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Introduction to Medical Protozoology for Beginners

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Review Article

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ABSTRACT

Aims: To introduce medically important protozoa through Medical protozoology for beginners
Discussion: Protozoan diseases are still major global health problem which affect both humans and animals, especially in poverty tropical and subtropical regions. Malaria, African trypanosomiasis, Chagas disease, leishmaniasis and enteric illnesses like amoebiasis, blastocytosis, giardiasis, and cryptosporidiosis. Those number of global protozoa infections increases annually, and this problem necessitates further study in order to improve understanding of these protozoan which will further help medical professionals to recognize its existence in nature, its virulence and pathogenesis, how to make correct diagnosis and prompt treatments. All of those previously mentioned problems can be reveal first by understanding the basic biology of protozoa. Elements to learn consists of its complex life cycles, general morphology with specialized built in organelle, nutritional requirement, their existence in the nature and interaction with other already existed microbiota. These factors will open the perspective of scholar who want to start their academic journey through parasitic infection. Better understanding will facilitate the effort of health promotion, specific protection, early diagnosis and prompt treatment, including sufficient education for the member of the community.

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1. INTRODUCTION

Medical protozoology is the study of protozoa, single-celled eukaryotic organisms that are often microscopic and can cause diseases in humans and animals. This field investigates the biology, epidemiology, and pathogenesis of these parasites, focusing on their life cycles, modes of nutrition, reproduction, and the specific human diseases they cause, such as malaria (World Health Organization. 2023), trypanosomiasis (Alencar, et al., 2025; Morrison, et al., 2023; Igbokwe, 2018), leishmaniasis (World Health Organization. 2023), amoebiasis (Nasrallah, et al., 2022) and other enteric protozoan (Tottey, et al., 2024). Understanding protozoa is vital for developing effective diagnostic methods, treatments, and preventative strategies, especially in regions where these infections are prevalent.

Besides those mentioned previously, key aspects for beginners to learn include understanding the biology of protozoa which are diverse, adaptable, and heterotrophic organisms with complex life cycles involving both asexual (like binary fission) and sexual reproduction. Its general morphology with specialized built in organelle and its nutritional requirement will open the perspective of each one who want to start their journey through parasitic infection. By firstly knowing its epidemiology, locally, regionally and globally, then the perspective regarding scope of the problem will be a good entry point to pay more attention to these global neglected health problems.

The lengthy and expensive nature of medical education can place significant pressure on medical students Beginners, in this context refer to Medical freshmen, face challenges such as:

1. Academic challenges, e.g.', overwhelming workloads and intense memorization, enormous new and sophisticated terminology which is different from the mother tongue used every day (Novelyn, et al., 2021), demanding exceptional time management to balance studies with personal life, and navigating imposter syndrome, a common feeling of inadequacy despite achievements and other academic resources (O' Sullivan, et al., 2024),
2. Mental and emotional health challenges and crisis (Picton, et al., 2022), e.g., anxiety and burnout, and must deal with the financial burden and the pressure of transitioning into a demanding professional environment which often lead to stigma where they are expected 1000% ready and should be able to cope with any challenge. Havemann et al., mentioned about 4 major themes regarding challenges first-generation college graduates face in medical school, namely: isolation and exclusion, challenges with access to resources, lack of institutional support, and need to self-rely on grit and resilience to survive (Havemann, et al., 2023).

Despite being high-achieving students in their previous education, many medical freshmen face academic challenges, particularly during their first year of study. Research indicates that self-regulated learning, involving metacognitive processes and adaptive strategies, can positively influence academic achievement, including in Protozoology. This paper aimed to reveal the early learning and study skills of medical freshmen in the context of learning what is needed to understand the basic principles of protozoa, especially those that have clinical/medical implications with the goal of developing a learner-centered educational intervention to promote self-regulated learning.

2. PROTOZOA STUDIED IN MEDICAL PROTOZOOLOGY

Protozoans mostly are a polyphyletic group of single-celled eukaryotes, autonomous protists (Verma, 2021) found worldwide in diverse habitats, aquatic or terrestrial environment. They are commonly found in freshwater (which can be used as an indicator of water quality) (El-Tohamy, et al., 2024) and in saltwater as an indicator of salinity stress (Ali, et al., 2024), vegetation related soil (Zheng, et al., 2024), and even within other organisms, including animals such as rodents (Seifollahi, et al., 2016), birds (Parsa, et al., 2023), etc. and also plants where its existence helped the plant to grow (Weidner, et al., 2017). Some protozoa are highly diverse free-living (Meshjel, 2024), while others are parasitic which inhabiting specific hosts (Mishra, et al., 2025) by developing distinct mechanism to maintain its parasitism's persistence (Tarannum, et al., 2023; Zanditenas & Ankri, 2023).

