



Rodent Borne Zoonosis and Its Epidemic Surveillance - An Overview

Manohar B. Vadela¹, Satyanagalakshmi Karri^{1,2} and Vijay A.K.B. Gundi^{1*}

¹MBIG Research Laboratory, Department of Biotechnology, Vikrama Simhapuri University, Nellore – 524 324, Andhra Pradesh, India.

²R & D Center, Sahasra Crop Science Pvt. Ltd., Hyderabad – 501 510, Telangana, India.

Received: 02 Jul 2019 / Accepted: 9 Aug 2019 / Published online: 1 Oct 2019

Corresponding Author Email: gundi.vijay@gmail.com

Abstract

Human health has been continually challenged from many years with a variety of pestilences and infections. Majority of the diseases are of zoonotic origin with different animal host range including reptiles, mammals, pet animals, livestock and wild animals. Among these, the species of the rodents are highly prevailed and distributed globally and hosts for variety of zoonotic pathogens. Until now, investigations of disease outbreaks have mostly been recorded with limited or non-availability of prior information. Due to the non-specific symptoms caused by these rodent-borne zoonotic pathogens and lack of clinical suspicion, transmission to human population probably left under-diagnosed or non-diagnosed and leads to spill over of disease. Identification of suspecting zoonotic pathogen along with reservoir host and transmission of emerging infectious diseases in different geographical regions are the important steps toward a preemptive approach to minimizing zoonotic disease risk in humans. In this review, we summarized the significance of rodent species as zoonotic carriers, associated diseases and their epidemic surveillance.

Keywords

Rodents; Zoonotic Pathogens; Epidemic Survey; Hantavirus; Bacteria.

INTRODUCTION

Zoonoses are the diseases and infections which are transmitted through a wide range of animals. More than half of the human pathogens are zoonotic and emerging infectious diseases (EIDs), which cause no significant signs or illness in their host species (1). The high impact spill over in past and present pandemic outbreaks are resulted from wildlife zoonotic pathogens and led to distressing global health and economic effects when transmit to human and livestock (2). Previous studies reported that 60-80% of EIDs in human are originated from wildlife animals and two thirds of EIDs are originated from rodents, bats, and other wildlife (3).

However, the order Rodentia is highly prevailed mammalian group on the earth comprising approximately 42% of the global mammalian

population (4). Rodents are small in size with short reproduction period and biologically, morphologically adoptable to different ecological lifestyles and environments including aquatic, semiaquatic and dry environments (5). Because of this compatibility rodents can live in different habitats than any other animal species. Despite of this, rodents are well known for zoonotic risk of human health by serving as reservoir hosts and transmitting a wide variety of microbial pathogens and cause diseases including plague, leptospirosis, brucellosis, leishmaniosis, bartonellosis, salmonellosis, and viral infections, haemorrhagic fevers (5-7). The zoonotic diseases transmitted directly by rats through bites, urine faeces and arthropod vectors, which affect 7-10 million people per year globally. The prevalence of the diseases may associate with rodent population and

socioeconomic lifestyle of humans, and human related activities such as urbanization and agriculture (8). The rodent species including *Rattus rattus*, and *Rattus norvegicus* are widely distributed to different geographical locations and live in urban and rural areas in close contact with humans and are of viewed to spread diseases more than other rodent species (9). The major bacterial pathogens associated to rodents include *Anaplasma*, *Borrelia*, *Leptospira*, *Coxiella*, *Bartonella*, *Francisella*, *Ehrlichia* and *Rickettsia*.

The increasing outbreaks of emerging and re-emerging infectious diseases in the world require the exploration of reservoir hosts of zoonosis to understand transmission dynamics and to develop buoyant response strategies. Moreover, it helps to predict and reduce the risk of future emergence of zoonotic diseases. Viral zoonotic pathogens can cause epidemic and pandemic outbreaks. The Integrated Disease Surveillance Program (IDSP) survey reported that in 2017, a total of 1683 outbreaks were reported in India and 71% of them were caused by viral pathogens, and nearly 72,000 individuals were affected in these outbreaks (10). In this review, we discuss the different diseases which are transmitting by rodent species and their epidemic surveillance.

