 'Cysticercus viscerotropica' in the case of *T. Solium*, *T. saginata*, and *T.S. asiatica*, respectively [5]. *T. solium*, unlike *T. saginata*, holds a greater significance in public health because of its lower specificity for intermediate hosts, potentially leading to human cysticercosis, frequently resulting in neurocysticercosis (NCC). Neurocysticercosis is a significant cause of epilepsy, associated with substantial morbidity and mortality. Beyond the public health risks, *T. solium* contributes to elevated levels of human morbidity and mortality and causes losses in livestock production in endemic areas [6]. Moreover, *T. solium* imposes a significant economic burden on regions already facing economic constraints.

2. Life cycle
Three species of tapeworms reach their mature stage in the human host. At the same time, cattle serve as intermediate hosts for *T. saginata*, and pigs act as intermediate hosts for both *T. solium* and *TS. asiatica*. Notably, *T. solium* poses a threat to human health due to its ability to cause NCC, a parasitic infection with a high affinity for neural tissues, making it a particularly severe form of taeniasis. Consequently, while *T. saginata* and *T.S. asiatica* primarily have economic implications related to livestock, *T. solium* is a substantial public health concern. In addition to intermediate host specificity variations, these taeniid parasites' life cycles are similar. As the definitive hosts, humans acquire the infection when they consume undercooked or raw pork or beef contaminated with viable cysticerci of the adult tapeworms. Upon ingestion, the cysticercus's outer layer is broken down in the stomach. Subsequently, the scolex protrudes and, upon reaching the duodenum, firmly attaches itself to the intestinal mucosa. Over time, the tapeworm grows in a chain of segments or proglottids known as the strobila. Approximately two to three months after the initial infection, segments containing eggs become gravid and detach from the strobila. These gravid proglottids are either expelled with the host's feces or, as is frequently observed in the case of *T. saginata*, actively migrate through the anus. These gravid proglottids are laden with thousands of eggs, each containing a fully developed larva capable of infecting an intermediate host. As natural intermediate hosts, pigs and cattle acquire cysticercosis by ingesting eggs in feces or contaminated food and water; eggs hatch within the stomach and become activated in the duodenum.

The larvae migrate through the intestinal wall with moving hooks and enzymatic secretions and disperse throughout the host's body via the circulatory system. In about three months, these oncospheres develop into cysticerci, capable of infecting humans (Figure 1).

