Eating Animal Products, a Common Cause of Human Diseases

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Abstract
The human population is plagued by hundreds of infectious agents that cause diseases, and many of these agents can infect a range of wild and domesticated animals as well. In fact, a large proportion of current pathological conditions in humans is caused by our close association with nonhuman animals, some of which we keep as pets, but most of which we raise, prepare as food sources, and ingest. It is established that most of these diseases are caused by a variety of infectious agents, the most important being bacteria, viruses, prions, and protozoans. In this article, we shall consider these agents and discuss their transmission from various animals and animal products to humans. It is noted that virtually none of these agents are obtained by eating plant-derived products unless the plants are grown and prepared with contaminated water. Consequently, we suggest that Homo sapiens could avoid a significant fraction of the diseases that plague us by shifting to a more vegetarian diet.

Introduction
About 10,000 years ago, humans started domesticating animals and living with them [Diamond, 1997, “Guns, Germs, and Steel”]. There are many human diseases and over 250 types of known causative agents that are transmitted to humans by raising animals; preparing meat, eggs, and dairy; and then eating these products [Laster and Frame, 2019; Fong et al., 2021]. There is a powerful link between our health and longevity and the complex ecology of bacteria, viruses, and other parasites that make up our gut microbiome, which in turn is directly related to what we eat [Maynard and Weinkove, 2018]. Examples involve misfolded “killer proteins” that cause prion diseases such as mad cow and Kuru, which can be transmitted from animals to humans when the latter eat the former, and when humans eat human brains as part of funeral rituals [Prusiner, 2013; Lambert et al., 2021]. Alzheimer’s and Parkinson’s diseases are also associated with misfolding of proteins but are not known to be transmitted by eating animals or affected humans.

While bacterial, viral, and protozoan diseases can be transmitted from animal products, very few, if any, of these diseases result from the consumption of plant products [Skandalis et al., 2021]. Thus, a vegetarian diet can
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Eating Animal Products recommended adaptation. Thus, optimism rather than pessimism is justified as long as people are willing to give up, or at least greatly diminish, the amounts of animal products consumed. Anyone can take advantage of the large selection of delicious vegetarian dishes that have been prepared for centuries, but more such dishes have recently been developed, in part, to avoid recurring zoonotic illnesses [Remde et al., 2022]. This is true everywhere, in every country on Earth.

Raising animals for meat consumption contributes to global warming, which in turn affects the quality and quantity of food we produce. Increased CO₂ and CH₄ levels are changing global temperatures, water availability, and the amounts of nutrients in the soil, causing reduced food production. Plant growth may occasionally increase due to increased atmospheric CO₂ levels (this is true for some C₃ plants, but not for most crops). However, the extreme weather patterns of drought and floods reduce the nutrient content of these plants, which in turn affects the nutrition of herbivores. The essential mineral and protein levels in plants, including wheat, rice, and beans, will be significantly reduced, threatening livestock with decreased productivity and increased vulnerability to diseases. Extreme weather patterns are also changing the biodiversity of our planet, causing the extinction of many plant and animal species, while contributing to increases in weed, pest, fungal, and parasitic populations. More parasites and pests mean that we are likely to use more pesticides, increasing the threat to human health. Increased pesticides in turn will end up in our rivers and seas, killing aquatic life, including numerous seafoods such as water plants, algae, and marine animals.

According to the United Nations, a quarter of the greenhouse gas emissions come from food production. Meat consumption in the USA is greater than 3 times the world average [Kuck and Schnitkey, 2021]. More than a billion chickens were culled in the UK in 2018 [BBC News, 2021]. According to the United Nations, more than 14% of all man-made greenhouse gases are livestock emissions, including methane, which is 34 times more damaging to the environment than CO₂ on a molecule for molecule basis. Beef production emits the most greenhouse gases in the world, an average of 110 pounds of greenhouse gases per 3.5 oz of protein prepared for human consumption, followed by lamb, with 50% less carbon emissions compared to beef. Preparation of the highest impact vegetable protein like tofu emits less greenhouse gases than the equivalent amount of lowest impact animal protein [Poore and Nemecek, 2018]. There is one cow on the planet for every human family!