Rodent Borne Diseases

The order Rodentia with 33 families and 2,277 species is the largest mammalian group on earth, representing 43% of all mammalian species, which are widely distributed in all continents (3). It forms a bridge between humans and wildlife animal by being in close contact with humans. Among rodent species, Norway and black rats (*Rattus* spp.) are distributed globally. The expansion in global transportation networks lead to consequences of infectious disease pandemics, vector invasion events and vector-borne pathogen importation. The initial disease outbreaks such as *Yersinia* spp. and Hanta virus in ports are very common than any other routes. Rodents transmit disease in 2 different ways such as either by (1) contaminating the food and water taken by humans or (2) by serving as host for pathogens can bring them to direct contact with humans. Rodents help pathogen transmission to diverse environments and landscapes including urban area to rural area as well desert lands. However, climate change and urbanization are noted to increase the risk of with rodent-borne diseases as the distribution of rodent species (11). Major zoonotic bacterial species and viruses associated with rodents and their diseases are given in Table 1.

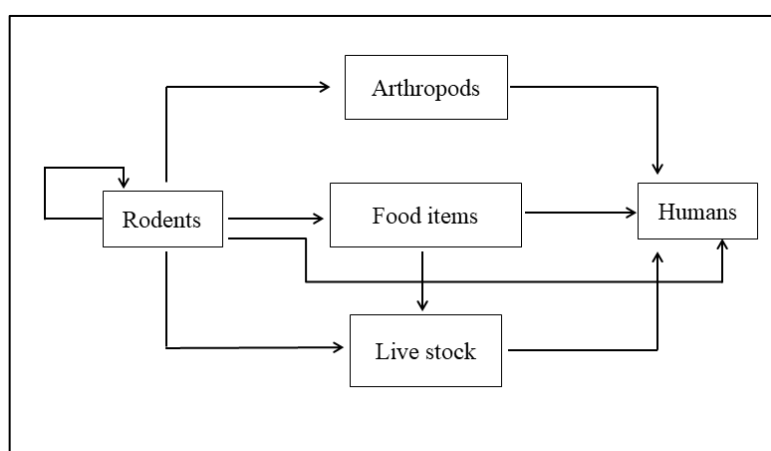


Figure 1. Transmission strategies of zoonotic pathogens from rodents.

Plague

The zoonotic pathogen which causes plague and responsible for three pandemics was attributed to *Yersinia pestis*. It is a Gram-negative bacterium belongs to Enterobacteriaceae. It was isolated by Alexandre Yersin during third pandemic plague. Other species of this genus *Y. pseudotuberculosis* and *Y. enterocolitica* were also found to infect humans (12). These pathogens spread from fleas, which were associated with live rodents and/or products that led to the plague spread. Since 2014, a total of 14 major outbreaks of Africa and Asia were reported to the WHO (13). The zoonotic pathogen *Yersinia pestis* was found to transmit by respiratory droplets and

uncooked contaminated food and also transmitted through contact with pet animals. Based on the mode of infection, this disease can be described as bubonic, pneumonic and septicaemic plague. Bubonic plague symptomized by common flu, fever, malaise, chills and headache, and if not treated it can develop into pneumonic and septicaemic plague. The early recognition and treatment with antibiotics for the patients is the recommended procedures. It will become fatal for the patients if the treatment is delayed by 24 hours. Though *Yersinia* species are sensitive to streptomycin, multi-drug resistant strains were identified in Madagascar. Fortunately, these

strains were never emerged naturally in these regions (14).

Hantavirus Pulmonary Syndrome

In 1993 in the Southwestern parts of the United States, this disease appeared due to anomalous weather patterns. It is a deer mouse borne disease caused by different strains of viruses belong to the genus of Hantavirus (15). Hantavirus is a single genus comprising 40 species with single stranded RNA which belong to bunyaviruses family. Presently, more than 50 hantavirus strains have been identified and 24 of those strains are having pathogenic relevancies to humans. Other hantaviruses may remain undetected, as infections are likely to go unreported in many areas, particularly in Africa, the Middle East, Central America, the Indian subcontinent and Mongolia (16). Based on the geographical and clinical manifestation, these species are grouped into 2 categories of strains. One variant strain causes pulmonary edema and effusions with respiratory failure and cardiovascular depression whereas another variant strain causes haemorrhagic shock and renal failure by targeting kidneys and vascular system. In a study conducted at the United States revealed that an average of 11% of SNV prevalence was observed. Moreover, the California mouse (*Peromyscus californicus*), cactus mice (*Peromyscus eremicus*), harvest mice (*Reithrodontomys megalotis*) and California voles (*Microtus californicus*) species of rodents were also found to have SNV antibody prevalence positive (17).