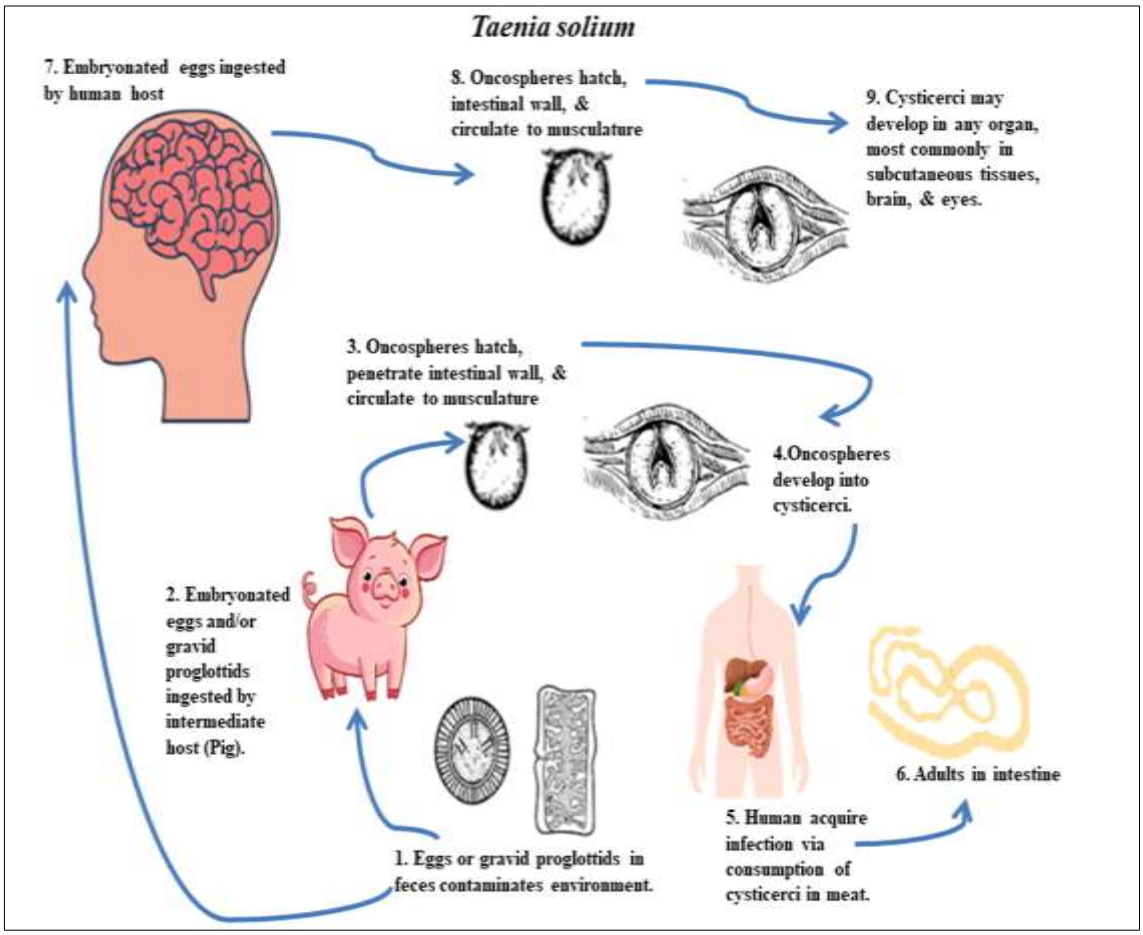

Fig 1: Lifecycle of *T. solium*

The uterus within these tapeworms contains spherical eggs, referred to as oncospheres. For *T. solium*, these oncospheres typically measure between 29 and 77µm in size, while for *T. saginata*, they fall within the range of 39 to 50µm [7, 8]. It is challenging to differentiate between the two species using standard light microscopy based on these measurements. The oncosphere includes three pairs of hooks (also known as the hexacanth embryo). The eggs of Taenia species exhibit notable resistance to external environmental conditions and common disinfectants. In environments with high humidity and shade, as well as in traditional wastewater treatment systems, these eggs can remain viable for weeks or even months [9, 10]. A cysticercus is an oval-shaped vesicle, typically 5-15mm in diameter, and encased in a transparent membrane. It contains an invaginated scolex and is filled with a colorless liquid [11]. The "cysticercus stage" describes the fully developed infective larvae, whereas the "metacestode" can encompass various larval stages. Furthermore, "taeniasis" denotes the presence of the adult (intestinal) stage of the tapeworm, while "cysticercosis" refers to the consequences of the larval stage residing in the body tissues. Taeniasis is typically subclinical or accompanied by mild symptoms, whereas human cysticercosis is considered one of the most pathogenic parasitic infections.

3 Clinical importance

3.1 Taeniasis: The most prominent indicator of taeniasis is the presence of proglottids, which can be found either in the feces or actively emerging from the host. In the case of *T. solium*, a few gravid proglottids are typically excreted in the feces daily or a few times a week. On the other hand, proglottids from *T. saginata* are often mobile and tend to exit the host through the anus independently. They may emerge individually or in chains, consisting of up to 7 segments, or they can be expelled daily in the feces [12]. Taeniasis typically presents with no or mild symptoms. However, carriers, especially of *T. saginata*, have reported experiencing pruritus in the peri-anal region. Some individuals may also exhibit non-specific symptoms such as gastrointestinal disturbances, loss of appetite, weight loss, and a general sense of discomfort [9]. These symptoms might be attributed to the excretions produced by the parasite [8].

3.2 Cysticercosis in humans

Cysticercosis is acquired by humans through fecal-oral contamination with *T. solium* eggs, even in individuals who do not consume pork, such as vegetarians. It can also result from exogenous autoinfection involving ano-oral contamination and endogenous autoinfection caused by reverse peristalsis. Upon ingesting these eggs, oncospheres are released in the duodenum, where they can penetrate the intestinal mucosa, enter local lymphatics, and travel through mesenteric vessels, potentially reaching various body parts as larval cysts [13]. Within 2-3 months, the oncospheres lose their

