

Giardia lamblia: Epidemiology and Molecular Pathogenesis

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Submitted:	Revised:	Accepted:	Published:
Sep 14, 2026	Oct 13, 2026	Oct 24, 2026	Oct 29, 2026

Abstract

Giardia lamblia (synonyms: *G. duodenalis* and *G. intestinalis*) is a widespread intestinal protozoan parasite of humans, particularly in settings with inadequate sanitation and poorly protected water sources. This overview examines its transmission, intestinal pathogenesis, clinical manifestations, genetic diversity, host immune responses, and diagnostic approaches. Infection occurs through ingestion of environmentally resistant cysts in contaminated water or food or through direct fecal–oral transmission. Following excystation in the small intestine, trophozoites attach to the intestinal epithelium without typically invading host tissues. Colonization can disrupt epithelial barrier function and impair nutrient absorption. The clinical spectrum ranges from asymptomatic infection to acute or chronic diarrhea, abdominal discomfort, malabsorption, weight loss, and impaired growth in children. The parasite exhibits substantial genetic diversity, with human infections predominantly associated with assemblages A and B, contributing to complex transmission patterns. Parasite persistence and pathogenicity involve variant surface proteins, cysteine proteases, and metabolic adaptations that support immune evasion and intestinal colonization. Host defense depends on coordinated innate and adaptive immune responses, including secretory immunoglobulin A production and CD4+ T-cell-mediated immunity. Diagnostic approaches include stool microscopy, antigen detection assays, and polymerase chain reaction-based methods. Molecular techniques also support parasite genotyping and epidemiological investigations, extending their application beyond the detection of infection. Together, these approaches provide complementary information for examining the occurrence and transmission of giardiasis.

Understanding interactions among parasite genetic diversity, virulence mechanisms, and host defenses provides a basis for interpreting clinical variability and infection persistence. The overview highlights the value of integrating parasitological, immunological, and molecular perspectives to strengthen understanding of giardiasis and guide further diagnostic and epidemiological research.

Keywords: Giardiasis; Fecal–Oral Transmission; Virulence Factors; Host Immunity; Molecular Diagnosis

Introduction

Giardia lamblia (syn. *Giardia duodenalis* (also known as *G. intestinalis*) is a flagellated enteric protozoan parasite capable of infecting a variety of vertebrate hosts, such as humans, domestic animals, livestock, and wildlife. It is regarded as one of the most common intestinal parasites in the world, and a common cause of parasitic gastroenteritis, especially in areas with poor sanitation facilities and clean drinking water (1,2). It is one of the oldest protozoan parasites described in scientific literature; it was first seen by Antonie van Leeuwenhoek in 1681 when he was studying a sample of his own feces (3). The discovery of *Giardia* has been followed by much interest due to its ubiquitous presence, frequent infectivity and its very great influence on human health. Giardiasis, caused by *Giardia*, is a Neglected Parasitic Disease (NPD) recognized by the World Health Organization (WHO). It causes around 280 million cases of illness every year and is a major cause of waterborne and foodborne outbreaks of diarrhoea all over the world (4). The infection can be found in both developed and developing countries, but tends to be more prevalent in low-income areas where the lack of proper hygiene, sewage disposal and water source contributes to the spread of the parasites (5). Among children in developing countries, infection rates can be more than 30% and this can have a significant impact on morbidity, malnutrition and physical and cognitive development (6). *Giardia* is transmitted mainly from the fecal–oral route through the ingestion of environmentally resistant cysts. Drinking water contamination is the most critical route of exposure, but foodborne transmission, person-to-person spread and zoonotic transmission from infected animals are also important routes of transmission for the spread of disease (7). The infective cysts are very hardy and can remain for long periods of time in colder water and so can be transmitted via the town's water supply, recreational water sources and natural freshwater. *Giardia* also has a very low infectious dose, meaning