In the case of medically important protozoans when induced infection, vulnerable host, especially with immune system derangement, can be affected with one or more species of protozoa (Chatterjee, et al., 2023). As protozoa are diverse, with thousands of species (Verma, 2021) and can cause disease individually or co-infect a host (Akoolo, et al., 2022), interacting with the host's immune system (Olatunde, et al., 2023), the host's microbiota or other local barrier (Lu & Stappenbeck, 2022) even with other bacterial pathogens (Eriksson, et al., 2022) which have strong influence on the host, including efficacy of vaccines given to their host which directed against bacterial and viral pathogens (Akoolo, et al., 2022) and even immune evasion strategies which is very detrimental to its host (Morrot, 2020). Factors like an individual's immune status (Chatterjee, et al., 2023), age (Ashby & Bruns, 2018), nutritional condition (Siagian, 2023) and also genetic background (Ye, et al., 2023) can increase their susceptibility to infection by different protozoan species.

Spectrum of infections ranging from asymptomatic carrier (Alvar, et al., 2020) to severe and life threatening, especially among the most vulnerable sub population (Siagian, 2020), depending on the species of the parasite (strain, virulence, density of parasite which enters the host) (Martins-Duarte, 2025) and also the vulnerability related resistance status of certain host (Attwood, 2025). Unfortunately, the relationship between protozoan parasite infection of discrete tissue niches and long-term persistence or transmission is still not fully understood.

Protozoan organism which harbor parasitic properties employ various intrinsic strategies involving modification or evasion of the host's behavior and immune system; all of these aimed to facilitate their transmission colonization and invasion (May et al., 2023). These strategies include fecal-oral routes of food borne and water borne protozoan parasites (Augendre, et al., 2023), biomechanical direct contact (Yeh, et al., 2024), vector-borne transmission (Baneth, et al., 2020), and even to the level of predator-prey interactions (Islas, et al., 2024). Behavioral modifications or even alterations in the host, whether induced by the parasite or resulting from the infection (Idan Al-Musaedi, 2024), can crucially impact transmission dynamics (Iritani & Sato, 2018). These deportments govern the sustainability of mutual interactions that facilitate pathogenic parasitic protozoan spread in one side but in the meantime ensuring the host's 'fake' well-being where parasites exaggerate its host and manipulate to some extent where the host's immune system failed to recognize and to destroy this parasite (Doherty, 2020). Understanding these connections is crucial for effective disease control and prevention.

Protozoan parasites actually responsible for a noteworthy burden of morbidity and mortality globally, affecting both humans and animals, in their unique specificity, e.g., intestinal protozoan parasites among food handlers (Eslahi, et al., 2023). These diseases range from asymptomatic carrier (Alvar, et al., 2020) to mild and self-limiting to life-threatening, e.g., malaria, being major public health concern, especially in tropical and subtropical regions. Other medically important protozoa cause intestinal illnesses (e.g., amoebiasis, giardiasis, cryptosporidiosis) and vector-borne diseases (e.g., leishmaniasis, Chagas disease). The significance of these medically important protozoan will be revealed in brief, with focus on its epidemiological importance and disease formation.

3. SCOPE OF THE PROBLEM: EPIDEMIOLOGY IMPORTANCE

Protozoan diseases represent a significant global health burden, affecting both humans and animals. These diseases, often poverty-related and prevalent in tropical and subtropical regions, include malaria which responsible for 597,000 deaths in 2023 (World Health Organization, 2023), African trypanosomiasis where approximately 90% of cases are fatal without treatment; therefore, prompt identification of trypanosomes and early treatment is critical (Wendt, et al., 2025), Chagas disease with estimated 10,000 deaths annually worldwide, primarily due to chronic cardiac complications like heart failure and sudden cardiac death (World Health Organization, 2023),, and leishmaniasis with Estimates have suggested that 0.5 million new cases and 20,000 to 40,000 deaths due to VL occur globally each year, particularly in South Asia and South America, which account for half of the new cases reported globally (Wu, et al., 2024). Protozoa are also responsible for noteworthy enteric illnesses like amoebiasis (Nasrallah, et al., 2022), blastocytosis (Barati, et al., 2022), giardiasis (Dunn & Juergen, 2024) and cryptosporidiosis (Gerace, et al., 2019), and can cause grievous conditions like toxoplasmosis (Madireddy & Mangat, 2024) and babesiosis (Kofman &