Leptospirosis

Leptospirosis is most common zoonotic, rodent-borne mainly, the brown rat (*Rattus norvegicus*) disease globally. It is also classified as re-emerging infectious disease by CDC and WHO. The zoonotic bacteria *Leptospira* spread all over and habitat in reservoir kidneys without causing any disease. These bacteria spread through the reservoir urine and acquire a new host. Once enter through the glomerulus or peritubular capillaries into the kidney and colonizes at proximal renal tubular epithelium (18). It is a nonspecific symptomatic and characterized by fever, myalgia and headache. Disruption of hepatocytes by disrupting the intracellular junctions leads to elevated bilirubin levels, as a results of it leaking of bilirubin out of bile canaliculi (19). In 1995, the first outbreak of leptospirosis in Colombia occurred in its principal sea-port, Barranquilla and resulted in four deaths. Later, the sea-port city of Colombia has been identified as "hot spots" for leptospirosis due to rodents transported on these visiting commercial ships (Romero-Vivas *et al.*, 2013). A 2012 study reported that annually 4713-5 cases in America (Costa *et al.*, 2012), 1.03 million human cases and 58,900 deaths occur globally (Costa *et al.*, 2015).

Bartonellosis

The members of the genus *Bartonella* are vector borne pathogens infect humans and a number of mammal species. *Bartonella* are facultative intracellular, gram-negative bacteria belong to the α -proteobacteria (20). They are able to parasitize in endothelial and erythrocytes of the mammals. A wide variety of mammalian species including bats, dogs, cats, rodents, ruminants and terrestrial animals have identified as potential reservoirs and hosts for *Bartonella* species. Rodents found to serve as hosts for a majority of *Bartonella* species including zoonotic species like *B. elizabethae*, *B. vinsonii arupensis* and *B. washoensis* (21). Moreover, A high prevalence of *Bartonella* was also reported in rodents from different geographical areas. Rodent species such as *Rattus norvegicus* and *Rattus rattus* are the most frequent studied ones for *Bartonella* prevalence. *Bartonella* was also detected in other species rodents such as *Apodemus*, *Microtus*, *Bandicota*, *Mus* and *Myodes* (21).

The infections associated with *Bartonella* are mild to lethal conditions, which are collectively called as bartonellosis. A wide verity of infections often caused by *Bartonella* species in humans including endocardial, myocardial, vascular infections, ophthalmological and lymph infections. The rodent associated species *B. elizabethae*, *B. vinsonii arupensis* and *B. washoensis* were reported to cause endocarditis (22). The other species including *B. grahamii* was suspected to cause neuroretinitis and *B. tribocorum* was suspected to cause symptomatic fever, apathy and chronic fatigue (23). The list of rodents- borne zoonotic pathogens, their host reservoir and disease are given in Table 1.

Table 1. Major zoonotic pathogens associated with rodents and their responsible diseases.

Zoonotic Pathogen	Microbial species	Rodent species	Associated diseases	Reference
Bacterial				
1. <i>Bartonella</i>	<i>B. tribocorum</i> , <i>B. queenslandensis</i> , <i>B. elizabethae</i>	<i>Rattus satarae</i> <i>Mus booduga</i> <i>Mus musculus</i>	Infective endocarditis, Neuroretinitis	(6, 24)
2. <i>Coxiella</i>	<i>Coxiella burnetii</i>	<i>Apodemus</i> spp. <i>R. norvegicus</i> <i>Eutamias sibiricus</i>	Q fever	(25)
3. <i>Orientia</i>	<i>O. tsutsugamushi</i>	<i>R. rattus</i> <i>S. murinus</i> <i>B. bengalensis</i> .	Scrub typhus	(26, 27)
4. <i>Rickettsia</i>	<i>Rickettsia typhi</i>	<i>R. rattus</i> , <i>A. agrarius</i>	Rickettsiosis, Murine typhus,	(26, 28, 29)
5. <i>Leptospira</i>	<i>R. rickettsii</i> NA	<i>Mus musculus</i> , <i>R. rattus</i>	Rocky mountain spotted fever Leptospirosis	(26, 30)
6. <i>Yersinia</i>	<i>Yersinia pestis</i> <i>Y. pseudotuberculosis</i> <i>Y. enterocolitica</i>	<i>R. rattus</i> , Indian Gerbil <i>Rattus rattus</i> , <i>R. norvegicus</i>	Plague, Yersiniosis	(31-33) (34)
7. <i>Borrelia</i>	<i>B. burgdorferi</i> , <i>B. afzelii</i> <i>B. garinii</i>	<i>P. xanthopygus</i> , <i>O. longicaudatus</i>	Lyme disease,	(35)
8. <i>Mycobacterium</i>	<i>Mycobacterium tuberculosis</i> complex	<i>Mus musculus</i>	Tuberculosis	(5)
9. <i>Listeria</i>	<i>Listeria</i> spp.	<i>Apodemus</i> spp. <i>Rattus</i> spp. <i>Bandicota indica</i>	Listeriosis	(36)
10. <i>Salmonella</i> spp.	<i>Salmonella</i> spp.	<i>Mus Musculus</i> , <i>R. rattus</i> , <i>R. norvegicus</i>	Salmonellosis	(5)

