Continental Veterinary Journal
ISSN: 3079-0212 (ONLINE)
www.cvetj.com; editor@cvetj.com

REVIEW ARTICLE

DOI: 10.71081/cvj/2026.076

# *Toxoplasma gondii*: Biology, Pathogenesis, Clinical Management, and Emerging Control Strategies (a review)

Munwar Ali[1*], Qazal Hina[2] and Jia Wang[1]

[1]College of Veterinary Medicine, Nanjing Agricultural University, Nanjing 210095, PR China; [2]School of Agriculture and Food Sustainability, University of Queensland, QLD 4343, Australia
*Correspondence: drmunwarali06@gmail.com

**ARTICLE INFO**

*ARTICLE HISTORY: CVJ-26-194*

Received: 15 February 2026
Revised: 15 April 2026
Accepted: 23 April 2026
Published online: 29 April 2026

**Key words:**
Biology
Epidemiology
Parasite
Pathogenesis
Therapeutics

**ABSTRACT**

Toxoplasmosis, caused by the intracellular protozoan parasite *Toxoplasma gondii* (*T. gondii*), remains a ubiquitous zoonotic disease affecting warm-blooded animals and humans worldwide. This parasite is known for its wide host range, adaptation to harsh climates, multistage life cycle, clinical complications, and zoonotic transmission. Despite advances in vaccine research and proteomics, treatment and prevention remain challenging, with current therapies showing limited efficacy against latent tissue cysts and significant toxicities. This review examines parasite biology (taxonomy, morphology, life cycle), global epidemiology with regional seroprevalence patterns, and molecular pathogenesis involving host cell invasion and immune evasion. We analyze clinical manifestations across immunocompetent, immunocompromised, and congenital populations, emphasizing cerebral and ocular complications. Diagnostic methodologies from serological assays (IgG/IgM, ISAGA, ELFA) to molecular techniques (PCR, NGS) are evaluated, alongside treatment protocols (pyrimethamine-sulfadiazine, spiramycin) and their limitations. Prevention strategies encompassing food safety, hygiene, and veterinary management are addressed. Synthesizing multi-omics advances, novel vaccine platforms (nucleic acids, VLPs), and emerging therapeutic targets, we identify critical gaps in bradyzoite elimination and clinical translation. By integrating these advances, this review provides a strategic framework for improving toxoplasmosis management and highlights priority areas for tissue cyst-specific vaccines and alternative therapies to address this neglected parasitic disease.

**To Cite This Article:** Ali M, Hina Q and Wang J, 2026. *Toxoplasma gondii*: biology, pathogenesis, clinical management, and emerging control strategies. Continental Vet J, 6(1): 14-24. http://dx.doi.org/10.71081/cvj/2026.076

## INTRODUCTION

Understanding *T. gondii* is crucial, as approximately one-third of the global human population is infected (Daher et al. 2021). Since its first isolation in 1908 from the rodent *Ctenodactylus gundii*, *T. gondii* has captivated researchers and clinicians for over a century. Its generic name derives from the Greek "Toxon" (bow), referencing the parasite's characteristic crescent morphology (El-Ashram et al. 2023). As an obligate intracellular protozoan capable of infecting virtually all warm-blooded animals, including humans, *T. gondii* exhibits a heteroxenous life cycle: sexual reproduction occurs exclusively in felid definitive hosts, while asexual propagation persists across diverse intermediate hosts. This biological versatility enables transmission across heterogeneous environments and facilitates long-term, often asymptomatic persistence within hosts, posing significant implications for both veterinary medicine and public health (Almuzaini, 2023). The seroprevalence of *T. gondii*, however, varies significantly by region: the USA reports 11% infection rates among individuals aged ≥ 6 years, while Brazil reaches 60%, and the endemic areas of Latin America and Africa exceeds 80% in some areas (Attias et al. 2020; Daher et al. 2021). The Centers for Disease Control and Prevention (CDC) recognizes toxoplasmosis as a neglected infectious disease, with over 40 million cases documented in the United States (Daher et al. 2021). Veterinary impact is substantial, with 30–50% of Chinese seroprevalence (exceeding 70% in hyperendemic areas) (Xia et al. 2020). Although most infections remain subclinical, immunocompromised persons (e.g., those with HIV/AIDS or receiving immunosuppressive therapy) face severe life-threatening CNS complications, accounting for 50–70% of

parasitic infections and representing the third leading cause of death in end-stage HIV disease (Suleimenova et al. 2022).

Pregnant women who acquire *T. gondii* infection can pass the parasite transplacental, resulting in congenital toxoplasmosis. Miscarriage or birth defects (hydrocephalus and retinochoroiditis) in pregnant women susceptible to *Toxoplasma* infection have also been reported (Xia et al. 2020; Sana et al. 2022). Moreover, the parasite also has the potential to have a high economic impact on livestock production globally, being responsible for abortion and neonatal mortality, particularly in small ruminants (Basso et al. 2022), as in Switzerland, using immunohistochemical staining (IHC),19% (16/86) and 15% (22/144) of experimental sheep and caprine embryos were aborted, respectively, positioning *T. gondii* as the second most lethal etiological agent for abortus (after *Chlamydophila abortus*) (Basso et al. 2022), calling for concern.

Considering the neglected public health status of *T. gondii*, this article adopts a multidisciplinary approach integrating insights from biology, epidemiology, clinical medicine, and public health. It provides an overview of *T. gondii* biology, morphology, life cycle, and pathogenesis to support effective treatment and prevention strategies. The clinical manifestations of toxoplasmosis are also discussed, highlighting differences between acute and chronic infections, as well as congenital and immunocompromised cases. Conclusively, this review emphasizes the need for continued research and strengthened public health efforts, serving as a resource for researchers, healthcare professionals, and policymakers involved in toxoplasmosis control.

## Taxonomy and Morphology of *T. gondii*

*T. gondii* belongs to the phylum Apicomplexa, which also includes malaria-causing agent *Plasmodium* and the *Cryptosporidium* genus (Javed and Alkheraije, 2023). *T. gondii* belongs to the family Sarcocystidae, the order Eucoccidiorida, and the class Conoidacida in this phylum (El-Ashram et al. 2023). Tachyzoite, bradyzoite, and sporozoite are the three infectious morphological forms of *T. gondii,* having an elongated shape and a characteristic apical complex as a basic structure, with structures and organelles such as micronemes, the conoid, and rhoptries attached to a typical apical complex (Fig.1) (Attias et al. 2020).

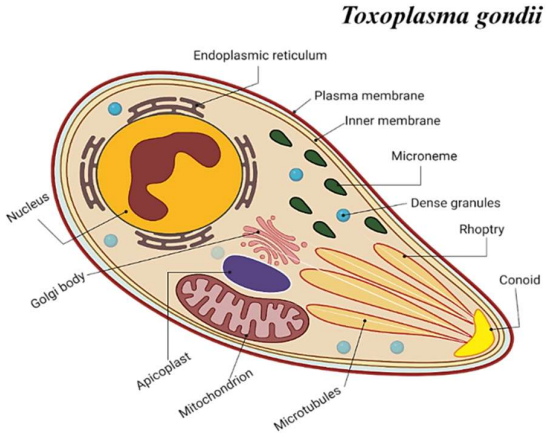


**Fig 1:** Structural characterization of *T. gondii.*

Tachyzoites are the most rapidly increasing pathogens, causing serious disease. They are crescentic, measuring 4-8 µm in length and 2-3 µm broad. They have a pointed front (conoid) and a rounded back, which enables them to attack host cells. Bradyzoites are detected during persistent infection and multiply slowly in vascular tissue. They are similar in shape to tachyzoites but slightly smaller. Bradyzoites invading tumors can persist in host tissues, especially in the brain and nervous system, throughout the life of the host. Oocysts are the environmental stage secreted into the feces of some felids, and they are spherical to sub-globose, about 11-13 µm in diameter (Tong et al. 2021). Oocysts have two spore sacs, each containing four sporozoites, and are infective after sporulation in the environment.