In the last 3 years, the number of critical illnesses has increased dramatically due to the SARS-CoV-2 infection (COVID-19) pandemic [Vitiello et al., 2022]. While these statistics seem discouraging, food-borne illnesses are largely preventable, and the simplest approach to reduce their occurrences is to greatly reduce the consumption of meat, dairy, fish, and poultry [English et al., 2021; Hidayat et al., 2022]. Anyone can do this with just a little highly recommended adaptation. Thus, optimism rather than
Global warming is contributing to the extinction of many plant and animal species while increasing the growth, and therefore the evolution, of other species like some parasites that thrive in wet and warm areas [Seersholm et al., 2020; Actel et al., 2021]. Due to urbanization, birds with varied food and nesting choices are adapting to urban areas, while others are leaving [Garroway and Schmidt, 2020; Friis et al., 2022]. Some urban birds collect cigarette butts and use harmful chemicals against ticks and other nest parasites. Unfortunately, these same substances are also harmful to the birds [Suárez-Rodriguez et al., 2012; Suárez-Rodriguez and Macías García, 2014]! Global warming additionally causes fish, turtles, crocodiles, and other organisms to produce primarily female offspring, which may lead to extinction of the affected species [Bleichschmidt et al., 2020; Lockley and Eizaguirre, 2021; Porter et al., 2021; Yu et al., 2022].

A lichen is one of the best examples of a symbiosis between three very different types of species [Stribille et al., 2022]. Algae, fungi and cyanobacteria, respectively, produce carbon compounds by photosynthesis, minerals by rock disintegration, and nitrogenous compounds by nitrogen fixation, allowing this interdependent symbiotic community to grow on bare rocks without input from other organisms. They stabilize the soil and provide food to some animals. However, the rates at which algae adapt to global warming are slow; adaptation to a 1°C increase in temperature is thought to take an estimated one million years. Warmer climates are driving some animals to migrate to environments with cooler temperatures, present in decreasing numbers and total areas on the globe. Those organisms that cannot migrate fast enough are likely to go extinct.

Human activities are driving an unnatural evolution, which in turn is impacting agriculture, fisheries, and other food supplies. We hope that future generations will take advantage of their educational opportunities, thereby understanding and adapting successfully to the anticipated environmental changes. They should also be more successfully equipped to solve problems with technologies like artificial intelligence [Li et al., 2022] and DNA site-specific mutagenesis tools including the Clustered Regularly Interspersed Short Palindromic Repeats/Clustered Regularly Interspersed Short Palindromic Repeats-associated 9 (Cas9) endonuclease system which is a facile, highly efficient, and selective site-directed mutagenesis tool for RNA-guided genome-editing [Dey and Nandy, 2021].

**Bacterial Food Poisoning**

Food poisoning is common throughout the >200 countries on Earth and is probably the most prevalent form of human/animal illnesses known. However, it should be noted that “food poisoning” is not a single disease; it is caused by numerous agents, each giving rise to a distinctive subset of symptoms. Food-borne illnesses are largely caused by bacteria present in our foods, although viruses, and to an even lesser extent, eukaryotic parasites (Fungi, Toxoplasma, Giardia, Cryptosporidium, Entamoeba, and helminths [worms]) in contaminated food products can also cause similar or even the same symptoms [Gallo et al., 2020]. Bacterial food poisoning affects roughly 50 million Americans (one in seven) every year, and worldwide, an estimated 600 million people (one in ten) are infected [Karesh et al., 2012]. Symptoms are similar to those of gastroenteritis (stomach flu) and usually involve diarrhea, or even bloody diarrhea, which can last for weeks and can even be life-threatening [Nakao, 2002]. In addition to bacterial, viral, and parasitic food poisoning, the presence of bacterial and fungal toxins as well as other metabolic products produced by some of these food-borne organisms can be responsible for the illness. Nevertheless, ingestion of the organisms is usually responsible for long-lasting symptoms [Liu et al., 2022]. It has been estimated that these pathogens cause a huge disease burden, with endemic and enzootic zoonoses causing about a billion annual cases of illness worldwide, with millions of deaths every year. The growing problem of resistance to antibiotics, antifungal agents, and antiviral compounds as well as resistance to a large variety of these and other drugs, is already a major health problem worldwide [Sørum and L’Abee-Lund, 2002].

