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REVIEW ARTICLE

Rodent-borne and rodent-related diseases in Iran

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Abstract

Rodents cause large financial losses all over the world; in addition, these animals can also act as a reservoir and intermediate host or vector of diseases. Rodents have an important role in the distribution of diseases in an area. Sometimes, the distribution of a particular disease in an area depends on the distribution of rodents in that area. This study focuses on the distribution of rodent-related diseases in Iran. Rodent-borne and rodent-related diseases and diseases with suspected relationship with rodents have been reviewed in this study. Iran, due to the circumstances in which different species of rodents are able to live, has a high prevalence of certain diseases associated with rodents in urban and rural areas. Awareness about the distribution of rodent-related diseases can be a great help to rodent's control and prevention against the spread of the diseases.

Keywords Rodent disease · Disease transmission · Pest control · Public health

Introduction

Rodents are the largest order of the class Mammalia, with a population more than the total populations of other mammals on the planet, are the source of abundant health and economic losses (Doroudgar and Dehghani 2000). Order of rodents has 34 families, 354 genera, and 1780 species. Approximately, two thirds of the known species of mammals have been allocated to rodents. Mostly, rodents have a small size, rapid reproduction, and remarkable morphological and biological adaptations to different environments, land, and trees. They are one of the most successful groups

Besides the high spread of rodents in the world, warmer climates increase their population.
Rodents have an important role in the transmission of a number of diseases to humans such as tularemia, leishmaniasis, and Q fever.
Because of warm weather and climate, Iran is located in a middle high-risk area of rodent-related diseases.

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on earth due to their high compatibility at all dry lands except poles. The Muridae family have more than 130 species and include the most important pests in terms of economic and human health, and probably the smartest of them that live in residential houses (Kay and Hoekstra 2008; Khaghani 2007). These rodents are considered as reservoirs and carriers of diseases such as plague, leptospirosis, salmonellosis, rat-bite fever, leishmaniasis, dermatophytosis, sporotrichosis, murine typhus, trichinellosis, relapsing fever, and viral hemorrhagic fever (Dehghani 2011a; Kia and Mirhendy 2008; Sedaghat and Salahi Moghaddam 2010).

It is estimated that 400 million people worldwide are infected with the *cutaneous leishmaniasis*, which is endemic in many parts of the world such as Iran (Kevric et al. 2015; Pourmohammadi et al. 2004). Besides prevalence of rat-related diseases that was approximately estimated to be 28 cases per 100,000 populations in Iran, the most cases of these diseases were reported in Isfahan province (8000 cases) (Doroodgar et al. 2009). Some diseases such as *relapsing fever* and *Crimean-Congo hemorrhagic fever*, although limited in transmission ways, have significant rates in some regions of Iran due to transmission by rodents (Esmaili et al. 2009; Kaboodvandpour and Leung 2010; Maryam and Ebrahimi 2010).

Rodents play the role of a reservoir or a carrier in transmitting disease. The transmission ways of diseases by rodents to humans are illustrated in Fig. 1.

In addition to the illustrated ways, some bacterial and fungal infections can occur in rodents by snake and arthropod bite and these infections may be transmitted to humans (Dehghani et al. 2014a, 2016b, c; Vazirianzadeh et al. 2009, 2014).

Because of high prevalence, and also the large number of rodent-related diseases in Iran, performing a study in this area is required.

Main rodent in Iran

The main orders of rodents in Iran include the families Sciuridae, Hystricidae, Dipodidae, Muscardinidae, Muridae, and Cricetidae (Sedaghat and Salahi Moghaddam 2010) (Fig. 2).

The families Sciuridae, Hystricidae, and Muscardinidae live far from human societies and, therefore, are less important for disease transmission. Although the family Dipodidae may be infected by some parasites and microorganisms, they have little significance for the transmission of the disease, because of their long distance with human habitats. Only in the northeast of Iran, this order is the reservoir of *Echinococcus multilocularis*. On the other hand, true rats play a significant role in the transmission of many diseases, because they live very close to humans in rural and urban areas.

The family Cricetidae is also important for disease transmission, but the number of diseases transmitted by them is less than those from true rats. The most important disease related to this family is the different types of leishmaniasis. *Cricetulus migratorius* and *Rhombomys opimus* are the reservoirs of visceral and cutaneous leishmaniasis in Iran. In addition, *Meriones tristrami* and *Meriones vinogradovi* are the main families involved in the transmission of plague in western Iran. However, a limited number of plague have been reported in the past decades.