hooks and develop into fluid-filled bladder worms or cysticerci. The most common locations for cysticerci are subcutaneous and intramuscular tissues, followed by the brain and eye. It primarily presents with neurological symptoms, yet even with central nervous system (CNS) involvement with a significant percentage of cases, ranging from 50% to 70%, remain asymptomatic [14]. They can also be found in the heart, liver, lung, abdominal cavity, and, rarely, the spinal cord. Symptomatic disease predominantly occurs due to nervous system invasion, leading to NCC and ocular involvement. Epilepsy stands out as the most common and often the sole clinical manifestation of NCC among symptomatic patients [15-17]. Other symptoms, such as migraines, nausea, increased intracranial pressure, cognitive decline, hormonal imbalances, and paralysis, have also been documented [9]. However, there are reports of extraneural forms manifesting as cystic masses affecting skeletal muscles, subcutaneous tissues, buccal mucosa, tongue, and lips, as well as rare cases of disseminated cysticercosis [18, 19] where they typically do not cause noticeable symptoms unless they occur in significant numbers, leading to muscular pain, cramps, and fatigue. In ocular manifestations of the disease, retinal and vitreous involvement is most commonly observed, followed by subretinal, conjunctival, and anterior segment localization, which can result in conditions like uveitis, iritis, retinitis, as well as palpebral conjunctivitis, and may impact the muscles of the eyeball [20, 21]. It is generally accepted that neurological symptoms are predominantly immuno pathological reactions linked to the degeneration of cysts within the brain [20-23].

3.3 Cysticercosis in animals

When metacestodes are localized in the muscles or surrounding tissues of animals, symptoms related to cysticercosis are typically absent. However, in experimental infections in pigs, common symptoms have been reported, including anorexia, fever, bradycardia (slow heart rate) coupled with an increased respiratory rate, nausea, diarrhea, an unsteady gait, and, in severe infestations, occurrences of abortion and even death [5, 9]. Neurological symptoms in pigs are not well-documented, and they likely occur infrequently. The signs evident in infected swine such as hypersensitivity of the snout, tongue paralysis, and epileptiform convulsions [20].

4. Epidemiology

NCC is a globally distributed disease with a significant presence in economically disadvantaged regions where households raise free-roaming pigs with access to human feces [2, 24]. These high-prevalence areas encompass Latin America, large parts of Asia (including China and the Indian subcontinent), Eastern Europe, and most of Africa. While the worldwide prevalence of NCC remains incompletely understood, efforts are underway to assess the disease's burden in endemic regions, including developed nations like the USA [24-27]. Epidemiological data related to the association between NCC and epilepsy is well-documented, and this information is instrumental in estimating the prevalence and incidence of NCC in endemic areas [24, 27]. Estimates suggest a substantial number of individuals who have epilepsy attributed to NCC, with figures as high as 0.31-4.6 million in sub-Saharan Africa, 0.45-1.35 million in Latin America, 1 million in India, and 0.3-0.7 million in China [2]. For example, in a community-wide survey conducted in rural Peru, a seroprevalence of 24% was observed, with an odds ratio of 2.1 for seizures. An additional 13% of individuals with negative serology exhibited characteristic NCC calcifications in computed tomography (CT) scans, resulting in an overall estimate of 37% cysticercosis prevalence in humans [2, 28]. Similar prevalence estimates from 15% to 38% have been reported in other Latin American countries [2]. A systematic review aiming to estimate the global frequency of NCC consistently found that approximately 29% of persons with epilepsy in Latin America, sub-Saharan Africa, and Southeast Asia had NCC [27]. In China, the average incidence of *T. solium* infection has been estimated at 0.11%, with 1.26 million individuals suffering from teniasis and 3-6 million affected by cysticercosis [29]. In the Indian subcontinent, NCC is endemic in countries such as India, Bhutan, parts of Indonesia (Bali and Papua), Nepal, and Timor-Leste. In India, the disease is prevalent in all states, and the World Health Organization estimates that NCC is responsible for up to 50% of partial seizures in Indian patients, with ocular cysticercosis being common [29]. In a rural pig farming community across 30 villages in north India, an alarming 48% of individuals with active epilepsy met the definitive or probable diagnostic criteria for NCC, with factors like a family history of epilepsy and the lack of a separate place to keep pigs identified as significant risk factors [30].