11.	<i>Campylobacter</i>	<i>Campylobacter</i> spp.	<i>Sciurus anomalus</i>	Campylobacteriosis	(5)
12.	<i>Francisella</i>	<i>Francisella tularensis</i>	<i>Microtus paradoxus</i> , <i>Tatera indica</i>	Tularemia	(37)
13.	<i>Escherichia</i>	<i>E. coli</i>	<i>R. rattus</i> , <i>R. norvegicus</i>	<i>E. coli</i> enteritis	(38)
14.	<i>Ehrlichia</i>	<i>Ehrlichia</i> spp.	<i>Apodemus</i> spp.	Ehrlichiosis	(39)
15.	<i>Anaplasma</i>	<i>A. phagocytophilum</i>	<i>Apodemus</i> spp.	Anaplasmosis	(39)
16.	<i>Brucella</i>	<i>Brucella</i> spp.	<i>Apodemus</i> spp. <i>Myodes glareolus</i>	Brucellosis	(40)
Viral					
1.	Hanta virus	Hantaan virus, Puumala virus, Dobrava virus, Seoul virus	Murinae rodents	Haemorrhagic fever with renal syndrome (HFRS)	(41, 42)
2.	Hepatitis virus	Hepatitis E virus	<i>Rattus</i> spp.	Hepatitis E	(42, 43)
3.	Rabies virus	Rabies virus	Rabid rodents	Rabies	(44)
4.	Nairovirus	Nairovirus	<i>Allactaga williamsi</i> , <i>Mus musculus</i> , <i>Meriones crassus</i>	Crimean-Congo haemorrhagic fever	(45)
5.	Lassa virus	Lassa virus	<i>Mastomys natalensis</i> <i>Mastomys erythroleucus</i> <i>Hylomyscus pamfi</i> <i>Mus baoulei</i>	Lassa fever	(46)
6.	Orthopoxvirus	Orthopoxvirus	<i>Myodes glareolus</i>	Smallpox	(39)
7.	Dobrava hantavirus	Dobrava hantavirus	<i>Apodemus flavicollis</i>	Hemorrhagic fever with renal syndrome (HFRS)	(39)

Epidemic Survey of Rodent Borne Diseases

Prevalence of diverse astroviruses, paramyxoviruses, hepeviruses and arenavirus was reported in both wild and synanthropic Kenyan rodents and shrews. Interestingly, majority of these viruses are found to be novel strains, and some belong to the families that contain important human viral pathogens. A novel arenavirus was detected in *Grammomys macmillani*, a rodent species newly identified to harbor arenavirus, and it potentially represent a novel arenavirus species (1). It was suggested that ChRCov HKU24 represent the murine origin of *Betacoronavirus* 1, with interspecies transmission from rodents to other mammals having occurred centuries ago, before the emergence of human coronavirus (HCoV) OC43 in the late 1800s (Susanna K. P. Lau et al 2015). Rodents are likely an important reservoir for ancestors of lineage A β CoVs (47). Accumulating data suggest that some *Bartonella* spp, being evolutionary and ecologically associated with rats of the genus *Rattus*, have been dispersed from Asia to many seaports around the globe, where these bacteria have subsequently become established among domestic rats. Recent investigations in Thailand, China, Vietnam, Bangladesh, and Nepal have demonstrated that rats harbour strains genetically related to *B. elizabethae*, a species firstly identified from a human patient in the USA.