Distribution of rodent-related diseases according to infectious agents

Bacterial diseases

Plague (black death)

Plague is a bacterial disease caused by *Yersinia pestis* and is one of the most important diseases in which mice play a major

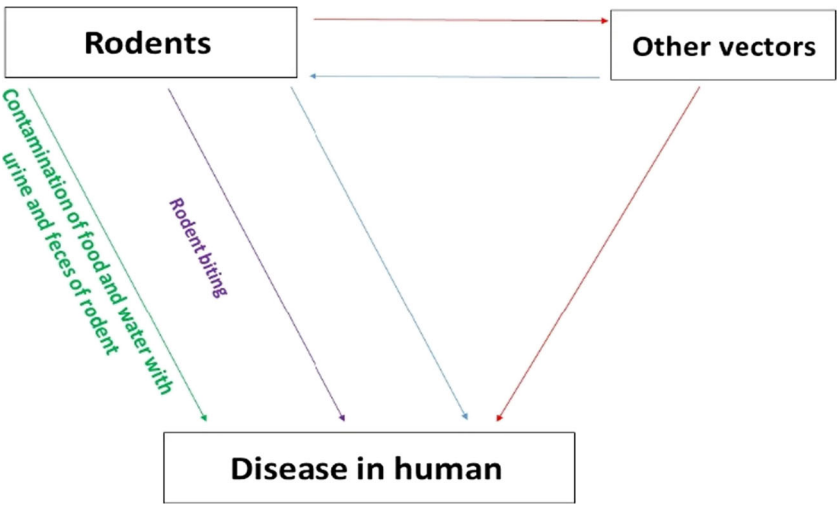

Fig. 1 The ways of transmitting disease from rodents to humans

Fig. 2 Geographic distribution of Muridae order in Iran (Sedaghat and Salahi Moghaddam 2010)

role in its maintenance and transmission to humans. Plague as a rodent-specific disease can be transmitted to humans in certain circumstances. *Meriones tristromic* and *Meriones vinogradovi* are two main reservoirs of plague in Iran.

In 1958, 6 cases of death by plague were reported in West Azerbaijan Province. The number of deaths due to plague in Kurdistan was reported to be 7 and 14 cases in 1961 and 1963, respectively (Azizi and Azizi 2010). In a period between 1947 and 1966, 9 cases of reported epidemics of plague in western provinces of Iran caused 156 deaths (Azizi and Azizi 2010).

In the past, most cases of plague were reported near the borders of north, northwest, and west, especially the common borders with Iraq. Although, no cases of human plague are reported from 1966 up to the present. Animal serum samples which contained *Yersinia pestis* F1 antibody (especially in rodents and fleas) showed that Iran can be considered as an area with possibility of plague reactivation (Esamaeili et al. 2013).

Tularemia

Tularemia is known as one of the most important public health problems of rodent-borne diseases. According to studies, rabbits, foxes, sheep, cattle, deer, and mice are introduced as the reservoirs of tularemia. Humans can be infected by tularemia pathogen by the bite of infected ticks, infected water, and some types of horse fly. *Rattus norvegicus* and *Mus musculus* can transmit tularemia bacterium. A study in 1973 was conducted by Arata on 4600 species of wild rodents in Iran. *Fransicella tularensis* bacterium was detected in the spleen of about 3458 cases of different rodents (Arata et al. 1973).

A significant prevalence of tularemia was reported in Iran (Esmaeili et al. 2014b) that can be related to infested animals living around human societies (especially rodents) (Arata et al. 1973). One of the major endemic areas of tularemia in Iran is Sistan and Baluchestan Province, which has a high population of rodents that can transmit different diseases (Esmaeili et al. 2014a; Nateghpour et al. 2013). In a recent study on nine trapped rodents in Sistan and Baluchestan, an evidence of tularemia infection in rodents was found, as demonstrated by a positive serological analysis in one sample (Pourhossein et al. 2015; Zargar et al. 2015).

Salmonellosis

Salmonellosis is an infectious disease with fever caused by Salmonella species. The disease is transmitted to humans through consumption of contaminated food by urine and feces of domestic mice (Akbarmehr 2011; Dallal et al. 2007; Jalali et al. 2008; Salehi et al. 2009). In a review article, rodents were referred as a main transmission factor for some serotypes of Salmonella (such as typhimurium, enteritidis, heidelberg, oranienburg, and agona) (Hoelzer et al. 2011).

There is no study in Iran about the rate of Salmonella infection in mice. However, several studies have investigated the infection among poultry (Akbarmehr 2011; Dallal et al. 2007; Jalali et al. 2008). The prevalence of Salmonella can be limited by controlling health standards, especially in places where a food distribution center provides food for a large number of people. Furthermore, places such as temporary

and permanent camps (barracks and camps created after natural disasters like earthquakes and floods) as well as accommodations and restaurants must be under supervision. Although the disease is transmitted to humans in various ways, accurate information is not available about its prevalence.