Recent studies have also shown new morphological features that facilitate the entry of *T. gondii* into host cells. The parasite and host cells first release tiny vesicles (about 25-100nm length followed by tunneling nanotubes that emerge from the host cell surface, connecting with the parasite (Teles et al. 2023). These novel results, including the emergence of host-cell surface projections, pseudopods, and nanotubes, have expanded the morphological characterization of *T. gondii*.

## Risk Factors, Diverse Transmission Routes, and the Infectious Life Cycle

The risk of *T. gondii* infection is influenced by several factors. In the veterinary sector, cats with access to outdoor environments or free-roaming ones are most likely to get infected and shed oocysts. A study conducted in China reported that 62/1478 urban cats, and 9/43 stray cats had serum antibodies to *T. gondii*, making the prevalence level highest in Sichuan (13%) and Chongqing (12.8%), while lowest in Guangdong (0.9%) (Xia et al. 2022). Additionally, wildlife can also act as reservoirs of infection and ultimately transmit it to the domestic animals. Thus, farm animals raised in free-range or outdoor environments are at greater risk of getting the infection through contaminated water, soil, and food (Rafique et al. 2022). Humans, however, can get infected after consuming undercooked or raw meat, through environmental exposure with infected cats, poor sanitary conditions, through occupational exposure: veterinarians or slaughterhouse workers who deal with animals or raw meat may get direct exposure, and vertical transmission if pregnant women get exposed to the *T. gondii.*

*T. gondii* can be transmitted through various routes. Firstly, oocysts are ingested by intermediate hosts such as humans. Secondly, there is tissue cyst ingestion by intermediate hosts (including humans) due to undercooked or raw infected meat from livestock such as sheep, pigs, and cattle, etc. Another type of transmission is congenital, and it occurs when pregnant women get exposed to *T. gondii* infection, which can eventually cross the placenta and infect the fetus. Other routes like blood transfusion, organ transplantation, or accidental inoculation are quite rare. The transmission rate is thought to be 25% in the first trimester, while 54% and 65% during the second and third trimesters, respectively (McAuley, 2014; Daher et al. 2021), and it proves that the severity of congenital toxoplasmosis is inversely related

to gestational trimester (Yamamoto et al. 2017; Daher et al. 2021).

There are asexual and sexual stages in the complex life cycle of *T. gondii*. All Felidae (cats, etc.) are definitive hosts for this parasite, whereas almost all the warm-blooded creatures, including birds, reptiles, mammals, including humans, act as intermediate hosts (Lazar et al. 2021). The definitive hosts (especially cats) get infected after consuming the intermediate hosts, having tissue cysts that contain bradyzoites. Thus, bradyzoites in the intestine differentiate into gametocytes, leading to sexual reproduction and forming oocysts. Cats excrete these unsporulated oocysts through their feces. Then, the environment triggers the maturation, and oocysts divide into two sporocysts (6-8 µm each); an infectious stage (Attias et al. 2020). Sporocysts are highly resistant to environmental conditions, and tolerant to disinfectants and dry or wet conditions; consequently, the crucial part of transmission to the intermediate hosts, such as humans; contacting with felids as pet animals (Fig. 2) (Attias et al. 2020; Lazar et al. 2021). When this sporulated oocyst is consumed by the intermediate hosts (humans or animals), the infection cascade begins (Fig. 2). The ingested cysts are broken down by proteolytic enzymes in the small intestine, which transform into tachyzoites (Lazar et al. 2021). Additionally, tachyzoites use specialized structures, known as conoids, to penetrate the cell membrane and spread the infection through the host's entire body via the bloodstream, which damages various organs and tissues. If the host's immune response is strong, then these tachyzoites convert back into bradyzoites and form tissue cysts, mainly in muscles, eyes, and the brain, forming the dormant stage of cysts, which can reactivate if the host becomes immunocompromised (Fig. 2).

*T. gondii* has a significant genetic diversity. The distribution of *T. gondii* genotype is different around the world, but three genotypes (type I, II, and III) are predominant, including Europe and North America (Attias et al. 2020; Xia et al. 2020). In China, ToxoDB#9 is the most prominent clonal lineage of *T. gondii*, which causes clinical toxoplasmosis in pigs (Dubey et al. 2020a; Jiang et al. 2020; Xia et al. 2020). Along with that, another type, ToxoDB#3, has also been found in pigs across Yunnan, Hubei, Guangdong province, and Liaoning, which makes it a prevalent lineage in China (Xia et al. 2020).

**Epidemiology of *T. gondii***

*T. gondii* is one of the most widespread parasites worldwide, and its prevalence varies from region to region, depending on certain factors: environment, climate change, cultural practices, and local wildlife. In one study, seroprevalence levels were found to be dominant in certain species among districts of China (Table 1) (Fig. 3) (Su et al. 2022).