What kinds of bacterial pathogens are responsible for these symptoms? While numerous types of bacteria cause food poisoning, several of these organisms cause most of the illnesses, and only these will be discussed here. Escherichia, Shigella, Salmonella, Vibrio and Campylobacter species (e.g., Escherichia coli, Shigella flexneri; S. typhimurium; Vibrio parahaemolyticus; and C. jejuni, respectively) are all related Gram-negative proteobacteria that are primary causes of variant forms of food poisoning [Biernbaum and Kudva, 2022]. Escherichia, Shigella, and Salmonella are very closely related genera within the gamma-proteobacteria, and E. coli, the most extensively studied and best understood organism on Earth, is among the primary causes of infant mortality worldwide, past and present. A very close relative of E. coli, Shigella flexneri, which causes bloody diarrhea, and Salmonella spe-
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with a very restricted range of fimbriae is *Helicobacter pylori*, also a proteobacterium, which infects stomach epithelial cells to cause ulcers and epithelial stomach cancers [Johnson et al., 2012]. *H. pylori* infects very few other organs and tissues because it has only one type of fimbrium that binds to cell surface glycoproteins, while other macromolecules on the surfaces of the cells of other tissues within the body are not recognized by that fimbrial adhesin [Tobias et al., 2017]. Interestingly, while *E. coli* and *Salmonella* species are common causes of gastroenteritis in the USA, *Vibrio* species, normally found in marine environments, are far more common causes of food poisoning in Japan where raw sushi is more often eaten [Shimohata and Takahashi, 2010].

Gram-positive bacterial species can also cause food poisoning. Among the most common species of these organisms are *Clostridium perfringens*, *Staphylococcus aureus*, and *Listeria monocytogenes* [Rajkovic et al., 2020]. *C. perfringens* is found in raw meat, poultry, fish, eggs, and unpasteurized dairy foods, but it frequently causes gastroenteritis when soups, stews, and gravies made with animal meat are not sterilized and subsequently refrigerated [Diaz Carrasco et al., 2016]. However, this species can also be found in contaminated vegetables and crops if they have been grown or prepared with contaminated water. Therefore, it is important to wash and often cook vegetarian products as well as animal products. *Listeria* species are found in deli meats, hot dogs, and store-made salads that contain meat and/or dairy products, but they are more frequently found in unpasteurized milk [Garner and Kathariou, 2016]. Finally, *Staphylococcus aureus* is a common contaminant of foods such as meats and egg salads, particularly if these products are not kept under refrigeration. Symptoms of these infections include fever and chills as well as difficulty breathing. *S. aureus* also causes serious infections such as pneumonia (infection of the lungs), bacteremia (bloodstream infection), and skin ulcers [Tasneem et al., 2022].

Not everyone is equally susceptible to food poisoning; anyone with a compromised immune system is at greater risk for infection. Thus, young children, older folks, and pregnant women are at risk to a greater extent than the general public. Young children have not yet fully developed their immune systems, while older people often have less effective such systems. Also, pregnant women and their fetuses experience continually changing immune systems, resulting in temporary lapses in defenses to specific agents of disease [Kline and Lewis, 2016]. Additionally, people with cancer (especially when receiving chemotherapy) and diabetes often have compromised immunity.

Fig. 1. A disease-causing bacterium (*Escherichia coli*). The short hair-like structures projecting from the cell body of the bacterium are fimbriae, organelles of adhesion, while the larger and longer structures are flagellae, organelles of motility. Image Credit: Center for Disease Control and Prevention, Antibiotic Resistance Coordination and Strategy Unit, Alissa Eckert, under the Creative Commons Attribution-ShareAlike license http://www.cdc.gov/cdcp/.

