Brucellosis; A Re-emerging Global Health Concern

Muqadas Noor[1,*], Ammar AL-Farga[2], Ayah Talal Zaidalkilani[3], Laraib Jabbar[4] and Fatima Zaka[1]

[1]Department of Epidemiology & Public Health, University of Veterinary & Animal Sciences, Lahore, Pakistan
[2]Department of Biological Sciences, College of Science, University of Jeddah, Jeddah, Saudi Arabia
[3]Faculty of Pharmacy and Medical Sciences, Department of Nutrition, University of Petra, Amman, Jordan
[4]Institute of Microbiology, University of Veterinary and Animal Sciences, Lahore, Pakistan
*Corresponding author: muqaddasnooor@gmail.com

Abstract

Brucellosis is a reawakening zoonotic disease that strongly influences public health, animal welfare, and the economy of a country. The main cause of this disease is *Brucella*, a genus of intracellular bacteria that infects domestic, wild, and marine animals. Direct and indirect contact with infected animals and their byproducts transmits the disease to humans. Although some progress has been made in controlling the disease, brucellosis continues to have a notable number of cases, especially in areas with limited healthcare services. Factors responsible for the occurrence, propagation, and re-emergence of *Brucella* are covered in this chapter. Further, it highlights that the disease's endemicity and the ability to transmit are due to different factors such as worldwide trade, climate change, and the movement of animals. Chronic infections in humans and animals, caused by *Brucella,* that can escape the immune system by hiding inside cells, create more chances for misdiagnosis and treatment. Brucellosis symptoms can vary from mild fever to serious health issues, causing economic losses through decreased livestock production and increased veterinary costs for infected animals. Along with vaccination and other control measures, this chapter also covers different diagnostic tools for brucellosis, including bacteriological, molecular, and serological tests. Furthermore, it points out the need for increased monitoring, awareness of the risk to the public, and the implementation of One Health approaches to decrease the effect of disease. Advancing the global fight against brucellosis requires the development of tools for disease tracking and an efficacious vaccine.

Keywords: Brucellosis, Re-emerging, Public health, Control, diagnostics

Cite this Article as: Noor M, AL-Farga A, Zaidalkilani AT, Jabbar L and Zaka F, 2025. Brucellosis; a re-emerging global health concern. In: Abbas RZ, Akhtar T and Arshad J (eds), One Health in a Changing World: Climate, Disease, Policy, and Innovation. Unique Scientific Publishers, Faisalabad, Pakistan, pp: 258-263. https://doi.org/10.47278/book.HH/2025.377

A Publication of Unique Scientific Publishers	**Chapter No:** 25-036	**Received:** 26-Jan-2025 **Revised:** 07-Apr-2025 **Accepted:** 14-May-2025

Introduction

Food and Agriculture Organization (FAO), World Health Organization (WHO), and World Organisation for Animal Health (OIE) has recognized brucellosis as one of the most globally widespread zoonotic diseases (Schelling et al.,2003). *Brucella* can infect humans and different animal species such as cattle, sheep, ponies, goats, and pigs, as well as wild animals like rodents and marine mammals (Cutler et al., 2005). Brucellosis may have been the cause of Egypt's Fifth Plague, as *Brucella* species have been recognized significantly since ancient times. A researcher at the Smithsonian Institution, Jamie Hodgkins, discovered symptoms of sacroiliitis, a common complication caused by *Brucella*, in 5.2% of ancient Egyptian pelvic bones dating back to approximately 750 BC (Pappas & Papadimitriou, 2007). The first individual from whom *Brucella melitensis* was isolated from tissue, a British soldier who died of Malta fever, giving the disease its name. Bang's disease was named after L.F. Benhard Bang, a Danish veterinarian, identified Bang's bacillus in 1897, also known as the bacillus of cattle abortion (*B. abortus*), as the cause of Bang's disease, giving the condition its name (Seleem et al., 2010). Due to its major implications for public health and the economy, brucellosis is now considered as an important re-emerging zoonotic disease that warrants attention. It greatly impacts the production and welfare of the livestock which affects the owners. In developing regions of Asia and Africa, brucellosis poses a hazard to agriculture, public health, and economic growth. This disease must be handled because of the intolerable economic and reproductive losses it causes (Pal et al., 2017). This chapter aims to identify the main causes and factors responsible for the disease's re-emergence.