that even 10-25 cysts are enough to cause infection, furthering its epidemiological success (8). Cysts pass through the stomach acid and excyst in the duodenum in the presence of gastric acid, pancreatic enzymes and bile salts. The released trophozoites then colonise the upper small intestine, mainly the duodenum and jejunum, where they attach to the epithelial cells by a special adhesive part (ventral adhesive disc (1)). *Giardia* is an intestinal protozoan parasite that does not invade the host tissues or spread throughout the body. However, as trophozoites attach to intestinal mucosa, a series of structural, biochemical and immunological changes are induced, which can lead to severe gastrointestinal disease (9). Gastrointestinal disease caused by *Giardia* infection can be acute or chronic and may include clinical signs or be asymptomatic. The typical clinical presentations include watery diarrhea, abdominal cramps, bloating, nausea, flatulence, fatigue and weight loss. Chronic infection can result in malabsorption syndrome, micronutrient deficiencies, growth retardation and long term gastrointestinal complications like lactose intolerance and post-infectious irritable bowel syndrome (IBS) in some people, especially children and those who are immunocompromised (10). Many factors such as parasite genotype, infectious dose, nutritional status, immune competence of the host and gut flora affect the severity of disease. Over the past 20 years, molecular biology has brought about a revolution in the understanding of *Giardia* pathogenicity and host-parasite interactions. *Giardia* has previously been considered a relatively simple noninfective organism but has now been demonstrated to have complex mechanisms that aid in colonization, persistence and immune evasion. These mechanisms involve antigenic variation via variant surface proteins (VSPs), secretion of cysteine proteases, disruption of epithelial tight junctions, induction of enterocyte apoptosis, modulation of nitric oxide metabolism and interference with host immune responses (1,9). These changes are adaptations that allow the parasite to survive in an unfriendly host environment and reduce the likelihood of the host eliminating the parasite. The *Giardia duodenalis* species complex has also been found to be genetically diverse based on molecular epidemiological studies. At present eight major assemblages (A–H) have been characterized, of which Assemblages A and B are responsible for most human infections in the world (1). Genotyping studies have led to better understanding of the transmission dynamics, zoonotic potential, geographical distribution and clinical variability of infections. Progress in whole genome sequencing, transcriptomics, proteomics and metabolomics have yielded useful information on the biology of the parasite and have suggested new targets for therapeutic interventions and for vaccine development (2). The host immune response is

important in the control of *Giardia* infection and outcome of the disease. Innate and adaptive immune mechanisms play a role in the clearance of parasites. Intestinal epithelial cells, dendritic cells, macrophages, antimicrobial peptides, and nitric oxide are important components of innate immune response, while CD4⁺ T lymphocytes, secretory IgA antibodies, and cytokines like interferon-gamma (IFN- γ) are essential components of adaptive immunity (9). Failure of these protective mechanisms can lead to persistent infection, greater numbers of parasites and more clinical signs. Although significant advances have been made in diagnosis and treatment, giardiasis continues to be a major public health problem around the world. Although traditional microscopic methods are still used for diagnosis, more sensitive techniques such as enzyme-linked immunosorbent assays (ELISA), immunofluorescence assays and polymerase chain reaction (PCR)-based methods have significantly bettered the accuracy of detection and epidemiological investigations (7). Nitroimidazole derivatives like metronidazole have been the mainstay of treatment, but the recent emergence of drug resistance and failure has encouraged continued efforts to find other treatments. *Giardia lamblia* continues to be a focus of parasitological and biomedical research based on its widespread distribution in the world, zoonotic nature, complex host–parasite interactions and important health impacts. To develop effective control strategies, improve diagnostic capabilities and minimize the global burden of giardiasis, a comprehensive understanding of its epidemiology, molecular pathogenesis, immune interactions, and transmission dynamics is essential.

Taxonomy and Classification

Giardia is a genus of flagellated protozoan parasites that inhabit the gastrointestinal tract of a wide range of vertebrate hosts, including humans, domestic animals, wildlife, livestock and marine mammals. The taxonomy of *Giardia* has been significantly modified in recent decades with the development of molecular biology, phylogenetics and genomics, which helps to understand the evolutionary relationships and genetic diversity of this important intestinal parasite (11). Traditionally, classification was mainly determined from morphological features seen with light microscopy such as the shape of the trophozoite, the arrangement of the nucleus, the structure of the flagellum and the morphology of the cyst. But the traditional classification methods were not adequate to demonstrate the great amount of genetic diversity within the genus because many isolates of *Giardia* are morphologically

indistinguishable (12). Today, *Giardia* is placed under the Domain Eukaryota, and is a part of a group of primitive anaerobic protists that represent a distinct position in the evolution of eukaryotes. *Giardia*'s taxonomic classification is:

- Domain: Eukaryota
- Kingdom: Protista
- Phylum: Metamonada
- Class: Fornicata
- Order: Diplomonadida
- Family: Giardiidae
- Genus: *Giardia*
- Hosts and reservoirs: variety of mammals including humans.

