Role of Vaccination and Immunization for the Prevention of Zoonotic Diseases

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Abstract

Zoonotic diseases pose a significant threat worldwide as they affect all ages, sexes, and settings and cause high morbidity and mortality. These diseases involve multiple transmission modes and are exacerbated by global trade, animal husbandry, climate change, and antibiotic resistance. They have a significant impact on the food industry, affecting food safety, food production, trade and commerce, which directly influence human health. Newly emerging and reemerging zoonoses require innovative vaccination strategies. New-Generation Vaccines have been developed to combat zoonoses which include viral vector, DNA-based, mRNA and subunit vaccines. Recent advancements in mRNA vaccines have shown promising results as they are stable, affordable, induce strong immune responses in trials, flexible, adaptable and have potential for combination vaccines. There is a great need for interdisciplinary collaboration through One Health approach to developing strong surveillance systems, extensive vaccination drives and make preventive measures to mitigate zoonotic disease impacts on human health, livestock and the environment.

Keywords: Zoonotic, Vaccination, Immunization, Prevention and Control

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Introduction

Zoonotic diseases are infectious diseases or pathogens that can be transmitted naturally and directly or indirectly from vertebrates (such as mammals, birds, reptiles, and amphibians) to humans or from humans to vertebrate animals (Qureshi et al., 2023). The transmission of these diseases is possible by multiple routes as direct contact with infected animals or their tissues, contaminated food, water, or fomites (Qureshi et al., 2022). It is also transmitted by air or by vectors, including insects, flies, ticks and fleas (Abbas et al., 2024; Fatima et al., 2023). Various pathogens, such as bacteria, viruses, parasites, protozoa and fungi, are the cause of zoonotic diseases (Siddique et al., 2023). Some common zoonotic diseases are rabies, anthrax, salmonellosis, brucellosis, rift valley fever, lyme disease, avian influenza, leptospirosis and tuberculosis (Muqadas et al., 2023; Qureshi et al., 2023). The recent and devastating zoonotic disease was COVID-19, which affects large human population (Mishra et al., 2021). Over 60% of human infections originate from zoonotic sources (Abebe et al., 2020).

Climate change, urbanization, animal trading, tourism, urban growth, human migration, habitat destruction, biodiversity loss, and human behavior are all interconnected factors that have great influence on zoonoses (Fatima et al., 2023). Zoonotic diseases greatly affect both animals and humans and lead to severe morbidity, mortality, and economical losses (Rahman et al., 2020). Both humans and animals are strongly connected in cases where zoonotic diseases in animals impair animal health and productivity and directly reduce the availability of nutritious food products necessary for human health and wellbeing (Magouras et al., 2020). The transmission of diseases from animals to humans can have severe and sometimes fatal outcomes, highlighting the necessity of vigilance and mitigating strategies (Singh et al., 2024).

Vaccines are considered one of the most important public health achievements in controlling and eliminating numerous infectious diseases, saving millions of lives, and improving the quality of life (Rodrigues & Plotkin, 2020). Vaccines have two primary objectives which are to defend vulnerable individuals against infection or disease and prevent the propagation of infectious agents by creating a barrier of immunity (Wagner & Weinberger, 2020). Vaccine is a cost-effective solution and proves a powerful tool for saving and promoting animal health, ensuring food and economic security. All these benefits making vaccines an essential component of public health strategies. However, botanical compounds are under study as an alternative control strategy for various zoonotic diseases (Abbas et al., 2025).