Sudoku fever or rat-bite fever

Rat-bite fever (RBF) is caused by bacteria *Spirillum minus* and *Streptobacillus moniliformis* and bites from rats and other rodents. Rodents are the most important reservoirs of the disease (Dehghani 2011a). *Rattus rattus* and *R. norvegicus* are known as natural host and asymptomatic carriers of disease agents. Wild mice (*Mus musculus*) are not identified as a natural host of *S. moniliformis*. This is maybe the reason that only a few human RBF cases have been reported after a mouse bite (Gaastra et al. 2009). The *S. moniliformis*- and *S. minus*-induced diseases are a little different in clinical symptoms (Dehghani et al. 2013b). According to the studies conducted so far, no case of this disease has been reported in Iran, but some cases have been reported in neighboring countries such as Turkey. Due to trips of many Iranian tourists to Turkey, it can either transmit or be transmitted to Iran (Elliott 2007; Gaastra et al. 2009).

Tuberculosis

The disease is caused by the bacillus *Mycobacterium tuberculosis*. Wide spectrum of animals, humans, ruminants, carnivores, birds, and even rodents, are sensitive to the Mycobacterium genus. Contagion of tuberculosis by cow to human has been well documented but about other animals is not conclusive. Some research conducted found that due to limited contact, domestic animals can transmit Mycobacterium to human (Fakur et al. 2007; Une and Mori 2007). It seems that because of the limited contact of humans and rodents, transmission of tuberculosis from rodents to human is very unlikely, unless in unhygienic places and involuntary contact. In total, about 13,000 new cases of tuberculosis are reported in Iran for 2015 (Organization 2016).

Leptospirosis

Leptospirosis is an infectious disease with fever in human and caused by *Leptospira* species, which have been extracted from blood, urine, and feces of mice and rats. Infected mice dispose *Leptospira*-infected urine in their whole lifetime. Human infection took place by ingestion of both food and water contaminated with rat urine (Aliyan et al. 2006; Babamahmoodi et al. 2009; Brown et al. 2010; Honarmand et al. 2009). In a study in Mazandaran Province, the most leptospirosis tests were positive in *Rattus norvegicus*, *R. rattus*, and *Apodemus sylvaticus*. In addition, leptospirosis was prevalent in rodents in this province (Esfandiari et al. 2015). In addition, leptospirosis was significantly prevalent in Khuzestan Province among rice farmers, which are highly exposed to contaminated water by urine of infected rodents (Alavi and Khoshkho 2014) (Table 1).

Rickettsial diseases

Q fever

Q fever is caused by a rickettsia named *Coxiella burnetii*. Goats, sheep, and cattle are the primary animal reservoirs for zoonotic transmission. However, rats such as *Rattus norvegicus* and *Rattus rattus* are known to contribute as a reservoir for maintenance and transmission of *C. burnetii* (Reusken et al. 2011). Infected ticks can also play an important role in the transmission of the bacteria between the mammals, rodents, and other mammals as well as wild and tame birds.

Rodents are reported to be infected by the infection agent in Iran during the 1970s; however, there is no report in recent decades regarding the infection among rodents and transmission to humans (Mostafavi et al. 2012). Although, there are several reports about the infection of other animals and their products with *C. burnetii* in different provinces of Iran such as Fars, Khuzestan, Yazd, Charmahal and Bakhtiari, Isfahan, Gilan, and Mazandaran (Rahimi 2010; Rahimi and Doosti 2012; Rahimi et al. 2010).

Mediterranean fever or boutonneuse fever

Familial Mediterranean fever or FMF is a hereditary recurrent inflammatory disease that is prevalent among the people of the Near East, Arabs, Turks, Armenians, and Jews. The disease agent is *Rickettsia conorii*. The most common symptoms of the disease are normally associated with abdominal attacks with fever and 90% of patients experience it. In this disease, dogs, wild rodents, and other mammals have been identified as reservoirs (Dehghani 2011a; Nakhaei et al. 2005).

Most studies on the disease in Iran are published in the form of case reports. The results of two studies reported two cases of the disease in the provinces of Tehran and Mazandaran. However, 44 patients were identified with FMF, so these provinces can be introduced as a high-prevalence area. About the one case reported in Tehran, one reason probably was high immigration rate in this city. Furthermore, the birth place of a baby in this report is not mentioned (Mobini 2011; Nobakht et al. 2011).