The names of *Giardia lamblia*, *Giardia duodenalis* and *Giardia intestinalis* are often used interchangeably in scientific literature. However, it is currently accepted that the species name of *Giardia* is *duodenalis* rather than *lamblia*, and that *G. lamblia* is still widely used in the clinical and biomedical research fields (13). Remarkable genetic heterogeneity within *G. duodenalis* has been found based on molecular investigations using the genes of the ribosomal RNA, glutamate dehydrogenase (*gdh*), triose phosphate isomerase (*tpi*), and β -giardin (*bg*) as well as whole genome sequencing. Such studies revealed that the species is actually a complex of genetically distinct lineages, called assemblages, each of which has its own host range, geographical distribution, pathogenic potential and transmission dynamics (14). A total of eight large assemblages are known up to now (A-H). The morphology is identical but there are significant differences at the genetic level between these assemblages, and sometimes they are host-specific.

Assemblage A

Assemblage A is the assemblage with the widest host range and is thought to be one of the main causes of human giardiasis worldwide. It is found in humans, animals, domestic and wild animals. Sub-assemblages AI, AII and AIII are further delineated from assemblage A based on molecular studies. These are two sub-assemblages, AI and AII, with AI being commonly found in zoonotic transmission, both in humans and animals, and AII being found mainly in humans and being regarded as the major anthroponotic genotype. AIII is mainly detected in wildlife species and wild ungulates (14).

Assemblage B

Assemblage B is the second large genotype that is involved in human infections worldwide. It's highly variable and commonly found in humans and animals. Assemblage B has a larger allelic sequence heterogeneity than Assemblage A leading to difficulties in molecular characterisation and epidemiological investigations. Although results have been inconsistent, many studies have found that gastrointestinal symptoms may be more severe, and infections may last longer, in people with Assemblage B (11).

Assemblages C and D

The predominant host for assemblages C and D are domestic and wild canids, such as dogs, wolves, foxes and related species. Infections in humans are very rare and host specificity is likely high. However, there have been sporadic reports of cross-species transmission, which led to the suspicion that they may have zoonotic importance (15).

Assemblage E

Assemblage E is strongly associated with cattle, sheep, goats, buffaloes and pigs. It is significant in veterinary medicine as infections may lead to reduced productivity and impaired growth and economic loss in agricultural situations. Assemblage E has historically been considered as livestock associated but molecular studies of a few human cases suggest that it may be zoonotic under certain conditions (14).

Assemblage F

Assemblage F is mainly present in domestic cats and other cats. It seems to be of very low host range and is rarely found in any other host population.

Assemblage G

Assemblage G is mainly found in rodents, such as mice and rats. It is found in laboratory and wild rodents and is regarded as host specific.

Assemblage H

Assemblage H is only reported in marine mammals, seals and sea lions. This discovery increased the knowledge of the ecological diversity and evolutionary adaptation of the *Giardia* species in aquatic environment.

Molecular Epidemiology and Genetic Diversity

The findings of the presence of multiple assemblages have changed the way *Giardia* epidemiology is thought about. Human infections have been found to mostly be caused by Assemblages A and B, while other assemblages have varying degrees of host specificity as demonstrated by molecular genotyping techniques. Such genetic variability is of significance in the transmission, pathogenicity, diagnosis, treatment outcome and public health surveillance (13). Modern phylogenetic analyses suggest that assemblages can be cryptic species as opposed to just simple genotypes within a species complex. As a result, a few researchers have suggested that the assemblages should be treated as separate species; but this is not yet a consensus within the scientific community (12). Comparative genomics has shown that there are important differences among assemblages in gene content, metabolic pathways, virulence associated proteins, antigenic variation mechanisms and host adaptation strategies. Such finds have enhanced the understanding of the host-parasite relationship and could be used in the future to develop specific diagnostic tools, vaccines and therapeutic interventions (11). To summarize, the taxonomy and classification of *Giardia* has undergone significant changes from morphology to more complex molecular classifications. The identification of genetically distinct assemblages has provided valuable insights into host specificity, zoonotic transmission, evolutionary biology, and disease epidemiology. Ongoing genomic- and phylogenetic-based studies will likely help further classify *Giardia* and better understand the global impact of the organism on human and animal health.