**Table 1.** Disease-causing bacteria and their cellular components

| Bacterium               | Cellular Component | Description |
|-------------------------|-------------------|-------------|
| *Escherichia coli*      | Fimbriae          | Adhesion    |
| *Salmonella*             | Flagellae         | Motility    |
| *Listeria monocytogenes*| Fimbriae          | Adhesion    |

**Note:** The fimbriae of bacteria are hair-like structures projecting from the cell body of the bacterium. They are organelles of adhesion, while the larger and longer structures are flagellae, organelles of motility.
Viral Food Poisoning

When a cell is infected with two related viruses, their genetic materials can mix, producing more virulent strains as they replicate. With so many strains of COVID in circulation among the human population, a recombination of Delta variant’s virulence with Omicron’s transmissibility is a scary possibility. Five different types of SARS-CoV-2 (Alpha, Beta, Gamma, Delta, and Omicron) with increased transmissibility have been identified globally, and we can expect more lethal strains to appear in the future.

A recent extensive meta-transcriptomic study of 1,941 wild game animals, representing 18 species that are hunted, traded, and consumed in China, identified 102 distinct viruses that infect mammals [He et al., 2022]. Twenty-one of these viruses are categorized as high risk to humans and domestic animals. This study provided a clear indication that wild animals hunted and consumed as exotic food sources are reservoirs of potentially dangerous viruses that may be responsible for emerging pandemics. Many exotic wild animals such as armadillos are imported into the USA and other developed nations. Therefore, we should not be surprised if the next epidemic starts in our own backyard. The occurrence of different wild animal species in the wet markets and the restaurants they supply, poor sanitary conditions, close association of humans with these exotic animals combined with warmer temperatures make ideal mixing bowls, creating new and dangerous recombinant viruses that may lead to future epidemics.

Viral food poisoning has been much less common than similar bacterially caused illnesses, particularly in the past, but higher percentages of viral infections in the present are due to the availability of effective antibiotics. However, the development of drug-resistant pathogenic bacteria is leading to re-emergence of bacterial pathogens such as Mycobacterium tuberculosis and the dominance of bacteria in food poisoning [Forrester et al., 2022]. For both viral and bacterial infections, sanitation and refrigeration are important preventative measures. Several viruses can cause food-borne infections, and these are frequently accompanied by a myriad of symptoms (mild to acute diseases, but sometimes chronic, debilitating diseases, leading to death). Since viruses, in contrast to bacteria, do not replicate in food, and they may be difficult to replicate in cell culture, viruses are frequently more difficult to detect than bacterial pathogens, and it is therefore much more arduous a task to identify and analyze food-borne viruses. Nevertheless, several well-established and emerging viruses implicated in food-borne infections are now recognized [Reddy and Saier, 2020].

Viral gastroenteritis is transmitted through contact with an infected animal or person, or by ingesting contaminated food, water, or ice. For many years, rotavirus had been recognized as a primary cause of gastroenteritis in the young of many animal species including humans [Flewett et al., 1975; Bishop, 2009]. In humans, rotavirus-associated diseases typically occur in children less than 5 years of age, but rotaviruses can infect people of all ages [Anderson et al., 2012; Collins et al., 2015]. In the year 2008, an estimated 500,000 deaths worldwide were attributed to rotavirus infections, with most deaths occurring in resource-poor countries [Tate et al., 2013].

