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Selected zoonotic diseases in rodents

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Abstract
Rodents, representing 43% of mammalian species, play a pivotal role in the transmission of zoonotic diseases, serving as reservoirs for pathogens including viruses, bacteria, fungi, protozoa, and helminths. Over 217 rodent species are reservoirs for 66 zoonotic diseases, such as salmonellosis, leptospirosis, toxoplasmosis, hantavirus, and Lassa fever. Prominent examples include Yersinia pestis (plague) and Borrelia burgdorferi (Lyme disease). Rodents transmit pathogens directly via bites or excreta and indirectly through food, water contamination, or vector organisms like fleas. Urbanization, migration, and habitat fragmentation amplify human-rodent interactions, increasing zoonotic risks. Rattus norvegicus and Rattus rattus, the most studied species, are primary carriers of zoonotic pathogens, harboring numerous helminths and bacteria. Brown rats dominate most of Europe, while black rats are confined to coastal areas and islands. Resistance to rodenticides and inefficient control measures exacerbate pathogen spread. Diseases like leptospirosis and hantavirus are resurging in Europe, highlighting the urgency for effective rodent control. Zoonotic pathogens include bacterial agents like Yersinia pestis and Leptospira spp., viral pathogens like hanta virus and Kyasanur Forest Disease virus, and parasitic agents such as Toxoplasma gondii. Rodents acquire pathogens via "parasite spillback" in new habitats, amplifying disease transmission risks. Effective control strategies include rodent-proof facilities, rodenticides, and antifertility agents. The global distribution and adaptability of rodents underline their central role in zoonotic disease emergence, necessitating intensified research and control measures to mitigate their impact on public health.

Keywords: *Infectious diseases, laboratory animals, rodent, zoonosis*

1. Introduction

Rodents are mammals that play a key role in the spread of zoonotic diseases and serve as significant reservoirs of human pathogens. Of the 2.277 known rodent species worldwide, 217 act as reservoirs for 66 different zoonotic diseases caused by various pathogens such as viruses, bacteria, fungi, helminths, and protozoa.[1,2] These diseases include infections of major public health concern, such as salmonellosis, leptospirosis, toxoplasmosis, hantavirus infections, rat-bite fever, and Lassa fever. Rodents also play a significant role in the transmission and dissemination of pathogens such as *Yersinia pestis* (plague), *Bartonella spp.*, *Mycobacterium tuberculosis*, and *Borrelia burgdorferi,* causative agent of Lyme disease.[3] Found on every continent except Antarctica, rodents constitute approximately 43% of mammalian species. Urbanization and habitat fragmentation, in particular, have increased rodent interactions with humans, farm animals, and pets.[4,5]

In peri-urban areas, rodents act as a bridge between wildlife creatures and humans, exposing people to zoonotic pathogens found in within these environments. For instance, brown and black rats (*Rattus norvegicus* and *Rattus rattus)* not only carry pathogens to new geographic regions outside their natural habitats but also acquire new macroparasites, thereby facilitating the efficient spread of pathogens among wild nature, pets, and humans.[6,7] Diseases transmitted by rodents can occur through both direct and indirect pathways. Direct transmission includes infections from rodent bites or inhalation of their excreta, while indirect transmission involves the consumption of nutriment and water infected with gnawer feces and urine.[8] Additionally, in vector-borne diseases, rodents act as amplifier hosts. For example, the eastern rat flea (*Xenopsylla cheopis*) is the important vector for the contamination of *Yersinia pestis* to humans, which has caused several major epidemics in the past. The more than 1,500 cases of human plague recorded in Madagascar between 1997 and 2001 are an important example of this.[9]

Human-driven processes such as urbanization, migration, agricultural activities, and large-scale trade are major factors that facilitate the spread of rodent-borne pathogens.[5] For instance, habitat fragmentation in New York has led to an increased density of Borrelia burgdorferi-infected ticks, elevating disease risk. The resurgence of *hantavirus* infections and rat-borne leptospirosis has also been seen in Europe.[10,11] Human-rodent interaction is further increased by rat resistance to rodenticides and increased rodent control efforts, which increases the danger of zoonotic disease outbreaks.[4,12] To sum up, rodents are essential to the development and spread of zoonotic illnesses. The biology and transmission of viruses are altered by increased human interaction, which

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poses a serious risk to public health. Thus, improving knowledge and management of rodent-borne zoonoses need to be a top priority in international health initiatives.