Life Cycle of *Giardia lamblia*

The life cycle of *Giardia lamblia* (formerly known as *Giardia duodenalis*) is direct monoxenous, that is, the parasite can develop in the same host without an intermediate host. There are two stages in the cycle: the infective cyst stage and the replicative trophozoite stage. The simple but very effective biological cycle is one of the reasons for the parasite's wide dispersal and its success as an epidemiologist in the world (16,17). Susceptible host ingests environmentally resistant cysts, via contaminated water, food or direct fecal–oral contact. The infectious dose is low and infection is set up with ingestion of a few cysts. After cysts come into the stomach, they can withstand the acidity because there is a tough cyst wall. In the duodenum, excystation occurs as a result of the action of bile salts and pancreatic enzymes plus the high pH and trophozoites are released. At the same time of excystation

each mature cyst gives rise to two trophozoites which will quickly be motile and ascend to the superior part of the small intestine—the duodenum and the jejunum. The trophozoite (active vegetative stage) is responsible for colonization and development of disease. It attaches to the intestinal epithelium by a specialized adhesive disc on the underside which prevents it from being washed away by peristalsis (17). The trophozoites multiply by binary fission and the population rapidly increases in the intestinal lumen. This colonization causes disruption of intestinal function mechanically, by changes in microvilli and by interfering with nutrient absorption. Encystation occurs in the distal portion of the small bowel as the trophozoites migrate, due to the higher bile concentration and less nutrients. The transformation of trophozoites to cysts resistant to the environment is known as encystation. This way the proteins of the cyst wall are formed and the organism divides its nucleus so that a mature cyst containing 4 nuclei is formed. These cysts are then passed out in the faeces and are immediately infective in the external environment. They can withstand cold and wet weather, and can be spread on contaminated surfaces and water systems (16,19). The life cycle is important because cysts are excreted immediately and are infective, therefore making them a real threat to spread rapidly in the community and especially in communities where sanitation is poor. Giardiasis is difficult to control due to environmental contamination from both the symptomatic and asymptomatic carrier(17).

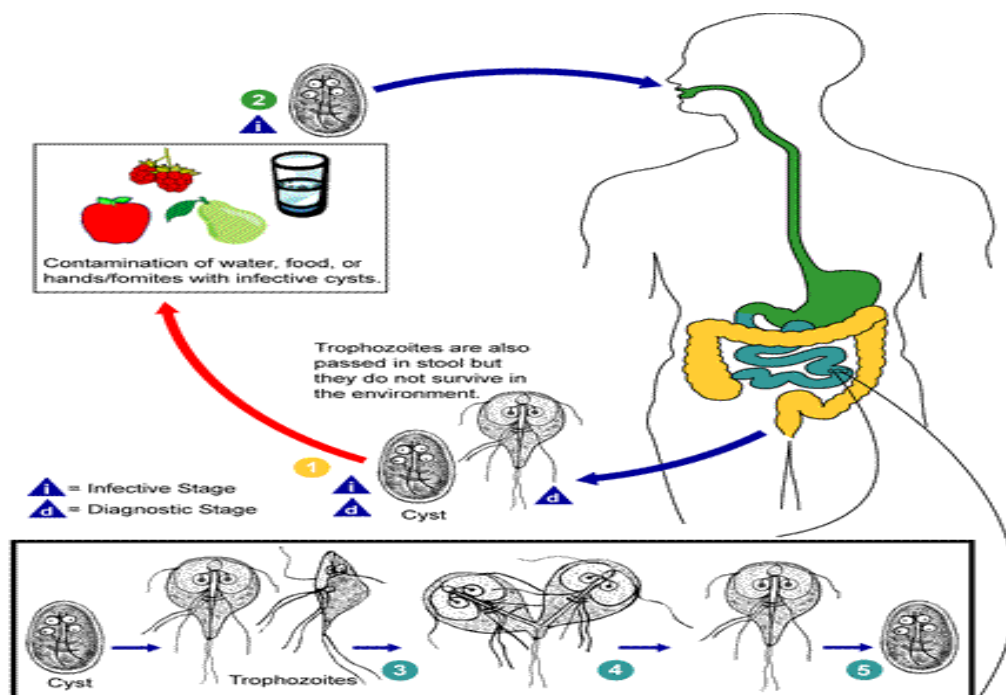


Figure 1. Life cycle of *Giardia lamblia* (*Giardia duodenalis*) - infective cysts are transmitted by contaminated food or water, excyst in the small intestine, trophozoites multiply, encyst and are excreted in feces(20).

