Review Article

Tracking Trends of *Toxoplasma gondii* Transmission from Environment to Animal to Human

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Abstract | Understanding the transmission strategy of any infectious microorganisms are very much critical for proper management and prevention of that particular microorganism mediated disease. In this review, we have explored the outmost transmission routes of *Toxoplasma gondii* into human and animal host.It has to be stressed that *T. gondii* has wide range of transmission pattern and therefore can infect any warm-blooded animals including one-third of human population world-wide. The major routes of *T. gondii* transmissions are ingestions of undercooked meats or meat-products and oocysts contaminated foods, vegetables and water. Congenital transmission is also play an important role for *T. gondii* transmission into developing fetus. In addition to these, there are considerably significant routes by which *T. gondii* can interchange its host through contaminated milk, fish, soil etc. Furthermore, a few minor routes are available i.e blood transfusion and organ transplantation. However, this review would cover the recent knowledge of *T. gondii* transmission from environment to animal to human. This one health approach might unrevealed knowledge in this particular area which would be helpful for the counties where *T. gondii* is highly prevalent. Controlling these transmission route with proper safety and carefulness, *T. gondii* mediated Toxoplasmosis can be prevented.

Keywords | *Toxoplasma gondii*, transmission, foods, vegetables, water, animal and human.

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INTRODUCTION

Toxoplasma gondii, having a facultative heterogenous life cycle, is a pervasive parasite and can infect a wide range of animals including mammals and birds (Dubey, 1998). The life cycle comprises of sexual and asexual phases which involve feline and non-feline infection respectively. The asexual part of life cycle determines the stage of infection in intermediate hosts, which are mainly warm blooded non-feline animals. There are two phases in the asexual part of *T. gondii* life cycle which consists of two different kinds of developmental stages. The first one is tachyzoites or endozoites which causes the acute infection in host cell because of their rapid multiplication by endodyogeny. They take 6 to 8 hours for replication, producing 64 to 128 parasites in each cell, then they exit the cell and infect nearby cells (Radke and White, 1998). The last generation of tachyzoites differentiate into bradyzoites, the second phase of development by forming a tissue cyst. They cause the chronic infection as they multiply slowly by endodyogeny in the tissue cysts. Therefore, they are also called the cystozoites. This stage of development is the terminal stage and it is highly infectious. The cysts have high affinity for brain and muscle tissues. So, they position themselves predominantly in central nervous system (CNS), eye, skeletal and cardiac muscle. In addition, they can also locate insignificantly in visceral organs, for example, kidney, lungs and liver. In some intermediate hosts, *T. gondii* can persist as long as the hosts live. The bradyzoites are "believed to occur a low rate" of spontaneous reactivation inside the host cells, transforming back to tachyzoites. They can again reinvade other cells and transform into bradyzoites which initiates another asexual phase of life cycle. Usually it happens when the host is immunocompromised and the reaction remains unprevented by the immune system, leading to a fatal disease (Tentere et al., 2000).

When a feline animal, i.e. cats, ingests the tissue cysts, the sexual cycle of *T. gondii* starts in the feline intestine. After several steps in the cycle, the cat sheds oocysts in the feces, followed by exposure of the oocyst in the environment. Those are infectious components and mature in the environment by surviving for a long time. The infectious oocysts are then accidentally ingested by warm-blooded animals which turns them into intermediate hosts of *T. gondii* asexual cycle. The oocysts release sporozoites, which infect the epithelial cells of intestine and differentiate into tachyzoites, initiating the asexual cycle (Black and Boothroyd, 2000).

Oocysts shed by infected felids can survive for a long time in the environment. Sporulated oocyst can remain infectious up to 18 months at 20-30 ^{O}C in environment, up to 54 months at 4^{O}C in water, and even in -20 ^{O}C. The outer shell of the sporulated oocysts make them resistant to adverse environmental condition, such as chemical disinfectants and physical stress (Yan et al., 2016). Domestic and stray cats are believed to be involved in increasing oocyst burden in environment as they shed hardy oocysts in their feces in the environment. Oocysts can be excreted in an amount of 20 million 4-13 days after a cat has been infected. This is an important factor for understanding the transmission mechanism as cats are the animals which some to close company with human the most (Shapiro et al., 2019). These oocysts in environment can then contaminate water, soil, foods and vegetables. Tachyzoites are not resistant to adverse environmental factors. They also cannot survive outside host for long time. So, infection by ingesting tachyzoites is not a significant route of transmission (Tenter, 2009). They are thought to get degraded by the proteolytic enzymes in the gastrointestinal tract. On the other hand, bradyzoites can survive in the presence of digestive enzymes more than tachyzoites (Pereira et al., 2010).