Despite the severity of this disease, it has been proposed that cysticercosis should be considered an internationally reportable disease [31]. However, taeniasis and cysticercosis do not typically lead to sudden, large-scale international disease outbreaks. Therefore, they may not be considered appropriate subjects for international notification [20, 32]. In the past decade, there has been a significant improvement in the comprehensiveness of data collected on cysticercosis. Prior to this period, the available data were confined mainly to statistics derived from hospitals, focusing on the frequency of neurocysticercosis (NC) among hospital patients or from examinations of autopsied cadavers [33]. Moreover, because many prevalence studies rely on the identification of eggs in fecal samples, and conventional methods cannot distinguish between the eggs of *T. solium*, *T. saginata*, and T. s. asiatica, the most reliable data on prevalence in regions where these species coexist do not differentiate between the species at the specific level [20]. It is important to note that the clinical presentation of NCC differs between parenchymal and extraparenchymal forms. Parenchymal NCC typically presents with seizures, while extra parenchymal NCC may lead to hydrocephalus due to mechanical obstruction of the ventricles or basal cisterns [23, 34, 35]. The prevalence of epilepsy in Mexico has been noted to increase with age, an essential consideration in the context of NCC [36]. Additionally, cooking practices in India involve heating food to high temperatures, contrasting with some South American and Chinese culinary traditions where cooking methods differ. This could result in milder exposure to *T. solium* eggs, leading to lower parasite loads and milder infections [37].

5 Diagnoses

5.1 Excision biopsy

Excision biopsy is typically employed for the biopsy procedure, aiming to remove the subcutaneous cysticerci, a condition detected in 4-25% of individuals with NCC. It's important to note that diagnosis confirmation usually necessitates the use of radiological and serological tests unless a biopsy of a CNS lesion is feasible [38].

5.2 Microscopic examination

Conventional diagnostic methods for taeniasis primarily involve the microscopic detection of Taenia spp.; oncospheres in direct smears or through concentration techniques such as the Kato-Katz and formol-ether methods. Diagnosing taeniasis based on morphology through proglottids examination in fecal samples; also cellulose acetate gel electrophoresis differentiates *T. solium* and *T. saginata* [39, 40].

5.3 Capro-antigen detection

An alternative approach involves identifying tapeworm metabolic products with antigenic properties, which can be used to create specific polyclonal antibodies, enabling the detection of coproantigens via ELISA. However, these methods do not allow differentiation between *T. solium* and *T. saginata*. Coproantigen detection demonstrated a high specificity of 100% and sensitivity of 98% [41, 42], contrary, certain studies conducted in Guatemala and Peru have reported lower sensitivity rates [43-45].