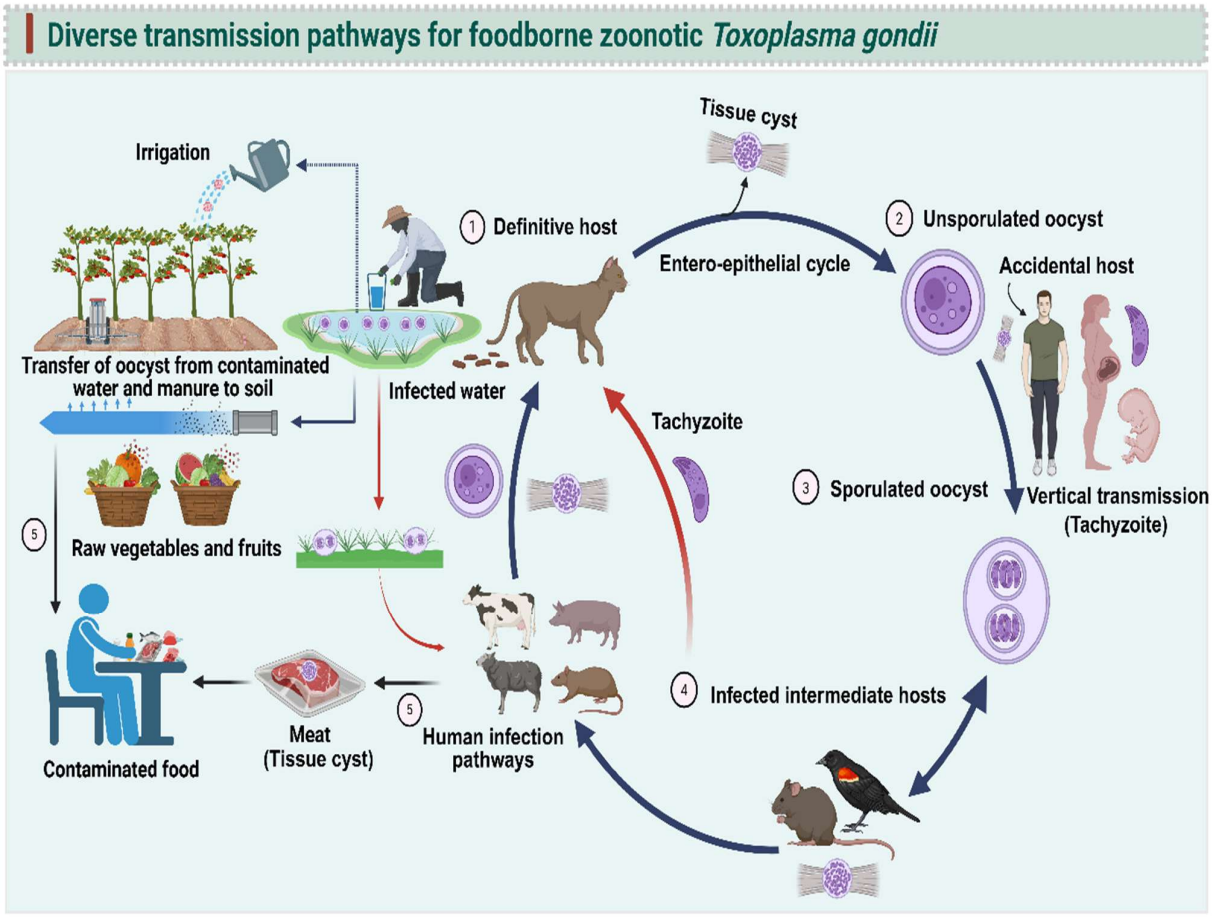


**Fig 2:** Life Cycle of *T. gondii* and diverse routes of transmission (Attias et al. 2020; Bollani et al. 2022).

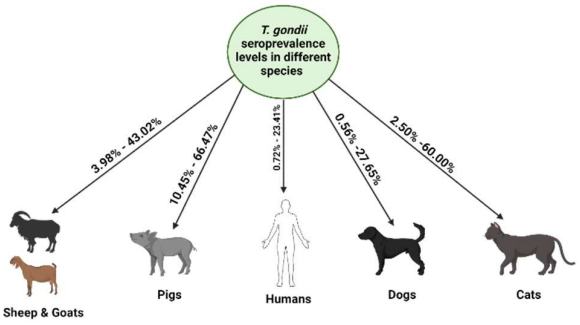


**Fig 3:** Seroprevalence levels across different species, studied in China (Su et al. 2022).

**Table 1:** The IgG and IgM seroprevalence level of *T. gondii* was also studied in pregnant women in a study conducted in different countries

| Country | IgG and IgM Seroprevalence % | 95% Confidential Interval (CI) |
|---|---|---|
| Highest IgG Seroprevalence | | |
| Ethiopia | 64.2 | 34.3–89.1 |
| Gabon | 56.7 | 54.4–59.0 |
| Brazil | 53.8 | 39.3–68.0 |
| Lowest IgG Seroprevalence | | |
| Mexico | 7.2 | 5.3–9.4 |
| South Korea | 2.1 | 0.6–4.3 |
| Canada | 0.2 | 0.2–0.3 |
| Highest Predicted IgG Seroprevalence | | |
| Namibia | 74.3 | 73.9–74.7 |
| Eswatini | 72.2 | 71.7–72.6 |
| Bahrain | 71.5 | 70.6–72.5 |
| South Africa | 70.1 | 69.6–70.6 |
| Algeria | 67.5 | 67.0–68.1 |
| Highest IgM Seroprevalence | | |
| Yemen | 6.0 | 1.6–12.8 |
| Egypt | 4.4 | 1.0–10.0 |
| Saudi Arabia | 4.1 | 2.2–6.5 |
| Lowest IgM Seroprevalence | | |
| New Zealand | 0.2 | 0.1–0.4 |
| South Korea | 0.1 | 0.0–0.4 |
| USA | 0.01 | 0.001–0.02 |
| Highest Predicted IgM Seroprevalence | | |
| Lebanon | 10.8 | 10.5–11.2 |
| Tunisia | 6.9 | 6.6–7.2 |
| South Africa | 6.2 | 5.8–6.5 |
| Egypt | 6.2 | 5.9–6.5 |
| Algeria | 5.7 | 5.3–6.0 |

Data were adapted from (Bigna et al. 2020)

Additionally, a study carried out in Egypt showed that the seroprevalence level of *T. gondii* antibodies in humans (study population) was around 35.2%, which increased up to 37.5% after contact with poultry. Other continents like Europe, Asia, Africa, and Latin America showed a prevalence range of 30-75%, whereas this range was lower in the case of the USA (3-42%) (Aboelhadid et al. 2013). In Japan, an investigation regarding seroprevalence of *T. gondii* at slaughterhouses showed that the seroprevalence was highest in Japanese black beef cattle at13.7%, followed by dairy Holstein cattle at 7.9%. In the case of pigs, the seroprevalence level was 5.2%, and in sheep was 28.7% (Matsuo et al. 2014). Furthermore, another study demonstrated that toxoplasmosis remained prevalent among the community regardless of season or month; *T. gondii* seroprevalence was highest during summer and autumn, reaching up to 37.4% and 34.9%, while it stayed 24.60% in spring and lowest during the winter season, ranging up to 23.9% (Xu et al. 2014; Yu et al. 2023). Additionally, serological surveys have shown that the ratio of domestic pigs exposed to *T. gondii* was detected up to 30%, and that's why the European Food Safety Authority (EFSA) announced this parasite as one of the public health hazards in swine, which should be checked out during meat inspection (Dubey et al. 2020b).

**Pathogenesis and Immune Response of *Toxoplasma gondii* Infection**

The infection is age-dependent; the immunocompetent elders stay asymptomatic even with infection. However, it can suddenly become an acute, semi-acute, or chronic infection in an immunocompromised person (Lazar et al. 2021). The process of invasion involves three major steps: attachment, secretion of effector proteins, and formation of the parasitophorous vacuole (PV). The parasite employs a unique structure known as a conoid to break through the cell membrane when it encounters the host cell. During the first step, the parasite attaches to the host cell surface using adhesions. After that, rhoptries and micronemes release effector proteins that facilitate entry. Lastly, after entering the host cell, *T. gondii* creates a PV, which serves as a barrier that keeps the parasite protected from lysosomal acidification and the host's immune system (Sanchez and Besteiro, 2021). Secondly, *T. gondii* secretes proteins that disrupt the host cell signaling pathways to reduce the immune response, e.g., the parasite disrupts NF-κB signaling, which will stop the production of pro-inflammatory cytokines. Thirdly, the parasite can induce IL-10 production, an anti-inflammatory cytokine, which lessens the host's immune response and facilitates chronic infection. Lastly, *T. gondii* proteins, encoded in the apicoplast genome, antigenic proteins such as ribosomal proteins L36 and S17 have significantly high antigenicity values, along with ribosomal proteins, other antigenic and nucleosomal proteins can modify the host immune response (Can et al. 2020). After the invasion, through endodyogeny, tachyzoites multiply inside the parasitophorous vacuole, two daughter cells are formed, and this replication causes the host cell to burst, ultimately releasing more tachyzoites to spread infection into the neighboring cells. This process continues, allowing *T. gondii* to spread throughout the whole body via the bloodstream and lymphatic system, and infects various organs such as the brain, eyes, and muscles. This causes an acute infection, and the patient feels muscle pain, swelling of lymph nodes around the neck, and fever (Lazar et al. 2021).

On the other hand, if the host's immune system responds due to a stronger defense mechanism, some tachyzoites get eliminated (Fig. 4), while the other escaped tachyzoites convert back into bradyzoites, the slowly replicating form, which aggregates into tissue cysts. In addition to that, INF-$\gamma$-mediated NO is an external stress factor that is also involved in maintaining the cyst stage, but in the absence of this, reactivation of dormant infection may occur (Nayeri and Sarvi 2024). These cysts stay in neural and muscular tissues in a dormant state for a long time, without any symptoms, if the host's defense is strong, leading to chronic

infections (Lazar et al. 2021). During infection, the innate immune response focuses on three steps: recognition, cytokine production, and activation of natural killer (NK) cells. During the recognition phase, it recognizes the pathogen by using pathogen recognition receptors such as toll-like receptors (TLRs), C-type lectins, and Nod-like receptors (Khan and Moretto 2022). These receptors detect pathogen-associated molecular patterns (PAMPs) on the parasite's surface. After recognition, immune cells like dendritic cells and macrophages produce pro-inflammatory cytokines, mostly interleukin-12 (IL-12), which activate NK cells and promote the production of interferon-gamma (IFN-γ). This cytokine, IFN-γ, enhances the microbicidal activity of macrophages and dendritic cells against the parasite (Lazar et al. 2021), hence activation of the adaptive immune response. CD8+ T cells (cytotoxic T lymphocytes) directly destroy the infected cells, whereas CD4+ T cells (helper T cells) help modify the immune response by generating IFN-γ. On the other hand, during humoral response, B cells produce antibodies against *T. gondii,* which help to neutralize the extracellular tachyzoites and aid in their clearance. However, the antibodies are not effective against the intracellular structure. In chronic infections, non-oxidative mechanisms like the production of IFN-γ and nitric oxide (NO) have an important role in preventing the spread of the parasite (Lazar et al. 2021).

