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# Current Innovations in the Diagnosis and Immunization of Emerging and Re-Emerging Zoonoses

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**Abstract** Zoonoses caused by multiple etiological agents pose a serious threat to humans as well as animals globally. These diseases affect both the sexes, all age groups, in rural and urban settings, and in all seasons. Zoonotic diseases occur in sporadic as well as in epidemic form causing high morbidity and mortality. Most zoonoses involve multiple modes of transmission, such as ingestion, direct contact, inhalation, animal bite and others. Also, more than 60% of recently emerging viruses exhibit zoonotic characteristics, thereby posing a significant menace to global public health. The spread of these diseases is mostly caused by a number of factors, such as global trade, intensive animal husbandry, climate change, variations to immunization protocols, and antibiotic resistance. Effective disease control necessitates the interdisciplinary collaboration advocated by the One Health approach. This study investigates novel diagnostic and vaccination techniques while doing a detailed analysis of newly emerging and re-emerging zoonoses and explaining the factors that led to their emergence. Next-generation sequencing and rapid diagnostic testing are examples of technological innovations that have improved disease surveillance and detection. Furthermore, advancements in mRNA vaccines show promising future, albeit their broad applicability is yet uncertain. Putting preventive and control measures into action- such as One Health campaigns, strong surveillance systems, and extensive vaccination drives- is essential to limit the adverse effects of zoonotic diseases on people's health, livestock and the environment.

***Keywords:*** *emerging infectious disease, factors, innovation, One Health, Re-emerging zoonoses*

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## 1. Introduction

Zoonotic diseases, or infections that can naturally transfer from vertebrate animals to humans, are significant worldwide health concern (Pal, 2005) [1]. Nearly 60% of newly discovered pathogens globally are zoonotic, meaning that 75% of these diseases originate in animals and spread to human beings (Tomori and Oluwayelu, 2023) [2]. Both in human and animal populations, the prevalence of newly emerging zoonotic disease outbreaks is rising. Some of these diseases have the potential to spread geographically or develop resistance to treatment (Alula, 2012) [3]. In addition, infectious diseases that have resurfaced are posing new concerns despite experiencing a significant drop (Alula, 2012) [3]. West Nile fever, Ebola virus disease, Zika fever, Avian Influenza, Middle East Respiratory Syndrome, Swine Influenza, Severe Acute Respiratory Syndrome, COVID-19, Nipah virus infection, and Monkeypox are just a few of the diseases that have emerged or returned in recent years, posing significant threats to the health of human beings, livestock and the environment (Rechel *et al.*, 2013; Pal and Mahendra, 2015; Pal and Gutama, 2021; Pal and Gutama, 2022; Haruna *et al.*, 2023; Pal and Gutama, 2024) [4,5,6,7,8,9]. Furthermore, there is a revival of historical zoonotic diseases, such as rabies, anthrax, leptospirosis, and tuberculosis due to several reasons, including the transfer of viruses from wild animals to domestic animals (Chomel *et al.*, 2007; Shaw, 2009) [10,11]. Several factors are associated with the emergence and resurgence of diseases. These include global trade, intensified animal husbandry, public health infrastructure, antimicrobial resistance, climate fluctuations, and lax vaccination policies (Elavarasi *et al.*, 2019) [12]. In this context, Belay and co-workers (2021) [13] reported that these components aid in the spread of diseases via species barriers and various environmental niches. In response, the cooperative, interdisciplinary One Health paradigm aims for optimal health outcomes for individuals, livestock, and the surroundings. This strategy advocates for sustainable development programs while placing a high priority on zoonotic disease prevention, surveillance, early detection, and containment (Banović *et*

*al.*, 2021) [14].

Novel diagnostic approaches are essential to identify new diseases, promote vaccine development, and improve the health of human and animal species. Therefore, the success of future technological initiatives depends on the development of veterinary diagnostic testing and the effective distribution of vaccines.The following are the objectives of the study:

- To carry out a thorough analysis of newly developing and resurgent zoonotic diseases, identifying the elements that contribute to their occurrence.
- To carefully examine the most recent developments in the identification and prevention of infectious diseases.
- To suggest methods for controlling and preventing the spread of these diseases.