Etiology of the Disease

Brucella is a tiny, intracellular, non-motile, facultative, Gram-negative coccobacillus that ranges in size from 0.5–0.7 by 0.6–1.5 µm. More than ten species of *Brucella* have been identified based on their host range and phenotypic characteristics (Golshani & Buozari, 2017). Different species are affected by these species of *Brucella* as humans by *B. neotomae*, cattle by *Brucella abortus*, sheep by *B. melitensis*, pigs by *B. suis*, rams by *B. ovis*, wild rodents by *B. microti*, pinnipeds by *B. pinnipedialis*, dogs by *B. canis*, marine toads by *B. inopinata*, and sea mammals by *B. ceti* (Galinska et al., 2013).

Epidemiology of Brucellosis

Ongoing emergence and reemergence of new foci constantly changing the geographical distribution of brucellosis. Continuous monitoring and preventive actions are needed to control its unpredictable dissemination and shifting patterns (Seleem et al., 2010). Human brucellosis patterns have changed significantly in recent years because of increased international travel, social and political factors, and improved hygiene (Pappas et al., 2006). Brucellosis in humans has propagated to many new localities, particularly in Central Asia, and it is worsening in some parts of the Middle East. In humans, it was first identified on the island of Malta in the early 20th century. It is more common in countries with ineffective public and animal health frameworks, though marine brucellosis exists worldwide (Gul & Khan, 2007). Domestic cattle brucellosis is widespread, particularly in developing and tropical regions like Pakistan. Human cases are more common in countries where animal brucellosis is prevalent, and when people return from endemic areas, the risk of human brucellosis increases, making its spread more likely even in non-endemic regions. Some countries, including those in Northern and Central Europe, Australia, New Zealand, Japan, and Canada, are considered free of the disease (Jamil et al., 2021).

Transmission of Brucellosis

The highly contagious bacterium *Brucella* is spread by indirect exposure to tainted food and waste or direct contact with diseased animals. It can live up to two months in milk and meat, 70 – 150 days in water, and 20 – 120 days in soil. However, it is easily destroyed by direct sunshine within hours and by high temperatures within minutes. Typically, symptoms don't appear in infected animals until 14–180 days following exposure. To control it, appropriate measures must be taken (Zhang et al., 2014).

Humans can get brucellosis by drinking unpasteurized milk or being near infected animals. Though rare, the disease can spread from person to person, including from mother to child. Some reports suggest it may also spread through blood transfusions. Animals catch the disease easily, and people are most often infected through raw milk or close contact with sick animals (Tuon et al., 2017).

Pathophysiology of Brucellosis

Due to the ability to survive and replicate within phagocytic cells, *Brucella* escapes detection more effectively than many other pathogenic bacteria, thereby resisting immune clearance. *Brucella* lacks conventional virulence factors such as capsules, plasmids, pili, or exotoxins, unlike typical virulent bacteria (Seleem et al., 2008). The bacterial virulence is primarily affected by the O-polysaccharide chain linked to their lipopolysaccharide layer. This O-polysaccharide chain plays a crucial role in immune evasion by preventing complement deposition on the bacterial surface in *Brucella* (Fontana et al., 2016). Entry of C1q is blocked, thus preventing access to the surfaces of target proteins. The size of O-chains acts as a barrier to complement activation, as indicated in studies (Conde-Alvarez et al., 2012). It contributes to disease progression by regulating the adenine and guanine monophosphate systems, preventing phagolysosomal fusion, inhibiting myeloperoxidase release, and modulating tumor necrosis factor (TNF) synthesis (Sangari et al., 2007). By preventing apoptosis, *Brucella* can occasionally survive within specialized macrophages. Further, by downregulating type 1-specific immune responses and suppressing TNF-α production, it evades the host immune defense (Cui et al., 2014). To suppress Th1 polarization, *Brucella* activates macrophages and stimulates the production of cytotoxic T cells. Infected macrophages release cytokines that modulate the immune response. Consequently, the infection weakens immune function by reducing cytokine production, including TNF (Skendros & Boura, 2013).