In Vietnam, rodents and bats liver and serum samples were examined for viral detection and found virus homologous to human hepatitis B, C, E viruses. Pegivirus and Hepacivirus-like viruses were frequently detected in the bamboo rat, *Rhizomys pruinosus*. The rodent hepacivirus-like viruses significantly diverged from currently classified variants and potentially represent a new species in the Hepacivirus genus (48). In a survey conducted in Iran, fast expansion of industry and agriculture and climate change throughout the globe led to change or increase in incidence of rodent-borne diseases (49). Considering the distribution of rodents throughout Iran, out of 70 known rodent-borne diseases 34 were reported in Iran. The rat borne diseases including plague, leishmaniasis and hymenolepiasis were the most frequent diseases occurred, and notable diversity in rodents was also observed, The survey suggested that it is crucial to pay more attention to control the spread of EIDs (49). Orthohanta viruses are the re-emerging rodent-borne pathogens circulating globally. In Germany, two stable PUUV strains were isolated from Central Europe and glycoprotein-specific monoclonal antibodies for this PUUV isolate was developed for future reservoir host studies (50).

The plague outbreak in Himachal Pradesh in 2002 was due to unhygienic lifestyle, hunting practices on rodents, and treatment practices through faith healers (51). The delay in the initiation of effective treatment of plague cases was a major factor that led to the spread of the disease (52). This report explained the unawareness of people resides in remote areas and emergency of survey on rodent-borne pathogens. Balakrishnan *et al.* (2008) suggested that zoonotic agents, especially *Bartonella* spp. are prevalent causative organisms of blood culture-negative endocarditis in India and recommended serologic screening for antibodies to zoonotic microorganisms as diagnostic tools for this disease in India (52).

High prevalence of leptospirosis in rodents in Mumbai and southern part of India (Kerala and Tamil Nadu) was detected, which proved possible role of these animals in transmission of leptospiral organisms to humans. Hence, it is imperative to take necessary control measures to prevent human leptospirosis (53). The zoonotic risks associated with *R. norvegicus* in wetland agroecosystems such as Kerala cannot be ignored in the wake of emerging zoonotic and fungal potent carrier of dermatophytes and other opportunistic fungi (54).

Gaps in Surveillance and Future Perspective

Rodents and bats are the largest group of mammalian species in the world, distributed globally and harbour a wide range of zoonotic pathogens. However, it has been neglected to investigate the prevalence and diversity of bacterial populations and viral pathogens distributed in rodent species. For example, discovering the entire viral diversity is estimated to cost about \$6.4 billion. The cost of the 2002 SARS outbreak has been pegged at \$54 billion and a severe flu pandemic could cost about \$3 trillion. This may be due to poor domestic research and lack of international collaborations in this area, of which the latter driven by restrictive policies on sharing clinical and research materials are responsible for these incidences.

Surveillance and discovery programs of emerging infectious diseases in wildlife have identified rodents and shrews as natural reservoirs of diverse viruses such as hantaviruses, arenaviruses, astroviruses, picornaviruses, paramyxoviruses and others (55). For the first time, feline astrovirus was detected in rodent species, but this virus cause infections domestic cats only. These findings indicate possible cross-species infection of astroviruses between cats and rodents. Urbanization and disturbance of natural habitats have brought rodents in close contact with humans. Based on the literature survey, rodents

might be the next source of zoonotic disease outbreaks.

Identification of known and novel pathogens in rodents and prevention strategies to control zoonosis transmission are the emerging and essential tasks for public health significance. As the frequency and prevalence of zoonotic diseases increase globally, investigation of how distribution of rodent hosts determines the patterns of disease transmission to human, and predicting which regions are at greatest risk for emergence of future zoonotic disease are two goals, which both require better understanding of the current distributions of zoonotic hosts and pathogens. Hence, there is a need to move from being reactive to proactively understanding zoonotic pathogens before they cause human disease. This will require preparedness by prior survey reports and strengthening inter-sectorial research on rodent borne zoonoses. Such type of research is useful in public health point of view.

ACKNOWLEDGEMENTS

The corresponding author is thanking DST-SERB (ECR/2015/000500) and Manohar Babu Vadela is thanking UGC, New Delhi for the financial support through RGNF.

CONFLICT OF INTEREST

No conflict of Interest was found between authors.