2. Transmission methods, habitats, and control of rodents

In Europe, brown (*R. norvegicus*) and black rats (*R. rattus*) are widely distributed across various geographical regions. However, black rats have been found to no longer inhabit some areas they previously occupied, such as Sweden. While the global population of black rats has reportedly declined significantly over the past century,[13] this trend is not consistent across all regions.[14] In Europe, brown rats have expanded over a wide area, whereas black rats are predominantly concentrated in warm coastal regions and oceanic islands. Brown rats inhabit most of Europe, while black rats are more localized to specific coastal areas and islands. In Europe, 53 rat-borne pathogens with potential public health impacts have been identified. Earlier studies by Cleaveland and colleagues reported that rodents could host up to 180 zoonotic agents.[15] Globally, *R. norvegicus* has been found to harbor 164 species of helminths, while *R. rattus* hosts 156 species. Between these two rat species, only 65 helminth species are shared.[7] In their natural habitats, brown rats and black rats are known to harbor 21 (12.8%) and 64 (41%) helminth species, respectively.[7] Both species have been found to carry up to 17 potential zoonotic helminths.

In general, commensal rats are believed to acquire new pathogens in addition to their natural ones through "parasite spillback" when they adapt to new environments.[7,16] For example, *Coxiella burnetii*, a zoonotic pathogen typically found in goats, sheep, and cattle, has recently been identified in rats in the Netherlands.[17]

In areas with fewer potential host species for pathogens, there is a possibility of a reduction in certain pathogen types.[5] A study found that rodents captured in human settlements exhibited lower densities of zoonotic helminths compared to those in forests and other natural habitats.[18] However, commensal rats are considered highly efficient reservoirs for some microbes, and the reduction of other mammalian species may facilitate the further spread of these microbes. This phenomenon, known as the "dilution effect," suggests that pathogen abundance may increase through dilution processes.[19] In regions where rat populations are on the rise, the number of pathogens carried by rats is also expected to increase.

In Europe, there is a larger diversity of pathogens in rural regions compared to metropolitan ones. This difference may be attributed to farmland providing more "vacant spaces" for brown rats compared to the living environments in cities. Furthermore, rats generally do not readily accept new individuals into their populations.[20,21] Consequently, the spread of exotic rat-borne pathogens is less common in cities than in rural areas. Limitations in research, such as the inability to control how shifts in research funding and surveillance efforts influence results, may skew reporting trends and mislead conclusions. A review of the literature reveals fewer studies on pathogens in black rats, although black rats in Oceania islands are known to harbor many helminth species. Therefore, the hypothesis that pathogens carried by rats on oceanic islands exhibit less diversity compared to other regions is not supported.

Brown and black rats have colonized the world at different times and through different routes.[17,21-23] It is believed that black rats settled in Europe before brown rats.[13,22] Molecular analyses have revealed a long history of colonization by black rats on the Canary Islands, allowing ample time for helminths co-evolved with this rat species to transfer to humans. Future studies are recommended to present comparative data from rural and urban areas within the same publication. For surveillance studies, sample size calculations based on expected prevalence are advised.

Rodent populations can be controlled by addressing factors such as birth rates, mortality rates, and migration, which depend on population density. Migration can be prevented through barriers, rodent-proof facilities, electric fences, baiting, ultrasonic devices, and electromagnetic devices. Nesting chances might be eliminated to lower the hazardous birth rate. House mice's tendency to procreate can be inhibited by scents, ultrasonic devices, and clean farming methods and sanitation measures. Additionally, treatments like the antifertility compound alphachlorohydrin have shown promising results. Increasing the harmful death rate can be achieved using traps, predators, and chemical methods.[24] Effective rodenticides include chemical agents such as zinc phosphide, aluminum phosphide, barium carbonate, and strychnine. Subacute rodenticides like bromethalin, flupropadine, and calciferol are also available.[24,25]