Clinical Findings

In Humans

Marine animals and nonhuman pathogens such as *B. suis*, *B. abortus*, *B. melitensis*, and *B. canis* can infect humans. Human brucellosis is a serious illness that can affect multiple organs and become chronic. Most cases are contracted by consuming raw dairy products or coming into close contact with infected animals (Megid et al., 2010). The symptoms include a persistent fever that can be intermittent. Other symptoms may include cephalgia, exhaustion, shivering, Excessive perspiration, fatigue, weight loss, cough, and stomach pain. In rare cases, localized infections may develop and form pus. Moreover, the risk of abortion may be higher in early trimester (Pal et al., 2020).

In Animals

Infected animals show various signs, with the main effect of *Brucella abortus* infection being reproductive failure. This often causes abortion and weak newborns that may spread the infection in the herd. In different animal species, brucellosis mainly affects the reproductive system. The incubation period can range from two weeks to several months (Khurana et al., 2021). The most common signs of infection in animals are abortion, placental inflammation, and swelling of the epididymis and testes (Poester et al., 2010). Infertility is a common result of infection in animals. Fistulous withers are the most common sign of brucellosis in horses. Some horses may suffer from a generalized infection, with symptoms including stiffness, lameness, fluctuating temperature, and lethargy (Addis, 2015). The disease in cattle also leads to reduced milk production and the release of the bacteria in uterine discharge and milk. Full-term calves may die shortly after birth (Kiros et al., 2016).

Diagnosis

a. Bacteriological Methods

The preferred materials for testing in animals include stomach contents, spleen, and lungs from aborted fetuses, placentomes, fetal membranes, vaginal swabs, milk, semen, and fluid from arthritis or hygroma in adult animals. For animal carcasses, the best tissues for culture are the mammary glands, medial and internal iliac lymph nodes, retropharyngeal lymph nodes, parotid lymph nodes, prescapular lymph nodes, and spleen. The most commonly used methods for stained smears are the modified Ziehl-Neelsen and modified Köster techniques. Several commercially available culture media can grow *Brucella*. The most common ones are Triptcase soy (BBL®), Bacto Tryptose (Difco®), Triptic soy (Gibco®), and Tryptone soya (Oxoid®). For culture specimens, blood, milk, tissues, and vaginal swabs are preferred. To identify *Brucella*, tests include observing colonial morphology, staining, slide agglutination with anti-*Brucella* serum (smooth or rough), and performing urease, catalase, and oxidase tests (Poester et al., 2010).

b. Molecular Methods

Brucella identification was accurately performed using various PCR assays. However, there was a need for an assay that could differentiate species in the same reaction. The AMOS PCR assay was able to distinguish *B. abortus* (biovars 1, 2, and 4), *B. melitensis* (all three biovars), *B. suis* (biovar 1), and *B. ovis* (all biovars). For faster and simpler identification of *Brucella*, a novel multiplex PCR assay called Bruce-ladder has been developed. This multiplex PCR assay offers a significant advantage over previously described PCR assays, as it can identify and differentiate most *Brucella* species, including vaccine strains, in a single test (Gupta et al., 2014).

c. Serological Method

Brucellosis was first diagnosed in 1897 by Wright and Smith using a simple tube agglutination test. Other agglutination tests include the Standard Tube (SAT) and Milk Ring Test. Rapid agglutination tests used for diagnosis include Rose Bengal, Modified Rose Bengal, Buffered Antigen Plate Agglutination, Card test, antigen with rivanol added, heat treatment of serum, and the addition of 10% sodium chloride (Nielsen & Yu, 2010).

Public Health Impact of Brucellosis

Reported cases are over half a million annually-making this the most common zoonotic infection in the world. Though the true incidence may be far greater, *Brucella suis*, *Brucella melitensis*, and *Brucella abortus* are bacteria that cause human and animal brucellosis infections. Brucellosis crosses borders with ease, but it is ill-tended most of the time. The distribution of the disease is determined typically regionally; some factors include animal husbandry practices or food safety practices, the species of *Brucella* involved, and sanitation practices (Pal et al., 2017). Over the years of livestock farming and animal husbandry expansion, inflation, and globalization, there has been a plateau where *B. melitensis* may have existed. Although brucellosis can still be successfully managed in low-income urban areas, its ever-increasing prevalence in these regions is not uncommonly attributed to poor controls. Modern economies have ever faced difficulties in improving sanitation and hygiene, which are vital for the perennial eradication of brucellosis (Khurana et al., 2021).