Guarner,.2022). Some of the most significant epidemiologically dominant protozoan pathogens include:

1. Blood protozoan, Plasmodium spp. Responsible of causing malaria, where globally just in the year 2023, roughly responsible for 2.63×10^8 morbidity and 5.97×10^5 mortality which ensued in 83 countries located in Africa and Asia. More specifically, 94% of these cases and also 95% deaths related malaria arised in the poorest region of Africa (World Health Organization, 2023),

2. Entamoeba histolytica responsible for amoebiasis, where in the year 2019, there were 2,539,799 cases with Disability-Adjusted Life Year (DALY) cases attributable to Entamoeba infection, and the global age-standardized DALY rate of Entamoeba infection-associated diseases (EIADs) was 36.77 out of 100,000 (Fu, et al., 2023),

3. Giardia lamblia responsible causing giardiasis, where in the year 2025, giardiasis pursues to be a global noteworthy public health concern. It is estimated around 3×10^8 vulnerable individual infected globally, ensuing in roughly 5×10^6 mortality annually (Dunn & Juergens, 2024),

4. Toxoplasma gondii (toxoplasmosis, where the global seroprevalence of Toxoplasma gondii in pregnant women was around 36.6% (Salari, et al., 2025) and in the greater picture of its epidemiology, roughly (more or less) one-third of the global population estimated to be infected (Madireddy & Mangat, 2024),

5. Leishmania spp. (responsible for causing leishmaniasis) where actually divided into

   5.1. Visceral leishmaniasis (VL), also known as kala-azar, is fatal if left untreated in over 95% of cases. It is characterized by irregular bouts of fever, weight loss, enlargement of the spleen and liver, and anemia. Most cases occur in Brazil, east Africa and India. An estimated 50 000 to 90 000 new cases of VL occur worldwide annually, with only 25–45% reported to WHO. It has outbreak and mortality potential,

   5.2. Cutaneous leishmaniasis (CL) is the most common form and causes skin lesions, mainly ulcers, on exposed parts of the body. These can leave life-long scars and cause serious disability or stigma. About 95% of CL cases occur in the Americas, the Mediterranean basin, the Middle East and central Asia. It is estimated that 600 000 to 1 million new cases occur worldwide annually but only around 200 000 are reported to WHO and

   5.3. Mucocutaneous leishmaniasis leads to partial or total destruction of mucous membranes of the nose, mouth and throat. Over 90% of mucocutaneous leishmaniasis cases occur in Bolivia, Brazil, Ethiopia and Peru (World Health Organization,2023))

6. Trichomonas vaginalis, etiological agent of trichomoniasis, the single most neglected sexually transmitted diseases (STDs), charges a significant global disease burden particularly among women in low-income areas and individuals aged 30-54 years, where counted from 1990 to 2021, the estimated annual percentage change (EAPC) in the global age-standardized incidence rate (ASIR) of trichomoniasis was 0.09 (95% CI: 0.06 to 0.13). In 2021, the global ASIR of trichomoniasis was 4,133.41 per 100,000 people (95% UI: 3,111.37 to 5,583.56 per 100,000). By population group, the ASIR was higher in men (4,353.43 per 100,000) than in women (3,921.31 per 100,000) in 2021, while the DALY rate was significantly higher in women than in men (6.45 vs. 0.23 per 100,000). When divided by age groups, the trend in ASIR among women aged 30-54 years aligned closely with the overall population incidence trend. In 2021, ASIRs were highest in low SDI regions, and the projected ASIRs by 2050 are 5,680.57 per 100,000 in males and 5,749.47 per 100,000 in females (Wei, et al., 2025)

Those number of global protozoa infections are a widespread and vicious circle problem affecting billions of vulnerable individuals, causing significant morbidity and mortality, especially in developing regions, and highlighting needs for improved sanitation and hygiene. Key infections like amebiasis, giardiasis, and cryptosporidiosis contribute and predispose to the more severe condition of malnutrition, anemia, and various symptoms like diarrhea, with transmission occurring through contaminated food, water, and poor hygiene. The problem necessitates further study in order to improve understanding of these protozoan which will further help doctors to recognize its existence in nature, its virulence and pathogenesis, how to make correct diagnosis and prompt treatments. Besides that, other aspect of this iceberg phenomenon including absence of effective vaccines and the appearance of protozoan strain which develop resistance to antiprotozoal medication. All of those previously mentioned conditions can be reveal first by understanding the basic biology of protozoa.