3. Bacterial zoonoses

3.1. Plague

Yersinia pestis, a Gram-negative bacillus that is a member of the *Enterobacteriaceae* family, is the cause of plague, a serious bacterial zoonotic disease that is spread by rodents. With intricate zoonotic and epizootic cycles, this infection, which can occasionally be transmitted to people, has caused large pandemics, epidemics, and isolated cases in the past.[26] The most prevalent clinical form of bubonic plague in humans is characterized by fever, chills, and swollen and sensitive lymph nodes. In 1% to 3% of cases, secondary pneumonic plague may develop, allowing for person-to-person transmission through respiratory droplets, and if left untreated, this form can evolve into septicemic disease. Within one to four days following the onset of symptoms, cases that go untreated can have a 100% fatality rate.[26] *Rattus rattus*, or black rat, and *Rattus norvegicus*, or brown rat, are the most frequent hosts of *Y. pestis*, an enzootic bacteria found in rodents. The oriental rat flea (*Xenopsylla cheopis*) is the most efficient vector of infection to these rodents.[27] Sub-Saharan Africa has reported more than 95% of all human plague cases globally, with Madagascar and the Ituri region of the Democratic Republic of the Congo having the highest rates. For instance, 255 probable cases of human plague were documented in the West Nile region of Uganda between 2008 and 2016 during active surveillance.[28] The World Health Organization (WHO) reports that 2,886 cases and 504 fatalities were reported worldwide between 2013 and 2018, which translates to a case-fatality rate of 17.5%.[29] According to Vallès et al. (2020), there have also been isolated reports of human plague cases in the US, China, Mongolia, the Russian Federation, Kyrgyzstan, Peru, Bolivia, Uganda, Tanzania, and other nations.[26]

Three significant pandemics have historically been brought on by plague: the first occurred in the sixth and seventh centuries AD, the second in the fourteenth and seventeenth centuries, and the third in the nineteenth and twentieth centuries. These pandemics caused a considerable death toll. At least 220 rodent species are known to be infected with *Y. pestis*, a bacterium that may infect a wide variety of rodents in both temperate and tropical settings. Furthermore, about 30 flea species have been found to be possible transmission vectors.[30] Clinically, there are four different types of plague:

Bubonic Plague: Characterized by chills, fever, and enlarged, sensitive lymph nodes.

Septicemic Plague: Shows up with organ hemorrhage, shock, fever, and stomach pain.

Pneumonic Plague: Manifests with coughing, difficulty breathing, and rapid shock development, often resulting in fatal outcomes if untreated.

Pharyngeal and Meningeal Plague: Rare clinical presentations.[31]

The disease can be effectively treated with common antibiotics, significantly reducing mortality rates when diagnosed early. Preventing plague outbreaks requires actions including flea eradication, rodent population reduction, and public health education.[32] Five to fifteen human cases of plague are reported each year in the United regions, with most occurrences occurring in the western regions. *Cynomys spp.* (prairie dogs), *Spermophilus spp.* (ground squirrels), *Neotoma spp.* (wood rats), and *Peromyscus spp.* (mice) are examples of reservoir species found in the United States.[33] Although contact with abraded skin or exposure to contaminated aerosols on the mucosa can also result in infection, flea bites are the main way that infections are spread.[33] Control methods are essential for preventing zoonotic transmission, especially in endemic areas where rodent and flea management is particularly important. Gloves, surgical masks, eye protection, and equipment disinfection are recommended for anyone handling the carcasses of wild animals.[34] In order to contain plague outbreaks and protect public health, early identification and treatment are essential.