Brucellosis is global injury threat to both economy and livestock welfare at the micro-level. For the economy, it reduces the productivity of animal herds in terms of milk production, induces abortions, causes stillbirths, causes early weaning of calves, causes veterinary services to be expensive, and, therefore, causes an increase in cost. Economic losses therefore entail loss of money from cattle farming and costs incurred in controlling the disease. In some regions, the rate of human brucellosis stands at less than 0.01 per 100,000 people, while in others, it rises to above 200. Six Countries; Syria, Saudi Arabia, Oman, Jordan, Iran, and Egypt-reported having human brucellosis with an annual incidence of about 90 cases in 1990 (Khurana et al., 2021). One Health is to boost the health of people, animals, and the environment. It developed from studies on brucellosis and is influenced by current political and ethical issues. Professionals in One Health include microbiologists, physicians, veterinarians, infectologists, and people from public health sectors. Understanding *Brucella* and the application of proper diagnostic, epidemiology, and preventive measures is paramount (Moriyón et al., 2023).

Prevention and Control

In the developed nations, brucellosis is eliminated or controlled; it is, however, still a major health concern in low-earning countries due to extreme poverty. Brucellosis control aims to reduce the chances of human infections from infected animals, animal products, or contaminated environments. In doing so, these programs are also designed to reduce both the health and economic impact of the disease. Major activities, including increased coverage in high-risk areas with vaccination of animals, animal control measures, and better monitoring. Animal control comprises managing animal health, organizing public awareness programs, vaccination, inspection, and slaughtering when necessary (Tabar & Jafari, 2014).

Vaccination is probably the most effective one among preventive measures for controlling and preventing brucellosis in livestock. Several live vaccines are available, such as *B. abortus* S-19, *B. melitensis* Rev-1, *B. suis* S-2, the rough *B. melitensis* strain M111, and *B. abortus* strain RB-51; in addition, a variety of inactivated vaccines like *B. abortus* 45/20 and *B. melitensis* H-38 are in use in different parts of the world (Pal et al., 2017). Smooth and rough vaccine candidates developed in the laboratory are expected to find an application for the control of brucellosis in light of advances in *Brucella* genome sequencing, recombinant DNA technology, and bioinformatics. However, their safety, efficacy, and other important parameters must be thoroughly investigated (Hou et al., 2019).

Pasteurization of Dairy Products

But it has been studied about heat resistance of *Brucella suis* in milk. Hermetically-sealed glass tubes do not allow viable bacteria within 20 minutes at 140°F, 15 minutes at 142°F, and 7 minutes at 144°F. For those tubes with cotton stoppers, however, *Brucella suis* demonstrated additional heat resistance. In lower concentrations of bacteria in milk, however, it had survival times of up to 30 minutes at 144°F when there were between 10,000,000 and 500,000,000 organisms per cubic centimeter. The results suggest that the degree of contamination affects thermal death time. While more work with commercial pasteurizers needs to be done before final conclusions can be drawn, this study suggests that effective pasteurization may prevent porcine brucellosis from the consumption of infected milk (Park et al., 1932). *Brucella* species can live for many years in a frozen state, in some cases perhaps up to twenty-five years. Pasteurization destroys *Brucella abortus*, and survival outside the host largely depends on environmental conditions (Pal et al., 2017).

Research about Community Awareness about Brucellosis

The mean level of public awareness over brucellosis in an investigation covering 79 research articles across 22 countries was 55.5&. The cut-off marks for different traits were zoonotic diseases 37.6%, human symptoms 35.9%, animal symptoms 41.6%, and modes of transmission 28.4%. The public knew beyond the knowledge possessed. When broken down by sub-groups, the awareness level of high-risk groups did not also differ across Asia or Africa. It's critical to mention the presence of health sector members at the top of awareness and knowledge, followed by livestock owners and herders and last by dairy farmers and abattoir workers, wherein those engaged in caprine and ovine production were more aware than the bovine production participants. This clearly shows that brucellosis awareness is still very low, especially in Asia and Africa, and calls for public education interventions with urgency (Zhang et al., 2019).