REFERENCES

- Onyuk SO, Hu B, Li B, Fan Y, Kering K, Ochola GO, et al. Molecular Detection and Genetic Characterization of Novel RNA Viruses in Wild and Synanthropic Rodents and Shrews in Kenya. *Frontiers in Microbiology*. 2019 2019-November-21;10(2696).
- Wu Z, Lu L, Du J, Yang L, Ren X, Liu B, et al. Comparative analysis of rodent and small mammal viromes to better understand the wildlife origin of emerging infectious diseases. *Microbiome*. 2018 Oct 3;6(1):178.
- Meerburg BG, Singleton GR, Kijlstra A. Rodent-borne diseases and their risks for public health. *Critical Reviews in Microbiology*. 2009 2009/08/01;35(3):221-70.
- Solari S, Baker RJ. *Mammal Species of the World: A Taxonomic and Geographic Reference* by D. E. Wilson; D. M. Reeder. *Journal of Mammalogy*. 2007;88(3):824-30.
- Rabiee MH, Mahmoudi A, Siahparv R, Kryštufek B, Mostafavi E. Rodent-borne diseases and their public health importance in Iran. *PLoS neglected tropical diseases*. 2018 Apr;12(4):e0006256.
- Gundi VA, Billeter SA, Rood MP, Kosoy MY. *Bartonella* spp. in rats and zoonoses, Los Angeles, California, USA. *Emerg Infect Dis*. 2012 Apr;18(4):631-3.
- Jones PW, Twigg GI. Salmonellosis in wild mammals. *The Journal of hygiene*. 1976 Aug;77(1):51-4.
- Islam MM, Farag E, Mahmoudi A, Hassan MM. Rodent-Related Zoonotic Pathogens at the Human-Animal-Environment Interface in Qatar: A Systematic Review and Meta-Analysis. 2021 May 31;18(11).
- Strand TM, Lundkvist Å. Rat-borne diseases at the horizon. A systematic review on infectious agents carried by rats in Europe 1995-2016. *Infection ecology & epidemiology*. 2019;9(1):1553461.
- Mourya DT, Yadav PD, Ullas PT, Bhardwaj SD, Sahay RR, Chadha MS, et al. Emerging/re-emerging viral diseases & new viruses on the Indian horizon. *The Indian journal of medical research*. 2019;149(4):447-67.
- Singla LDS, N.; Parshad, V.R.; Juyal, P.D.; Sood, N.K. Rodents as reservoirs of parasites in India. *Integrative Zoology*. 2008 01/01;3(1):21-6.
- Anisimov AP, Amoako KK. Treatment of plague: promising alternatives to antibiotics. *Journal of medical microbiology*. 2006 Nov;55(Pt 11):1461-75.
- Yang R. Plague: Recognition, Treatment, and Prevention. *Journal of clinical microbiology*. 2018 Jan;56(1).
- Galimand M, Guiyoule A, Gerbaud G, Rasoamanana B, Chanteau S, Carniel E, et al. Multidrug resistance in *Yersinia pestis* mediated by a transferable plasmid. *The New England journal of medicine*. 1997 Sep 4;337(10):677-80.
- Nichol ST, Spiropoulou CF, Morzunov S, Rollin PE, Ksiazek TG, Feldmann H, et al. Genetic identification of a hantavirus associated with an outbreak of acute respiratory illness. *Science (New York, NY)*. 1993 Nov 5;262(5135):914-7.
- Jiang H, Zheng X, Wang L, Du H, Wang P, Bai X. Hantavirus infection: a global zoonotic challenge. *Virologica Sinica*. 2017;32(1):32-43.
- Lonner BN, Douglass RJ, Kuenzi AJ, Hughes K. Seroprevalence against Sin Nombre virus in resident and dispersing deer mice. *Vector borne and zoonotic diseases (Larchmont, NY)*. 2008 Aug;8(4):433-41.
- Haake DA, Levett PN. Leptospirosis in humans. *Current topics in microbiology and immunology*. 2015; 387:65-97.
- Adler B, de la Peña Moctezuma A. *Leptospira* and leptospirosis. *Veterinary microbiology*. 2010 Jan 27;140(3-4):287-96.
- Krugel M, Pfeffer M, Krol N, Imholt C, Baert K, Ulrich RG, et al. Rats as potential reservoirs for neglected zoonotic *Bartonella* species in Flanders, Belgium. *Parasit Vectors*. 2020 May 7;13(1):235.
- Krugel M, Krol N, Kempf VAJ, Pfeffer M, Obiegala A. Emerging rodent associated *Bartonella*: a threat for human health? *Parasit Vectors*. 2022 Mar 31;15(1):113.
- Ellis BA, Regnery RL, Beati L, Bacellar F, Rood M, Glass GG, et al. Rats of the genus *Rattus* are reservoir hosts for pathogenic *Bartonella* species: an Old-World origin for a New World disease? *J Infect Dis*. 1999 Jul;180(1):220-4.
- Inoue K, Maruyama S, Kabeya H, Yamada N, Ohashi N, Sato Y, et al. Prevalence and genetic diversity of