## 2. Emerging and Re-Emerging Zoonoses

**Table 1. Some of the Most Commonly Prioritized Zoonotic Diseases Worldwide**

| Bacterial | Viral | Parasitic | Fungal |
|---|---|---|---|
| Anthrax, | Rift Valley Fever | Leishmaniasis | Cryptococcosis |
| Brucellosis, | Monkeypox Disease | Hydatid Disease | Histoplasmosis |
| Multidrug-resistant TB | West Nile | Schistosomiasis | |
| Leptospirosis | Ebola Virus | | |
| | Zika Virus | Toxoplasmosis | |
| | Avian Influenza (H5N1) | | |
| | Middle East Respiratory Syndrome (MERS-Cov) | | |
| | Swine Influenza (H1N1) | | |
| | Severe Acute Respiratory Syndrome (SARS) | | |
| | COVID-19 | | |

Source: WHO, 2022 [44]; Haruna *et al*., 2023 [8].

The term "emerging and re-emerging diseases" was initially introduced in 1987 by Mary Wilson, Joshua Lederberg, and Robert B. Shope. It is used to describe infectious diseases that have surged in frequency in human populations during the past 20 years or those that are predicted to rise in frequency subsequently. A high percentage of emerging and re-emerging infectious diseases, according to the World Health Organization (WHO, 2021) [15], have zoonotic origins, which means that they were initially transmitted from animals to humans across the species barrier. Most of zoonoses emerge from wildlife reservoirs, while some have originated from domesticated animals and modern animal husbandry techniques (Jones *et al.*, 2008; Stephens *et al.*, 2021) [16,17]. In accordance with the World Health Organization, zoonotic diseases are infections that are transmitted from non-human animals to people and can be bacterial, fungal, viral, or parasitic. (Rahman *et al*., 2020) [18]. As stated by Haruna and others (2023) [8], a range of zoonotic diseases that are emerging or have re-emerged before (see Table 1) have triggered epidemics and pandemics that have significant global implications.

## 3. Key Factors Affecting the Emerging and Re-emerging Zoonotic Diseases

The intricate geography of re-emerging and emerging zoonoses is shaped by a multitude of biological, socio-demographic, and environmental factors. The dynamics of disease genesis and transmission are determined by the interactions between pathogens, hosts, and their surrounding environment. When it comes to the establishment of infectious diseases, environmental factors are especially important. Inadequate land management techniques and unsustainable resource extraction can upset ecosystems, which may weaken the natural barriers that prevent disease formation. Floods, droughts, and forest fires are examples of climate change-related occurrences that worsen ecosystem disruptions and, as a result, promote conditions that encourage the spread of diseases (Erkyihun and Alemayehu, 2022) [19]. Furthermore, pollution of the air, water, and soil, a sign of environmental degradation, has been linked to the speed of the replication of disease (Multi-partner, 2021) [20].

**Table 2. Some Examples of Emerging and Re-Emerging Infectious Diseases and Their Root Causes (Factors)**

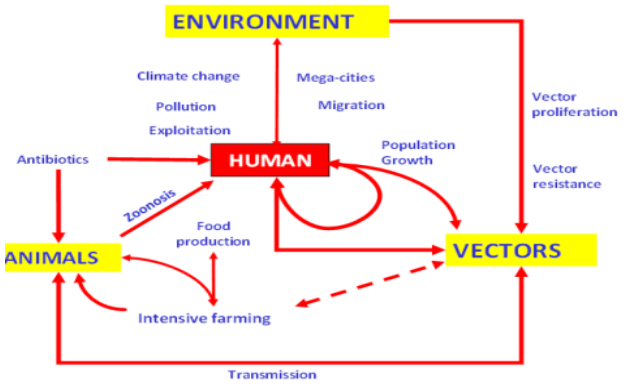
| Disease | Contributing Factor |
|---|---|
| Middle East respiratory syndrome | Wildlife, travel |
| Highly Pathogenic Avian Influenza (HPAI) viruses | Animal-animal influenza virus gene reassortment; emergence of H5N1 avian influenza, extensive chicken farming |
| Ebola virus | Technology and Industry Developments (Health care) |
| Leptospirosis | Ecosystem change |
| Severe acute respiratory syndrome | Hunting and feeding on infected wild animals |
| Crimean-Congo Haemorrhagic fever | Ecological changes favoring increased human exposure to ticks of sheep and small wild animals |
| Lassa fever | Hospital exposure to index case—rodent exposure |
| Cryptosporidiosis | Inadequate control of water supply, international travel, increased use of child-care facilities |
| Rabies | Breakdown in public health measures, change in land use, travel, bites from rabid dogs |
| Rift Valley fever | Climate change |
| Tuberculosis | Drug resistance; Breakdown in public health or control measures |