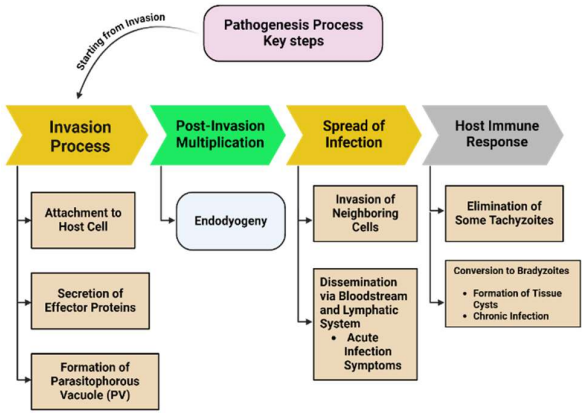


**Fig 4:** Flowchart highlights the key steps in the pathogenesis process (Lazar et al. 2021; Nayeri et al. 2024).

## Clinical Manifestations of Toxoplasmosis

Mostly, acute toxoplasmosis remains asymptomatic in the case of immunocompetent individuals, with symptoms like those of the flu, including swelling of lymph nodes, fever, fatigue, muscle aches, headaches, rashes, and sore throats (Lazar et al. 2021), typically resolve within a few weeks or months and don't require any specific treatment. A recent investigation was conducted on Canadian deer hunters with a travel history to the United States. After the serological testing, six out of 10 individuals had the same symptoms, and the cause of infection was the consumption of undercooked deer meat (Gaulin et al. 2020).

In chronic toxoplasmosis, *T. gondii* forms tissue cysts in the brain, muscles, and eyes. Most of the people stay asymptomatic, but some may experience headaches and muscle pain. Another significant manifestation of chronic toxoplasmosis is "ocular toxoplasmosis", which affects the retina and choroid and ultimately leads to eye pain, blurred vision, redness, and even vision loss in severe cases. In immunocompromised patients, the infection can reactivate periodically and cause retinal damage along with other symptoms; other complications like vitritis and choroiditis also accompany it to make the condition more severe (Smith et al. 2021). This is also a major cause of posterior uveitis all over the globe, which affects individuals of different age groups across different regions (Goh et al. 2023). Ocular toxoplasmosis is a leading cause of chorioretinitis in the United States and often causes bilateral chorioretinitis (30-80%) in congenitally infected individuals rather than individuals with acute acquired *T. gondii* infection (Mcauley 2014; Inchauspe et al. 2023).

## Toxoplasmosis in Immunocompromised Individuals

Toxoplasmosis can lead to severe complications in immunocompromised individuals, such as patients who have HIV/AIDS, cancer patients undergoing chemotherapy, or the recipients of organ transplantation, who are taking immunosuppressive therapy. In these types of patients, the latent infection can be reactive, or a new acute infection may lead to serious complications. The manifestation of patients with HIV/AIDS can be ocular toxoplasmosis, which can mimic other intraocular infections, and can show the presence of panuveitis along with single or multiple retino-choroidal lesions (Torre and Marín, 2020). Another important manifestation that can occur due to the reactivation of a latent infection in HIV-infected patients is cerebral toxoplasmosis, and the most common symptoms are seizures, headaches, mental confusion, psychomotor or behavioral changes, fever, ataxia, focal neurological deficit, and visual abnormalities (Dian and Ganiem 2023).

Pulmonary toxoplasmosis (PT) may also occur in the recipients of hemopoietic stem cell transplantation (HSCT) if the reactivation occurs, and it can be fatal in immunocompromised hosts. The symptoms of PT include fever, myalgia, arthralgia, dyspnea, and lymphadenopathy (Omori et al. 2021). These severe types of toxoplasmosis usually require aggressive treatments to reduce the chances of morbidity and mortality.

## Diagnostic Methods for Toxoplasmosis

Serological and molecular techniques are the most efficient ways to detect *T. gondii* infection accurately, and these techniques are used by many researchers nowadays. However, the advantages, disadvantages, specificity, limitations, and sensitivity of different serological techniques are being addressed in many other studies, and methods are being revised to improve their efficacy (Uddin et al. 2021). In the case of serological testing, antibodies are detected against *T. gondii*. IgG and IgM are the most important antibodies that are used for the confirmation of *T. gondii* infection (Souza et al. 2023; Elfadaly et al. 2023).

The presence of IgM demonstrates that the infection is recent because the antibodies can be detected within the first week, while the presence of IgG shows latent or chronic infection as the antibody level starts to rise within 1-2 weeks post-infection, peaking after 1-2 months, and remaining evident for life. A different test with a higher than 97% specificity level is the immunosorbent agglutination assay (ISAGA), which is used to identify IgM and IgA (Table 2). Additionally, enzyme-linked fluorescent immunoassay (ELFA) is a technique with the most accurate sensitivity (92%) and specificity (80%) for

the IgG markers, because it allows the detection of low-level antibodies, after the acute phase, for a longer period (Souza et al. 2023).

In contrast, several molecular methods such as LAMP, PCR, MLST, PCR-RFLP, RAPD-PCR, microsatellite analysis, WGS, and micro-genomics analysis have been used for the detection and identification of *T. gondii* (Uddin et al. 2021). Among all these, qPCR is the commonly used molecular technique because of its better results and diagnostic accuracy, but it cannot be used on a large scale due to its high cost (Souza et al. 2023). In the case of cost-effective and standardized techniques, chimeric epitope and recombinant proteins in single or double forms are recommended ones, for the diagnosis of different phases of *T. gondii* infection with satisfying sensitivity and specificity (Uddin et al. 2021).

**Treatment Options for Toxoplasmosis**

In immunocompetent patients, if the infection is acute and self-limiting, the symptoms are mild and resolve without therapy. However, if the infection is in a chronic phase and the patient is immunosuppressed as well, then it mostly requires an aggressive treatment approach. The standard treatment protocol in immunocompromised individuals includes pyrimethamine (PYR) and sulfadiazine (SDZ), where SDZ acts as an antibiotic, and PYR inhibits the folic acid metabolism in the parasite (Dunay et al. 2018); however, PYR suppresses bone marrow. Therefore, to avoid this side effect, leucovorin (folinic acid) is administered along with the prescribed treatment. Some patients are intolerant to SDZ, and for them, clindamycin or atovaquone may be used as an alternative, along with PYR (Singh and Munawwar 2010).

Ocular toxoplasmosis requires the combination of PYR, SDZ, and leucovorin (folinic acid), along with steroids in case of severe inflammation, to treat the active form of infection, and should be continued for at least 1-2 weeks after the termination of clinical signs (Bollani et al., 2022). Another analysis indicates that the combination of sulfamethoxazole + trimethoprim can be used as an alternative treatment (Silveira et al. 2015; Bollani et al. 2022). However, this combination can help to reduce the chances of chorioretinitis from recurring, if used in the long term and intermittently (Wallon et al. 2004; Bollani et al. 2022).

In pregnancy, the treatment for primary maternal toxoplasmosis (during the first 18 weeks of gestation) will use the combination of spiramycin + trimethoprim + sulfamethoxazole because it can cross the placental barrier and kill the parasite in fetal tissues, ultimately reducing the risk of maternal-fetal transmission of *T. gondii* (Bollani et al. 2022; Buonsenso et al. 2022). However, if the infection emerges after 18 weeks of gestation, then the combination of PYR + sulfonamides + leucovorin is the best treatment regimen, but it should not be used before 14 weeks (about 3 months) of gestation, to avoid the risk of teratogenicity (Peyron et al. 2019; Bollani et al. 2022). The PYR and SDZ are called “the drugs of choice for toxoplasmosis,” and their combination is used to suppress the growth of tachyzoites, while not affecting bradyzoites (Murata Et Al. 2017; Golec et al. 2021). That’s why most of the current techniques are not effective in the latent stages of infection (Murata et al. 2017; Augusto et al. 2021).