The epidemiology of *Giardia lamblia*

Giardiasis is a cause of diarrheal illness in children and adults and one of the most prevalent intestinal parasitic diseases in the world caused by *Giardia lamblia* (*G. duodenalis*). Epidemiological distribution is very dependent of environmental conditions, socioeconomic status, sanitation infrastructure and population hygiene. The parasite has a cosmopolitan distribution and is endemic in developed and developing countries but with a higher burden of disease in low and middle income countries where access to safe drinking water and sanitation is limited (21,22).

Global Distribution

Around 200-300 million people are infected with *Giardia lamblia* every year, all over the world. The prevalence is very much geographically dependent. The prevalence of the infection is usually 2–7% in developed countries and in developing countries it is higher than 20–30%, particularly among children under 10 years of age (21). Poor water treatment infrastructure and hygienic conditions is associated with high prevalence rates and found in regions of Africa, Asia, Middle East and Latin America (23). Municipal water contamination, recreational water (swimming pools, lakes) and foodborne transmission are all associated with outbreaks of giardiasis. In nature, *Giardia* cysts are likely to be transmitted and widely distributed because they can survive for extended periods of time in cold water (22).

Reservoirs of Infection

Assemblage A and B infections are primarily of humans but many domestic and wild animals are also important hosts such as cattle, sheep, goats, dogs, cats, rodents and wildlife species. In the rural and agricultural population, zoonotic transmission plays an important part in the environmental cycle of infection due to high incidence of human–animal contact (21). Several animal reservoirs make control difficult and there is the potential of reinfection and environmental contamination. Molecular techniques have shown that giardiasis is zoonotic, as transmission of cross-species can be demonstrated between humans and animals (24).

Transmission Dynamics

Giardia is spread primarily via the fecal–oral route. The cyst stage is very resistant to environmental factors and persists for weeks to months in water supplies. A few cysts are enough for infection and this adds to the epidemic potential and the ease of rapid

transmission of infection within communities (21). The most common is waterborne, followed by person-to-person and foodborne outbreaks. Zoonotic transmission is also important, especially in those areas where animals are reservoirs of infection, in agricultural or rural settings, for instance (22).

Seasonal and environmental influences

Seasonal trends occur within many areas for giardiasis, and more cases are reported during the warmer months when there is increased recreational water use. Contamination of drinking water sources and outbreaks can also be caused by flooding and heavy rainfall events (23). Cyst survival in the environment is a very significant factor in the epidemiology. Cysts can survive in cold fresh water and are resistant to chlorine levels typically employed to treat water and require either boiling or filtration to be inactivated (24).

Public Health Importance

Public health perspective, giardiasis is a significant burden since it is ubiquitous, outbreaks occur and may lead to chronic sequelae such as malabsorption and growth failure in children. It leads to nutritional deficiencies and reduced mental development and productivity in its victims. Integrated strategies, such as improving water treatment systems, sanitation infrastructure, hygiene education and surveillance programmes are needed to control giardiasis. Increasingly molecular epidemiology tools have been used to monitor outbreaks and identify the source of infection, and this can help to target interventions (21–25).

Global Distribution of *Giardia lamblia*

Giardia lamblia (*Giardia duodenalis*) is an intestinal protozoan parasite that is one of the most common parasites of humans and animals and has been shown to be widely distributed in the world. Very sensitive to environment sanitation, provision of safe drinking water, socio-economic factors, population density and hygiene. Therefore, giardiasis is endemic in both developed and developing countries, and has varying intensities and burdens in different populations (26,27). In developed countries, the overall proportion of infected people with *Giardia* is lower (2-7%). Despite the availability of water treatment and sanitation systems, there are still occasional events and outbreaks, particularly in day care centres, institutions and communities, where there is contamination of water sources used for recreation. The outbreaks illustrate the resistance of *Giardia* cysts to the usual range of chlorination treatment in municipal water treatment plants (MWTPs) (26). In contrast, in the