Viruses most frequently reported to have the highest cost of detection and treatment include, but are not limited to, noroviruses (a common cruise ship problem) and rotaviruses, but hepatitis viruses, adenoviruses, and coronaviruses (including SARS-CoV-1 and -2; shown in Fig. 2) are also known to cause intestinal inflammation [Pena-Gil et al., 2021]. The body’s innate immune defense system is the first line of protection, although it does not distinguish between antibodies of infectious agents [Zhao and Lu, 2014]. It is interesting to note that low-level exposure to these agents activates the immune system, and consequently, limited exposure can stimulate protection against larger, more dangerous doses of these vectors. Thus, for example, wild and domestic animals are much less susceptible to diseases caused by these agents than are humans, merely because exposure to these pathogens and related commensals has been more extensive throughout their lives [Butts and Sternberg, 2008].
The intestinal microbiota of all animals also serves to compete with pathogens for ecological space, providing additional protection, both for the body and the brain [Tang et al., 2014]. Moreover, the secreted mucus layer and antimicrobial peptides (e.g., defensins and cathelicidins) provide additional defenses against all such pathogens, especially envelop viruses. However, their actions are often insufficient to prevent disease [Bosi et al., 2020]. It is important to recall that viruses are likely to be the most common cause of gastroenteritis in infants and very young children, although these infections are symptomatically similar to other types of gastroenteritis. Some of these viruses infect only humans, while others more generally cause a variety of zoonotic diseases. Probably the most common and costly viral gastroenteritis is due to noroviruses, usually taken into the body by consumption of contaminated raw oysters and other seafoods. However, fruits and vegetables that have been irrigated with or exposed to contaminated water (e.g., by human feces) have been shown to cause the disease as well.

Prevention of viral infections requires a detailed understanding of the disease agents and the mechanisms of their transmission between animals and humans. While in the past, zoonotic bacterial diseases had been far more common and serious than zoonotic viral diseases, the development of antibiotics has to a considerable extent reversed this situation as noted above. Many viral diseases such as influenza (e.g., jumping from avian flocks or porcine herds) and COVID-19 (caused by SARS-CoV-2, probably originally from bats) have reached pandemic levels, causing huge numbers of illnesses, hospitalizations and fatalities [Shi et al., 2021].

Other pathogenic viruses (including the West Nile and Nipah viruses, which cause encephalitis and meningitis, respectively, can be life-threatening) [Stahl and Mailles, 2014]. Symptoms include weakness and fatigue, encephalopathy, fever, head and body aches, sore throat, coughing, and diarrhea, and these symptoms can last for weeks, even months. These viruses are spread to people by direct contact with infected animals (e.g., pigs, chickens, dogs, cats, other humans, and bats) or by exposure to bodily fluids such as blood, urine, and saliva, or to the meat of these animals [Sewald et al., 2016]. Bats may have been the original hosts of many viruses because of their unusual host defense systems and immune tolerance, which allows viruses to coexist in bats without causing disease [Hauser et al., 2021; Irving et al., 2021; Parolin et al., 2021]. Additionally, bovine spongiform encephalopathy and endemic zoonotic diseases such as rabies are still prevalent in many countries [Saegerman et al., 2012].

Recent outbreaks of the avian influenza A (H5) virus in the USA were reported in Colorado and confirmed by the US Center for Disease Control and Prevention (CDC), and another case appeared in the United Kingdom involving an individual who raised birds in 2021. H5N1 viruses have been reported in commercial and domestic birds in 29 states of the USA and in wild birds in 34 states, resulting in the culling of millions of poultry in dozens of USA states. Earlier, infections of H5N1 being transferred from one infected person to another individual rarely occurred. But recombination is the viral version of sex that remains an ever-present global threat with significant impact on health as well as economic consequences, causing misery and societal disruptions. Influenza viruses are continually mixed among birds, pigs, and other animals, shuffling their genes with those of human viruses and creating novel viruses, thus making future flu pandemics inevitable.

The CDC website has provided recommendations for food preparation that are meant to minimize the occurrence of food-borne diseases. Most of these measures require the simple implementation of good hygiene, washing fruits and vegetables and cooking or boiling all animal products, especially seafoods such as shellfish (e.g., oysters and clams). Of course, other practices such as avoiding contact with people who are ill for at least 48 h after symptoms have abated are recommended. Another precautionary measure involves decontamination using ap-
propriate disinfectants and detergents. The CDC website notes that some people are particularly vulnerable and should take extra measures to avoid norovirus infections, which can be especially dangerous for infants, older adults, and people with underlying diseases. Also, remember that vomiting and diarrhea can be severely dehydrating and may require medical attention. Washing of foodstuffs and sterilization should be undertaken in these instances [Filip et al., 2021; Biernbaum and Kudva, 2022]. A little care can go a long way!