5.4 Serological diagnosis

Regarding antibody detection, various immunodiagnostic techniques and antigens, including total metacestode soluble antigens, metacestode membrane or scolex soluble extracts, and semi-purified proteins, have been evaluated for NCC diagnosis, showing variable sensitivity and specificity [46-50]. Tests based on crude antigen preparations have demonstrated, at best, moderate sensitivity and specificity [51]. When it comes to antibody detection, the enzyme-linked immune-electro transfer blot (EITB), which employs glycoprotein antigens purified by affinity chromatography, is regarded as the method with the highest sensitivity and specificity [52-55]. This test is reported to have 100% specificity for detecting antibodies in serum and cerebrospinal fluid (CSF) [4, 52]. However, its sensitivity decreases to 50-62% when dealing with single or calcified lesions, compared to the 90% sensitivity in patients with more than two lesions [56]. It is important to note that many cured patients remain seropositive for up to one year after anti-parasitic therapy, primarily due to the persistence of antibodies post-resolution of the active infection. Cross-reactions with antibodies from extraneural cysticercosis and other cestodes or helminths can also lead to false-positive results when serum antibodies are used for diagnosis [57, 58]. An EITB assay based on two-dimensional polyacrylamide gel electrophoresis has shown high sensitivity (100%) in seropositive NCC cases and 60% sensitivity in suspected NCC cases where patients were seronegative for NCC [59]. While this method holds promise for serodiagnosis in endemic areas, it demands expertise and specialized facilities. As an alternative to the EITB, several researchers have developed enzyme-linked immunosorbent assays (ELISA) that utilize either crude or purified antigens from *T. solium* cysticerci or synthetic peptides [54, 55, 60-62]. These ELISA tests have varying degrees of sensitivity and specificity. For the detection of antigens, sandwich-ELISAs based on monoclonal antibodies have been developed by researchers [63-66]. These tests allow the detection of excretory/secretory products from Taenia spp. Cysticerci in serum. (ELISA), which is highly sensitive and specific for identifying living cysticerci (vesicular) located in the subarachnoid space at the base of the skull [67, 68]. These antigen detection tests also enable the monitoring and follow-up of anti-parasitic treatment [69]. However, it is essential to note that a positive antigen detection test does not definitively confirm active NCC, as cysts can be located outside the central nervous system (CNS). However, it is worth noting that these assays are limited to detecting the presence of viable larvae, and degenerated or calcified cysts are not detected. The specificity of these assays is at the genus level, allowing them to be used to diagnose *T. saginata* in bovines and *T. solium* in humans and pigs. False positive serology results can also occur due to past infections with *T. solium*. Antibody-ELISAs were found to have similar sensitivity and specificity to EITB for the differential serodiagnosis of NC. EITB has been used in pigs to detect circulating antibodies with high sensitivity and specificity. The sensitivity and specificity of Antigen-ELISA (Ag-ELISA) have been estimated at around 85% and 97%, respectively. However, one limitation is that Ag-ELISA cannot differentiate between infections with *T. solium*, T. s. asiatica, and Taenia hydatigna when multiple Taenia species coexist in the same host, such as in pigs. In bovines, the sensitivity and specificity of antigen detection ELISA are reported to be 98.7% and 92.3%, respectively, but these high values are observed in animals with more than 50 viable cysticerci [66]. However, in cases where the bovine carcass contains fewer than 20 larvae, the sensitivity of this method decreases significantly, dropping to 12% [70]. Although different serodiagnostic tests using various parasitic antigens have been developed, none achieve 100% sensitivity and specificity, particularly for single-lesion parenchymal NCC. Additionally, dot blots have been used for serodiagnosis of several parasitic infections, providing high sensitivities similar to ELISA while being rapid, user-friendly, and easy to interpret. A study demonstrated that in-house ELISA and dot-blot assays could achieve good sensitivity in detecting anti-cysticercal IgG, particularly among pediatric NCC cases with multiple brain lesions [71].

The utility of detecting circulating parasite antigens in the sera of patients with hydrocephalus secondary to NCC has also been explored. Positive results were obtained in 48% of patients with hydrocephalus but consistently negative in patients with calcifications [23]. A Peruvian study demonstrated a sensitivity of 86% for antigen detection in CSF by ELISA, with negative results primarily limited to patients with only a single live cyst or only enhancing lesions. Therefore, while the sensitivity was high in cases with multiple cystic lesions, it had limited diagnostic value in patients with a single cyst. However, it is worth noting that most of the existing immunodiagnostic tests require thorough standardization and may need to be more efficiently conducted in rural and underdeveloped regions with a high disease burden. This underscores the need to explore more straightforward tests that may or may not rely on invasive samples, allowing for point-of-care diagnosis. Despite these advancements, such tests have yet to become widely available for patient care in large-scale settings. For example, a simple and rapid latex-based agglutination test has been evaluated for diagnosing NCC by detecting *T. solium* metacestode antigen in cerebrospinal fluid and serum samples. It exhibited sensitivities and specificities of 64% and 85% in cerebrospinal fluid and 52% and 96% in serum samples, respectively [72]. Non-invasive samples like urine and saliva have also been explored for antigen detection. For instance, a urine-based polyclonal antibody-based ELISA assay showed a sensitivity of 62% and a specificity of 91% for detecting cysticercus antigen in urine specimens [73]. Another study reported 92% sensitivity in urine antigen detection for viable parasites, which decreased to 62% in patients with single

cysts [74]. However, there is limited literature regarding the utility of molecular diagnosis of NCC in patients with single lesions, in serum samples, and whether measuring parasite DNA load in CSF can be employed for monitoring NCC patients. Single NCC lesions are often challenging to detect using serological methods, making the detection of parasite DNA by PCR a valuable tool for diagnosing such cases. This approach can complement existing radiological and immunological tests and help confirm the presence of NCC in a broader range of clinical scenarios. It is important to note that while PCR-based techniques offer significant advantages in sensitivity and specificity, they also require well-equipped laboratories and technical expertise, which may not be readily available in resource-limited settings. Nonetheless, these molecular methods hold promise for enhancing NCC diagnosis, particularly in challenging cases, and further research is needed to explore their full potential in clinical practice [75-78].