developing world the prevalence of infection is much greater, often greater than 20-30% and possibly more than 40% in some very endemic areas. This incremental has been closely associated with poor sanitation, unsafe drinking water, poor hygiene practices and limited public health resources in these areas. Rural and peri-urban communities are especially at risk because they have to depend on untreated surface water sources like rivers, wells and ponds (27,28). Giardiasis is a world-wide disease that is more prevalent in children. A number of factors are thought to contribute to this increased susceptibility such as immature immune responses, close interpersonal contact, failure to practice good hand hygiene, and increased exposure in daycare and school settings. Pediatric infections are of particular concern as chronic or repeated infections can lead to malnutrition, growth retardation, iron-deficiency and impaired cognitive development. These have long-term implications which are a major cause of disease burden in endemic areas (26,29). Climate is also a factor in geographical variations in the prevalence of Giardia. Cysts survive and are transmitted efficiently in warm and humid environments, and in colder climates, may be able to persist in the environment for long periods in water sources. This could be seasonal with higher infection rates in wet seasons or warmer weather when there is increased risk of both water loss and contamination due to rain events (28). Molecular epidemiological studies have also shown that geographic variation in the distribution of different assemblages exists for Giardia. There are more cosmopolitan assemblages (Assemblage A and B) and there are more host or region specific assemblages. That genetic diversity also equates to differences in transmission patterns of the disease and may have an impact on disease severity and patterns of disease outbreaks between local populations (27,29). The general distribution of Giardia lamblia is multifactorial, depending on environmental contamination, susceptibility of the hosts, socioeconomic factors, and the variability of the parasites. Hence, the prevention of giardiasis must be approached in a wholistic way, and this consists of water quality, sanitation system, hygiene education and a permanent epidemiologic monitoring.

Factors that increases the likelihood of infection with Giardia lamblia

The occurrence of giardiasis is closely associated with a number of environmental, behavioral, socio-economic and host factors, as is the case for other infections caused by G. lamblia (G. duodenalis). The spread of infection does not occur at random, but is related to patterns of exposure to contaminated sources, population density, hygiene habits and host immune status. These risk factors need to be understood, as they play a vital role in the effective prevention and control strategies (31,32).

Use of untreated water

Drinking water contaminated with Giardia is still the greatest risk factor for giardiasis worldwide. Giardia cysts are highly adapted to the environment and have a very long survival time in the freshwater environment. They are also able to withstand the amount of chlorination typically employed in municipal water treatment facilities, a significant public health concern for the waterborne route of transmission. Contaminated well, municipal water supplies, recreational water (swimming pool, lakes and more) is often associated with epidemics. The virus can infect with a very low infectious dose (31) and so widespread outbreaks can occur as a result of a simple contamination.

No sanitation and hygiene measures

Limited sanitation facilities are a major risk factor for transmission. The open defecation, lack of clean water for washing hands and failure to provide sewage disposal systems are the reasons cysts are transmitted through the faecal–oral route. Poor personal hygiene (inadequate hand washing after using the toilet or before eating food) is a cause of direct person-to-person transmission. The above are typically observed in low resource areas, in slums with high population density (32)..

Day-care Attendance

Due to the close contact of humans, the sharing of equipment and the children's lack of good hygiene habits, day cares are particularly vulnerable to the spread of infectious diseases. Children and carers are easily infected as they use diapers and have poor hand hygiene. It is worth noting that infection control measures are in place in child care centres (33) and day-care associated outbreaks are well documented both developed and developing countries..

International Travel

Those who have travelled to endemic regions are more at risk of contracting giardiosis, particularly if they have come into contact with food or water that is contaminated with the parasite. This is called 'traveler's diarrhea' when it is due to Giardia. Street vendors (backpackers, military and tourists) are particularly vulnerable as they eat the food they buy from these vendors after drinking untreated water. Susceptibility is also enhanced if there has been no prior immunity and exposure to novel strains (34).

