How to Cite:
Alenezi, A. R., Alanazi, M. A., Aldhafeeri, F. S., Alotaibi, B. N., Alshamri, A. S., Alenezi, M. F., Alkhathami, B. M. A., Alenazi, N. S. D., Alhazmi, F. K. M., Al-Jasser, S. A., Alharbi, S. S., Gaddourah, A. M. I., Alrakhimy, H. D., Albishri, A. A., & Alanizi, A. (2022). EMS response to infectious disease outbreaks: Prehospital preparedness and intervention. *International Journal of Health Sciences*, *6*(S10), 1914–1929. https://doi.org/10.53730/ijhs.v6nS10.15221

EMS response to infectious disease outbreaks: Prehospital preparedness and intervention

Abdulrahman Ramadhan Alenezi
KSA, National Guard Health Affairs

Mohammed Ayyat Alanazi
KSA, National Guard Health Affairs

Fares Saqir Aldhafeeri
KSA, National Guard Health Affairs

Bader Naif Alotaibi
KSA, National Guard Health Affairs

Ahmed Saer Alshamri
KSA, National Guard Health Affairs

Meshal Falah Alenezi
KSA, National Guard Health Affairs

Bandar Mohammad Abdullah Alkhathami
KSA, National Guard Health Affairs

Nawaf Subhi Dobayan Alenazi
KSA, National Guard Health Affairs

Fares Khalid Mohammed Alhazmi
KSA, National Guard Health Affairs

Saleh Abdullatif Al-Jasser
KSA, National Guard Health Affairs

Sanad Samah Alharbi
KSA, National Guard Health Affairs

Ahmad Mohammed Isa Gaddourah
KSA, National Guard Health Affairs

International Journal of Health Sciences E-ISSN 2550-696X © 2022.
Corresponding email: *akk29337@gmail.com*
Manuscript submitted: 01 Jan 2022, Manuscript revised: 09 Jan 2022, Accepted for publication: 15 Jan 2022

Hamad Dafalh Alrakhimy
KSA, National Guard Health Affairs

Abdullah Atiyyan Albishri
KSA, National Guard Health Affairs

Anoud Saud Alanizi
KSA, National Guard Health Affairs

***Abstract*---Background:** Emerging infectious diseases (EIDs) often originate from wildlife, with zoonotic transmissions, such as those causing pandemic influenza, Ebola, and COVID-19. Ecological disruptions, including deforestation and land-use changes, have heightened the risk of these diseases by increasing human contact with wildlife. Aim: The aim of this article is to examine emergency medical services (EMS), paramedics, and nursing preparedness and intervention strategies during infectious disease outbreaks. **Methods:** Methods include analyzing zoonotic spillover factors and reviewing prevention strategies under the One Health framework. **Results:** The findings reveal that efforts to prevent zoonotic spillover are minimal, with most attention focused on post-spillover measures like vaccine development and healthcare response. Results suggest that a comprehensive approach, including forest conservation, biosecurity in animal husbandry, and regulating wildlife markets, can reduce the risk of future outbreaks. **Conclusion:** It concludes that true prevention requires addressing the root causes of zoonotic transmission, enhancing community-driven initiatives, and improving biosecurity to mitigate spillover risk.

***Keywords*---**infectious diseases, zoonotic transmission, EMS response, One Health, pandemic preparedness.

Introduction

Most emerging infectious diseases in humans originate from animal species, particularly wildlife, before crossing over to humans. Diseases such as pandemic influenza, Ebola, mpox, and HIV/AIDS have had significant impacts on human populations, with many of these diseases emerging through zoonotic transmission [1]. SARS-CoV-2, responsible for the COVID-19 pandemic, likely followed a similar spillover process [2,3]. Factors such as land-use changes, animal husbandry practices, and the commercial trade of wildlife create conditions conducive to zoonotic spillover, with climate change further exacerbating the risk of emerging infectious diseases [4].

Ecological disruption, particularly when intact ecosystems are transformed for agricultural purposes, increases interactions between humans, domestic animals, and wildlife, facilitating the transfer of pathogens. Among different ecosystems, the clearing and degradation of tropical and subtropical forests likely pose the greatest risk for zoonotic spillover [5,6]. This process brings humans closer to forest edges, enhancing contact with wildlife and domestic animals, thereby increasing the risk of pathogen transmission [6-9]. Additionally, the loss of biodiversity associated with forest degradation disrupts natural species communities, often favoring animals like bats and rodents that thrive near human settlements and are linked to zoonotic diseases [10]. Wildlife species affected by habitat disruption may also experience physiological stress, heightening their susceptibility to viral infection and shedding [8]. Furthermore, commercial exploitation of wildlife increases when previously undisturbed forests are accessed, creating additional opportunities for pathogen spillover and the potential for viral recombination [11].