Categorization of Zoonoses

Zoonotic diseases are triggered by a diverse array of microorganism. Zoonoses are classified into multiple types based on etiology, direction of transmission, and route of transmission (Esch & Petersen, 2013). Zoonoses are classified into the following groups listed in Table 1

Table 1: Classification of Zoonotic Diseases

Based on Etiology		
Sr. no.	Types of zoonoses	Examples
1.	Bacterial zoonoses (caused by bacteria)	Anthrax, salmonellosis, tuberculosis, lyme disease, brucellosis, leptospirosis and plague
2.	Viral zoonoses (caused by viruses)	Rabies, acquired immune deficiency syndrome- AIDS, ebola, rift valley fever, monkeypox, crimean-Congo Hemorrhagic fever, severe acute respiratory syndrome (SARS), COVID-19 and avian influenza
3.	Parasitic zoonoses (caused by parasites)	Trichinosis, toxoplasmosis, trematodosis, giardiasis, malaria, hydatid disease, schistosomiasis and echinococcosis
4.	Fungal zoonoses (caused by fungus)	Ring worm (dermatophytosis), cryptococcosis, coccidioidomycosis, aspergillosis and histoplasmosis
5.	Rickettsial zoonoses (caused by bites of infected ticks, fleas, and other arthropods)	Q-fever, anaplasmosis, Rocky Mountain Spotted Fever, typhus, ehrlichiosis
6.	Chlamydial zoonoses (by bacteria of the genus Chlamydia)	Psittacosis, Chlamydophila abortus
7.	Mycoplasma zoonoses (caused by bacteria of the genus Mycoplasma)	Mycoplasma pneumoniae infection
8.	Protozoal zoonoses (caused by protozoan parasites)	Toxoplasmosis, trypanosomiasis, babesiosis, sarcocystosis, leishmaniasis, giardiasis and cryptosporidiosis
Based on direction of transmission		
9.	Anthropozoonoses (transmitted to humans by animals)	Rabies, lyme disease
10.	Zooanthroponoses (transmitted to animals from humans)	Tuberculosis in cat and monkey, Influenza
11.	Amphizoonoses (transmitted in any direction, from human to animal and from animal to human)	Staphylococcal infection, salmonellosis, campylobacteriosis
12.	Euzoonoses (disease primarily maintained in animal populations but can occasionally be transmitted to humans)	Leptospirosis, hantavirus, cysticercosis
Based on route		
13.	Direct Zoonosis (directly transmit to humans from animals by air or by bite)	Avian influenza, rabies
14.	Indirect zoonoses (Transmitted from animals to humans through an intermediate host or vector.)	Malaria, lyme disease, Plague, dengue fever

Emerging and Re-Emerging Zoonotic Diseases of Global Importance

The term "emerging and re-emerging diseases" describes infectious diseases that have increased more commonly among humans in the past 20 years or are predicted to become more prevalent (Tian et al., 2022). According to the World Health Organization (WHO), most of these diseases originate from animals and are transmitted to humans (Fong & Fong, 2017). The majority of zoonoses emerge from wildlife, while some come from domesticated animals and modern farming practices (Bengis et al., 2004).

Some of the main factors that are a cause of Emerging and Re-Emerging Zoonotic diseases are wildlife, ecosystem change, hunting and feeding on infected wild animals, human exposure to ticks of sheep and small wild animals, rodent exposure, international travel, bites from rabid dogs and drug resistance etc. (Tazerji et al., 2022). Increased population density and reduction in public health facilities are one of the causes of increasing susceptibility to outbreaks (Li et al., 2018). Outbreaks of zoonotic diseases can also be influenced by inadequate vaccination practices, poor sanitation, and concerns about food safety (Abebe et al., 2020).

Global healthcare organizations rank bacterial diseases as their top zoonotic concerns because they include anthrax, brucellosis, multidrug resistant TB and leptospirosis (Chowdhury et al., 2021). The list of urgent zoonotic diseases includes viral infections including Rift Valley Fever and monkeypox, Ebola, Zika, avian influenza (H5N1), West Nile, Middle East Respiratory Syndrome (MERS-CoV), Crimean-Congo Hemorrhagic fever and Rabies, Severe Acute Respiratory Syndrome (SARS) and COVID-19 as identified by Qureshi et al. (2023). Leishmaniasis together with hydatid disease and schistosomiasis and toxoplasmosis represent major parasitic conditions which affect the population. Fungal illnesses include cryptococcosis together with histoplasmosis (Chastain et al., 2017).