Animal-Borne Prion Diseases

Prion diseases, also known as transmissible spongiform encephalopathies (TSEs), are neurodegenerative protein misfolding diseases that often lead to death of the infected individual. TSEs occur when a cellular protein (PrP\textsuperscript{C}) misfolds to form the pathological prion protein (PrP\textsuperscript{Sc}) (shown in Fig. 3), which then causes further conversion of additional PrP\textsuperscript{C} proteins to become misfolded PrP\textsuperscript{Sc}. This can lead to a cascade of pathologic processes in cells and tissues [Lambert et al., 2021]. Various types of prion proteins have different clinical phenotypes. Thus, different prion diseases may result from the differential accumulation of PrP\textsuperscript{Sc} in brain regions and tissues of natural hosts and can then be transmitted to humans upon ingestion of the infected animal. Differential penetration of the disease proteins occurs in the retinal ganglion cells, cerebellar cortex, white matter of the brain, and plexuses of the enteric nervous systems in cattle with bovine spongiform encephalopathy, in sheep and goats with scrapie, in cervids (deer, reindeer, moose, etc.) with chronic wasting disease (CWD), and in humans with any of a spectrum of prion diseases [Lambert et al., 2021]. Describing TSEs in their natural animal hosts will allow us to gain a better understanding of the pathogenesis of the different prion diseases and might allow us to evaluate and even discover potential therapeutics, most of which are still not available. Prion diseases are the most recently discovered form of pathology in animals and humans, and they are the least well understood. Consequently, there are still few therapeutic treatments for these conditions that result in cures.

As noted above, prion diseases are fatal neurodegenerative disorders with natural occurrences in humans and many other wild and domestic mammalian species such as deer, cows, goats, and sheep. The diseases are transmissible, and the agents are derived from the host-encoded PrP\textsuperscript{C}, which misfolds into a pathogenic conformation, PrP\textsuperscript{Sc} (e.g., mad cow disease and scrapie). Aggregates of PrP\textsuperscript{Sc} molecules are proteinaceous infectious particles (shown in Fig. 3). Scrapie in sheep and goats and CWD in cervids are known to be infectious under natural conditions. Infected animals with CWD can shed prions via bodily excretions, allowing indirect host-to-host transmission, or directly via prion-contaminated animals [Tranulis et al., 2021]. Transmission via both routes is frequent, and therefore, limiting the spread of CWD has proven difficult. In 2016, CWD was diagnosed for the first time in Europe, in reindeer (Rangifer tarandus) and European moose (Alces alces). Both were diagnosed in Norway. Subsequently, more cases were detected in a semi-isolated wild reindeer population in the large, ecologically diverse, Norwegian Nordfjella wild reindeer area. 2,400 reindeer were tested for CWD revealing 18 infected animals. Further cases were later identified in moose, with a total of 8 in Norway, 4 in Sweden, and 2 cases in Finland. The mean age of these infected animals was 15 years, and the pathological features resembled those of other known prion diseases. Red deer (Cervus elaphus) has also been found to be infected. CWD is clearly an important disease in European cervid populations and a major food-safety challenge. The surveillance, epidemiology, and disease characteristics of CWD, including prion strain features of the newly identified European CWD agents, have been reviewed [Tranulis et al., 2021]. The highly prevalent mys-
tergy neurodegenerative disease (ND) in the Cycad Island of Guam has been attributed to the islanders’ taste for a cuisine of “flying foxes” (fruit bats) that eat cycad seeds containing a neurotoxin [Sacks, 2011]. This case is a very good example of one type of food, causing symptoms similar to dementia, Parkinson’s, and other neurological disorders. We are faced with many toxins in our food, water, and environment causing these illnesses, a majority of which have zoonotic origins [Kesika et al., 2021].