There are three major routes of human toxoplasmosis, which include: 1) vertical transmission of tachyzoites from mother to fetus, 2) horizontal transmission by ingesting tissue cyst contained in animal tissues, and 3) horizontal transmission by ingesting oocyst from environment (water, soil or food) (Shapiro et al., 2019). In this review, the main focus will be the transmission from environmental components such as foods, vegetables, water, soil as well as the congenital transmission and direct transmission through blood.

Infection by Meat and Food

Toxoplasma oocysts are killed while treating with heat at a high temperature, so it is more likely to be present in undercooked or raw meat. Therefore, it is one of the most common routes of human toxoplasmosis (Jones and Dubey, 2012). A study showed that the risk of infection is higher in meats from free-ranged chicken, non-confinement-raised pigs, goats and lamb than from cattle, confinement-raised pigs and caged chickens. For example, high number of new infection recently are related to pork consumption in USA. It is studied that animal friendly approach such as free range and organic way of raising pigs increased the number of infected pigs (Hussain et al., 2017). It was shown in a study that 0 of 621 conventionally raised pigs were seropositive for *T gondii*, while 38 of 1295 pigs raised in an animal friendly system were positive. In Michigan, 17 of 33 organic pigs were positive for *T. gondii* in another recent study (Dubey et al., 2012). European countries showed 30-60% of infection were meatborne, where lamb other meat was predominant in northern and central centers than Italy. 10-14% of infection in Milan, Naples and Brussels were from eating salami (Cook et al., 2000). In this study, it was concluded that the risk of infection increases with consuming dry or cured meat and salami more than once a week.

In USA, free range chicken is infected in high percentage (17%-100%) than indoor raised chickens (Dubey, 2010). But transmission of infection by consumption of raw eggs is very insignificant so it is not considered as a risk factor. Horse and goat meats are important in transmission. There is an outbreak of toxoplasmosis in France due to consumption of horse meat imported from Canada and Brazil (Pomares et al., 2011). Iranian population study showed a high seropositivity in those groups which consumes undercooked meat of beef, lamb and birds as they are the main ingredients in all kinds of Iranian foods. Moreover, eating sausage and other meat products were also indicated to be a source of transmission due to their preparation process (Daryani et al., 2014).Seafood and marine animals can be potent source of toxoplasmosis transmission. Clams, mussels, oysters, and fishes from several countries including Brazil, China, Turkey, and the USA were reported as source of infection. Eating raw shell fishes is also a significant risk for transmission (Shapiro et al., 2019). In a case study by Simone Belluco showed that infrequent knife washing, and tasting meat while cooking were two important hygiene habit factors for acquiring *T. gondii* infection (Belluco et al., 2018). Furthermore, unwashed hands before food preparation after getting in contact with cat, cat feces or cat litter box can be a factor for transmission (Hussain et al., 2017).

Infection by Fruits and Vegetables

Consumption of raw vegetables and fruits can be potential sources of toxoplasma transmission. Fresh products can get contaminated in the production farms during planting, harvesting, transport and distribution. Using contaminated water in irrigation and cultivating in fecally contaminated soil are both sources of infection in plant produces (Pinto-Ferreira et al., 2019; Shapiro et al., 2019). In underdeveloped countries, hygiene, sanitation and water quality are not maintained, which causes the fresh products contamination in low-income countries. Interestingly, because of the global trade of vegetables and fruits, high income countries also have to face the transmission by contaminated fresh products indirectly. Brazil China, Italy and Poland face frequent fruit and vegetable contamination according to a study, and the strains isolated were type I and II (Li et al., 2020).

Contamination of fresh products also can occur while processing, selling and consumption. A study in Brazil including 11 cases of acute toxoplasmosis in a factory with 2300 employees revealed consumption of vegetables as the source of infection (Ekman et al., 2012). Another outbreak occurred in Brazil in 2013, due to consumption of a fruit Açaí which infected 73 people (dos Anjos Pinheiro Bogoevich Morais et al., 2020). A 16-case-control studies in 2010 showed high frequency of seropositivity (24-47%) among vegetarians in some population (Petersen et al., 2010). In a recent study in 2019 in Czech Republic, it was shown that the rate of contamination is higher during processing and selling of vegetables (Slany et al., 2019). An Iranian population studies suggests that housewives and farmers are more prone to infection as housewives come to direct contact with pet cats, do gardening in rural area then cooks without sanitizing their hands and tastes uncooked meat and vegetables. Farmers are the second risk group in this case (Daryani et al., 2014).

Fruit and vegetable workers are analyzed in another study, where among 200 workers, 15 were positive for *T. gondii*. This study explained that handling of unwashed fruits and vegetable is not a potential risk factor, rather consumption of unwashed raw fruits or with unwashed hands, living in a house with soil floors, or being frequently exposed to sewage, water and soil are more important risk factors (Alvarado-Esquivel et al., 2011).