4. BASIC BIOLOGY OF PROTOZOA

Basic protozoan structure are simple microscopic scale unicellular eukaryotes that frequently have advanced independent internal organelle and carry out complex self-reliant metabolic activities. protozoa are structurally equivalent to a single metazoan cell: basically, a mass of cytoplasm bounded by some kind of limiting membrane and containing one or more nuclei. The cytoplasm may contain most, if not all, of the organelles found in metazoan cells (Rehfeld, et al., 2017), including endoplasmic reticulum, Golgi apparatus, mitochondria, ribosomes, specialized bodies resembling lysosomes, fibrils and microtubules of various kinds, flagella, cilia and even centrioles (Elson, et al., 2016). Not all protozoa, naturally, possess all these previously mentioned organelles. Supplementary important structures, evidently proprietary only to protozoa, are sometimes existent, e.g., endomembrane system in some pathogenic protozoa (Wiser, 2021).

4.1 Its Size and Relation to its Environment

Protozoa are unicellular eukaryotes (Warren & Esteban, 2019; Yaeger, 1996) which typically measure 5 -1000 µm in size (Warren & Esteban, 2019). Most human parasitic protozoans having size which are less than 50 µm under microscopic examination (Zhang, et al., 2022). The smallest which mainly exist in intracellular forms are between 1 to 10 µm in their longest where this intracellular lifestyle influence direct access to nutrients, interaction with host cell signaling pathways, and detection by pathogen recognition systems (Sibley, 2011). But on the contrary, one species of protozoa called Balantidium coli may measure up to 150 µm or more precisely the trophic ciliate measures 30 to 150 µm in length by 25 to 120 µm in width (Schuster & Ramirez-Avila, 2008).

Free-living amoebae (FLA) are actually prevalent in nature, even in the extreme environment (Salazar-Ardiles, et al., 2022; Krishnamoorthi, et al., 2022) and any artificial man-made aquatic milieu (Krishnamoorthi, et al., 2022; Chaúque, et al., 2022) and they can survive in extreme/harsh and dangerous conditions (Salazar-Ardiles, et al., 2022) by forming cysts. Transformation into cyst, named “encystment” or “encystation”, is a common feature found in testate, naked, or flagellated free-living amoebae (Samba-Louak 2023). All free-living protozoa need water to survive (Fan, et al., 2024), hence being elementally aquatic and thriving in freshwater (Salazar-Ardiles, et al., 2022; Chaúque, et al., 2022; Krishnamoorthi, et al., 2022), soil (Pérez-Pérez, et al., 2025), brackish water (Lotonin, et al., 2022), and marine habitats (Layson, et al., 2024). There is considerable morphological and physiological diversity within the group and can be seen through their organelle diversity.

4.2 Protozoan Organelle and its Function

The organelles of protozoa have functions similar to the organs of higher animals. Function of organelles in protozoa include:

1. locomotor organelles such as flagella known as flagellar movement (using whip-like flagella) (Krüger, et al., 2015), cilia known as ciliary movement (using hair-like cilia) (Párducz, 1967) and pseudopodia known as amoeboid movement (by extending pseudopodia or "false feet") (Grebecki & Kłopocka, 1981) which protozoa use for movement. Different protozoa use different method of movement. Other methods include gliding movement (Sibley, et al., 1998) and specialized movement through alterations in their body shape, known as metabolic movement. Metabolic movement is not a single process but a combination of a cell's overall metabolic state (the ability of the cells to sense secreted factors which upon binding to a cell surface receptor, initiate signaling cascades that transduce information and regulate metabolism) (Gomes & Blenis, 2015) and its capacity for physical movement (Ginger, 2006),

both of which are essential for cellular functions like growth, division, and interaction with the environment (Kreier & Baker, 1987). These complex build-in strategies allow protozoa to find food essentials for their survival, mates, shelter and protection, end even escape predators in their environments.

Motility plays an important role in protozoal survival, e.g., gliding motility in Plasmodium sporozoites is critical for invasion of the salivary gland in the mosquito, also in ookinete migration across the midgut epithelium in the mosquito (Sibley, 2011) and also important when this Plasmodium sporozoites inside the vertebrate host in order to exit the skin safely and ultimately reach the liver hepatocytes (Tardieux & Menard, 2008). Most parasitic protozoa are mandatory to move in order to find its essentials nutrition (Smith-Somerville, et al., 2005) or to avoid unfavorable environmental conditions as survival strategies (Behringer, et al., 2018). In the context of its mandatory nutritional fulfillment, protozoa also rely mainly on the use of locomotory appendages to trap or capture or collect food and direct it to the feeding apparatus (Ehrlich, 2010). As a consequence, all free-living protozoa must maintain some motility capableness and can move between two point independently in their current milieu at some time during their life cycle. The different free-living protozoa groups actually have developed diverse mechanisms for their kinetics (Ricci, 1989).