Brucellosis as a Re-emerging Threat

Brucellosis, with cases mostly due to *Brucella melitensis*, being one of the most prevalent zoonotic diseases, afflicts about half a million people every year. The Centers for Disease Control and Prevention consider this bacterium a Category of B threat and thus a potential agent of bioterrorism. Laboratory-acquired infections have primarily been associated with *Brucella* species. Brucellosis continues to expand its geographic range as new outbreaks emerge or reinvigorate long past ones. It occurs in many areas but not where bovine brucellosis has been completely eliminated. Human and animal populations are affected. Brucellosis causes major economic losses worldwide in terms of human health and animal production. At present, no effective vaccine against human brucellosis exists, although several effective animal vaccines have been developed (Seleem et al., 2010).

Climate Change and Animal Migration

Migration of animals is going to be permanently changed due to climate change probably, which will affect all zoonotic disease patterns, including brucellosis. Brucellosis infection is primarily a bacterial infection spread by livestock and wildlife to humans, though it can be acquired through accidental lesions from infected tissues of animals.

Brucellosis Transmission Influence

Supporting their entry into and use of livestock and human habitats increases the probability of transmission through brucellosis. Whenever environmental perturbations preside over modeling brucellosis, full consideration ought to be given to climate change in relation to all other infectious diseases, which have certainly received such attention (Arotolu et al., 2023). Definitely, bringing changes in the management of wildlife and livestock will be needed as brucellosis will dynamically interact with climate change, animal migration, and transmission of diseases. Understanding these interactions is an essential step in the development of effective strategies for the control of the spread of zoonotic diseases under changed climatic conditions (Ma et al., 2024).

Research Gaps and Future Directions

Brucellosis that is from the zoonotic pathogen known as *Brucella* has a very extensive view: public health threats, broad routes of infection. Hence, there is a necessity to compile the existing and unfilled gaps on the role of ticks in their spreading of brucellosis. The identification of 16 tick species that possess *Brucella* suggests that ticks are likely to act as a vector in brucellosis transmission because of the total prevalence in ticks is 33.87% (from 0.00 to 87.80%). The review cites most developmental stages of parasitic ticks of *Brucella* having a risk of transmission to humankind and other animals. Between 1963 and 2019, three human incidents were recorded that can be tied to tick bites (Ma et al., 2024).

Future Trends

The early twenty-first century has brought technology into the fast lane of vaccine development and the study of brucellosis by immunoproteomics, i.e., finding pathogen immunogenic proteins. Therefore, not all immunogens are protective antigens, and further studies are needed in the area of effective vaccines. The sequencing of the genomes of various species, namely humans, mice, and *Brucella*, has overtly opened the way for genome-wide analysis of host responses and reverse genetic identification of virulence determinants. Subsequently, recent fluorescent-based monitoring and genetic assays, 'gain' and 'loss of function,' have clued in on *Brucella* infections and their treatments (Tabar & Jafari, 2014).

Importance of Multisectoral Collaboration

Various organizations, like the WHO, FAO, and OIE, have come together to work on the One Health Approach. Endemic areas had been recognized for the application of brucellosis prevention activities. The participation of the communities concerned remains crucial in making disease prevention a reality at the grassroots level such as educating farmers, herders, and rural communities. The essence of intersectoral collaboration is resource pooling toward effective brucellosis prevention and the complete holism in addressing the disease. This also complements the ongoing improvements of the regulatory framework that provides for better economic viability, animal welfare, and public health. It keeps the involvement of the relevant communities in heightening disease prevention at the grassroots level, which necessitates educating farmers, herd owners, and rural communities in a more widespread sense. The essence of intersectoral collaboration is resource pooling toward effective brucellosis prevention and the complete holism in addressing the disease. This further complements the ongoing reform of the regulatory framework which provide for better economic viability, animal welfare, and public health (Tabar & Jafari, 2014).