Infection by Water

Waterborne toxoplasmosis is highly dominant as a source because oocysts can survive up to 54 months in cold water. Drinking unfiltered water and water from streams contaminated by cats may be important sources of *T. gondii* infection. Chlorine treatment, detergents and disinfectant solutions cannot inactivate *T. gondii*, but 2% iodine solution can do with a 3h exposure. Even after exposure to aqueous 2% sulfuric acid for 18 months at 4 ^{O}C, the oocysts can still remain viable (Shapiro et al., 2019). Access of cats near the water reservoir and tanks plays important role for contamination of water. Also, cat feces are flushed into municipal sanitation system in developed countries which may cause contamination. High dosage of oocyst in water, or contamination by highly virulent strains are the factors for transmission (Jones and Dubey, 2010).

In a study in 2019, Fernanda et al analyzed the pattern of toxoplasmosis outbreaks and they showed that the frequency of waterborne transmission was 20.6% (Pinto-Ferreira et al., 2019). A study in USA proved the absence of association between *T. gondii* seropositivity of people not born in USA and the tap water sources – which provides knowledge that the drinking water is the potential source of the infection (Krueger et al., 2014). In Brazil, an outbreak was reported caused by a contaminated underwater tank reservoir delivering unfiltered water. 155 persons were infected at that outbreak (de Moura et al., 2006). In 2009, a military man got severely infected after consuming untreated water during an operation in the jungle (Luis et al., 2009).

Infection by Soil

People who generally work and frequently exposed to soil are especially prone to *T. gondii* infection (Egorov et al., 2018). Soil can be contaminated by oocysts if infected felids shed them by defecation (Gilot-Fromont et al., 2012). This is the reason for which the oocysts are concentrated near defecation sites rather than being thoroughly distributed in the soil. But this is to be noted that the oocysts can disperse by wind, rain water, or different insects and worms. These oocysts sporulate in a favorable condition and can persist upto 18 months in a large range of temperature (-20' to 35'^{O}C) in moist soil (Dumètre and Dardé, 2003; Du et al., 2012). On the other hand, unsporulated oocyst cannot persist for a long time and lose the ability to sporulate if they are exposed to UV radiation, high temperature of 50'^{O}C for 10 minutes, as well as in a freezing temperature of -21^{O}C for 1 day or -6^{O}C for 7 days (Shapiro et al., 2019).

A study showed that there is low chance of transmission of oocysts through picking up fruits and vegetables from the farms, which caused the low number of toxoplasmosis-positive farmers who works with fruits and vegetables. It can be suggested that, contaminated soil is mainly the culprit for farmers getting infected with toxoplasmosis. Growing crops on contaminated soil also is a risk factor for infection. In conclusion, coming in touch with contaminated soil, then eating foods with unwashed hands afterwards; as well as residing in soil-made houses play important roles in transmission of *T. gondii* (Alvarado-Esquivel et al., 2011).

Infection by milk

Dairy animals can secrete *T. gondii* oocysts in their milk and it is an important risk factor for the transmission of toxoplasmosis. The oocysts can be preserved in the mammary glands to establish a latent period during the pre-lactation time of the mother. These oocysts are then secreted into the milk in the form of the milk fat globules surrounded by host cell membrane via exocytosis (Boughattas, 2017). Some of the present studies showed a correlation of the transmission with consumption of raw animal derived milk. But pasteurized milk is suggested to be much safer in a study by Malik et al, as they have provided information about the presence of *T. gondii* in unpasteurized animal milks such as goat, cow and sheep milk (Hussain et al., 2017).

There have been some researches regarding the infection via drinking raw goat milk as some outbreaks were observed in Iran, Italy, Brazil and Egypt (Costa et al., 2020). One of the studies showed that goats can release tachyzoites in their milk (Pinto-Ferreira et al., 2019) which are also unchanged after being converted into cheese. Even more shockingly, another study in Italy, where 10 out of 77 samples were positive with *T. gondii*, obsereved that these tachyzoites are able to survive at $4^{O}C$ temperature for 3 to 7 days (Mancianti et al., 2013). In Iran, a research has been done with milks from different kinds of animals like camel, buffalo, cow, goat, sheep etc. Among these animals, camel milk happened to contain lowest amount of *T.gondii* (Dehkordi et al., 2013). The study in Egypt after the outbreak, presented that the reason behind the lower occurrence of *T. gondii* in camel milk than goat and sheep milk can be the feeding system of these species. More specifically, goat, cattle and sheep live on green grass which can be contaminated with feline faeces easily, where on the other hand, camel usually live on dry environment in desert region, which have the lowest chance of getting contaminated (Saad et al., 2018). Transmission through drinking milk is more severe for younger individuals and offspring of pre-mentioned animals because of their lower proportion of the proteolytic enzymes in their intestine which facilitates *T. gondii* to persist and differentiate into infectious stages (Boughattas, 2017).