Table 1 Summary of rodent-borne and rodent-related diseases in Iran

Disease	Involved provinces in disease	Country overview
Plague	Kurdistan and other western provinces	There were some epidemics in the past, but no cases are reported in the last few decades.
Tularemia	Sistan and Baluchestan	Endemic in all over the country.
Salmonellosis	Almost in all provinces	Because of easy transmission, it can be seen everywhere.
Whooping cough	Mazandaran, Razavi Khorasan, Tehran, Khuzestan, and East Azarbaijan	Some cases are reported from different areas of the country.
Sudoku fever	No reported cases	There is the possibility of disease entrance from western neighboring countries.
Tuberculosis	Kurdistan, Tehran*	There were some cases of disease, but these cases had also other diseases.
Leptospirosis	Khuzestan, Mazandaran	There is a possibility of disease spread in other parts of Iran, especially in animals.
Q fever	Central, northern, and south-western provinces	Almost all cases were in animals.
Mediterranean fever	Some case reports in Tehran* and Mazandaran	It is very rare in Iran.
Murine typhus	Coastal provinces of north and south	Endemic in coastal areas.
Tick-borne relapsing fever	Ardabil, Hamadan, Zanjan, Qazvin, and Fars	A relatively common disease in Iran.
Lyme disease	Case reports around Tehran*	It is very rare in Iran.
Rabies	Northern provinces	Transmission by mice to humans has not been reported.
Hemorrhagic fevers	Central and south-eastern provinces	Transmission by mice to humans has not been reported.
Tick-borne encephalitis (TBE)	–	No case is reported in Iran.
Sindbis fever	–	Transmission by rodents to humans has not been reported.
Histoplasmosis	Case reports in Tehran*	It is very rare in Iran.
Sporotrichosis	Case reports in Tabriz	It is very rare in Iran.
Dermatophytosis	Golestan, Gilan, and Lorestan	It is almost dispersed in all over Iran.
Trichinellosis	Animal cases in Isfahan and Tehran*	It is so rare in human cases.
Leishmaniasis	Endemic in western, central (especially in Isfahan), and eastern provinces	It is endemic in Iran.
Toxoplasmosis	Sistan and Baluchestan (human cases) and East Azarbaijan (animal cases)	Transmission by mice has not been reported.
Cryptosporidiosis	Tehran and Isfahan	All over the country is involved in this disease.
Hymenolepiasis	Case reports in Tehran*, high prevalence in Khuzestan, and animal cases in Kashan (Isfahan)	It is endemic in southern areas.
Capillariasis	Rare animal cases in Tehran*	It is very rare in Iran.
Babesiosis	Animal cases in northern provinces, West Azarbaijan, East Azarbaijan, Razavi, and North Khorasan	Human cases has not been reported.
Clonorchiasis	A case report in one of the southern areas	It is very rare in Iran

*Due to better diagnostic and therapeutic facilities in Tehran, some reported cases in Tehran may be come from other provinces

Murine typhus

In fact, murine typhus is a disease of mice, but sometimes, this disease is transmitted to humans by rat fleas. The agent of disease is called *Rickettsia mooseri*. The agent is maintained in the body of mice and is transferred from one mouse to another by some arthropods, and through the feces of some fleas, it is transmitted to humans. The fleas of *Pulex irritans*, *Nosopsyllus fasciatus*, *Ctenocephalides felis*, and *Echidna gallinacea* can experimentally transmit this disease.

Murine typhus is known in Iran as an endemic disease. The disease is predominantly seen in coastal areas of north and south, in other words Mazandaran, Gilan, Golestan, and Hormozgan provinces (Dehghani et al. 2013b; Tihrān 1970).

Spirochetal diseases

Tick-borne relapsing fever

Relapsing fever or Borreliosis is an acute infectious disease that occurs by the Borrelia genus. Borreliosis disease is divided into two types of tick and louses Borreliosis. Tick Borreliosis is the most common relapsing fever in Iran. Four types of Borrelia in Iran include *Borrelia persica*, *Borrelia latyschewii*, *Borrelia microti*, and *Borrelia baltazardi*. *Borrelia persica* and *Borrelia baltazardi* have been detected from the blood of patients with this disease. Soft ticks and wild rodents are the parasite reservoirs of the disease (Aghighi et al. 2007). Two 16-year-old teenager cases of this disease have

been reported in the Khalkhal city (in the Ardabil Province) and Fars Province in 2003 and 2008, respectively (Asl et al. 2009; Majid-Pour 2003; Pouladfar et al. 2008). In a study during 1997 to 2006, 1415 samples that were suspected of tick-borne relapsing fever were collected across of Iran. In this report, the highest rate of patients has been reported from Ardabil (625 positive patients) and then Hamadan, Zanjan, Qazvin, and Kurdistan provinces (Asl et al. 2009).