**Strategies to Prevent Toxoplasmosis**

Prevention of *T. gondii* infection calls for an all-inclusive effort in public health advice, individual practice, and management of wildlife and livestock. Public health initiatives should prioritize community education on the different modes of transmission and associated risks of *T. gondii*; these are the prevention protocols provided by the Centers for Disease Control and Prevention (CDC), USA. (https://www.cdc.gov/toxoplasmosis/prevention/) to avoid toxoplasmosis.

The USDA-recommended temperature for cooked meat is 160°F. The color of meat is not a good indication of the cooked level of *Toxoplasma*; however, in seafood, it is. Despite these risks, for all these years, the US government and the meat industry have still tried to bring down *T. gondii* in meat. The whole cuts of meat (excluding poultry) should be cooked at least to an internal temperature of 145°F (63°C) and let rest for three minutes after the cooking process. Fish with fins should be cooked until opaque and fork-tender, or until the internal temperature reaches 145°F. In case of ground meat (excluding poultry), a minimum internal temperature of 160°F (71°C) without rest time is needed. It is recommended to cook all poultry to a minimum of 165°F (74°C) to kill disease-bearing microorganisms, whether considering the innermost part of the thigh or wing, or the thickest part of the breast. Rest periods are not necessary. However, having a "rest time" ensures that the meat continues to cook after removal from the heat source, killing off the pathogens. Freeze the meat at sub-zero (0°F) temperature for several days before cooking as an additional precautionary measure. Moreover, rinse fruits and vegetables under running water, pasteurize goat's milk, and avoid consuming raw or undercooked mussels, clams, or oysters (https://www.cdc.gov/toxoplasmosis/prevention/).

**Table 2:** Overview of serological techniques used for detecting *T. gondii*, highlighting their main attributes and differences.

| Technique | Type | Key Markers | Advantages | Disadvantages | Specificity | Sensitivity |
|---|---|---|---|---|---|---|
| Serological Techniques | | | | | | |
| - IgM and IgG detection | Serological | IgG, IgM | Commonly used; Determines acute vs. chronic infection | May give false positives in cross-reactivity | High | Moderate to High |
| -Immunosorbent Agglutination Assay (ISAGA) | Serological | | High specificity | Complex and labor-intensive | >97% | High |
| - Enzyme-Linked Fluorescent Immunoassay (ELFA) | Serological | IgG | Accurate, detects low-level antibodies | Moderate specificity | 80% | 92% |

The data presented in the given table were adapted from (de Souza et al. 2023; Elfadaly et al. 2023)

Extra care is required in pregnant women to prevent congenital toxoplasmosis. They include avoiding contact with cat feces, refraining from consuming raw or undercooked meat, and ensuring good kitchen hygiene. Prenatal screenings in women against *T. gondii* play a critical role, as if the infection is detected, immediate treatment can be provided to lower the risk of passing the infection to the developing fetus (Sawers et al. 2022). These measures are critical in avoiding a high health risk for the mother and the developing child.

In veterinary places, the risk of *T. gondii* infections would involve reducing stray cat populations and their access to intermediate hosts such as rodents and birds. Many risks can be minimized with regular veterinary care, including proper nutrition, vaccination of cats (if available), and not feeding your cat a raw-meat diet. Public health campaigns should emphatically state that cats should be kept indoors and away from wildlife to reduce environmental oocyst distribution. Proper disposal of cat litter also plays a crucial part in preventing environmental contamination (Opsteegh et al. 2015).

Only 14 European countries have currently provided data related to toxoplasmosis in animals; however, it's limited due to the small number of tested animals, no obvious data regarding their age or the housing system, and the use of different detection and sampling methods (Kuruca et al. 2023). For livestock, including sheep, goats, and pigs, proper biosecurity needs to be considered. Correct management and hygienic techniques, which are effective in keeping cats or cat litter away from crops, gardens, and animal feed, play a crucial role in controlling *T. gondii* spread on farms (García and Planas 2022). Veterinary management jointly carried out at the community level, biosecurity practices for livestock, wildlife control activities, and individual practices will substantially reduce the risks. This is a critical approach for at-risk groups, like pregnant women, immunocompromised persons, young children, livestock, and wildlife (Aguirre et al. 2019).

## Recent Advances in *Toxoplasma gondii* Research and Future Directions

Our knowledge of parasites' biology, host interactions, and therapeutic strategies for *T. gondii* has developed exponentially over the last few years. Notably, progress was seen in vaccine development. A wide range of vaccination strategies with nucleic acids (Chen et al. 2022), protein subunits, attenuated vaccines, and nanoparticles have been carried out in rodent models with promising results. To date, however, the translation of such promising *in vivo* findings into human studies remains a big challenge that must be hurdled (Chu; Quan, 2021a). Along with that, live-attenuated vaccines are highly effective and immunogenic in the majority of animals, but these cannot be used or tested in humans because attenuated vaccines have the possibility of getting back to their wild virulent stage (Chu; Quan, 2021b; Müller; Hemphill, 2023). There is also another disadvantage concerning the classical methods: obtaining enough quantities of purified immunogenic components of the antigen is complicated. The effectiveness and safety of the *T. gondii* vaccine using recombinant antigens are very significant, especially in pregnant women who might be at risk for the first time (Table 3) ( Mamaghani et al. 2020; Mamaghani et al. 2023). The meticulous selection of highly immunogenic antigens and their fusion into a multi-antigenic vaccine on a platform are currently prerequisites for the future development of a toxoplasmosis vaccine, such as virus-like particles (VLPs) or possibly oral vaccines, using recombinant baculovirus expressing *T. gondii* antigen for use in non-human intermediate hosts, which would greatly enhance the *T. gondii* vaccine to benefit humans and intermediate hosts, with continued multidisciplinary efforts and diverse strategies (CHU; QUAN, 2021b).

In the case of recent therapies, some progress has been made in identifying novel drugs and therapeutic agents. One study shows that di-hydroquinone (DHQ) is very effective in inhibiting the growth and disrupting the replication, invasion, transcriptional, and translational machinery of *T. gondii*, rendering it a secure and substitute substance for the management of toxoplasmosis (Huffman et al. 2022). Another study confirms that research on essential proteins of *Toxoplasma gondii* over the past two decades has raised hopes for novel treatments. Although many compounds have emerged as promising *in vitro*, few are effective in rodent models, however, so far none are effective in humans, suggesting that target-based drug discovery is no better than classical methods, both of which must take account of off-target effects and unwanted side effects, with proteomics-driven analyses possibly providing an important tool in the characterization of drug targets regardless of the discovery approach (Table 4) (Müller and Hemphill 2023).

**Table 3:** A Concise Evaluation of Vaccine Development Strategies for Toxoplasmosis: Descriptions, Advantages, and Challenges

| Strategy | Description | Advantages | Challenges |
|---|---|---|---|
| Nucleic Acids, Protein Subunits, Attenuated Vaccines, Nanoparticles | Tested in rodent models with promising results | Effective in animal models | Translation to human studies is challenging |
| Live-Attenuated Vaccines | Highly effective and immunogenic in animals | Effective, strong immune response | Risk of reversion to the virulent stage, not suitable for humans |
| Recombinant Antigens | Focus on pregnant women at risk | Safe and effective | Difficult to obtain enough purified immunogenic components |
| Multi-Antigenic Platforms | Using virus-like particles (VLPs) or oral vaccines with recombinant baculovirus expressing *T. gondii* antigen | Potential for use in non-human intermediate hosts, a multidisciplinary approach is needed. | Requires meticulous selection of highly immunogenic antigens, complex development |

Data were adapted from (Javadi Mamaghani et al. 2020; Chu and Quan, 2021b; Müller and Hemphill, 2023; Mamaghani et al. 2023).