Adapted from Rabozzi *et al*. (2012) [24], Nii-Trebi (2017) [25], Elvarasi *et al*. (2019) [12], Stevenson and Halpin (2021) [26]

Infectious disease onset as well as transmission are significantly influenced by sociodemographic variables. Increased population density increases the probability of host-microbe interactions, which in turn facilitates the spread of diseases. Additionally, the reduction in public health facilities could render it more difficult to implement

efficient disease management strategies, increasing the susceptibility to outbreaks (Defo, 2014) [21]. The rapid spread of infectious diseases across geographical borders is facilitated by rising human mobility, and the disruption of healthcare systems by social unrest and conflicts can exacerbate disease transmission. Furthermore, a reduction in biodiversity, an increase in the interaction between disease vectors and hosts, and a rise in the spread of disease among domestic animals, wild animals, and humans have resulted from the fragmentation of wildlife habitats caused by the expansion of metropolitan areas, infrastructure, and unrestricted exploitation such as extensive hunting, trading, and consumption. (Tidman *et al.*, 2021) [22]

Biological factors like mutations in genome of virus are significant factors. Drug-resistant pathogen strains can emerge as a consequence of chemical and antimicrobial agent exposure, making disease management and therapeutic interventions more challenging (Alcaïs *et al.*, 2009) [23]. Moreover, factors including lapses in vaccination protocols, inadequate sanitation procedures, and worries about food safety may significantly influence the emergence and spread of diseases (Elavarasi *et al.*, 2019) [12].




**Source:** (Elvarasi *et al*., 2019) [12]

**Figure 1.** The global initiative for emerging infectious diseases aims to combat the threat of new and dangerous diseases

## 4. Innovative Approaches to Diagnosing and Immunizing Against Infectious Diseases

### 4.1. Innovation in Diagnosis

The global economy and public health are facing a growing crisis due to the prevalence of newly emerging and re-emerging diseases. In this context, diagnostic techniques are essential for disease identification and play a crucial role in treatment, preventive, and control efforts (Castelli and Sulis, 2017) [27]. Advances in the diagnostics of infectious diseases have significantly improved our ability to identify and understand the microbiological world. From the invention of the light microscope in 1716 until the introduction of polymerase chain reaction (PCR) in 1983 (Falkow, 2004) [28], the primary goal of these developments has been the identification and clarification of microbiological species. Later developments have focused on improving pathogen detection portability, efficiency, and speed of pathogen detection methods.

Recent advances in diagnostic technologies have revolutionized the detection of zoonotic pathogens, enabling faster and more accurate identification in both clinical and environmental samples. Molecular diagnostic techniques, such as polymerase chain reaction (PCR) and next-generation sequencing (NGS) have significantly improved the sensitivity and specificity of pathogen detection. These methods allow for the rapid characterization of novel pathogens as well as the monitoring of their genetic evolution.

The Next Generation Sequencing (NGS) technologies are of paramount significance since they provide higher sensitivity, specificity, and economy of scale as compared to conventional methods (Caliendo *et al.*, 2013) [29]. These advancements make it possible to diagnose and monitor infectious diseases quickly and precisely, which is crucial for tracking outbreaks of epidemics and pandemics in real time (Ellwanger et al., 2019) [30]. NGS makes it easier to examine pathogen genomes meticulously, which helps with epidemic management and investigation (Lo Cascio et al., 2020) [31]. Notably, during the Ebola epidemic of 2014 in West Africa, NGS played a crucial role in tracking the transmission of virus and locating potential treatment facilities.

The diagnosis of infectious diseases has changed in the 21st century, progressing and surpassing traditional laboratory procedures. According to Fournier and others (2013) [32], molecular techniques such as point-of-care diagnostics and gene sequencing, mass spectrometry, and rapid immunoassays have become standard procedures. The development of point-of-care testing (POCT) devices has facilitated on-site diagnosis in resource-limited settings, enabling timely intervention and control measures. Viral disease surveillance and monitoring have been transformed by innovations including Digital Platforms, Next-Generation Sequencing Technologies, Swift Diagnostic Procedures, and Nanoparticle-Based Lateral Flow Biosensors.