2. contractile vacuoles for regulating water balance (Du, et al., 2008). This system function as an osmoregulatory organelle required for survival for many free-living cells under hypotonic conditions. which controls the intracellular water balance by accumulating and expelling excess water out of the cell, allowing cells to survive under hypotonic, hyposmotic stress, e.g., as shown in T. cruzi, probably increasing the osmotic pressure of the contractile vacuole and facilitating water movement (Rohloff & Docampo, 2008).

3. nucleus containing genetic material where nuclear structures that are intimately linked with most aspects of nuclear genome function, including chromosome organization, DNA maintenance, replication and segregation, and gene expression controls. (McCulloch & Navarro, 2016). As in all eukaryotes, the nucleus is enclosed in a membrane. In protozoa other than ciliates, the nucleus is vesicular, with scattered chromatin giving a diffuse appearance to the nucleus, all nuclei in the individual organism appear alike. One type of vesicular nucleus contains a more or less central body, called an endosome or karyosome. The endosome lacks DNA in the parasitic amebas and trypanosomes. In the phylum Apicomplexa, on the other hand, the vesicular nucleus has one or more nucleoli that contain DNA. The ciliates have both a micronucleus and macronucleus, which appear quite homogeneous in composition.

4. Protozoa may also possess other organelles such as mitosome, the simplest class of mitochondrion-related organelles (MROs) which was an organelle present in a few anaerobic protozoan parasites such as Entamoeba histolytica, Giardia intestinalis and Cryptosporidium parvum (Tottey, et al., 2024; Santos & Nozaki, 2022). Besides that, other specialized organelle such as endoplasmic reticulum function in metabolism and transport, depending on the type and environment of the protozoa.

Many other structures occur in parasitic protozoa, including the Golgi apparatus, mitochondria, lysosomes, food vacuoles, conoids in the Apicomplexa, and other specialized structures.

4.3 Reproduction, Life Cycle and Survivability

Reproduction in the protozoa may be asexual (Sibly & Calow, 1982) as in the amebas (Biron, et al., 2001) and flagellates (primarily through binary fission) (Sibly & Calow, 1982) that infect humans, or both asexual and sexual, as in the Apicomplexa of medical importance (Cruz-Bustos, et al., 2021). The most customary type of asexual multiplication is binary fission, in which the organelles are duplicated and the protozoan then divides into two complete organisms (Isaksson, et al., 2021). Division is longitudinal in the flagellates, as in the genus Trypanoplasma (Pecková & Lom, 1990) and transverse in the ciliates as in the marine free-living ciliate

Glauconema trihymene (Long & Zufall, 2010). It turns out that for amebas, they have no fixed and apparent anterior-posterior axis which means it does not affect this fundamental asexual process. Since the amoeba does not have a specific "front" or "back," the division can occur in various directions, simply splitting the organism into two genetically identical clones, making the body plan irrelevant to the reproduction method itself.

Further study conducted by Isaksson, et al., revealed that cells, whether they reproduce via binary fission or budding, can affect the rate of adaptation. By using mathematical models, she and her colleague can predict the spread of beneficial, growth rate mutations in unicellular populations and populations of multicellular filaments reproducing via binary fission or budding (Isaksson, et al., 2021). By comparing populations once they reach carrying capacity, the spread of mutations in multicellular budding populations is qualitatively distinct from the other populations and in general slower. Since budding and binary fission distribute age-accumulated damage differently as the effects of cellular senescence. When growth rate decreases with cell age, beneficial mutations can spread significantly faster in a multicellular budding population than its corresponding unicellular population or a population reproducing via binary fission. The result showed us that basic aspects of the cell cycle can give rise to different rates of adaptation in multicellular organisms.

Endodyogeny is a form of asexual division seen in Toxoplasma and some related organisms (Berry, et al., 2018). In the context of Toxoplasma gondii, it rapidly propagates through endodyogeny of tachyzoites, a process in which smaller daughter parasites divide within the cell of the mother parasite, coordinated by transcription factor TgAP2IX-5, and the smaller daughter cell must grow to full size before repeating the process (Wang, et al., 2021). Experimentally, addition of Itraconazole affects Toxoplasma gondii endodyogeny by way of the formation of a mass of daughter cells, suggesting the interruption of the scission process during the parasite's cell division (Martins-Duarte, et al., 2008).