Infection by Direct Contact with Cat or Cat Box

Cat is the definitive host for *T. gondii* reproduction. After acute infection, parasite shedding occurs either in cat box or into environment through cat feces. Transmission of *T. gondii* into human and animal host is therefore could be either direct contact with cat feces or cat box. Although cat do not transmit infection through biting but changing cat litter box without maintaining proper hygiene is a risk factor for *T. gondii* infection in animal and human. In USA, it was shown that large portion of domestic cats carry *T. gondii* infection throughout the life and can shed upto hundreds of millions of oocysts in acute infection and after reactivation of tissue cysts in any immunocompromised condition (Dubey et al., 1970). Furthermore a recent meta-analysis study conducted by Wei HX and colleagues also showed that there is a significant association of cat contact and *T. gondii* infection in general population, immunocompromised people and cat owner (Wei et al., 2016).

Congenital Transmission

Fetus can be infected inside the placenta through infected pregnant woman, which causes the congenital transmission of *T.gondii* in fetus. Among the typical genotypes, the type II strains of the parasite are believed to be exclusively at fault of congenital toxoplasmosis as per the studies in USA and Europe. The atypical strains are more potent and cause severe cases of the disease as presented in another study (Delhaes et al., 2010). The most common mode of acquiring congenital toxoplasmosis is from a mother infected during the gestational period. Differences in the occurrence are created in particular trimesters in pregnancy period. The rate of infection is lowest in the first trimester, but highest in the third trimester which is mostly caused by typical strains (McAuley, 2014). Pregnant women can also be infected a few months before pregnancy and contribute to the congenital transmission. Reactivation of toxoplasmosis in HIV infected or having modified immunity due to other blood diseases (Lindsay and Dubey, 2011). In most of the cases the disease does not show any distinct symptoms in the infants, rather it is misunderstood and misidentified as any other common health problems like fever, jaundice, rash, hearing loss, convulsion, chorioretinitis, pneumonia and many more. In the worst-case scenario, the mother may have to experience miscarriage, stillbirth and premature delivery of the infant. Interestingly, a study suggests that even the antigen against *T.gondii* can travel through blood to the fetus and thus can create tolerance to the parasite by binding to the fetal immature B lymphocytes. It can lead to a continual B-cell inhibition against the antigen (Rejmanek et al., 2010).

Infection Through Blood Transfusion and Organ Transplantation

Some of the recent studies have suggested that there is a high risk of transmission through blood transfusion from those persons who are frequently donating blood. It can bring fatal consequences to the regular recipients suffering from thalassemia, sickle cell anemia etc. Various cases of seropositivity after blood transfusion are reported in some countries, indicating B group of blood as the mostly infected group whereas A and O groups are the least infected groups (Shaddel et al., 2014). This type of transmission is occurred via intracellular tachyzoites in blood, which can spread throughout the body after infection, and via the parasitized leukocytes as well. Rh factor is not been considered as any contributing element in any of the studies (Modrek et al., 2014; Alvarado-Esquivel et al., 2018).

Solid organ transplantation (SOT) and hematopoietic stem cell transplantation (HSCT) are two more risk factors of acquiring toxoplasmosis. The risk for transmission in higher in HSCT because of the longer time period of immunosuppression. In the case of SOT, the rate of occurrence varies among the types of transplantation. Heart transplant has the highest rate of occurrence and then comes the liver transplant. Renal transplant has the lowest number of incidents of transmission in this case, according to recent studies (Khurana and Batra, 2016). This kind of transmission occurs due to absence of serologic screening and inadequate matching of seropositivity of *T.gondii* between donor blood and recipient blood (Patrat-Delon et al., 2010). Deprivation of prophylaxis and chemoprophylaxis in transplant patients are included as risk factors for transmission. Patients who are susceptible to the disease have to be taken care of exclusively by prophylactic dosages for 6 months of TMP-SMZ (Trimethoprim / Sulfamethoxazole) (FernàndezSabé et al., 2009).

CONCLUSION

Toxoplasmosis caused by the zoonotic protozoan parasite *Toxoplasma gondii* is one of the most neglected infectious diseases that is overlooked in many countries of the world. Although less impact of the parasite is observed in immunocompetent individual but this disease is devastating particularly in immunocompromised patient (AIDS, cancer and organ transplantation or surgery) and fetus bearing pregnant women. In addition, infected person may carry this parasite specially in brain and skeletal muscle for their life time. Therefore, much attention need to provide on how to limit the transmission of the parasite from its environmental reservoir to animal to human host. This study would further open up the major research area of *T. gondii* in context of Bangladesh.

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CONFLICT OF INTEREST

The authors declare no conflict of interest for this publication.

AUTHORS CONTRIBUTION

Each author contributed to all sections of the article.

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