In the field of pathogen identification, Rapid Diagnostic Tests (RDTs) have become a major breakthrough, especially in areas where access to advanced laboratory facilities is limited. These tests get over the logistical challenges associated with conventional laboratory-based assays and provide a rapid and effective way to identify particular diseases. The creation of a pan-species CoV RT-PCR assay, demonstrating the ability to identify different coronaviruses across human, animal, and environmental samples, serves as an instructive example. Wang *et al.* (2021) [33] stated that this assay might prove to be an effective tool for screening for the early detection of coronavirus outbreaks or potential pandemics, allowing for timely intervention and containment measures in both human and animal populations.

Additionally, further noteworthy advancement in molecular diagnostics is Loop-Mediated Isothermal Amplification (LAMP), which has a number of benefits over traditional PCR-based techniques. Through the use of multiple primers that target distinct portions of the target DNA sequence, LAMP improves amplification specificity

and reduces the possibility of false-positive results. LAMP assays are also particularly well-suited for implementation in resource-constrained environments due to their streamlined workflow, which requires less sample preparation and eliminates the need for complex laboratory equipment. According to Barac *et al.* (2020) [34], the ability of LAMP to detect pathogens rapidly and efficiently in many kinds of environments with limited access to conventional laboratory facilities renders it a priceless instrument for point-of-care testing and fieldwork.

A paradigm changes in identifying diseases has been brought about by nanotechnology and microtechnology, which have enabled the development of highly sensitive diagnostic platforms such as lateral flow biosensors based on nanoparticles. These developments have greatly improved disease management and diagnosis, particularly in isolated or in areas with scarce resources (Li *et al.*, 2020) [35].

In addition, wearables, drones, mobile devices, and temperature scanning technologies have become indispensable instruments for monitoring and surveillance of diseases. These digital platforms provide real-time data on disease incidence and transmission, which aids in the early detection and management of infectious disease outbreaks such as Dengue fever and Zika virus infections (Donelle *et al.*, 2023) [36]. These platforms also support public health initiatives by being essential in tracking vaccination uptake and efficacy. When everything is considered, advances in infectious disease testing have great potential to enhance public health outcomes by facilitating prompt and precise detection, monitoring, and management of infectious diseases. These developments could drastically lessen the negative effects of infectious illnesses on the economy and public health throughout the world.

### 4.2. Innovation in Immunization

Vaccination remains one of the most effective strategies for preventing zoonotic diseases in both humans and animals by creating a significant barrier. Recent advancements in vaccine development have focused on novel platforms, such as recombinant protein subunit vaccines, viral vector vaccines, and nucleic acid-based vaccines. These platforms offer advantages, such as improved safety, scalability, and flexibility in vaccine design. Additionally, advancements in adjuvant technology have enhanced vaccine efficacy and durability of immune responses. Furthermore, One Health approaches that integrate human and animal vaccination programs have shown promising results in controlling zoonotic transmission at the human-animal interface.

The invention of mRNA vaccines has significantly boosted immunization efforts against infectious diseases by harnessing the cellular machinery to generate targeted antigens and trigger robust immune responses. In contrast to traditional vaccinations, mRNA vaccines provide rapid and affordable development and manufacturing along with the potential to swiftly adapt to new infections (Sahin *et al.*, 2014) [37]. The COVID-19 pandemic has drawn attention on the importance of adaptation in mitigating the problems presented by rapidly developing infectious illnesses. Although mRNA vaccines are innovative and show promise for some Emerging Infectious Diseases (EIDs). For several kinds of EIDs, including those brought on by bacteria or gastrointestinal bacteria, it is still too soon to declare that they constitute a universal vaccination technique (Excler *et al.*, 2021) [38].

Furthermore, even though numerous DNA vaccines have been permitted for application in animal medicine and documented to be safe and immunogenic in human clinical studies, none of these vaccines have been certified for use in humans (Liu, 2019) [39].

## 5. Zoonotic Disease: Comprehensive Prevention and Control Strategies

Despite significant progress, challenges remain in the diagnosis and immunization of emerging and re-emerging zoonoses which include the need for improved surveillance systems, enhanced global collaboration, and sustainable funding mechanisms. Furthermore, addressing vaccine hesitancy and ensuring equitable access to vaccines are critical for achieving herd immunity and preventing disease outbreaks.