Meanwhile in schizogony, a common form of asexual division in the Apicomplexa, the nucleus divides a number of times, and then the cytoplasm divides into smaller uninucleate merozoites. In Plasmodium (Voß, et al., 2023), Toxoplasma (Dubey, 2017) and other non-human parasitic apicomplexans (Cruz-Bustos, et al., 2021), the sexual cycle involves the production of gametes (gametogony), fertilization to form the zygote, encystation of the zygote to form an oocyst, and the formation of infective sporozoites (sporogony) within the oocyst.

The protozoa life cycle involves active trophozoite and dormant cyst phases, with asexual or sexual reproduction depending on the species and environmental conditions (Wallder, 2024; Tarannum, et al., 2023; Auld & Tinsley, 2015). Some protozoa, e.g., Plasmodium, also have distinct stages such as sporozoites and merozoites (Prudêncio, et al., 2006).

Trophozoites stage are recognized as an active, moving, feeding, multiplying stages within a vulnerable host and usually linked with pathogenesis. while cysts are resistant resting forms (Verni & Rosati, 2011) that guarantee survivability outside the host (Aguilar-Díaz, et al., 2011) and transmission between hosts. Environmental transmission is closely governed by the physicochemical properties of the cysts, e.g., Giardia spp. and oocysts, e.g., Cryptosporidium and Toxoplasma, allowing their transport, retention, and survival for months in water, soil, vegetables, and mollusks, which are the main reservoirs for human infection (Dumetre, et al., 2012).

Some protozoa form cysts that contain one or more infective forms. Multiplication occurs in the cysts of some species so that excystation releases more than one organism. For example, when the trophozoite of Entamoeba histolytica first forms a cyst, it has a single nucleus. As the cyst matures nuclear division produces four nuclei and during excystation four uninucleate metacystic amebas appear. Similarly, a freshly encysted Giardia lamblia has the same number of internal structures (organelles) as the trophozoite. However, as the cyst matures the organelles double and two trophozoites are formed. Cysts passed in stools have a protective wall, enabling the parasite to survive in the outside environment for a period ranging from days to a year, depending on the species and environmental conditions. Cysts formed in tissues do not usually have a heavy protective wall and rely upon carnivorism for transmission. Oocysts are stages resulting from sexual reproduction in the Apicomplexa. Some apicomplexan oocysts are passed in the feces of the host, but the oocysts of Plasmodium, the agent of malaria, develop in the body cavity of the mosquito vector.

Some protozoa (e.g., Plasmodium spp, Toxoplasma or Cryptosopridium) have complex life cycles requiring two different host species; others require only a single host (e.g., Entamoeba histolytica) to complete the life cycle. Completing the life cycle is vital for protozoan survival, reproduction and transmission (Wallder, 2024; Tarannum, et al., 2023). The completion of life cycle allows for the generation of new, infective stages (like oocysts or cysts) that can transmit the parasite to new hosts or the environment (Wallder, 2024; Auld & Tinsley, 2015). Completing each stage in their life cycle also facilitates genetic recombination, restores vitality, and enables the parasite to adapt to changing conditions, ensuring its continued propagation and the long-term viability of the species (Wallder, 2024; Isaksson, et al., 2021). Even if only an individual infective protozoan throws oneself into a susceptible host, it still has the potency to initiate an immense population due to its multiplicity ability which related to their frequency and repertoire (Jokipii, et al., 1985). However, reproduction is limited by events such as death of the host or by the host's defense mechanisms, which may either eliminate the parasite or balance parasite reproduction to yield a chronic infection (Duneau, et al., 2025).

4.4 Nutritional Requirement

Parasitic protozoa, such as malaria parasites, trypanosomes, and Leishmania, acquire a plethora of nutrients from their hosts, employing transport proteins located in the plasma membrane of the parasite (Landfear, 2011). The use of molecular genetic approaches and the accomplishment of genome projects have permitted the identification and characterization (functionally) of a series of transporters and their genes in these parasitic organisms. A subset of these membrane transport protein that facilitates the movement of specific molecules, such as sugars or other small solutes, across the cell membrane into or out of a cell is called permeases, which actually responsible for the uptake of critical nutrients needed by protozoa (Landfear, 2019). The unique internal niche inside the host directs the mode of nutrient acquisition, eventhough there is always obstacle and challenges for the parasitic organism (Best & Kwaik, 2019). For example, African trypanosomes are extracellular parasites that live in the blood and interstitial spaces of the host and thus retrieve nutrients directly from these extracellular fluids (Alencar, et al., 2025; Morrison, et al., 2023; Igbokwe, 2018). While on contrary, both Plasmodium (Tardieux & Menard, 2008) and Leishmania (World Health Organization, 2023) live within parasitophorous vacuoles inside the red blood cell and macrophage, respectively. The condition of Intracellular parasitism provides constraints and opportunities regarding sustainable nutrient acquisition (van Dooren & McConville, 2025), explicitly the need to deliver essential nutrients across three membrane systems without ruin them and last but not least the possibility to exploit components of the host cytosol or vacuolar lumen as important sources of their nutrition (Landfear, 2011; Landfear, 2019).