Immunodeficiency

Individuals with compromised immune systems are more likely to have persistent, complicated or recurring infections. This is for patients with HIV/AIDS, patients taking immunosuppressive drugs and patients with congenital immunodeficiency disorders. In such patients, defective CD4+ T-cell responses and decreased mucosal immunity result in failure to clear parasites, leading to persistent intestinal colonization and to more severe clinical manifestations (32,34).

Contact with infected animals

A key epidemiological role for zoonotic transmission in the epidemiology of giardiasis. Domestic animals (dogs, cats and cattle) and sheep and goats are reservoirs of infection. Infected animals are the source for direct infection, or environment contaminated with cyst infected feces is the source for indirect infection. The involvement of zoonotic pathways in human-to-human transmission has been confirmed by molecular studies, especially in rural and farming areas (33).

Crowded Living Conditions

High population density brings with it high concentrations of people living in close proximity, resulting in a greater number of people sharing sanitation facilities and a greater amount of person to person contact, and thus the potential for a rapid spread of Giardia from person to person. Prisons, refugees camp, Orphanages, military barracks are very susceptible to outbreak. Lack of water quality and hygiene infrastructure also plays a role in the spread of this in these contexts (31,33).

Outbreak Association

Exposure to drinking water from a public water system has been associated with many giardia outbreaks, as has been exposure to recreational water. Swimming pools, water parks or lakes may not have adequate disinfection or filtering systems and can cause infection. Numerous cases of these outbreaks have involved large numbers of persons, due to the stability of cysts in water and their tolerance of routine chlorination treatment (34)..(

Giardia lamblia spread

The transmission of Giardia lamblia is mainly fecal–oral route and is one of the most common routes for enteric protozoan infections all over the world. The infectious stage is the cyst which is excreted in the faeces and causes a new host to be infected when eaten.

Giardia is very easy to infect in humans at low doses, and is very resistant to environmental conditions, making it easily spread in communities without good sanitary practice or clean water supplies (36,37).

Waterborne Transmission

Waterborne is the most important and worldwide route of infection with Giardia. Water is a significant vector of transmission especially in areas where water treatment is poor or contaminated. Giardia cysts are very resistant to environmental stress and can survive for long periods of time in cold freshwater environments. Important is that they are also not affected by the chlorination process used in the water treatment plants. Therefore, even treated water could be infectious if filtration and/or advanced disinfection process is not properly done (36).

Foodborne Transmission

Foodborne transmission is by ingestion of contaminated food, especially raw or poorly washed fruits and vegetables. In cultivation, there is a risk of contamination from contaminated irrigation water, in handling from infected persons. Untreated water also can be a potential route of infection when used to prepare drinks. Poor hygiene practices by food handlers and poor food safety regulations are often related to foodborne outbreaks (37).

Person-to-Person Transmission

In these settings, direct fecal–oral spread via contaminated hands, surfaces or shared objects is a significant mechanism for person-to-person transmission. Children are at a special risk as they do not have good hygiene and have a habit of putting their hands in their mouths. Day Care centers have been the source of outbreaks in the past and an outbreak can occur in a matter of days if proper infection control precautions are not taken (36,38).

Zoonotic Transmission

Zoonotic transmission means to spread Giardia from infected animals to humans. Domestic animals (cattle, sheep, goats, dogs and cats) or wild animals are reservoirs of infection. Transmission can take place either directly from infected animals, or indirectly via contamination of water sources, soil or food with infected animal faeces containing cysts. Molecular epidemiology studies have helped to demonstrate that some assemblages of Giardia are common to humans and animals, which is indicative of its zoonotic nature. This is particularly the case in rural and agricultural areas where there is a higher risk of interacting

with animals and the environment is often contaminated (37,38). *Giardia lamblia*, Host Immune Response to Host immune response to *Giardia lamblia* is complex and a coordinated interplay of innate and adaptive immune mechanisms. Although *Giardia* is a non-invasive intestinal parasite, it causes extensive immunological responses in the intestinal mucosa. The parasite, however, has also developed several ways to evade or modify host immunity to allow persistent or recurrent infections in susceptible individuals (39,40).

Innate Immune Response

Innate immunity is the first line of defence against *Giardia* infection. Intestinal epithelial cells are important as a physical and immune barrier. Trophozoites attach to the intestinal epithelium, and epithelial cells detect molecules associated with the parasite and begin to signal, resulting in the production of antimicrobial peptides, chemokines, and cytokines (39).