- Bartonella species isolated from wild rodents in Japan. Appl Environ Microbiol. 2008 Aug;74(16):5086-92.
24. Ansil BR, Mendenhall IH. High prevalence and diversity of Bartonella in small mammals from the biodiverse Western Ghats. 2021 Mar;15(3):e0009178.
 25. Liu L, Baoliang X, Yingqun F, Ming L, Yu Y, Yong H, et al. Coxiella burnetii in rodents on Heixiazhi Island at the Sino-Russian border. The American journal of tropical medicine and hygiene. 2013 Apr;88(4):770-3.
 26. Chaudhari SP, Kalorey DR, Awandkar SP, Kurkure NV, Narang R, Kashyap RS, et al. Journey towards National Institute of One Health in India. The Indian journal of medical research. 2021 Mar;153(3):320-6.
 27. Candasamy S, Ayyanar E, Paily K, Karthikeyan PA, Sundararajan A, Purushothaman J. Abundance & distribution of trombiculid mites & Orientia tsutsugamushi, the vectors & pathogen of scrub typhus in rodents & shrews collected from Puducherry & Tamil Nadu, India. The Indian journal of medical research. 2016 Dec;144(6):893-900.
 28. Peniche-Lara G, Dzul-Rosado K, Pérez-Osorio C, Zavala-Castro J. Rickettsia typhi in rodents and R. felis in fleas in Yucatán as a possible causal agent of undefined febrile cases. Revista do Instituto de Medicina Tropical de Sao Paulo. 2015 Mar-Apr;57(2):129-32.
 29. Aleksandraviciene A, Paulauskas A, Stanko M, Fricova J, Radzijeuskaja J. New Records of Bartonella spp. and Rickettsia spp. in Lice Collected from Small Rodents. Vector Borne Zoonotic Dis. 2021 May;21(5):342-50.
 30. Flores B, Sheleby-Elias J, Pérez-Sánchez T, Fischer R, Múzquiz J, Fuertes H, et al. Leptospira spp in Rodents from Peridomestic Sites in Endemic Regions of Nicaragua. EcoHealth. 2020 Dec;17(4):469-76.
 31. Mahesh S, Shukla J, Tuteja U, Batra HV. Molecular detection of Yersinia pestis isolates of Indian origin by using Pla specific monoclonal antibodies. Comparative immunology, microbiology and infectious diseases. 2005 Mar;28(2):131-44.
 32. Biswas S, Lal S, Mittal V, Malini M, Kumar S. Detection of enzootic plague foci in peninsular India. The Journal of communicable diseases. 2011 Sep;43(3):169-76.
 33. Khushiramani R, Tuteja U, Shukla J, Panikkar A, Batra HV. Virulence markers of LCR plasmid in Indian isolates of Yersinia pestis. APMIS : acta pathologica, microbiologica, et immunologica Scandinavica. 2006 Jan;114(1):15-22.
 34. Dezfoolimanesh Z, Tohidnia MR, Darabi F, Assarezagdegan M. Antibiotic resistance of bacteria isolated from mice's intestine in Lahijan. Journal of Kermanshah University of Medical Sciences. 2009;13:242-51.
 35. Sánchez RST, Santodomingo AMS, Muñoz-Leal S, Silva-de la Fuente MC, Llanos-Soto S, Salas LM, et al. Rodents as potential reservoirs for Borrelia spp. in northern Chile. 2020;29(2):e000120.
 36. Wang Y, Lu L, Lan R, Salazar JK, Liu J, Xu J, et al. Isolation and characterization of Listeria species from rodents in natural environments in China. Emerging microbes & infections. 2017 Jun 7;6(6):e44.
 37. Hemati M, Khalili M, Rohani M, Sadeghi B, Esmaeili S, Ghasemi A, et al. A serological and molecular study on Francisella tularensis in rodents from Hamadan province, Western Iran. Comparative immunology, microbiology and infectious diseases. 2020 Feb;68:101379.
 38. H LEH, Koizumi N, Ung TTH, Le TT, Nguyen HLK, Hoang PVM, et al. Antibiotic-resistant Escherichia coli isolated from urban rodents in Hanoi, Vietnam. The Journal of veterinary medical science. 2020 May 20;82(5):653-60.
 39. Tadin A, Tokarz R, Markotic A, Margaletic J, Turk N, Habus J, et al. Molecular Survey of Zoonotic Agents in Rodents and Other Small Mammals in Croatia. Am J Trop Med Hyg. 2016 Feb;94(2):466-73.
 40. Hammerl JA, Ulrich RG, Imholt C, Scholz HC, Jacob J, Kratzmann N, et al. Molecular Survey on Brucellosis in Rodents and Shrews - Natural Reservoirs of Novel Brucella Species in Germany? Transboundary and emerging diseases. 2017 Apr;64(2):663-71.
 41. Blanco P, Arroyo S, Corrales H, Pérez J, Álvarez L, Castellar A. [Serological evidence of hanta virus infection (Bunyaviridae: Hantavirus) in rodents from the Sucre Department in Colombia]. Revista de salud publica (Bogota, Colombia). 2012 Oct;14(5):755-64.
 42. He W, Wen Y, Xiong Y, Zhang M, Cheng M, Chen Q. The prevalence and genomic characteristics of hepatitis E virus in murine rodents and house shrews from several regions in China. 2018 Dec 22;14(1):414.
 43. He J, Innis BL, Shrestha MP, Clayson ET, Scott RM, Linthicum KJ, et al. Evidence that rodents are a reservoir of hepatitis E virus for humans in Nepal. Journal of clinical microbiology. 2006 Mar;44(3):1208.
 44. Fitzpatrick JL, Dyer JL, Blanton JD, Kuzmin IV, Rupprecht CE. Rabies in rodents and lagomorphs in the United States, 1995-2010. Journal of the American Veterinary Medical Association. 2014 Aug 1;245(3):333-7.
 45. Saidi S, Casals J, Faghih MA. Crimean hemorrhagic fever-Congo (CHF-C) virus antibodies in man, and in domestic and small mammals, in Iran. The American journal of tropical medicine and hygiene. 1975 Mar;24(2):353-7.
 46. Olayemi A, Fichet-Calvet E. Systematics, Ecology, and Host Switching: Attributes Affecting Emergence of the Lassa Virus in Rodents across Western Africa. Viruses. 2020 Mar 14;12(3).
 47. Lau SKP, Woo PCY, Li KSM, Tsang AKL, Fan RYY, Luk HKH, et al. Discovery of a Novel Coronavirus, China >Rattus Coronavirus HKU24, from Norway Rats Supports the Murine Origin of >Betacoronavirus 1 and Has Implications for the Ancestor of >Betacoronavirus Lineage A. Journal of Virology. 2015;89(6):3076-92.
 48. Van Nguyen D, Van Nguyen C, Bonsall D, Ngo TT, Carrique-Mas J, Pham AH, et al. Detection and Characterization of Homologues of Human Hepatitis Viruses and Pegiviruses in Rodents and Bats in Vietnam. Viruses. 2018;10(3):102.