**Table 4:** Novel Therapeutic Agents: Key Descriptions, Advantages, and Challenges

| Agent | Description | Advantages | Challenges |
|---|---|---|---|
| Di-Hydroquinone (DHQ) | Inhibits growth and disrupts replication, invasion, transcriptional, and translational machinery | Effective *in vitro* | Needs validation in humans |
| Target-Based Drug Discovery | Focus on essential proteins of *T. gondii* identified over two decades | Raised hopes for novel treatments | Few compounds are effective in rodent models, ineffective in humans; off-target effects and side effects. |

Data were adapted from (Huffman et al. 2022; Müller & Hemphill, 2023).

**Table 5:** Overview of Emerging Technologies: Applications, Advantages, and Challenges

| Technology | Application | Advantages | Challenges |
|---|---|---|---|
| Multi-Omics Integration | Proteomics, genomics, transcriptomics | Reveals novel drug and vaccine targets, identifies unique or enriched proteins in parasites | Complex data analysis required |
| Next-Generation Sequencing (NGS) | High-resolution sequencing of biological molecules in apicomplexan parasites | Deeper insights into parasite-host interactions, transmission, and epidemiology | Requires advanced bioinformatic approaches |
| Single-Cell RNA Sequencing | Overcomes limitations of high heterogeneity and analytical variability | Provides detailed cellular-level insights | Technically demanding, requires specialized equipment |

Data were adapted from (Tomazic et al. 2022; Deng et al. 2024).

Emerging technologies have also played an important role in advancing our understanding of the biology and host interaction system of *T. gondii*, which can be beneficial for new therapy and vaccine developments. Multi-omics data integration such as proteomics, genomics, and transcriptomics could be used in understanding parasite biology and reveal novel drug and vaccine targets and the comparison of the protein expression profile between different life stages as well as the differentially expressed proteins among parasites and host cells can lead to the identification of proteins that are either unique to the parasites or highly enriched in them (Deng et al. 2024). For example, one of the identification keys is histone variant H2B.Z acetylation, which is critical for *T. gondii* fitness and is a putative target for drug development (Vanagas et al. 2023; Deng et al., 2024). Additionally, now that 90% of the human proteome has been mapped (Adhikari et al. 2020; Deng et al. 2024), there is a growing integration of proteomics with other multi-omics techniques in future proteomics research, including with *T. gondii*, which will allow for an even greater deepening of our understanding and identification of novel targets (Deng et al. 2024). The advent of next-generation sequencing (NGS) technologies, combined with the use of multiplexing platforms and high-resolution techniques and their corresponding novel bioinformatic approaches, has revolutionized the sequencing of biological molecules in apicomplexan parasites, eventually allowing for deeper insights into parasite-host interactions, including transmission and epidemiology, and opening new avenues for the identification of new therapeutic targets (Table 5). Along with that, single-cell RNA sequencing can provide a route toward the transcendence of limitations of high heterogeneity and analytical variability associated with current "bulk measures" (Tomazic and Hernandez 2022).

Future investigations should further concentrate on translating these findings into practice. The Development of the vaccine and its optimization for human use will be one of the important steps, and the next goal is to ensure that the process is safe and shows efficacy through clinical trials. Apart from that, more in-depth investigations combining new drugs with already approved drugs for severe diseases like cancer could enhance the effectiveness of the treatments. Furthermore, the long-term damages of *T. gondii* infection and their possible connections to chronic diseases and neurological disorders warrant further study.

In addition, the research on the intersectional factor between parasitology, immunology, and advanced technologies is important for understanding the intricate interactions between *T. gondii* and its host. The cooperation between the researchers, the doctors, and the public health authorities in the discovery and translation of scientific research should be implemented to develop effective prevention and treatment strategies, and the global burden of toxoplasmosis will be alleviated.

## Conclusion

*T. gondii* remains an unresolved global challenge with profound implications for human and veterinary medicine, its intricate biology and sophisticated immune evasion mechanisms continuing to complicate disease management. While recent advances in vaccine development, novel pharmacological interventions, and technologies such as proteomics and advanced imaging offer promising avenues for improved intervention, the critical bottleneck persists in translating experimental findings into applicable, field-ready solutions. Ultimately, sustainable control necessitates a paradigm shift toward community-centric prevention, wherein rigorous hygiene practices, food safety protocols, and comprehensive animal management strategies, including proper handling of companion animals and wildlife, serve as primary defenses against transmission. Future progress will depend upon the integration of interdisciplinary resources, bridging the gap between laboratory science and practical public health implementation, thereby reducing disease burden among vulnerable populations through the convergence of innovative therapeutics and evidence-based preventive measures.

## DECLARATIONS

**Funding:** There is no funding involved in this review

**Acknowledgement:** NA

**Conflict of interest:** The authors declare no conflict of interest with anyone.

**Data Availability:** NA

**Ethics Statement:** NA

**Authors contribution:** MA conceived the idea and synthesized the manuscript; QH and JW proofread and approved the paper for submission.

**Generative AI Statement:** The authors confirm that no AI-contributed technologies were utilized when preparing this manuscript.

**Publisher's Note:** All claims stated in this article are exclusively those of the authors and do not necessarily represent those of their affiliated organizations or those of the publisher, the editors, and the reviewers. Any product that may be evaluated/assessed in this article or claimed by its manufacturer is not guaranteed or endorsed by the publisher/editors.

## REFERENCES


Aboelhadid SM, Abdel-Ghany AE, Ibrahim MA and Mahran HA, 2013. Seroprevalence of *Toxoplasma gondii* infection in chickens and humans in Beni Suef, Egypt. Global Veterinaria 11(2): 139-144.

Adhikari S, Nice EC, Deutsch EW, Lane L, Omenn GS, Pennington SR, Paik YK, Overall CM, Corrales FJ, Cristea IM and Van Eyk JE, 2020. A high-stringency blueprint of the human proteome. Nature Communications 11(1): 5301.

Aguirre AA, Longcore T, Barbieri M, Dabritz H, Hill D, Klein PN, Lepczyk C, Lilly EL, McLeod R, Milcarsky J and Murphy CE, 2019. The one health approach to toxoplasmosis: epidemiology, control, and prevention strategies. EcoHealth 16(2): 378-390. https://doi.org/10.1007/s10393-019-01405-7

Almuzaini AM, 2023. Flow of zoonotic toxoplasmosis in food chain. Pakistan Veterinary Journal 43(1):1-16.

Attias M, Teixeira DE, Benchimol M, Vommaro RC, Crepaldi PH and De Souza W, 2020. The life cycle of *Toxoplasma gondii* reviewed using animations. Parasites and Vectors 13(1): 588. https://doi.org/10.1186/s13071-020-04445-z

Augusto L, Martynowicz J, Amin PH, Carlson KR, Wek RC and Sullivan WJ, 2021. Tgif2k-b is an eif2a kinase in *toxoplasma gondii* that responds to oxidative stress and optimizes pathogenicity. MBio 12(1): 10–1128. https://doi.org/10.1128/mbio.03160-20

Basso W, Holenweger F, Schares G, Müller N, Campero LM, Ardüser F, Moore-Jones G, Frey CF and Zanolari P, 2022. *Toxoplasma gondii* and Neospora caninum infections in sheep and goats in Switzerland: seroprevalence and occurrence in aborted foetuses. Food and Waterborne Parasitology 28: e00176. https://doi.org/10.1016/j.fawpar.2022.e00176

Bigna JJ, Tochie JN, Agbaeze FE, Ze MB, Temgoua MN, Ngouana AJ, Karlowsky JA and Jean-Luc BN, 2020. Global, regional, and country seroprevalence of *Toxoplasma gondii* in pregnant women: a systematic review, modelling and meta-analysis. Scientific Reports 10(1): 12102. https://doi.org/10.1038/s41598-020-69078-9