5.6 Molecular diagnosis

In recent developments, highly specific PCR methods have been introduced for the detection of Taenia DNA in fecal samples [79-84]. However, these methods have yet to undergo comprehensive field validation.

Various molecular methods have been established for detecting and differentiating Taenia species, employing both genomic DNA (gDNA) and mitochondrial DNA (mtDNA). These techniques encompass Dot Blot analysis [85], Multiplex-PCR [80, 82, 86, 87], PCR-Restriction Fragment Length Polymorphism (RFLP) [83, 87-89], thymine-base reader analysis based on excision sequences [90], and Random Amplified Polymorphic DNA (RAPD) [91, 92].

DNA probes offer an attractive option for a sensitive, rapid, and non-invasive diagnostic test that distinguishes *T. solium* and *T. saginata* tapeworms [85]. In their research, Chapman and colleagues developed highly sensitive, species-specific DNA probes by isolating and characterizing recombinant clones containing repetitive sequences from *T. solium* cysticerci, adult *T. solium*, and *T. saginata*. These DNA probes were created using labeled [32P] cystidine triphosphate (dCTP) and random primer extension. Subsequently, the generated probes were used to screen corresponding libraries to identify high-abundance sequences through a dot blot analysis. Two non-coding DNA probes, HDP1 and HDP2, from a genomic library of *T. saginata* were employed in a Multiplex-PCR, and revealed that the HDP1 probe specifically amplified *T. saginata* gDNA, while the HDP2 probe allowed the differential amplification of gDNA from *T. solium*, *T. saginata*, and *Echinococcus granulosus* [86, 87]. A comparative assay for distinguishing *T. solium* and *T. saginata* based on the amplification of a 1300bp segment in the 5.8S ribosomal region developed and demonstrated a clear difference between these cestode species using three digestion enzymes (AluI, DdeI, and MboI) [88]. However, this technique yielded suboptimal results when applied to fecal samples spiked with Taenia eggs. Furthermore, the 12s rRNA mitochondrial gene in a PCR-RFLP assay employed to differentiate *T. s. asiatica* from *T. saginata* and *T. solium* and proved to be a reliable tool for distinguishing among the species and subspecies in Asia, even when proglottids were in an advanced state of disintegration [89].

The diverse nature of DNA sources and the presence of PCR inhibitors, such as hemoglobin, bilirubin, bile salts, and chelating agents, complicate the isolation and purification of Taenia DNA from fecal samples [93-96]. However, novel techniques for detecting Taenia DNA in fecal samples have been introduced. A multiplex-PCR assay employing HDP2 gDNA outlined with primers to identify *T. saginata* in feces spiked with eggs with the lower limit of detection at 137 eggs per gram (1096pg of DNA) [80]. Another approach involved using the Cox1 gene as a target gene to design primers specific for *T. saginata*, *T.S. asiatica*, and *T. solium* in a multiplex-PCR [82]. However, only 11 out of 23 samples, confirmed positive by the coproantigen detection test, tested positive using this method. This discrepancy may have been influenced by the duration of sample storage, potentially affecting test sensitivity. Hence nested PCR approach employed to reduce the likelihood of amplifying unwanted DNA (non-specific bands). It enhanced the detection of target DNA copies in cases where the target DNA is only sometimes readily apparent. In another study, Cox1 gene to create a PCR-RFLP method for distinguishing between *T. saginata* and *T. solium* in fecal extracts [83] and could detect DNA at a lower limit of 34 eggs in 2 grams of feces.

5.7 Post mortem diagnosis (animals)

In animals, the diagnosis of cysticercosis in pigs is commonly conducted before death through techniques like visual inspection and palpation of the tongue. There have been reports of attempts to detect metacestodes in the eyes, although this method is associated with low sensitivity [97]. Due to their coprophagic behavior, pigs often exhibit extensive infestations with cysticerci throughout their entire carcass, including the brain, as opposed to cattle. The sensitivity and specificity of both ante-mortem and post-mortem inspections are high when dealing with massive infections. However, the effectiveness of these techniques diminishes when applied to animals with low cyst burdens. A sensitivity of 21% reported for tongue inspection and 22% for meat inspection in pigs, although the specificity in both cases remained at 100% [98].