Lyme disease (Erythema chronicum migrans)

Lyme disease or chronic migrating redness is intense and sometimes is a debilitating human disease caused by *Borrelia burgdorferi*. Reservoir of Lyme is small and large mammalian animals such as mice, gazelles, and animals which can host a lot of hard ticks. The most prevalence of this disease is reported in China, the countries that collapsed from the Soviet socialist, Europe, and America (Dehghani et al. 2011; Karmi et al. 1979; Zangeneh et al. 2012). There are conflicting reports about the disease in Iran. In 2001, a 9-year-old boy from a village in Varamin with Lyme disease symptoms including joint pain in the left elbow was referred to the children's Infectious Diseases Medical Center in Tehran where the Lyme disease was confirmed after doing required tests (Siadati 2006).

Viral diseases

Hemorrhagic fevers

The viral hemorrhagic fever is a collection of findings from a series of unstable coronary and reduction of vascular wall integrity, a direct or indirect damage to the microvasculature, leading to increased permeability and regional bleeding, especially in cases in which platelet function is impaired (Mostafavi et al. 2014). Disease virus is found in different species of small mammals, including rabbits, hedgehogs, and rodents. The most important viral hemorrhagic fevers with the rodent's reservoir can be referred to as Lassa fever, Argentine hemorrhagic fever, Bolivian hemorrhagic fever, hemorrhagic fever with renal syndrome, and hantavirus cardiopulmonary syndrome (Majidzadeh Ardabili et al. 2012; Mardani et al. 2003; Mehrabi-Tavana et al. 2002). Prevalence plans of the disease in Iran were made in 1999. The findings reported that 24 provinces are affected and three provinces, including Sistan and Baluchestan, Fars, and Isfahan, had the highest rates of infection (Chinikar 2009). Crimean-Congo hemorrhagic fever (CCHF) was reported in 23 provinces out of 30 provinces in 2000. Sistan and Baluchestan has accounted for most of the infections, because of its two neighboring countries Pakistan and Afghanistan, where infection has been reported as endemic (Chinikar et al. 2010). Chinikar research in 2004 performed necessary tests on samples taken from a suspected butcher in Sistan and Baluchestan and Crimean-Congo hemorrhagic fever virus was identified in blood samples (Chinikar et al. 2004).

Tick-borne encephalitis

The disease is caused by Flavio viruses that lead to two different clinical diseases, Far Eastern encephalitis, also called encephalitis Russian spring-summer, and Central European encephalitis that also called biphasic meningoencephalitis or diphasic milk disease. This disease is transmitted to humans by the bite of infected ticks or by crushing infected ticks on skin scratches. The infection can also be transmitted to humans through the consumption of raw milk or unpasteurized dairy products in which, usually, in that situation, hobgoblin mice are transmission agents. Natural infection has been found in 16 species of tick's genus Ixodidae. Important hosts of disease also are hedgehogs, hobgoblin and stray mice (Dehghani et al. 2013b). According to the studies done so far, no patients have been reported in Iran (Dehghani 2011b).

Fungal diseases

Histoplasmosis

Pathogen causing histoplasmosis is a fungus called *Histoplasma capsulatum*. Iran is a non-endemic area of this disease. Rarely, the infection is diagnosed and treatment is not usually needed. However, in patients with impaired immune systems, it may be fatal. Rodents have been identified as an important reservoir of the disease. In 2003, a 42-year-old person was referred to a therapeutic center in Tehran with the symptoms of cold, joint pain, and long fever in which necessary experiments identified fungi infection of *Histoplasma capsulatum* in his blood (Pourfarziani and Taheri 2009).

Sporotrichosis

Sporotrichosis is a granulomatous infection in humans and also in a wide range of domestic and wild animals that is created by *Sporothrix schenckii* (Mahmoudi and Zaini 2015). Rodents have been identified as reservoirs of this disease. Infection is generated by *Sporothrix schenckii* fungi entering the body through skin contact with infected soil or other organic materials, if there are scratches and wounds in the body. The disease is widely seen as endemic in South America (Kazemi and Razi 2007; Sandeepa et al. 2011). A 23-year-old florist and gardener man with the suspected symptoms of sporotrichosis was admitted in Medical Mycology of Tabriz University of Medical Sciences. After necessary tests, sporotrichosis fungal infection was detected (Kazemi and Razi 2007).

Dermatophytosis

Dermatophyte infection is a fungal infection of keratin tissues such as nails, hair, and skin layer. Zoophilic species (*Microsporum canis*, *Trichophyton verrucosum*, and *T. mentagrophytes*) are the most important dermatophytes which cause tinea in Iran. Cattle, dogs, cats, rodents, and other animals have been identified as reservoirs of dermatophytosis (Dehghani 2011a). In a study done on 200 patients who were suspected of dermatophytosis in Babol city from 2003 to 2005, after conducting the necessary tests, dermatophyte fungi infection was confirmed (Rezvani et al. 2010). During a 5-year study from 2003 to 2007 on 108 clinically suspected patients of dermatophytosis in Gorgan city, 351 of 1108 samples (31.6%) were positive (Dehghan et al. 2009). In another study on 294 patients suspected of dermatophytosis in Khorramabad during 2007 and 2008, 172 (58.5%) were positive (Sepahvand et al. 2009).