The implementation of a transboundary and multidisciplinary approach, like "One Health" is essential to address the complex containment problems presented by re-emerging and new zoonotic diseases (Prasad *et al.*, 2020) [40]. Within the context of One Health approach, laws controlling animal mobility is combined with a deep understanding of the ecological dynamics of zoonoses (Ellwanger *et al.*, 2021) [41]. Furthermore, it is crucial to promote personal hygiene practices, especially in areas with limited resources. To this end, extensive awareness campaigns and the provision of medical and diagnostic facilities at both local and national levels are required.

Moreover, the development or reinforcement of surveillance systems is vital for tracking potential zoonotic threats (Simonin, 2023) [42], which incorporates early warning systems that rapidly identify epidemics of national and global public health concern.

In order to facilitate strategies for prevention, laboratory science and epidemiology must be integrated with public health data about emerging diseases in an efficient manner (Moro *et al.*, 2013) [43]. To mitigate medication resistance, it is essential to enforce international health rules, promote global collaboration, and employ antimicrobials sparingly (WHO, 2022) [44]. Maintaining adequate environmental sanitation, which implies having access to sewage systems and purified water, is essential for lowering the risk of disease spread. Maintaining biodiversity is essential to the balance of host-pathogen ecology, which lowers the probability of new infectious illnesses developing.

Immunization and vaccination against diseases that can be eliminated by vaccination (VPDs) are two very effective preventative measures. Furthermore, limiting human contact with domestic and wild animals can dramatically reduce the occurrence of newly discovered infectious diseases (Ellwanger *et al.*, 2021) [41]. Protecting public health and controlling the spread of emerging infectious diseases necessitate a multifaceted approach that includes efficient communication techniques, environmental control, and vaccination campaigns (Pal, 2013) [45].

## 6. Conclusion and Recommendations

The surging prevalence of emerging and re-emerging infectious diseases poses noteworthy concerns for the global population, economy, and environment. The emergence and spread of these diseases are attributed to various factors, including but not limited to international trade, intensive animal farming, antibiotic resistance, climate change, and inadequate public health infrastructure. In order to effectively address these complex concerns, the One Health approach -which emphasizes collaboration among the human, animal, and environmental health sectors- is essential.

Our capacity to identify and track infectious diseases has significantly increased as a result of the development of novel diagnostic tools like nanotechnology, loop-mediated isothermal amplification, quick diagnostic testing, and next-generation sequencing.

By enabling prompt and precise diagnosis, monitoring, and management, these developments eventually minimize the impact that infectious diseases impose on society. Similarly, new developments in vaccination, especially with regard to mRNA vaccines, present encouraging paths forward in combating against infectious diseases. Despite the efficacy of mRNA vaccines against certain viruses such as SARS-CoV-2, additional investigation is needed to ascertain their wider relevance about diverse infectious ailments. These findings lead to the following suggestions being made:

- Boost global coordination and collaboration to tackle emerging and re-emerging infectious diseases by implementing programs such as the One Health initiative.
- Invest in the study and creation of innovative diagnostic methods to improve the ability to detect and track diseases.
- Vaccination and immunization initiatives should be given priority, including both the development and implementation of innovative vaccine technology.
- Reduce human-wildlife interaction and prevent the propagation of zoonotic diseases by setting precautions in place.

## Abbreviations

| | |
|---|---|
| H5N1 | Avian influenza |
| COVID-19 | Coronavirus disease 2019 |
| DNA | Deoxyribonucleic acid |
| EIDs | Emerging Infectious Diseases |
| HPAI | Highly pathogenic avian influenza |
| LAMP | Loop-mediated isothermal amplification |
| MERS-CoV | Middle East Respiratory Syndrome |
| NGS | Next-generation sequencing |
| PCR | Polymerase chain reaction |
| POCT | Point-Of-Care Testing |
| RDTs | Rapid diagnostic tests |
| RT-PCR | Real-time reverse transcriptase-polymerase chain reaction |
| mRNA | Ribonucleic acid |
| SARS | Severe Acute Respiratory Syndrome |
| SARS-CoV-2 | Severe Acute Respiratory Syndrome Coronavirus 2 |
| H1N1 | Swine Influenza |
| TB | Tuberculosis |
| VPDs | Vaccine-preventable diseases |
| WHO | World Health Organization |

## Contribution of Authors

All authors contributed significantly to the manuscript.

## Conflict of Interest

The authors declare no conflicts of interest.

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