On the other hand, in bovines, antemortem inspection is considered impractical, primarily due to the localization of the cysticerci and the low infection rates [9, 99]. Therefore, the standard procedure for bovines is post-mortem meat inspection, which is also the sole legally compulsory and accepted method. This process involves incising and inspecting various parts, including the tongue, masseter muscles, heart, diaphragm, esophagus, and sometimes leg muscles, as these are considered predilection sites [100]. Typically, the number of cysticerci is low in bovines, resulting in many cases going undetected even after a thorough post-mortem inspection [99-101].

Human neurocysticercosis can be identified through Magnetic Resonance Imaging (MRI) and Computerized Axial Tomography (CT-scan). These neuroimaging techniques are considered the gold standard for diagnosis, capable of detecting vesicular (viable), colloidal (degenerating), and calcified cysticerci or related lesions in the central nervous system [9, 102, 103]. Although radio imaging methods can be valuable, they are limited in their use in developing countries due to the unavailability of facilities and the associated high costs. Additionally, imaging findings may sometimes resemble those of other neurological disorders, complicating the diagnostic process [104-105]. In some instances, mainly when the parasites are not situated in the subarachnoid basal cisterns, CT nor MRI may be able to detect them. In such instances, the diagnosis of NCC is supported by clinical,

epidemiological, and serological data, along with the patient's response to cysticidal treatment [106]. Despite the availability of neuroimaging and sensitive serological tests, diagnosing neurocysticercosis remains challenging. As a result, a group of experts has established diagnostic criteria for neurocysticercosis, which consider clinical, radiological, immunological, and epidemiological data to evaluate patients. These criteria are absolute, primary, minor, and epidemiological, each reflecting their diagnostic strength individually [106]. Absolute criteria can diagnose the disease independently; significant criteria strongly suggest the diagnosis. However, they are inconclusive, and minor criteria are common clinical and radiological signs of the disease. However, they are relatively non-specific, and epidemiological criteria consider factors that increase the likelihood of cysticercosis. Correctly applying these criteria can assist healthcare providers in avoiding misdiagnoses and determining appropriate treatment. However, it is worth noting that the prospective validation of these criteria has yet to be established.

6. Treatment

The treatment of human neurocysticercosis has long been debated [107]. There is concern that metacestodicidal treatment may induce or worsen symptoms, assuming that symptoms are related to the degeneration process of brain cysticerci. As a result, many neurologists prefer alleviating symptoms in patients with positive CT scans or MRI results without using anthelmintic drugs. Others consider various criteria, such as the number, location (parenchymal or extra parenchymal cysticercosis), viability (viable, degenerated, or calcified cysts), and the size of the cysts when deciding on treatment. They may not recommend anthelmintic treatment for single viable cysts, calcified cysts, or asymptomatic neurocysticercosis [103, 108, 109]. Praziquantel is the preferred drug for treating human taeniasis, given orally at 10 mg/kg body weight [110]. This medication is known for its low toxicity and minimal side effects [111]. An alternative treatment involves using niclosamide followed by a purgative, as it typically leads to the complete recovery of tapeworms, including the scolex, which is crucial for species identification and differentiation. This drug is not absorbed in the intestine, reducing the risk of causing neurological symptoms when the carrier has neurocysticercosis [112]. Albendazole has also been used to treat taeniasis, but its efficacy is relatively low [113].

Oxfendazole, administered as a single oral dose of 30 mg/kg body weight, was reported to be 100% effective in treating porcine cysticercosis [114]. Two innovative pig health products have emerged to combat a significant parasitic disease responsible for around 30% of epilepsy cases in people residing in developing regions. A new vaccine, Cysvax, was created as collaboration between Indian Immunological Limited (IIL) and GALVmed, drawing on technology initially developed by Professor Marshall Lightowlers at the University of Melbourne. This vaccine designed to prevent porcine cysticercosis and has received licensing in India. IIL commercially developed it, and has been available for purchase in India since November 2016. In the context of porcine cysticercosis treatment, only one anthelmintic is officially registered for use on pigs. Based in Morocco, MCI Sante Animale registered their antiparasitic solution, Paranthic (containing oxfendazole 10%), in Morocco in June 2013. Paranthic® can be employed alongside Cysvax to manage the cystic phase of the parasite in pigs. This combined approach disrupts the tapeworm's life cycle responsible for transmission to humans [115].