49. Rabiee MH, Mahmoudi A, Siahsarvie R, Kryštufek B, Mostafavi E. Rodent-borne diseases and their public health importance in Iran. *PLOS Neglected Tropical Diseases*. 2018;12(4):e0006256.
50. Binder F, Reiche S, Roman-Sosa G, Saathoff M, Ryll R, Trimpert J, et al. Isolation and characterization of new Puumala orthohantavirus strains from Germany. 2020 Apr 23.
51. Goel S, Kaur H, Gupta AK, Chauhan U, Singh A. Socio-epidemiological determinants of 2002 plague outbreak in Himachal Pradesh, India: a qualitative study. *BMC Public Health*. 2014 Apr 8;14:325.
52. Kaur H, Goel S, Sharma Y, Kessar RR. Socioenvironmental Etiology of Plague Outbreak in Himachal Pradesh: A Retrospective Enquiry. *Journal of Postgraduate Medicine, Education and Research*. 2013;47(2):112-6.
53. Patil D, Dahake R, Roy S, Mukherjee S, Chowdhary A, Deshmukh R. Prevalence of leptospirosis among dogs and rodents and their possible role in human leptospirosis from Mumbai, India. *Indian J Med Microbiol*. 2014 Jan-Mar;32(1):64-7.
54. Thomas M, Samuel K A, Kurian P. Rodentborne fungal pathogens in wetland agroecosystem. *Brazilian Journal of Microbiology*. 2012;43:247-52.
55. Meheretu Y, Cizkova D, Tesikova J, Welegerima K, Tomas Z, Kidane D, et al. High diversity of RNA viruses in rodents, Ethiopia. *Emerg Infect Dis*. 2012 Dec;18(12):2047-50.