Parasitic diseases

Trichinellosis

Trichinellosis disease is caused by an infection of a small worm called *Trichinella spiralis*. Humans are usually infected by Trichinella through eating raw or improperly cooked infected foods. In normal situations, continuous contamination is established between meat-eater rodents and pigs (Rostami et al. 2017). Pigs are infected when they are fed food residues or infected mice. Mice also are infected through eating meat pork. Infection between mice continues because they have a habit to eat each other (Hassan et al. 2010). The disease has been reported in countries such as Bulgaria, Romania, Yugoslavia, Lithuania, Russia, China, Argentina, and Mexico (García et al. 2005). A study reported a dog that was infected with *Trichinella spiralis* among 75 dogs in Isfahan (2000) (Dehghani et al. 2013b; Mahdavi 2009). Recently, using a molecular test, one case of trichinellosis was identified in a family in Tehran. This family had used the male boar meat infected with *Trichinella spiralis* (Kia and Mirhendy 2008).

Zoonotic cutaneous leishmaniasis

The most important reservoir of disease is the gerbil family of rats, *Rhombomys opimus*, and secondary reservoir of disease is *Meriones libicus* in central Asia (Miranzadeh et al. 2017). *Phlebotomus papatasi* also play an important role in the establishment and transmission of disease from rodents to humans. Mice infection is seen in the ear and sometimes in the snout. In some places, the infestation of rats is high that is correlated with high dispersion and high percentage of infection that it causes the establishment of disease in a region as a natural focus. *Rhombomys opimus* usually excavate their nest very deep that this deep nest can be a suitable place for sand flies. Therefore, the spread of zoonotic cutaneous leishmaniasis in the *Rhombomys* distribution region is almost associated with this rodent (Azani et al. 2011; Azizi et al. 2011; Doroodgar et al. 2009; Doroudgar and Dehghani 2000; Doroudgar et al. 1997; Gholamrezaei et al. 2016; Kia and Mirhendy 2008; Rasti et al. 2002). In addition to *Rambus opimus*, many species from the family Cricetidae are involved in the transmission of leishmaniasis, including *Cricetulus migratorius*, *Tatera indica*, and *Merinos persicus*.

The disease is known to be endemic in Iran. Prevalence has been reported in three main zones. The first zone is eastern north and central areas including Isfahan, Esfarayen, Lotf Abad, and Bakran region in the Shahrood's countryside. The second zone is western areas of Iran, and the third zone relates to Sistan and Baloochestan Province. This classification is based on the kind of rodents that is the reservoir of the disease (Michael 2011). On the other hand, the disease has been observed more often in the sub-urban areas and the disposal sites of construction wastes, as the appropriate places for the rats and Phlebotomus.

Toxoplasmosis

Toxoplasmosis disseminates in the world by an intracellular protozoa, *Toxoplasma gondii*. Small rodents can play an important role in the life cycle of *Toxoplasma gondii* and as one of the causes of infection of domestic and wild cats (Foroutan et al. 2017). In some parts of the world, *Toxoplasma gondii* infection in small rodents has been reported up to 73%. Infection in rodents occurs with the ingestion of soil, vegetables, or water contaminated with cysts (Gharavi et al. 2008; Sandeepa et al. 2011). In a study that was conducted by Raeghi in Uromia from 2008 to 2010, the prevalence of *Toxoplasma gondii* in 130 stray and domestic cats has been reported to be 38.35% of cases (Raeghi et al. 2011). In another study in 2010, the prevalence of *Toxoplasma gondii* has been reported to be 41.4% (248 of 519 collected serum samples) (Mostafavi et al. 2011). In another study in 2006 that was conducted on pregnant women in Zahedan, 15 of 54 (27%) human samples were positive (Sharifi-Mood et al. 2011). According to studies, any reported case of disease transmission through mice to humans has not been established.