As noted above, Alzheimer’s disease (AD), Parkinson’s disease, and other NDs, though not usually caused by eating prion-infected tissues, are a consequence of protein misfolding, aggregation, and spread [Carlson and Prusiner, 2021]. This conclusion arose from the prion hypothesis, which argues that the causative infectious agent is a proteinaceous “pathogen” devoid of nucleic acids, and not a virus, viroid, or bacterium. It took years of investigation to demonstrate that the proteinaceous infectious agent could induce misfolding and exist as a unique microbiological entity. However, prion proteins proved to be the cause of disease conditions such as Creutzfeldt-Jakob disease and Gerstmann-Sträussler-Scheinker syndrome, which are similar to other NDs in humans. Carlson and Prusiner [2021] discussed the diseases caused by prion protein misfolding, emphasizing principles of pathogenesis that were later found to be core features of other NDs. For example, the discovery that familial prion diseases can be caused by mutations in the gene encoding the native protein was important for understanding prion replication and disease susceptibility for common NDs involving other proteins. The authors compared diseases caused by misfolding and aggregation of prion-derived peptides such as tau and α-synuclein with other prion disorders. These authors also argued for the classification of ND diseases caused by misfolding of these proteins as “prion diseases.” Deciphering the molecular pathogenesis of NDs as prion-mediated has led to novel approaches for finding therapies for these intractable, invariably fatal disorders [Carlson and Prusiner, 2021].

Alzheimer’s disease results from the accumulation of intracytoplasmic aggregates of the tau protein, which spreads like other prions between interconnected brain regions. The genetics of susceptibility to making the misfolded protein have been well described. Spreading is attributed to the secretion and uptake of tau from the extracellular space or direct cell-to-cell transmission through cellular protrusions [Annadurai et al., 2021]. The endogenous normal tau converts into its pathological form(s), promoting neurodegeneration and the characteristic “neurofibrillary tangles” seen by pathologists in brain biopsies. Tau secretion through unconventional secretory pathways involves delivering misfolded and aggregated tau to the plasma membrane and its release into the extracellular space by various poorly understood mechanisms. Although cytoplasmic tau was originally thought to be released only from degenerating cells, subsequent studies revealed that cells constitutively secrete tau at low levels under normal physiological conditions. The mechanisms of secretion of tau under pathological conditions remain unclear, and a better understanding of these pathways will be necessary for the development of therapeutic approaches that can target prion-like tau forms, thereby preventing AD. Annadurai et al. [2021] have reviewed this topic, focusing on unconventional secretion pathways involved in the spread of tau pathology in AD. They also discussed these pathways as prospective areas for future AD drug discovery and development.

**Protozoan Food Poisoning**

Pathogenic protozoa are commonly transmitted to humans in foods, particularly in developing countries, but protozoan food-borne outbreaks have been relatively rare in developed countries [Macpherson, 2005]. The most devastating protozoa in developed countries are *Toxoplasma, Cryptosporidium*, and *Giardia*. Immuno-compromised people are highly susceptible to these infections. Diverse unicellular protozoa inhabit the intestinal tracts of humans and other animals [Skotarczak, 2018, Caudet et al., 2022]. Disease conditions often arise through ingestion of contaminated food or water. For example, *Toxoplasma gondii* often contaminates animals including marine mammals [Dubey et al., 2020], and therefore, ingestion of these sources of nutrition is risky, especially when cooked at an insufficient temperature. Another example is the protozoan parasite *Cryptosporidium* which has emerged as a leading cause of diarrheal illnesses worldwide, being a particular threat to young children and immunocompromised individuals. While endemic in the vast majority of developing countries, *Cryptosporidium* also has the potential to cause large-scale outbreaks in both developing and developed nations [Couso-Perez et al., 2022]. Anthropic and zoonotic transmission routes are well defined [O’Leary et al., 2021]. Still another disease condition, caused by the protozoan parasite, *Entamoeba histolytica* (shown in Fig. 4) causes amebiasis [Gupta et al., 2022; Silvestri and Nugasala, 2022]. This condition causes symptoms of acute diarrhea, dysentery, and amebic colitis and may result in the produc-
tion of amebic liver abscesses. As the fourth leading parasitic cause of human mortality, *E. histolytica* mainly infects children in developing countries, transmitted by food or water contamination. In a majority of infected individuals, *Entamoeba* species asymptptomatically colonize the large intestine but may flare up with full-fledged disease symptoms later in the infection cycle.