Basics of Immunity and Immunization

Immune system is the defense system of the body which protects against viruses and diseases and produces antibodies to kill pathogens (Sattler, 2017). It plays a crucial role in maintaining health and shields the body from harm caused by external factors (Rook, 2013). The main component is white blood cells, which travel through the body and monitor for invading microbes (Humphry & Armstrong, 2022). The lymphatic system plays a crucial role in exchanging cells and fluids between blood and lymphatic vessels (Petrova & Koh, 2020). Lymph nodes

contain specialized compartments where immune cells encounter antigens. Body possesses three types of immunity: innate, adaptive and passive immunity (Janeway Jr et al., 2001). Innate is the immediate response, adaptive is the delayed response and passive is the acquired immunity. Passive immunity is further divided into natural immunity (maternally derived) and artificial immunity (medicine or vaccine induced). In case a virus enters the body, the B cells, with the help of T cells, transform into plasma cells, which produce antibodies that specifically target a viral antigen (Dörner & Radbruch, 2007). These antibodies, particularly neutralizing ones, effectively block the virus from entering host cells, limiting infection and preventing relapses (Pantaleo et al., 2022). Meanwhile, T-lymphocytes mediate a cellular immunity response within infected cells (Lillehoj, 1991). Helper T cells direct the overall adaptive immune response, while cytotoxic T cells play a crucial role in eliminating infected cells (Copeland & Heeney, 1996).

To prevent the outbreak and spread of any disease, we vaccinate animals or humans to produce immunity against that disease before exposure (Monath, 2013). A vaccine typically contains antigens, which are basically proteins or sugars, that are derived from a disease-causing agent and stimulate the body's immune system to produce a targeted response (Bhattacharya et al., 2024). Immunizing companion animals can reduce the risk of transmission of zoonotic diseases to humans and vaccinating wildlife reservoirs can also potentially prevent the spread of disease to humans or domestic animals (Carpenter et al., 2022). However, vaccination to wild animals is challenging because of difficult access and their unpredictable behavior (Haydon et al., 2006). Vaccinating one species can help prevent disease in another is called indirect prevention. It is considered the best technique, but it can be costly and may have safety issues, and it is difficult to cover animals on a large scale. Concept of creating a vaccine that can be used for both human and animal health will increase market potential, enhance public health and reduces costs of development. There are different thoughts of developing vaccines which protect spread of zoonotic disease in both animals and humans. Veterinary vaccines are developed and approved faster than human vaccines because of simpler manufacturing requirement, easier clinical trials and no large-scale efficacy trials (Aida et al., 2021).

Type of Vaccines for Zoonotic Diseases

Older vaccines didn't work well and had safety issues. Killed and attenuated vaccines are used for many zoonotic diseases. Attenuated vaccines contain a weakened form of the pathogen and can provide long-term immunity and mimic natural infection (Chumakov et al., 2021). Killed vaccines contain an inactivated or killed form of the pathogen and provide short-term immunity and require multiple doses and booster shots to maintain immunity (Vetter et al., 2018). Attenuated vaccines can be administered orally or via mucosal routes, while killed vaccines are typically administered via injection. There are some limitations to their use like difficulty in developing effective vaccines for certain disease, limited use in immunocompromised individuals and risk of adverse effects, etc. Because of advancement of technology and a better understanding of the immune system, newer vaccines are being developed to address the limitations of earlier generation vaccines (Koff et al., 2013). There are different type of vaccines adjuvant. mRNA, DNA, viral vector and subunit vaccines etc.