Cryptosporidiosis

The agent of disease is a worldwide parasitic protozoa called *Cryptosporidium parvum* that can infect humans and animals. Some of them may infect ruminants and rodents as hosts; however, some species of this protozoa may have the less hosts or even just have one host (Berahmat et al. 2017). This parasite is regarded as a water-borne pathogen that can be transmitted to humans through drinking water. Human-to-

human transmission has been also documented (Mirza-Qavami and Sadraei 2012). In Tehran, 77 wild rats from different areas were hunted for the presence of Cryptosporidium. After PCR testing, 21 samples (27.3%) were positive (Bahrami et al. 2012). In another study on 75 selected ostriches from six ostrich farms in Shiraz, 21 samples were reported containing Cryptosporidium oocyst (Behzadi et al. 2009). From 794 stool samples that were collected from children with diarrhea in Tehran, 19 samples were reported containing a Cryptosporidium oocyst (Taghipour et al. 2011).

Rat tapeworm or hymenolepiasis

Hymenolepis nana is a common tapeworm that is found in the small intestine of rats, mice, and humans. Human infection with *Hymenolepis diminuta* or rat tape worm is created by the accidental ingestion of insects such as immature fleas, beetles, meal worms, and cockroaches that carried the cystic stage of the parasite (Yang et al. 2017). When rodents and rarely humans eat contaminated insects, larvae will be converted to an adult tapeworm in the small intestine. A 16-month-old child with symptoms of diarrhea and occasional vomiting was admitted in a hospital in Tehran. After stool test, tapeworm eggs were found in the feces of the child (Mowlavi et al. 2008). In the capital of Iran, the prevalence of parasitic disease in *Rattus norvegicus* and *Meriones persicus* has been reported to be 11 and 38.8% respectively (Makki et al. 2011). The highest rate of hymenolepiasis's morbidity at Iran belongs to Khuzestan that prevalence of this disease was estimated to be 315.8 in 100,000 persons (Mohammadzadeh et al. 2007). In a study that was conducted in Kashan on 120 captured wild and domestic rats, 68 mice (56.7%) were infected with intestinal worms such as *Hymenolepis diminuta* and *Hymenolepis nana* (Rasti et al. 2000).

Babesiosis

Babesiosis is a haemoparasitic protozoan disease that is transmitted by ticks. High incidence and mortality of this disease are responsible for high economic losses in breeding and selling livestock universal industry. Six different Babesia species have been identified that can infect sheep and goats (Haghi et al. 2017; Ranjbar-Bahadori et al. 2012; Shayan et al. 2008). Cattle and wild rodents have been identified as reservoirs of the disease (Ranjbar-Bahadori et al. 2012). Samples of 400 sheep were randomly collected and tested in terms of the disease presence in north of Iran, and the contamination of the 28 blood samples to *Babesia ovis* was observed. In another study in 2010, microscopic observation of blood samples collected from 154 sheep of six breeding sheep provinces (East Azarbaijan, West Azarbaijan, Khuzestan, North Khorasan, Ilam, and center of Iran) was done and the presence of the disease agent in 38 cases (24.67%) was confirmed (Dehkordi et al. 2010).

Capillariasis

Capillariasis is a common infection in humans and animals that is caused by intestinal nematodes of genus Capillaria. The species that cause human infections include *Capillaria hepatica*, *Capillaria philippinensis*, and *Capillaria aerophila*. *C. philippinensis* is the most important emerging worm which is common between humans and animals. Heron birds are host and reservoir of the disease. Fish will be infected with parasites from the feces of infected birds or through the discharged human feces in water. Man is infected by eating raw or undercooked fish and fresh drinking water. Rodents and other domestic and wild animals have been identified as reservoirs of the disease (Dehghani 2011a). The first cases of infection were reported in the Philippines and Thailand and then Indonesia, Iran, Japan, Taiwan, and India (Berger 2017; Intapan et al. 2006). Two raised discus fish from two fish-farming centers were referred to the water-related diseases laboratory of Veterinary Faculty of Tehran University with symptoms including anorexia, weight loss, skin darkening, and necrosis. After carrying out the necessary tests, Capillaria species were identified in the intestines of fishes (Rahmati-Holasoo et al. 2010).

Clonorchiasis

Clonorchiasis infection or Chinese (Asian) liver worm is endemic among heron mammals in Southeast Asia and humans are accidental hosts (Qian et al. 2016). Outbreaks of human infections are common in China, Vietnam, and Korea. Some of these worms have been seen in Iran's neighboring countries such as Turkey, India, and southern areas of Russia. Iran is one of the endemic areas of the disease. Liver worm infection is created by eating contaminated fish with fresh waters containing metacercariae worms. Common hosts of *Clonorchis sinensis* are fish and snails of fresh water. Other limited hosts are dogs, cats, rats, pigs, camels, buffaloes, badgers, and weasels. Humans are accidental hosts, and the incidence of human infection is more common in China, Vietnam, and Korea (Heidarpour et al. 2007). In a case report study, a 55-year-old woman from Genaveh port (Southern Iran) with 1 month history of jaundice, pruritus, and abdominal pain was admitted. After examination tests, clonorchiasis helminthic infection was confirmed (Heidarpour et al. 2007).