The risk of water contaminated with pathogens such as *Giardia, Cryptosporidium,* and *Cyclosporum* is increasing every year in wealthy nations such as the USA and those in Western Europe. Contaminated drinking water problems are no longer confined to developing countries. Industrialized nations are poorly prepared to deal with the problem if challenged with such infections, and the diseases can spread quickly due to a lack of immunity in the population. Water from the mountains of a famous tourist destination, Banff in Western Canada, made tourists sick with the intestinal protozoan parasite, *Giardia lamblia,* which is known to infest mountain streams in Western North America. The parasite resides in beavers and muskrats as well as in water contaminated with their feces. The sickness has been named “Beaver Fever,” and stringent water treatment procedures are now in place in Banff [Tsui et al., 2018]. Other eukaryotic disease agents, including fungi and other protozoa, cause diseases in humans as well as domesticated and wild animals. We are restricting our discussion of these organisms in this article because the topic of protozoan diseases will be covered in another article to be published in *Microbial Physiology* in the foreseeable future [Reddy et al., manuscript in preparation].

**Conclusions and Perspectives**

We have seen that many disease conditions in humans are transmitted from animals by the raising, preparation, and consumption of meat and other animal products such as dairy and eggs. In fact, the number of such infectious agents far exceeds the number of diseases anyone can keep track of. To make matters even more compelling, some human cancers are promoted by the consumption of animal products that contain preservatives, carcinogens, and toxins [Wirkus et al., 2021]. It should be apparent that ridding ourselves of these and other common diseases would be tremendous to the advantage of the entire human population, for personal, economic, and health reasons. This is true both for *Homo sapiens* and for wild and domesticated animal populations worldwide. It is startling to realize that humans are estimated to consume roughly 40 million (M) cows, 120 M pigs, 300 M turkeys, 7 billion (B) fish, 9 B chickens, and 64 B shellfish per year, and these numbers, unfortunately, increase every year as the human population expands, in spite of the well-recognized connection between eating animal products and the causation of human diseases discussed in this article. These are staggering numbers that account for the tremendous infection rates including virtually all human pandemics, worldwide, past, present, and future. How simple it would be (and is) to switch to a predominantly (or exclusively) vegetarian diet! So many vegetarian dietary items are now available for consumption. It must be accepted that by slaughtering so many animals, we are inflicting immeasurable pain on these sensitive creatures. Their welfare should be taken into account, and the detrimental environmental impact of eating meat cannot be overemphasized [Macdiarmid, 2021; Neufingerl and Eilander, 2021]. Thus, a vegan diet, the best possible scenario, would benefit everyone and the entire animal kingdom. Without the raising of animals for human consumption, wild animals will be subject to far fewer diseases. It is a win-win situation, but can we, for practical, economic, environmental, and moral reasons make the switch? Only time will tell.

**Fig. 4.** A disease-causing protozoan (*Entamoeba histolytica*). This eukaryotic parasite has all of the typical eukaryotic cell organelles such as nuclei, mitochondria, lysosomes, peroxisomes, etc., all of which are lacking in bacteria. Image Credit: Stefan Walkowski under the Creative Commons Attribution-Share Alike 4.0 International license. https://commons.wikimedia.org/wiki/User:Navaho#/media/File:Entamoeba_histolytica.jpg.
Conflict of Interest Statement

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