7. Control

The World Health Organization formulated control measures for neurocysticercosis in 2002 based on several key facts.

1	Cysticercosis is caused by the larval stage (cysticerci) of the pork tapeworm *T. solium*
2	It is humans' most significant neurological disease of parasitic origin
3	Human cysticercosis is associated with poverty in areas where pork consumption is prevalent, and traditional pig husbandry practices are followed
4	Cysticercosis of the central nervous system is a leading cause of chronic epilepsy, which places specific demands on healthcare services

In light of these facts, control measures have been proposed, including the elimination of infected pigs and pig carcasses through meat inspection, improved sanitation, hygiene, pig husbandry practices, health education, treatment of intestinal taeniasis, chemotherapy for infected swine, and mass treatment in both humans and pigs [87, 111, 116]. These strategies primarily focus on eliminating infected pig carcasses through rigorous meat inspection, supported by improved sanitation, hygiene, and pig husbandry practices and comprehensive health education. Additional measures may involve the treatment of intestinal taeniasis, pig vaccination, and chemotherapy for infected animals [117]. Notably, the shift towards agro-industrialization has indirectly contributed to eradicating the parasite in industrialized countries. However, as long as traditional pig husbandry persists in developing nations, the life cycle of *T. solium* is likely to endure [118].

The strategic use of anthelmintics against the adult parasite in humans and the larval parasite in swine, in combination with health education and the regulation of pig slaughter, should be adequate to interrupt transmission. However, it is worth noting that this approach has yet to be proven in practice. These constraints arise due to a need for more information available to official sanitary services, economic obstacles, difficulties in sustaining control programs, and the persistence of poor hygienic habits. Inadequate knowledge about the true prevalence and impact of taeniasis and human, porcine, and bovine cysticercosis and the absence of adequate infrastructure and technical skills to collect essential data makes it highly unlikely that national control measures will be effectively executed.

8. Conclusions

The taeniasis-cysticercosis complex has been the subject of extensive research, primarily focusing on epidemiology, risk factors, and diagnostic methods. endemic stability and secondary transmission have added complexity to the overall comprehension of this complex. Many epidemiological investigations have relied on detecting the antibody response. However, the utility of this tool for assessing infection needs to be improved by the absence of a gold standard for human cysticercosis, making test validation challenging. Additionally, exposure to the oncospheres does not necessarily lead to establishing cysticerci. In the case of pigs, where the gold standard for porcine cysticercosis involves the dissection of the entire carcass, moreover multiple diagnostic tools like meat inspection, tongue examination, and

serological methods for detecting antibodies and antigens can contribute to a more accurate understanding of the taeniasis-cysticercosis complex in endemic regions. It holds promise for a better understanding of the human population's infection status and transmission dynamics

The assessment of taeniasis prevalence is typically based on microscopic examination or antigen detection in stool samples limits the differentiation of infections with *T. solium*, *T. saginata*, and *T. s. asiatica*, even though these cestodes often coexist in specific geographic areas. Consequently, a species-specific diagnosis of tapeworm carriers would significantly enhance our understanding of the taeniasis-cysticercosis complex. Furthermore, despite the availability of prevalence data and the established link between NCC and epilepsy and other neurological disorders in endemic regions, the overall burden of disease, its impact on human health, and the economic repercussions of this parasitic infection remain poorly documented. NCC is a significant public health concern, but through comprehensive prevention measures, including health education, improved living conditions, vaccination of pigs, and advancements in diagnosis and treatment, there is hope for better control and eventual eradication of this disease.

NCC represents a significant health burden for affected populations, particularly in socio-economically disadvantaged communities. Controlling this disease demands a comprehensive, multi-sectorial approach. It not only involves the application of scientific tools for diagnosis, treatment, and prevention but also necessitates a commitment at the administrative and political levels to enhance the fundamental healthcare infrastructure in endemic regions. Implementing straightforward measures like providing proper sanitary facilities to deter open defecation can be highly effective in preventing countless cases of epilepsy. Despite being the leading cause of adult-acquired epilepsy on a global scale, the impact of NCC on morbidity is often underestimated. To improve the quality of life for millions of affected individuals, allocate balanced resources and efforts to develop more effective strategies for treating and controlling NCC.

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