An adjuvant is a vaccine additive that boosts and prolongs the body's immune response, making the vaccine more effective and release it in body slowly (Bastola et al., 2017). Alum is one of the common adjuvants and used in vaccines against hepatitis B, diphtheria, tetanus and human papilloma virus etc. oil in water is also considered as an adjuvant for vaccine. mRNA vaccines offer a promising solution for preventing and treating infectious diseases (Rzymski et al., 2023). It is beneficial because of the low risk of genetic mutation, high potency, rapid development and low-cost of production. These vaccines are developed against various zoonotic diseases like FMD, Ebola, influenza, rabies, and Zika virus, etc. DNA vaccines use a small, circular piece of DNA called a plasmid (Shafaati et al., 2022). This plasmid contains genetic instructions for making a specific protein from a pathogen, such as a virus or bacteria (Kazi et al., 2022). After injecting such vaccine cell take up the plasmid and produce antigenic protein which recognizes as foreign body and triggers an immune response, preparing the body to fight future infections. Viral vectors are modified viruses that deliver genetic material into cells, triggering an immune response. The different classes of this vaccine serve as tools for vaccine development through cell insertion of pathogen genetic components. The vaccine technology depends on using particular components of a pathogen to activate an immunological reaction through antigenic determinants and epitopes. The production technique for subunit vaccines remains straightforward while also providing better safety than traditional vaccines but patients typically need follow-up vaccinations for sustained protection (Kozak & Hu 2023).

Innovations in Vaccine Development

Immunization functions as an essential weapon that stops zoonotic diseases from affecting humans along with animals through the creation of a strong protective measure (Warimwe et al., 2021). Efficacy of the vaccines have been improved since the most recent advancement in the vaccine development technology. These include the formation of viral vector vaccines, recombinant protein subunit vaccines, and nucleic acid-based vaccines. These advancements offer enhanced safety, scalability, and adaptability in vaccine design. Moreover, improvements in adjuvant technology have augmented vaccine effectiveness and immune response durability. When One Health practices implement complete human-animal vaccination programs they succeed in blocking zoonotic disease transmission.

The creation of mRNA vaccines introduces an innovative anti-infectious disease strategy according to Chaudhary et al. (2021). By leveraging the cell's own machinery, mRNA vaccines produce specific antigens, eliciting a strong and targeted immune response. Modern vaccines based on mRNA technology allow quick development and production and affordable creation leading to faster responses against newly emerging infections.

Holistic Health Protection Strategy is necessary for protecting public health and controlling emerging infectious diseases (Singh et al., 2024). It includes effective communication techniques for raising awareness, promoting vaccination, and providing timely updates during outbreaks and measures to limit human contact with domestic and wild animals. Immunization and vaccination efforts should be prioritized, and it is essential to emphasize on developing innovative vaccine technologies (Kristensen et al., 2021).

Challenges in Implementing One Health and Innovation Strategies

Various sectors maintain independent operations in human health and veterinary medicine plus environmental conservation and this prevents collaborative information sharing (Horvat & Kovačević, 2025). The fundamental need for implementing One Health and developing vaccines is insufficient funding and scarce resources. Various sectors need their policies and regulatory barriers to transform into One Health approaches to support data exchange and enhance sectorial teamwork. The implementation requires training sessions to promote cross-sector work while raising public consciousness about One Health principles through educational initiatives. Fundamental vaccination efforts should inform the public about crucial health benefits for both human beings and animal species. Local communities who make their income from livestock production sometimes choose financial gains over protecting public wellness (Qureshi et al., 2023). The policy of restricting livestock movements together with animal culling hurts local economies which creates a challenging situation for maintaining proper health vs economic development balance.

Conclusion

Veterinary vaccines play a vital role in ensuring safe and efficient food production by preventing diseases in livestock and help ensure a safe and stable food supply. It also prevents diseases that can be transmitted from animals to humans, such as rabies and salmonellosis. Such vaccines help control the spread of emerging and exotic diseases, such as Avian influenza and African swine fever, and are very essential for combating antibiotic resistance issues. Recent advances in veterinary vaccines have led to the development of more effective and targeted vaccines, which include DNA vaccines, genetically engineered viral vaccines, live viral vector vaccines, and subunit vaccines. To protect both human and animal populations from infectious diseases, it's essential to continue researching and developing new vaccines which help to tackle emerging animal health issues. To solve all the zoonoses problem, we must adhere to the principles of One Health, which recognize the interconnectedness of human, animal, and environmental health and promote collaboration across disciplines to address health challenges.