Conclusion

Brucellosis poses a significant global health concern due to its ability to spread between animals and humans, leading to economic losses and displaying a complex disease pattern. The disease frequently resurfaces, especially in low-income countries where control measures are weak and awareness is limited. The Brucella bacteria can survive within cells and evade the immune system, making diagnosis and treatment challenging. While recent advances in diagnostic methods, such as molecular and serological testing, have improved disease detection, effective control of brucellosis remains a pressing issue. Key economic problems associated with the disease include reduced livestock productivity, increased veterinary costs, and restrictions on the movement of animals and animal products from brucellosis-infected areas. Brucellosis in humans shows a range of symptoms, from mild flu to severe complications. Integrating human, animal, and environmental health, a one health approach, is crucial for efficiently mitigating the effects of brucellosis. Animal vaccination, public education, and improving farm hygiene are included in important control measures. Moreover, pasteurization of dairy products and sanitation management are effective strategies for decreasing cases in humans. For the protection of public health and control of brucellosis, a cooperative mutual global effort is needed.

References

Addis, M. (2015). Public health and economic importance of brucellosis: A review. *Public Health, 5*(7), 68-84.

Arotolu, T. E., Wang, H., Lv, J., Shi, K., Huang, L., & Wang, X. (2023). Modeling the current and future distribution of Brucellosis under climate change scenarios in Qinghai Lake basin, China. *Acta Veterinaria, 73*(3), 325-345.

Conde-Alvarez, R., Arce-Gorvel, V., Iriarte, M., Manček-Keber, M., Barquero-Calvo, E., Palacios-Chaves, L., & Gorvel, J. P. (2012). The lipopolysaccharide core of Brucella abortus acts as a shield against innate immunity recognition. *PLoS Pathogens*, *8*(5), e1002675.

Cui, G., Wei, P., Zhao, Y., Guan, Z., Yang, L., Sun, W., & Peng, Q. (2014). Brucella infection inhibits macrophages apoptosis via Nedd4-dependent degradation of calpain2. *Veterinary Microbiology*, *174*(1-2), 195-205.

Cutler, S. J., Whatmore, A. M., & Commander, N. J. (2005). Brucellosis–new aspects of an old disease. *Journal of Applied Microbiology*, *98*(6), 1270-1281.

Fontana, C., Conde-Álvarez, R., Ståhle, J., Holst, O., Iriarte, M., Zhao, Y., & Widmalm, G. (2016). Structural studies of lipopolysaccharide-defective mutants from Brucella melitensis identify a core oligosaccharide critical in virulence. *Journal of Biological Chemistry*, *291*(14), 7727-7741.

Galinska, E. M., & Zagórski, J. (2013). Brucellosis in humans-etiology, diagnostics, clinical forms. *Annals of Agricultural and Environmental Medicine*, *20*(2).

Golshani, M., & Buozari, S. (2017). A review of brucellosis in Iran: epidemiology, risk factors, diagnosis, control, and prevention. *Iranian Biomedical Journal*, *21*(6), 349.

Gul, S. T., & Khan, A. (2007). Epidemiology and epizootology of brucellosis: A review. *Pakistan Veterinary Journal*, *27*(3), 145.

Gupta, V. K., Nayakwadi, S. N., Kumar, A. K., Gururaj, K. G., Kumar, A. K., & Pawaiya, R. S. (2014). Markers for the molecular diagnosis of brucellosis in animals. *Advances in Animal and Veterinary Sciences, 2*(3), 31-39.

Hou, H., Liu, X., & Peng, Q. (2019). The advances in brucellosis vaccines. *Vaccine, 37*(30), 3981-3988.

Jamil, T., Khan, A. U., Saqib, M., Hussain, M. H., Melzer, F., Rehman, A., & Schwarz, S. (2021). Animal and human brucellosis in Pakistan. *Frontiers in Public Health*, *9*, 660508.

Khurana, S. K., Sehrawat, A., Tiwari, R., Prasad, M., Gulati, B., Shabbir, M. Z., & Chaicumpa, W. (2021). Bovine brucellosis–a comprehensive review. *Veterinary Quarterly, 41*(1), 61-88.

Kiros, A., Asgedom, H., & Abdi, R. D. (2016). A review on bovine brucellosis: Epidemiology, diagnosis and control options. *ARC Journal of Animal and Veterinary Sciences*, *2*(3), 8-21.