3.2. Leptospirosis

A serious worldwide public health concern, leptospirosis is an acute bacterial infection brought on by pathogenic spirochetes of the *Leptospira genus*. There are currently more than 250 known serovars of *Leptospira spp.,* each with a unique animal host. *Leptospira icterohemorrhagiae* is said to be the most prevalent serovar in rats among these. Humans can become infected by leptospires by coming into direct contact with the urine of infected animals or by coming into touch with contaminated environmental items.[35] The main carriers of several Leptospira serovars that can infect humans and animals are wild rats, specifically *Rattus norvegicus* (brown rat) and *Rattus rattus* (black rat). These rodents' proximal renal tubules have been found to have spirochetes.[36]

Leptospirosis is categorized by the World Health Organization (WHO) as an emerging and re-emerging disease that is commonly spread from humans to animals. Every year, more than 1 million individuals get infected, and about 60,000 of them die as a result.[37] With estimated rates of more than 10 cases per 100,000 people annually, leptospirosis is most common in tropical countries including the Asia-Pacific, Latin America, and the Caribbean. Frequent outbreaks are frequently caused by intense seasonal rains in urban slum areas. For example, significant outbreaks were documented in the Philippines in 2009 and Nicaragua in 2007.[38] Over the past ten years, leptospirosis has been the source of multiple epidemics in India. It is a disease that must be reported in Malaysia, where the number of cases steadily rose to 4,557 between 1976 and 2013. Heavy rainfall and inadequate sanitation cause yearly epidemics in urban slum areas in South American nations like Brazil.[39]

A tiny proportion of human leptospiral infections develop into severe icteric disease with hemorrhagic pneumonia or kidney failure, despite the fact that the majority are asymptomatic or mild. On the other hand, rodent Leptospira infections are usually subclinical, with little to no visible lesions.[35] People should refrain from drinking or swimming in water that might be tainted with animal urine in order to lower their risk of contracting leptospirosis. It is recommended that people who are exposed to contaminated water or soil for work-related or leisure-related reasons wear protective clothing, such as boots, gloves, and masks. Another crucial personal precaution is to thoroughly wash your hands with soap and water after handling pet rats or cleaning their cages.

3.3. Scrub typhus

Orientia tsutsugamushi is the vector-borne zoonotic illness scrub typhus, which is spread to people by rats. This disease, which was first discovered in Japan in 1889, is primarily seen in the Asia-Pacific region, namely in the "*tsutsugamushi triangle*." *Apodemus agrarius* (striped field mouse), *Mus musculus* (house mouse), *Bandicoota indica* (bandicoot rat), and *Rattus norvegicus* (Norway rat) are among the rodent species that are home to trombiculid mites, sometimes known as chiggers, which bite humans and carry the disease. These rodents are the primary vectors, and the pathogen carried by mites is rapidly disseminated in urban areas, particularly in hot climates following heavy rains.[40]

Scrub typhus can be found in regions ranging from Afghanistan and Pakistan in the west to Russia, Korea, and Japan in the north, and further south to northern Australia, Indonesia, and Papua New Guinea. Additionally, some tiny islands in the western Pacific are home to it. The disease poses a significant public health concern in tropical and subtropical regions, affecting an estimated 13 million km² globally.[41] In India, particularly in Kerala, scrub typhus is frequently misdiagnosed as leptospirosis or dengue fever, complicating its diagnosis. During cooler months (October–December) in Uttar Pradesh, acute febrile illnesses (AFIs) were observed in a large portion of patients. Similar rates of acute infection, around 20%, have been reported in Assam and other regions.[42]

Symptoms of scrub typhus in people usually include fever, headache, gastrointestinal problems, and muscle soreness. More virulent strains, however, have the potential to result in serious side effects as hemorrhage and disseminated intravascular coagulation.[43] Humans typically get the disease by coming into touch with environmental elements tainted by rodent urine. In several instances, especially in situations involving acute illness, the infection has spread throughout different geographical areas.

In rodents, scrub typhus is generally subclinical, with no significant clinical signs observed in infected animals. However, the *Orientia tsutsugamushi* excreted via rodent urine presents a substantial health risk to humans. The disease is especially dangerous for individuals with compromised immune systems and can have severe consequences if left untreated.

Antibiotics such as doxycycline are commonly used to treat scrub typhus, as they are effective against most *O. tsutsugamushi* strains. Early treatment can control disease progression. However, prevention through rodent control and environmental hygiene is crucial. Avoiding direct contact with rodents, using protective clothing in rodent-inhabited environments, and refraining from using contaminated water sources significantly reduce infection risks. In conclusion, in tropical and subtropical areas where rodents aid in its spread, scrub typhus continues to pose a major risk to public health. In emerging nations, urban slum areas are especially vulnerable. Controlling environmental variables and vectors is essential to halting the disease's spread, even though early detection and treatment help manage it.