References

Abbas, R. Z., Muqadas, Z. S., Qureshi, M. A., & Fatima, Z. (2024). Bovine brucellosis. *Biological Times*, *3*(6), 27-28.

Abbas, R. Z., Qureshi, M. A., & Saeed, Z. (2025). Botanical compounds: A promising control strategy against Trypanosoma cruzi. *Boletín Latinoamericano y del Caribe de Plantas Medicinales y Aromáticas*, *24*(3), 308-327.

Abebe, E., Gugsa, G., & Ahmed, M. (2020). Review on major food-borne zoonotic bacterial pathogens. *Journal of Tropical Medicine*, *2020*(1), 4674235.

Aida, V., Pliasas, V. C., Neasham, P. J., North, J. F., McWhorter, K. L., Glover, S. R., & Kyriakis, C. S. (2021). Novel vaccine technologies in veterinary medicine: a herald to human medicine vaccines. *Frontiers in Veterinary Science*, *8*, 654289.

Bastola, R., Noh, G., Keum, T., Bashyal, S., Seo, J.-E., Choi, J., Oh, Y., Cho, Y., & Lee, S. (2017). Vaccine adjuvants: smart components to boost the immune system. *Archives of Pharmacal Research*, *40*, 1238-1248.

Bengis, R. G., Leighton, F. A., Fischer, J. R., Artois, M., Morner, T., & Tate, C. M. (2004). The role of wildlife in emerging and re-emerging zoonoses. *Revue Scientifique et Technique-office International Des Epizooties*, *23*(2), 497-512.

Bhattacharya, S., Bohara, V. S., Sevda, S., & Kumar, S. (2024). Vaccine and vaccine types. In *Bioreactor Design Concepts for Viral Vaccine Production* (pp. 73-82). Elsevier.

Carpenter, A., Waltenburg, M. A., Hall, A., Kile, J., Killerby, M., Knust, B., Negron, M., Nichols, M., Wallace, R. M., & Behravesh, C. B. (2022). Vaccine preventable zoonotic diseases: challenges and opportunities for public health progress. *Vaccines*, *10*(7), 993.

Chastain, D. B., Henao-Martínez, A. F., & Franco-Paredes, C. (2017). Opportunistic invasive mycoses in AIDS: cryptococcosis, histoplasmosis, coccidiodomycosis, and talaromycosis. *Current Infectious Disease Reports*, *19*, 1-9.

Chaudhary, N., Weissman, D., & Whitehead, K. A. (2021). mRNA vaccines for infectious diseases: principles, delivery and clinical translation. *Nature Reviews Drug Discovery*, *20*(11), 817-838.

Chowdhury, S., Aleem, M. A., Khan, M. S. I., Hossain, M. E., Ghosh, S., & Rahman, M. Z. (2021). Major zoonotic diseases of public health importance in Bangladesh. *Veterinary Medicine and Science*, *7*(4), 1199-1210.

Chumakov, K., Avidan, M. S., Benn, C. S., Bertozzi, S. M., Blatt, L., Chang, A. Y., Jamison, D. T., Khader, S. A., Kottilil, S., & Netea, M. G. (2021). Old vaccines for new infections: Exploiting innate immunity to control COVID-19 and prevent future pandemics. *Proceedings of the National Academy of Sciences*, *118*(21), e2101718118.

Copeland, K. F., & Heeney, J. L. (1996). T helper cell activation and human retroviral pathogenesis. *Microbiological Reviews*, *60*(4), 722-742.

Dörner, T., & Radbruch, A. (2007). Antibodies and B cell memory in viral immunity. *Immunity*, *27*(3), 384-392.

Esch, K. J., & Petersen, C. A. (2013). Transmission and epidemiology of zoonotic protozoal diseases of companion animals. *Clinical Microbiology Reviews*, *26*(1), 58-85.