Ma, R., Li, C., Gao, A., Jiang, N., Feng, X., Li, J., & Hu, W. (2024). Evidence-practice gap analysis in the role of tick in brucellosis transmission: a scoping review. *Infectious Diseases of Poverty, 13*(1), 3.

Megid, J., Mathias, L. A., & Robles, C. (2010). Clinical manifestations of brucellosis in domestic animals and humans. *The Open Veterinary Science Journal*, *4*, 119-126.

Moriyón, I., Blasco, J. M., Letesson, J. J., De Massis, F., & Moreno, E. (2023). Brucellosis and one health: inherited and future challenges. *Microorganisms*, *11*(8), 2070.

Nielsen, K., & Yu, W. L. (2010). Serological diagnosis of brucellosis. *Prilozi*, *31*(1), 65-89.

Pal, M., Gizaw, F., Fekadu, G., Alemayehu, G., & Kandi, V. (2017). Public health and economic importance of bovine Brucellosis: an overview. *American Journal of Epidemiology*, *5*(2), 27-34.

Pal, M., Kerorsa, G. B., Desalegn, C., & Kandi, V. (2020). Human and animal brucellosis: a comprehensive review of biology, pathogenesis, epidemiology, risk factors, clinical signs, laboratory diagnosis. *American Journal of Infectious Diseases*, *8*(4), 118-126.

Pappas, G., & Papadimitriou, P. (2007). Challenges in Brucella bacteraemia. *International Journal of Antimicrobial Agents*, *30*(1), 29-31.

Pappas, G., Papadimitriou, P., Akritidis, N., Christou, L., & Tsianos, E. V. (2006). The new global map of human brucellosis. *The Lancet Infectious Diseases*, *6*(2), 91-99.

Park, S. E., Graham, R., Prucha, M. J., & Brannon, J. M. (1932). Pasteurization of milk artificially infected with two strains of Brucella suis. *Journal of Bacteriology*, *24*(6), 461-471.

Poester, F. P., Nielsen, K., Samartino, L. E., & Yu, W. L. (2010). Diagnosis of brucellosis. *Open Veterinary Science Journal*, *4*(1), 46-60.

Sangari, F. J., Seoane, A., Rodríguez, M. C., Agüero, J., & García Lobo, J. M. (2007). Characterization of the urease operon of Brucella abortus and assessment of its role in virulence of the bacterium. *Infection and Immunity*, *75*(2), 774-780.

Schelling, E., Diguimbaye, C., Daoud, S., Nicolet, J., Boerlin, P., Tanner, M., & Zinsstag, J. (2003). Brucellosis and Q-fever seroprevalences of nomadic pastoralists and their livestock in Chad. *Preventive Veterinary Medicine*, *61*(4), 279-293.

Seleem, M. N., Boyle, S. M., & Sriranganathan, N. (2008). Brucella: a pathogen without classic virulence genes. *Veterinary Microbiology*, *129*(1-2), 1-14.

Seleem, M. N., Boyle, S. M., & Sriranganathan, N. (2010). Brucellosis: a re-emerging zoonosis. *Veterinary Microbiology*, *140*(3-4), 392-398.

Skendros, P., & Boura, P. J. R. S. T. (2013). Immunity to brucellosis. *Revue scientifique et technique (International Office of Epizootics)*, *32*(1), 137-147.

Tabar, G. H., & Jafari, A. (2014). Preventive and control programs for brucellosis in human and animals. *Journal of Zoonoses*, *1*(1).

Tuon, F. F., Gondolfo, R. B., & Cerchiari, N. (2017). Human-to-human transmission of Brucella–a systematic review. *Tropical Medicine & International Health*, *22*(5), 539-546.

Zhang, J., Sun, G. Q., Sun, X. D., Hou, Q., Li, M., Huang, B., & Jin, Z. (2014). Prediction and control of brucellosis transmission of dairy cattle in Zhejiang Province, China. *PLoS One*, *9*(11), e108592.

Zhang, N., Zhou, H., Huang, D. S., & Guan, P. (2019). Brucellosis awareness and knowledge in communities worldwide: A systematic review and meta-analysis of 79 observational studies. *PLoS Neglected Tropical Diseases*, *13*(5), e0007366.