Adaptive Immune Response

Clearance of *Giardia* infection and development of protective immunity is dependent on adaptive immune response. CD4+ T helper cells play a special role in the coordination of immune response (40).

Humoral Immunity

Secretory Immunoglobulin A (sIgA) is an important factor involved in inhibiting *Giardia* attachment to the intestinal epithelia. sIgA antibodies neutralize trophozoites, prevent their attachment and promote clearance of parasites from the intestinal lumen. Persons with IgA deficiency have been shown to be susceptible to chronic or recurrent giardiasis (40).

Immunity and Protection

Protection against giardiasis is not sterilizing, but may shorten the duration and severity of disease. Repeated exposure can result in some immunity, especially in endemic regions. Immunocompromised persons, particularly HIV infected individuals and those with congenital immune defect, are, however, more likely to become infected chronically and have more severe clinical outcome (40).

Laboratory diagnosis of *Giardia lamblia*

Laboratory diagnosis of giardiasis is important for proper treatment, surveillance, and controlling outbreaks. The non-specific clinical presentation and overlap with other causes

of infectious diarrhea makes laboratory confirmation the gold standard for diagnosis. There are several diagnostic methods available for the detection of infection, such as microscopic examination, antigen detection assays and molecular methods (39).

Microscopic Examination

Microscopic detection of *Giardia* residues continues to be a popular diagnostic tool, especially in resource poor environments. The stool sample is tested for cysts and trophozoites.

Direct Wet Mount

Saline or iodine wet mounts are used to examine a fresh stool specimen. Motile trophozoites are seen in the stool from diarrheic episodes and cysts are usually found in formed stools. But trophozoites are fragile and lose motility quickly when outside the host, which may decrease the sensitivity of diagnosis (40).

Concentration Techniques

Stool concentration techniques (formalin–ethyl acetate sedimentation or zinc sulfate flotation) are employed to increase the chance of detecting parasites. These techniques improve the chances of detecting cysts in low intensity infections.

Antigen Detection Tests

Immunological assays are much more sensitive and specific in the diagnosis. The tests look for *Giardia*-specific antigens in stool.

Enzyme-Linked Immunosorbent Assay or ELISA.

The sensitivity of ELISA and its capacity for processing large numbers of samples have made it a popular technique in clinical laboratories. It is able to detect soluble antigens including *Giardia*-specific cyst wall proteins.

Rapid Immune chromatographic Tests

These POCTs yield a quick result and can be helpful in outbreak situations or field diagnostics. These are easy to do and do not need special equipment in the lab. Overall, antigen detection methods are more sensitive than microscopy, particularly in the presence of intermittent shedding of cysts (40).

Histological Diagnosis

Sometimes, intestinal aspirates or biopsy of the duodenum may be studied. Histology shows trophozoites on the epithelial surface of the small intestine, villous atrophy and epithelial damage. This is normally reserved for those that are atypical or persist despite a strong clinical suspicion and repeated stool examination (39).

Conclusion

Giardia lamblia (*Giardia duodenalis*) is one of the most significant protozoan parasites affecting the intestines in humans around the world and is regarded as a significant public health issue due to its ability to be efficiently transmitted, its low infectious dose and the ability of the organism to survive in the environment as a cyst. Giardiasis is particularly prevalent in children and immunocompromised individuals in regions with poor sanitation, and can cause malnutrition and growth retardation. Recent progress in molecular parasitology has shown *Giardia* has more complex mechanisms of survival and persistence, including those involving antigenic variation (Variant Surface Proteins (VSPs)), secretion of cysteine proteases, disruption of intestinal epithelial integrity and modulation of host immune responses. These processes contribute to poor nutrient assimilation, and may have many different clinical manifestations ranging from a silent presentation to extreme diarrhoea and malabsorption. Molecular epidemiological studies have revealed multiple genetic assemblages of which Assemblages A and B are responsible for the majority of human infections. Although effective drugs such as metronidazole and tinidazole exist, there are reports of therapeutic failures and emergence of drug resistance, indicating the need for new drugs and therapeutic strategies. The key drivers of prevention are safe water supplies, good sanitation practices and hygiene. Further research is required in the areas of molecular biology, immunology and epidemiology of *Giardia* to facilitate diagnosis, treatment, and prevention.

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