3.4. Salmonellosis

Bacteria belonging to the *Salmonella* genus are the cause of salmonellosis. This genus's taxonomic categorization and subdivision are still controversial and could change. There are more than 2,500 serovars of *Salmonella enterica*, which includes all of the species found in rats.[44,45] Serovar classification is essential for epizootiological study because of the notable variations in virulence and geographic distribution among these serovars. In the interest of simplicity, *S. enterica* is discussed as a single organism. Salmonellosis is common in many vertebrate species, including wild rodents, however it is uncommon in laboratory rats in the United States.[33] The consumption of tainted feed, bedding, or water can spread *S. enterica.* The danger of transmission is increased when wild rodents enter experimental settings.[46] Although symptoms including stooped posture, ruffled fur, lethargy, weight loss, and conjunctivitis may occur, infected rats typically show little to no clinical signs.[47] Gastrointestinal problems such diarrhea or soft stools occur in less than 20% of infected rats.[33]

Laboratory diagnosis typically involves microbiological culture or PCR testing of fecal samples.[33] Preventive methods include making sure that food and bedding are not contaminated and implementing strict pest control. Staff hygiene is critical in preventing the introduction of *Salmonella* or other enteric pathogens into colonies. Infected colonies require stringent decontamination or extermination measures.[48] Since treating salmonellosis in rats is not recommended due to risks of chronic carrier status and zoonotic spread, infected animals should not be used in research.[47]

4. Viral zoonoses

4.1. Kyasanur forest disease (KFD)

Kyasanur Forest Disease (KFD) is a zoonotic disease caused by a virus from the *Flavivirus* family, primarily found in forest rodents in southwestern India. The illness, which was first identified in 1955 in *Shimoga, Karnataka*, is spread to people by infected tick bites.The causative agent, Kyasanur Forest Virus (KFDV), is hosted by rats, with ticks acting as the primary vectors that transmit the disease to humans, particularly monkeys. KFD commonly affects high-risk groups such as forest workers, farmers, hunters, and herders. The seasonality of the infection is notable, with cases peaking during the dry season, from November to June.[4] The epidemiology of KFD is concentrated in Karnataka, India, particularly in the regions of Shimoga, Chikmagalur, Udupi, Uttar Kannada, and Dakshina Kannada. Between 2004 and 2012, 556 human cases were reported in Karnataka, with several outbreaks recorded. Additionally, an outbreak was observed among forest workers in the Bandipur Tiger Reserve during 2012–2013. New outbreaks were also reported in Wayanad and Malappuram districts of Kerala between 2014 and 2015, as well as in Goa in recent years.[49]

Kyasanur Forest Disease transmission occurs through the bite of infected ticks. Ticks acquire the virus from infected animals and subsequently transmit it to humans. The main symptoms in humans include sudden onset of high fever, headache, nausea, vomiting, diarrhea, and occasionally neurological and hemorrhagic manifestations. The mortality rate of KFD ranges between 2% and 10%.[50] The disease is endemic in areas with high tick populations, placing individuals working in or traveling to forested regions at greater risk. Although there is currently no antiviral treatment for KFD, its symptoms can be managed. However, an effective vaccine is available and is widely used in endemic areas. The vaccine is administered in two doses at least one month apart to individuals aged 7–65 years. A booster dose is recommended 6–9 months after the initial vaccination, followed by annual booster doses for five years after the last confirmed case. Public health measures and tick control in forested areas are crucial for preventing the spread of KFD.[50]

4.2. Hantavirus

Hantaviruses are enveloped, single-stranded RNA viruses belonging to the Hantavirus genus within the *Bunyaviridae* family. These viruses possess a negative-sense genome comprising three segments. Rodents serve as their natural reservoirs, with each hantavirus species being specifically associated with a particular rodent species. Infected rodents typically exhibit subclinical and chronic infections while continuously shedding the virus through saliva, feces, and urine.[51]