While actually all common and ordinary organisms must acquire nutrients from their environment, the parasitic organisms, including protozoa, has several items of consequences regarding nutrient uptake, namely:

1) clear competition between the parasite with its already exist normal microflora (Zanditenas & Ankri, 2023) belongs to the intermediate host (usually invertebrate) and also with vertebrate hosts for obtainment of many crucial compounds and thus must polish and develop more efficient uptake apparatus (Zhou, et al., 2022),

2) the common parasitic life cycle necessitates at least two distinct hosts, one of them which is oftentimes an invertebrate organism act as a vector and the other a vertebrate host. Thus, the different stage of life cycles between multiple physiologically distinguishable environment that definitely present pronounced differences in available internal body temperature, nutritional composition, pH, ionic composition, electric charges, etc. (Wallder, 2024; Zhou, et al., 2022; Landfear, 2011),

3) The parasite supposed to practice sensing of host’s abundant nutrient (Zuzarte-Luís & Mota, 2018); and also to refine express and convincing nutrient uptake systems efficiently that accommodate these profound alterations in environment and may employ regulatory mechanisms to alter the level of uptake according to nutrient availability and/or life cycle stage

(Zhou, et al., 2022; Piro, et al., 2021; Zuzarte-Luís & Mota, 2018). The capacity of a parasite to salvager critical nutrients is cardinal to its further ability to be transmitted, followed with infecting a vulnerable host, and initiating parasitic disease and hence is an important component of pathogenesis (Attwood, 2025; Wallder, 2024; Best & Abu Kwaik, 2019).

4) Protozoa nutritional requirements vary by species but generally involve predation act (Islas, et al., 2024), which consist of heterotrophy (Attwood, 2025; Wiser, 2024; Núñez, et al., 2024), or expressed in a terminology holozoic, in other word they need organic matters for nutritional requirement (Potapov, et al., 2022), which can include bacteria (Eriksson, et al., 2022; Rønn, 2002), fungi- yeast (Williams, et al., 2020; Ekelund, 1998) and algae (Bergman, 2024). That is why protozoa serve as essential decomposers, breaking down organic matter and recycling nutrients in the environment (Iqbal, et al., 2021; Clarholm, 2005). Nutrient uptake occurs through:

4.1 endocytosis through their lysosomal-like compartments that function as digestive vacuoles; this feeding mechanism used by the pathogenic protozoa of humans such as Entamoeba histolytica, Giardia, Trypanosoma brucei, Trypanosoma cruzi, Leishmania, Cryptosporidium, Plasmodium, and Toxoplasma. (Wiser, 2024),

4.2 pinocytosis (absorbing dissolved organic substances from their surroundings by forming tiny, temporary openings in the cell membrane) (Prusch, 1985); this mechanism uses by amoeba, such as Amoeba proteus, and certain ciliates like Paramecium, Entamoeba histolytica and Noctiluca scintillans, a dinoflagellate.