Fatima, Z., Qureshi, M. A., Muqadas, M. L., & Najaf, D. E. (2023). Heat stress in animals. *Biological Times*, *2*(6), 32-33.

Fatima, Z., Qureshi, M. A., Muqadas, M. L. S., & e Najaf, D. (2023). Crimean Congo Haemorrhagic Fever. *Biological Times*, *2*(6), 20-21.

Fong, I. W., & Fong, I. W. (2017). Animals and mechanisms of disease transmission. *Emerging Zoonoses: A Worldwide Perspective*, 15-38.

Haydon, D. T., Randall, D. A., Matthews, L., Knobel, D. L., Tallents, L. A., Gravenor, M. B., Williams, S. D., Pollinger, J. P., Cleaveland, S., & Woolhouse, M. E. J. (2006). Low-coverage vaccination strategies for the conservation of endangered species. *Nature*, *443*(7112), 692-695.

Horvat, O., & Kovačević, Z. (2025). Human and Veterinary Medicine Collaboration: Synergistic Approach to Address Antimicrobial Resistance Through the Lens of Planetary Health. *Antibiotics*, *14*(1), 38.

Humphry, E., & Armstrong, C. E. (2022). Physiology of red and white blood cells. *Anaesthesia & Intensive Care Medicine*, *23*(2), 118-122.

Janeway Jr, C. A., Travers, P., Walport, M., & Shlomchik, M. J. (2001). Principles of innate and adaptive immunity. In *Immunobiology: The Immune System in Health and Disease. 5th edition*. Garland Science.

Kazi, T. A., Acharya, A., Mukhopadhyay, B. C., Mandal, S., Arukha, A. P., Nayak, S., & Biswas, S. R. (2022). Plasmid-based gene expression systems for lactic acid bacteria: a review. *Microorganisms*, *10*(6), 1132.

Koff, W. C., Burton, D. R., Johnson, P. R., Walker, B. D., King, C. R., Nabel, G. J., Ahmed, R., Bhan, M. K., & Plotkin, S. A. (2013). Accelerating next-generation vaccine development for global disease prevention. *Science*, *340*(6136), 1232910.

Kozak, M., & Hu, J. (2023). The integrated consideration of vaccine platforms, adjuvants, and delivery routes for successful vaccine development. *Vaccines*, *11*(3), 695.

Kristensen, D., Giersing, B., Hickling, J., Kazi, F., Scarna, T., Kahn, A.-L., Hsu, V., Gandrup-Marino, K., & Menozzi-Arnaud, M. (2021). A global collaboration to advance vaccine product innovations–The Vaccine Innovation Prioritisation Strategy. *Vaccine*, *39*(49), 7191-7194.

Li, R., Richmond, P., & Roehner, B. M. (2018). Effect of population density on epidemics. *Physica A: Statistical Mechanics and its Applications*, *510*, 713-724.

Lillehoj, H. S. (1991). Lymphocytes involved in cell-mediated immune responses and methods to assess cell-mediated immunity. *Poultry Science*, *70*(5), 1154-1164.

Magouras, I., Brookes, V. J., Jori, F., Martin, A., Pfeiffer, D. U., & Dürr, S. (2020). Emerging zoonotic diseases: should we rethink the animal–human interface? *Frontiers in Veterinary Science*, *7*, 582743.

Mishra, J., Mishra, P., & Arora, N. K. (2021). Linkages between environmental issues and zoonotic diseases: with reference to COVID-19 pandemic. *Environmental Sustainability*, *4*(3), 455-467.

Monath, T. P. (2013). Vaccines against diseases transmitted from animals to humans: a one health paradigm. *Vaccine*, *31*(46), 5321-5338.

Muqadas, A. S., Qureshi, A., Imdad, N., Fatima, Z., Khalid, A., Ahmad, B., & Sindhu, I. A. (2023). Rift valley fever. *One Health Triad, Unique Scientific Publishers, Faisalabad, Pakistan*, *3*, 151-156.