Hantaviruses cause two major clinical syndromes in humans: Hemorrhagic Fever with Renal Syndrome (HFRS) and Hantavirus Pulmonary Syndrome (HPS). HFRS is more common in Europe and Asia and is associated with hantavirus species carried by rodents of the *Murinae* and *Arvicolinae* subfamilies. For instance, the Hantavirus is carried by *Apodemus agrarius*, while the Seoul virus is hosted by *Rattus norvegicus*. Conversely, HPS is prevalent in the Americas and is linked to rodents of the *Neotominae* and *Sigmodontinae* subfamilies. Among these, the Sin Nombre virus, primarily carried by the deer mouse (*Peromyscus maniculatus*), accounts for most HPS cases in the United States.[34,52]

Risk groups for hantavirus infections include farmers, rodent control workers, public health personnel, and military personnel. Infection typically occurs through the inhalation of aerosolized virus particles present in the saliva, feces, or urine of infected rodents. Direct contact with rodents is not necessary, but exposure to their secretions is a significant risk factor.[33] Environmental factors such as climate change also play a role in the emergence of hantavirus infections. For example, droughts in the southwestern United States have increased populations of piñon nuts and grasshoppers, which are primary food sources for rodents, while subsequent floods have displaced rodents from their nests, increasing human contact.[53,54]

The epidemiology of hantavirus infections varies globally. In Europe, 3,754 confirmed HFRS cases were reported in 2014. In South America, HPS is a significant public health concern. For instance, in Argentina, a gradual increase in HPS cases was observed between 1997 and 2011, with 11 deaths reported in 2018–2019. Similarly, in Chile, eight confirmed cases and two deaths were reported in 2018. In Canada, 109 cases and 27 deaths were recorded as of 2015.[34,55]

While hantavirus infections in rodents typically do not cause visible disease, infected rodents can shed the virus through their saliva, urine, and feces for weeks or even their entire lifespan,[51] increasing the risk of human transmission. In humans, hantavirus infections begin with nonspecific viral symptoms during the initial phase and can rapidly progress to capillary leak syndrome, respiratory failure, and cardiac complications.[33,56] Preventive strategies against hantavirus infections include trapping and removing rodents, using personal protective equipment such as masks and eye protection, and minimizing exposure to infected rodents and their secretions. Cleaning rodent-infested areas using appropriate methods to prevent aerosolization of virus particles is also critical.[56] Effective control measures are essential for preventing the spread of hantavirus infections.

4.3. Crimean-congo hemorrhagic fever (CCHF)

Crimean-Congo Hemorrhagic Fever (CCHF) is a tick-borne viral disease caused by the CCHF virus, a negative-sense RNA virus belonging to the *Nairovirus* genus within the *Nairoviridae* family. The virus is primarily transmitted by ticks of the *Hyalomma* genus and is widely found across regions below the 50th parallel north in Africa, Asia, and Europe.[57] CCHF has been associated with outbreaks of high mortality rates, ranging from 10% to 40%.[57] While ticks serve as the primary vector, rodents also play a significant role in the transmission cycle.[58]

The disease is particularly prevalent among individuals with direct contact with ticks, such as agricultural workers. Rodents that harbor immature stages of ticks play a crucial role in maintaining the pathogen in nature.[59] In humans, symptoms include fever, muscle pain, back pain, photophobia, and sudden mood changes.[59]

Crimean-Congo Hemorrhagic Fever (CCHF) is endemic in regions such as Africa, the Balkans, the Middle East, and Asia, with 10,000–15,000 cases reported globally each year.[29] Though considered an emerging disease in Southern Europe, imported cases have been identified in France in 2004 and the United Kingdom in 2013.[57] Higher prevalence rates have been reported in rural areas of Pakistan between 2015 and 2017.[60] While ticks are the primary vectors, rodents serve as key reservoirs in maintaining and spreading the infection. The case-fatality rate for CCHF ranges between 3% and 30%, underscoring the severity of the disease.[59]