Bollani L, Auriti C, Achille C, Garofoli F, De Rose DU, Meroni V, Salvatori G and Tzialla C, 2022. Congenital toxoplasmosis: the state of the art. Frontiers in Pediatrics 10: 894573. https://doi.org/10.3389/fped.2022.894573

Buonsenso D, Pata D, Colonna AT, Iademarco M, de Santis M, Masini L, Conti G, Molle F, Baldascino A, Acampora A, Luciano R, Gallini F and Valentini P, 2022. Spyramicine and trimethoprim-sulfamethoxazole combination to prevent mother-to-fetus transmission of *Toxoplasma gondii* infection in pregnant women: a 28-years single-center experience. Pediatric Infectious Disease Journal 41(5): e223–e227. https://doi.org/10.1097/inf.0000000000003469

Can H, Erkunt Alak S, Köseoğlu AE, Döşkaya M and Ün C, 2020. Do *Toxoplasma gondii* apicoplast proteins have antigenic potential? An in-silico study. Computational Biology and Chemistry 84: 107158. https://doi.org/10.1016/j.compbiolchem.2019.107158

Chen R, Peng JJ, Mohsin M, Huang X, Lin X, Aguilar-Marcelino L, Huang Z and Yin G, 2022. Construction and evaluation of the *Toxoplasma gondii* DNA vaccine targeting DEC-205. Pakistan Veterinary Journal 42(2). http://dx.doi.org/10.29261/pakvetj/2022.020

Chu KB and Quan FS, 2021a. Advances in *Toxoplasma gondii* vaccines: current strategies and challenges for vaccine development. Vaccines 9(5): 413. https://doi.org/10.3390/vaccines9050413

Daher D, Shaghlil A, Sobh E, Hamie M, Hassan ME, Moumneh MB, Itani S, Hajj RE, Tawk L, Sabban ME and Hajj HE, 2021. Comprehensive overview of *Toxoplasma gondii*-induced and associated diseases. Pathogens 10(11): 1351. https://doi.org/10.3390/pathogens10111351

de Souza IMFNB, Siqueira VdaS, Ribeiro IdaC, Moraes LSP, Do Prado DPG, Rezende SR, da Costa WLG and Rezende HHA, 2023. Molecular and serological diagnosis of toxoplasmosis: a systematic review and meta-analysis. Revista Do Instituto de Medicina Tropical de São Paulo 65: e19. https://doi.org/10.1590/S1678-9946202365019

Deng B, Vanagas L, Alonso AM and Angel SO, 2024. Proteomics applications in *Toxoplasma gondii*: unveiling the host–parasite interactions and therapeutic target discovery. Pathogens 13(1): 33. https://doi.org/10.3390/pathogens13010033

Dian S, Ganiem AR and Ekawardhani S, 2023. Cerebral toxoplasmosis in HIV-infected patients: a review. Pathogens and Global Health 117(1): 14–23. https://doi.org/10.1080/20477724.2022.2083977

Dubey JP, Cerqueira-Cézar CK, Murata FHA, Kwok OCH, Hill D, Yang Y and Su C, 2020. All about *Toxoplasma gondii* infections in pigs: 2009–2020. Veterinary Parasitology 288: 109185. https://doi.org/10.1016/j.vetpar.2020.109185

Dunay, I.R., Gajurel, K., Dhakal, R., Liesenfeld, O. and Montoya, J.G., 2018. Treatment of toxoplasmosis: historical perspective, animal models, and current clinical practice. *Clinical microbiology reviews*, *31*(4), pp.10-1128. https://doi.org/10 .1128/CMR.00057-17

Elfadaly HA, Shaapan RM, Barakat AM, Hassanain NA and Maher A, 2023. The accuracy of developed peroxidase *Toxoplasma gondii* IgG ELISA plates for evaluating toxoplasmosis in sheep. International Journal of Veterinary Science, 236-241.https://doi.org/10.47278/journal.ijvs/2022.174

El-Ashram S, Dincel GC, Farouk MH, Alouffi A, Abdel-Latif HM, Iqbal S, Tellez-Isaias G, Hargis BM, Petrone-García VM, Aguilar-Tipacamú G and Castellanos-Huerta I, 2023. Introductory chapter: the significance of *Toxoplasma gondii* in humans, and in domestic and wild animals. Towards New Perspectives on *Toxoplasma gondii*. https://doi.org/10.5772/INTECHOPEN.110405

Gaulin C, Ramsay D, Thivierge K, Tataryn J, Courville A, Martin C, Cunningham P, Désilets J, Morin D and Dion R, 2020. Acute toxoplasmosis among Canadian deer hunters associated with consumption of undercooked deer meat hunted in the United States. Emerging Infectious Diseases 26(2): 199. https://doi.org/10.3201/EID2602.191218

Goh EJH, Putera I, La Distia Nora R, Mahendradas P, Biswas J, Chee SP, Testi I, Pavesio CE, Curi ALL, Vasconcelos-Santos DV, Arora A, Gupta V, Agrawal R, 2023. Ocular toxoplasmosis. Ocular Immunology and Inflammation 31(7): 1342–1361. https://doi.org/10.1080/09273948.2022.2117705

Huffman AM, Ayariga JA, Napier A, Robertson BK, Abugri DA, 2022. Inhibition of *Toxoplasma gondii* growth by dihydroquinine and its mechanisms of action. Frontiers in Cellular and Infection Microbiology 12: 852889. https://doi.org/10.3389/FCIMB.2022.852889/BIBTEX

Inchauspe S, Palacio A, Arriazu G, Bellón M, Morales Roldan V, Torres de Leon P, Olivera Plata SL, Dodds EM, 2024. Association between ocular trauma and activation of ocular toxoplasmosis. Ocular Immunology and Inflammation 32(6): 1065-1069. https://doi.org/10.1080/09273948.2023.2203215

Javadi Mamaghani A, Seyyed Tabaei SJ, Ranjbar MM, Haghighi A, Spotin A, Ataee Dizaji P, Rezaee H, 2020. Designing diagnostic kit for *Toxoplasma gondii* based on GRA7, SAG1, and ROP1 antigens: an in-silico strategy. International Journal of Peptide Research and Therapeutics 26(4): 2269-2283. https://doi.org/10.1007/S10989-020-10021-X/METRICS

Javed K, Alkheraije KA, 2023. Cryptosporidiosis: a foodborne zoonotic disease of farm animals and humans. Pakistan Veterinary Journal 43. http://dx.doi.org/10.29261/pakvetj/2023.038

Jiang N, Su R, Jian F, Su C, Zhang L, Jiang Y, Yang Y, 2020. *Toxoplasma gondii* in lambs of China: heart juice serology, isolation and genotyping. International Journal of Food Microbiology 322: 108563. https://doi.org/10.1016/J.IJFOODMICRO.2020.108563

Khan IA, Moretto M, 2022. Immune responses to *Toxoplasma gondii*. Current Opinion in Immunology 77: 102226. https://doi.org/10.1016/J.COI.2022.102226

Kuruca L, Belluco S, Vieira-Pinto M, Antic D, Blagojevic B, 2023. Current control options and a way towards risk-based control of *Toxoplasma gondii* in the meat chain. Food Control 146: 109556. https://doi.org/10.1016/J.FOODCONT.2022.109556

Mamaghani AJ, Fathollahi A, Arab-Mazar Z, kohansal K, Fathollahi M, Spotin A, Bashiri H, Bozorgomid A, 2023. *Toxoplasma gondii* vaccine candidates: a concise review. Irish Journal of Medical Science 192(1): 231-261. https://doi.org/10.1007/S11845-022-02998-9/TABLES/3

Matsuo K, Kamai R, Uetsu H, Goto H, Takashima Y, Nagamune K, 2014. Seroprevalence of *Toxoplasma gondii* infection in cattle, horses, pigs and chickens in Japan. Parasitology International 63(4): 638-639.