Pantaleo, G., Correia, B., Fenwick, C., Joo, V. S., & Perez, L. (2022). Antibodies to combat viral infections: development strategies and progress. *Nature Reviews Drug Discovery*, *21*(9), 676-696.

Petrova, T. V., & Koh, G. Y. (2020). Biological functions of lymphatic vessels. *Science*, *369*(6500), eaax4063.

Qureshi, M. A., Fatima, Z., Muqadas, M. L., & Najaf, D. E. (2023). Rabies; A Potential Human Threat. *Biological Times*, *2*(3), 9-10.

Qureshi, M. A., Fatima, Z., Muqadas, S. M. L., Najaf, D. E., Husnain, M., Moeed, H. A., & Ijaz, U. (2023). Zoonotic diseases caused by mastitic milk. *Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan*, *4*, 557-572.

Qureshi, M. A., Samad, M. A., & Muqadas, Z. F. (2022). An Overview of Avian Flu. *Biological Times*, *1*(1), 3.

Rahman, M. T., Sobur, M. A., Islam, M. S., Ievy, S., Hossain, M. J., El Zowalaty, M. E., Rahman, A. M. M. T., & Ashour, H. M. (2020). Zoonotic diseases: etiology, impact, and control. *Microorganisms*, *8*(9), 1405.

Rodrigues, C. M. C., & Plotkin, S. A. (2020). Impact of vaccines; health, economic and social perspectives. *Frontiers in Microbiology*, *11*, 1526.

Rook, G. A. (2013). Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health. *Proceedings of the National Academy of Sciences*, *110*(46), 18360-18367.

Rzymski, P., Szuster-Ciesielska, A., Dzieciątkowski, T., Gwenzi, W., & Fal, A. (2023). mRNA vaccines: The future of prevention of viral infections? *Journal of Medical Virology*, *95*(2), e28572.

Sattler, S. (2017). The role of the immune system beyond the fight against infection. *The immunology of Cardiovascular Homeostasis and Pathology*, 3-14.

Shafaati, M., Saidijam, M., Soleimani, M., Hazrati, F., Mirzaei, R., Amirheidari, B., Tanzadehpanah, H., Karampoor, S., Kazemi, S., & Yavari, B. (2022). A brief review on DNA vaccines in the era of COVID-19. *Future Virology*, *17*(1), 49-66.

Siddique, M. H., Samad, M. A., MemoonA, N., Rehman, F. U., Kalim, F., Ali, A., & Khawar, W. (2023). Burkholderia (mallei and pseudomallei) Related Zoonosis Drastic Zoonotic and Biological Warfare Potential. *Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan*, *4*, 82-99.

Singh, S., Sharma, P., Pal, N., Sarma, D. K., Tiwari, R., & Kumar, M. (2024). Holistic one health surveillance framework: synergizing environmental, animal, and human determinants for enhanced infectious disease management. *ACS Infectious Diseases*, *10*(3), 808-826.

Tazerji, S. S., Nardini, R., Safdar, M., Shehata, A. A., & Duarte, P. M. (2022). An overview of anthropogenic actions as drivers for emerging and re-emerging zoonotic diseases. *Pathogens*, *11*(11), 1376.

Tian, Y., Hu, D., Li, Y., & Yang, L. (2022). Development of therapeutic vaccines for the treatment of diseases. *Molecular Biomedicine*, *3*(1), 40.

Vetter, V., Denizer, G., Friedland, L. R., Krishnan, J., & Shapiro, M. (2018). Understanding modern-day vaccines: what you need to know. *Annals of Medicine*, *50*(2), 110-120.

Wagner, A., & Weinberger, B. (2020). Vaccines to prevent infectious diseases in the older population: immunological challenges and future perspectives. *Frontiers in Immunology*, *11*, 717.

Warimwe, G. M., Francis, M. J., Bowden, T. A., Thumbi, S. M., & Charleston, B. (2021). Using cross-species vaccination approaches to counter emerging infectious diseases. *Nature Reviews Immunology*, *21*(12), 815-822.