Preventive measures include the use of protective clothing by individuals engaged in agriculture and livestock farming, application of acaricides, and effective tick control strategies. Ribavirin has been identified as an effective treatment option, and available vaccines are considered a protective strategy for managing the disease.[59]

5. Parasitic zoonoses

5.1. Toxoplasmosis

Toxoplasma gondii, a protozoan parasite belonging to the *Apicomplexa* phylum, is one of the most widespread infectious agents in humans and warm-blooded animals globally. First discovered in 1908 in the liver and spleen fluids of a rodent species (*Ctenodactylus gondii*) in North Africa by Nicolle and Manceaux, this parasite is prevalent in developing regions.[61] *T. gondii* requires both intermediate and definitive hosts to complete its asexual and sexual reproduction cycles. While members of the *Felidae* family serve as definitive hosts, rodents act as intermediate hosts and play a crucial role in infection dynamics.[62,63]

Rodents can carry *T. gondii* as tissue cysts, facilitating environmental dissemination via predatory animals such as cats. Humans acquire the infection primarily through the consumption of undercooked meat containing cysts or ingestion of oocysts from environmental contamination.[64] Other less common transmission routes include congenital transmission, organ transplantation, and blood transfusion.[65]

The parasite's diverse transmission pathways contribute to its global distribution. Ingestion of cyst-containing meat or oocyst-contaminated water are the most common transmission routes.[66,67] Cats, as definitive hosts, shed oocysts into the environment via their feces. These oocysts sporulate within days, becoming infective and facilitating transmission.[68] Toxoplasmosis is prevalent in tropical and subtropical regions, and global warming has significantly influenced the distribution of the disease.[69] Approximately one-third of the global population is estimated to be infected with latent toxoplasmosis, with high prevalence observed in regions such as Latin America and the Middle East.[70] In the U.S., feline *T. gondii* seroprevalence ranges between 30% and 40%, varying by regional climatic conditions.[70]

In immunocompetent individuals, toxoplasmosis is typically asymptomatic. However, in immunosuppressed individuals, such as those with HIV, organ transplant recipients, or cancer patients, the infection can reactivate during the acute phase, causing severe complications. These complications include encephalitis, brain abscesses, myocarditis, and chorioretinitis.[71,72] Furthermore, chronic toxoplasmosis has been associated with neurodegenerative and autoimmune diseases, complicating the long-term impacts of the infection.[73,74]

In Iran, several studies have reported high morbidity and prevalence of *T. gondii* infection.[63,75] Rodents play a critical role in the transmission and dissemination of *T. gondii*. These animals are well-adapted to various habitats due to their biological and morphological characteristics, making them significant reservoirs and carriers of multiple infectious agents, including *T. gondii*, *Babesia*, *Neospora*, and *Giardia*.[4,76] Transmission of *T. gondii* frequently occurs through rodent feces and consumption of infected rodent meat. [4,77]

In conclusion, *T. gondii* represents a global public health threat due to its complex transmission pathways. Effective prevention strategies are essential to limit its spread, including public health measures to monitor and control infection in both immunosuppressed individuals and the general population.

6. Conclusion

Rodents, especially in regions where human interaction with their natural habitats is increasing, play a significant role in the transmission and spread of numerous zoonotic diseases. Various microorganisms, viruses, bacteria, and parasites harboring in rodents pose potential threats to human health. Among these diseases, hantavirus, leptospirosis, toxoplasmosis, and plague are particularly prominent. The spread of zoonotic diseases is directly linked to the dynamics created by rodents in their natural environment. Preventing and controlling zoonotic diseases require careful monitoring and measures in both human and animal health. Early diagnosis, effective vaccinations, and regulation of environmental factors are critical in halting the spread of these diseases. Furthermore, controlling rodent populations and strengthening public health policies related to their habitats will reduce the risk of zoonotic diseases being transmitted to humans.

In conclusion, rodent-associated zoonotic diseases represent global health threats, making interdisciplinary approaches and international collaboration essential for their control.

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Ethical approval

This study does not require approval from the Ethics Committee for Animal Experiments.

Conflict of interest

There is no conflict of interest between the authors

Author contribution

All authors contributed equally and were involved in all stages of the manuscript.

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