McAuley JB, 2014. Congenital toxoplasmosis. *Journal of the Pediatric Infectious Diseases Society* 3(supp_1): S30-S35. https://doi.org/10.1093/JPIDS/PIU077

Müller J, Hemphill A, 2023. *Toxoplasma gondii* infection: novel emerging therapeutic targets. Expert Opinion on Therapeutic Targets 27(4-5): 293-304. https://doi.org/10.1080/14728222.2023.2217353

Murata Y, Sugi T, Weiss LM, Kato K, 2017. Identification of compounds that suppress *Toxoplasma gondii* tachyzoites and bradyzoites. PLOS ONE 12(6): e0178203. https://doi.org/10.1371/JOURNAL.PONE.0178203

Nayeri T, Sarvi S, Daryani A, 2024. Effective factors in the pathogenesis of *Toxoplasma gondii*. Heliyon 10(10). https://doi.org/10.1016/J.HELIYON.2024.E31558

Omori K, Imoto N, Norose K, Maeda M, Hikosaka K, Kurahashi S, 2021. Acute exacerbation of pulmonary toxoplasmosis during corticosteroid therapy for immune thrombocytopenia: a case report and literature review. Medicine 100(51): e28430. https://doi.org/10.1097/MD.0000000000028430

Opsteegh M, Kortbeek TM, Havelaar AH, Van Der Giessen JW, 2015. Intervention strategies to reduce human *Toxoplasma gondii* disease burden. Clinical Infectious Diseases 60(1): 101–107.

Peyron F, L'ollivier C, Mandelbrot L, Wallon M, Piarroux R, Kieffer F, Hadjadj E, Paris L, Garcia-Meric P, 2019. Maternal and congenital toxoplasmosis: diagnosis and treatment recommendations of a French multidisciplinary working group. Pathogens 8(1): 24. https://doi.org/10.3390/PATHOGENS8010024

Rafique A, Nasir S, Ashraf A, Nawaz Z, Zahid FM, Abbas A, Masood S, 2022. Sero-surveillance and risk factors analysis of caprine toxoplasmosis in Faisalabad Punjab, Pakistan. Pakistan Veterinary Journal 42(1). http://dx.doi.org/10.29261/pakvetj/2021.020.

Sana M, Rashid M, Rashid I, Akbar H, Gomez-Marin JE, Dimier-Poisson I, 2022. Immune response against toxoplasmosis—some recent updates RH: *Toxoplasma gondii* immune response. International Journal of immunopathology and harmacology 36: 03946320221078436. https://doi.org/10.1177/03946320221078436/ASSET/IMAGES/LARGE/10.1177_03946320221078436-FIG2.JPEG

Sanchez SG, Besteiro S, 2021. The pathogenicity and virulence of *Toxoplasma gondii*. Virulence 12(1): 3095–3114.

Sawers L, Wallon M, Mandelbrot L, Villena I, Stillwaggon E, Kieffer F, 2022. Prevention of congenital toxoplasmosis in France using prenatal screening: a decision-analytic economic model. PLoS One 17(11): e0273781. https://doi.org/10.1371/JOURNAL.PONE.0273781

Silveira C, Muccioli C, Nussenblatt R, Belfort R, 2015. The effect of long-term intermittent trimethoprim/sulfamethoxazole treatment on recurrences of toxoplasmic retinochoroiditis: 10 years of follow-up. Ocular Immunology and Inflammation 23(3): 246–247. https://doi.org/10.3109/09273948.2014.964422

Singh S, Singh N, Munawwar A, Pandit A, Somvanshi R, Bhattacharya D, Mehrotra AS, Verma A, Gard SP, Venkatesh P, Biswas NR, Deka D, Dubey JP, 2010. Toxoplasmosis in India. https://www.researchgate.net/publication/318338943

Smith JR, Ashander LM, Arruda SL, Cordeiro CA, Lie S, Rochet E, Belfort R, Furtado JM, 2021. Pathogenesis of ocular toxoplasmosis. Progress in Retinal and Eye Research 81: 100882. https://doi.org/10.1016/J.PRETEYERES.2020.100882

Su YJ, Ma ZD, Qiao X, Wang PT, Kang YT, Yang NA, Jia W, Zhao ZJ, 2022. Geospatial epidemiology of *Toxoplasma gondii* infection in livestock, pets, and humans in China, 1984–2020. Parasitology Research 121(2): 743–750. https://doi.org/10.1007/S00436-021-07415-1/METRICS

Suleimenova ZI, Doskozhaeva ST, Park EA, Tokburaeva SD, 2022. Toxoplasmosis of the central nervous system in HIV patients. Interdisciplinary Approaches to Medicine 3(2): 28–31. https://doi.org/10.26577/IAM.2022.V3.I2.06

Lazar LTY, Al-Ammash MSJ, Abass KS, 2021. *Toxoplasma gondii*: life cycle, pathogenesis, immune response: a review. Plant Archives 21(1): 1057–1059. https://doi.org/10.51470/PLANTARCHIVES.2021.v21.S1.163

Tomazic ML, Marugan-Hernandez V, Rodriguez AE, 2022. Next-generation technologies and systems biology for the design of novel vaccines against Apicomplexan parasites. Frontiers in Veterinary Science 8: 800361. https://doi.org/10.3389/FVETS.2021.800361/BIBTEX

Tong WH, Pavey C, O'Handley R, Vyas A, 2021. Behavioral biology of *Toxoplasma gondii* infection. Parasites & Vectors 14(1): 77. https://doi.org/10.1186/S13071-020-04528-X/METRICS

Uddin AHMM, Hossain D, Ahsan MI, Atikuzzaman M, Karim MR, 2021. Review on diagnosis and molecular

characterization of *Toxoplasma gondii* in humans and animals. Tropical Biomedicine 511–539. https://doi.org/10.47665/tb.38.4.091

Vanagas L, Muñoz D, Cristaldi C, Ganuza A, Nájera R, Bonardi MC, Turowski VR, Guzman F, Deng B, Kim K, Sullivan WJ, Angel SO, 2023. Histone variant H2B.Z acetylation is necessary for maintenance of *Toxoplasma gondii* biological fitness. Biochimica et Biophysica Acta (BBA) - Gene Regulatory Mechanisms 1866: 194943. https://doi.org/10.1016/J.BBAGRM.2023.194943

Wallon M, Kodjikian L, Binquet C, Garweg J, Fleury J, Quantin C, Peyron F, 2004. Long-term ocular prognosis in 327 children with congenital toxoplasmosis. Pediatrics 113(6): 1567–1572. https://doi.org/10.1542/PEDS.113.6.1567

Xia NB, Lu Y, Zhao PF, Wang CF, Li YY, Tan L, Fang R, Zhou YQ, Shen B, Zhao JL, 2020. Genotyping and characterization of *Toxoplasma gondii* strain isolated from pigs in Hubei province, central China. 489–498.

Xia N, Ji N, Li L, Huang Y, Yang C, Guo X, Guo Q, Shen B, Xiao L, Feng Y, 2022. Seroprevalence and risk factors of *Toxoplasma gondii* in urban cats from China. BMC Veterinary Research 18(1) 331. https://doi.org/10.1186/S12917-022-03427-W/TABLES/3

Xu Y, Li RC, Liu GH, Cong W, Zhang XX, Yu XL, Zhu XQ, 2014. Seroprevalence of *Toxoplasma gondii* infection in sows in Hunan province, China. The Scientific World Journal 2014(1): 347908. https://doi.org/10.1155/2014/347908

Yamamoto L, Targa LS, Sumita LM, Shimokawa PT, Rodrigues JC, Kanunfre KA, Okay TS, 2017. Association of parasite load levels in amniotic fluid with clinical outcome in congenital toxoplasmosis. Obstetrics and Gynecology 130(2): 335–345. https://doi.org/10.1097/AOG.0000000000002131

Yu CP, Chen BC, Chou YC, Hsieh CJ, Lin FH, 2023. The epidemiology of patients with toxoplasmosis and its associated risk factors in Taiwan during the 2007–2020 period. PLoS One 18(8): e0290769. https://doi.org/10.1371/JOURNAL.PONE.0290769