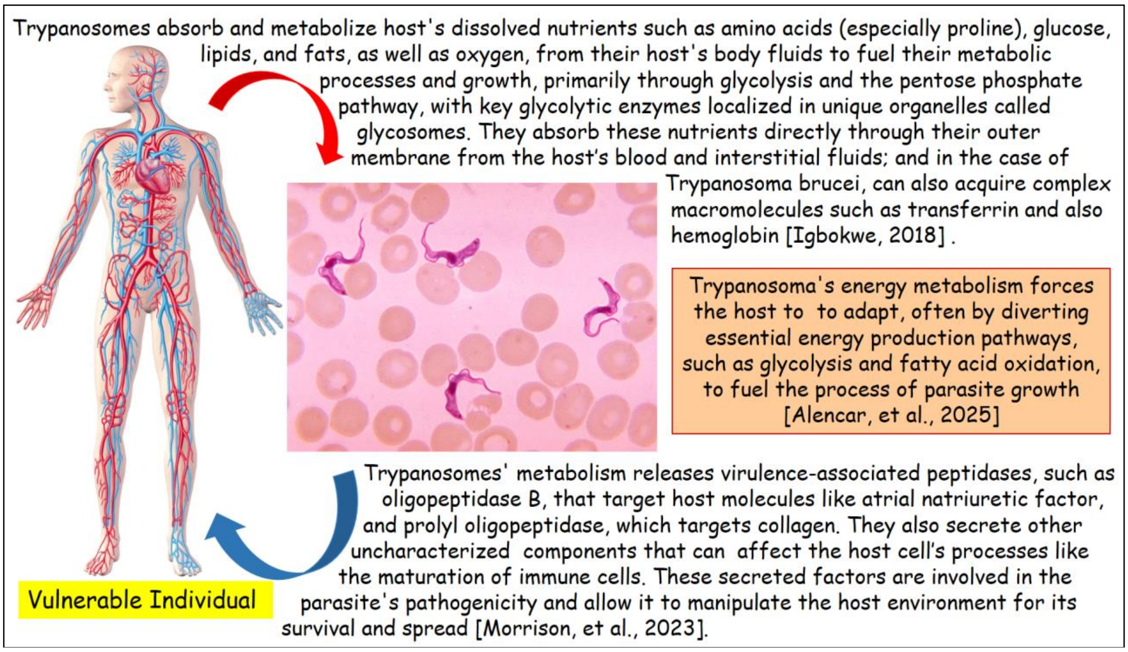

Fig. 1. The way that the hemoflagellates Trypanosomes manipulate, hijack, absorb and metabolize host's nutrients and in turn release its metabolites back to their vulnerable host. From this Trypanosoma's energy metabolism, it is revealed that the parasite relying on host glucose and showing some capacity for nutrient salvage from the bloodstream rather than extensive metabolic flexibility with complex compounds like phenylpyruvate and tryptophol. The parasites exploit hosts metabolic processes by commandeering host resources and altering host cell function to facilitate their own survival and replication within the host environment (Alencar, et al., 2025; Morrison, et al., 2023; Igbokwe, 2018)

Competition for nutrients is not the ultimate factor in the pathogenesis of harmful protozoa because the amounts utilized by parasitic protozoa are relatively small. Eventhough that the assertion that parasitic protozoa utilize small amounts of nutrients is not universally true. The protozoa specific needs and mechanisms depend on their species, life stage, and especially host environment (Zhou et al., 2022), but they are highly adapted to efficiently scavenge or absorb what they need (Ye, et al., 2023), often circumventing complex biosynthetic pathways present in free-living organisms. Factors like their small size, host availability, and efficient transport systems allow them to scavenge on host metabolites (Attwood, 2025). In this case, nutrient availability and sustainability act not only as the main fountain of essential energy but also as important determinators of gene expression that regulates its metabolism and growth, through various signaling networks that enable parasites to survive (Yeh, et al., 2024; May, et al., 2023). The advancement of nutritional uptake strategies can also modify host metabolism to adjust to the level of specific nutritional requirements of the parasite, in this case including protozoa (Zhou, et al., 2022).

Some parasites that inhabit the small intestine can significantly interfere with digestion and absorption and affect the nutritional status of the host, e.g., the intestinal protozoa Giardia (Dunn & Juergens, 2024) and Cryptosporidium (Tottey, et al., 2024; Santos & Nozaki, 2022). The destruction of the host's cells and tissues as a result of the parasites' metabolic activities actually increases the host's nutritional needs (Best & Abu-Kwaik, 2019; Landfear 2011). This may be a major predispose factor in the later outcome of chronic infection in a malnourished and even stunted individual (Siagian, 2023). Finally, extracellular or intracellular parasites that dismantle host’s cells massively while feeding can escort to catastrophe conditions such as organ dysfunction, full blown infection and or other life-threatening consequences.

In recent years, important achievements actually have been made in characterizing chemically engineered correct media for the in vitro cultivation of protozoa in general and in a more specifically, parasitic protozoa. Future research on the biology and metabolism of parasites is always encouraged because better knowledge regarding the parasitic protozoa are potential targets for (1) understanding the complex life cycle, its virulence and its behavior inside the host, (2) its interaction with other inhabitant microorganism which already exist, (3) searching potent antiprotozoal substance with its susceptibility rate and last but not least (4) checking for the potency of benefits due to the protozoa existence in a certain environment.

5. CONCLUSION

Eventhough protozoan parasitic diseases are still major global health problem which affect both humans and animals, many efforts have been made to understand its biologic properties and also to recognize its existence in nature, its virulence and interaction with other microorganism. Efforts to study and understand more deeply about these parasitic protozoa will open up insights regarding prevention, protection and even management efforts, including adequate education for the community.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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