Myiasis

Among diptera, *Musca domestica* has a close relationship with human life and is considered as a mechanical carrier that can transmit many pathogens to humans and animals. These

flies can transmit the pathogen agent through food contamination. Some opportunistic species may enter their larvae in living or dead tissues through wounds and skin lesions, mouth, ear, eye, and genitourinary system. The infection of different organs and tissues of living organisms by the early stages of flies is called myiasis.

Various studies have been carried out on different species of *Musca domestica* in Iran. These studies show that diptera choose a variety of different hosts for their larvae. When the flies cannot find their own exclusive hosts, they choose other animals such as rodents (e.g., rats), reptiles (e.g., Iranian snake *Pseudocerastes persicus*), and other mammals, except for humans (Dehghani et al. 2012b, 2014b, c; Rasti et al. 2016; Talar et al. 2002).

Fungal disease

Dermatophytes are one of the fungal species that cause disease in humans. *Trichophyton mentagrophytes* is transmitted through rodents, i.e., mice to other animals. *Microsporum gypseum* is also a fungal microorganism that can infect humans, rodents, dogs, cats, horses, cows, and pigs (Ahmad et al. 2009; Mackenzie 1962; Pollock 2003; Schweizer and Schröppel 2009).

The factors affecting rodent-related diseases in Iran include:

1. Growth of slums

Iran as a developing country is experiencing a rapid increase in urbanization and modernization (Dehghani et al. 2015; Sahraian et al. 2017). However, this process has been led to the rapid growth of slums. This is mainly due to the migration of low-income people to cities. Slums cause the outbreak of rodent-related diseases, because of the lack of adequate sanitation, low level of health services, and lack of proper disposal facilities for sewage and solid waste.

2. Non-sanitary disposal of waste and construction waste

In the past, the destruction of rodent nests during the Iran-Iraq war in southern and southwestern Iran was led to the growth of leishmaniasis among the soldiers. But nowadays, non-sanitary disposal sites of construction wastes in sub-urban areas are a major cause of rodent-related diseases in Iran. For example, leishmaniasis has been observed constantly in slums located in central, eastern, and northeastern Iran (Dehghani et al. 2012c, 2016a).

3. Inappropriate control and prevention actions

The use of rodent control methods by ordinary people causes the rodents not to be properly controlled, and show resistance to rodenticides (Dehghani et al. 2012a). According to studies, the amount of pesticides and rodenticides use by non-specialists and the general population in cities like Tehran and Kashan is high (Dehghani et al. 2013a; Mostafaii et al. 2017). The tools used to control the sale of these toxins have not been effective. In some places, the resistance of some rodent species to rodenticides has been observed (Dehghani et al. 2012a). Many activities have been carried out in Tehran to control rodents, especially rats over the past years, but these activities have not shown good results, mainly due to the lack of inadequate theoretical facts and operational supports.

4. Climate change and drought

Climate can determine the distance between human and animal habitats (Githeko et al. 2000). For instance, long-term drought in Iran has decreased water resources in recent years and led to the approach of many animals to water and food sources near human habitats. Rodents are no exception to this, and their distances are decreasing from human habitat constantly.

Conclusion

Rodent-related diseases and their affecting factors were investigated and discussed. The families Muridae and Cricetidae have a more important role in disease transmission in Iran, comparing to other rodents. Some diseases such as plague have not been reported during the last five decades, due to proper control actions in the transmission cycle of disease. On the other hand, improper sanitation and non-sanitary disposal sites of construction wastes have led to an increase in the prevalence of some disease. In addition, it must be noted that rodent control may not have any effect on some diseases such as salmonellosis, which are transmitted to humans by several pathways.

Several factors are introduced to be related to the increase of rodent-related diseases during recent years: growth of slums, non-sanitary disposal of solid wastes, inappropriate control and prevention actions, and climate change. Other factors may include the ability of rodents and humans to develop disease and access food by rodents, and the quality of habitats.

Due to the wide variety of climates and many different species of domestic and wild rodents in Iran, the continuing studies on rodents, supervision of the mobility and displacement and diversity situation of rodents are necessary. Continuing studies of ectoparasites, endoparasites, and other microbial agents of rodents for the prevention and control of transmissible animal diseases have a special importance. Identification of habitats and faunistic composition of rodents

should always be considered, because these can simplify rodent control ways. Furthermore, the particularly molecular studies are useful. Regional studies to assess the risk of transmitted diseases by rats and increase awareness of local people through the media about the adverse effects of these animals are recommended.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent This is a review article which does not require informed consent.

Human participants and/or animals We do not have any sample or participant.

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