As spillover events occur more frequently, the interconnected nature of the modern world accelerates the spread of outbreaks, epidemics, and pandemics unless the root causes of spillover are addressed [12]. However, efforts to prevent spillover have largely been neglected in the discussions on pandemic preparedness following the COVID-19 pandemic [13]. Instead, much of the focus, labeled as prevention, has been on postspillover measures such as outbreak response, strengthening healthcare systems, and vaccine development [14,15]. Although these interventions are critical, they do not constitute true prevention. Relying solely on postspillover strategies is inadequate to protect against the severe threats posed by pandemics. Even when outbreaks are promptly identified, postspillover interventions may fail, and effective vaccines or treatments may not be available for every emerging disease. Moreover, challenges related to vaccine supply, distribution, and public uptake, particularly in low-income regions, as well as the influence of misinformation and personal beliefs, can limit the effectiveness of such measures at the population level [16].

These challenges underscore the urgent need for investment in interventions aimed at preventing spillover and controlling early disease transmission between domestic animals and humans. This approach aligns with the One Health framework, which promotes an integrated and sustainable strategy for optimizing the health of humans, animals, and ecosystems [17]. We provide a summary of expert recommendations on how to reduce the risk of spillover and control early disease spread. The proposed interventions are categorized into five areas: halting the clearing and degradation of tropical and subtropical forests, improving the health and economic stability of communities in emerging infectious disease hotspots, enhancing biosecurity in animal husbandry, strictly regulating or closing wildlife markets and trade, and expanding pathogen surveillance at the interfaces between humans, domestic animals, and wildlife.

Mitigating Tropical and Subtropical Forest Clearing and Degradation

Various strategies can be employed to mitigate the risk of pathogen spillover linked to the deforestation and degradation of tropical and subtropical forests. Integrated policy frameworks, with enhanced enforcement, aim to reduce deforestation incentives while upholding the rights of Indigenous Peoples and local communities (IPLCs). A successful example of this approach occurred in Brazil's Amazon Basin. In 2004, Brazil, with the support of international donors, implemented policies that led to a 70% reduction in deforestation annually.

However, after 2012, weakened enforcement led to a resurgence of deforestation, highlighting the importance of sustained commitment. Notably, during the period of reduced deforestation, agricultural output continued to rise, indicating that economic development was not hindered [18–20]. Approximately 50% of the intact forests in the Amazon Basin are situated in Indigenous territories, where deforestation rates are considerably lower [21].

Regulatory and market-driven interventions can also set international standards to reduce deforestation by influencing supply and demand for commodities. For example, Europe is considering restrictions on imports of products like soybeans, beef, cocoa, and palm oil if their production contributes to deforestation [22]. Furthermore, more than 30 financial institutions, managing trillions of dollars, have pledged to cease investment in activities associated with deforestation [23]. Providing financial incentives for ecosystem services can motivate landowners to preserve or enhance forest cover, thereby increasing ecosystem services. However, the effectiveness of this approach varies across different implementation sites. Greater success could be achieved by targeting local or regional levels, offering in-kind contributions rather than direct cash payments, and emphasizing equity [24].

Community-led initiatives offer an alternative approach by delivering essential services, such as healthcare, to IPLCs living near forests, reducing their dependence on deforestation for income. In Indonesian Borneo, for instance, illegal logging was partly driven by high healthcare costs. When local communities were empowered to devise their own solutions, they chose to build a medical center and establish alternative livelihood programs. Over a decade, at a total cost of US $5.2 million, illegal logging decreased by 90%, forest regrowth covered 21,000 hectares, and US $65 million in carbon loss was prevented [25]. Similar initiatives have been successfully implemented in Madagascar and Brazil.

Enhancing Health and Economic Security in Emerging Infectious Disease Hotspots

In many emerging infectious disease hotspots, limited intact forests remain, and the risk of spillover is heightened by the proximity of dense human and domestic animal populations to wildlife. These regions constitute only 4% of the global land area (10% of the tropical area), yet account for 60% of global spillover risk [26]. Consequently, community-designed interventions to reduce interactions between humans, domestic animals, and wildlife are likely the most effective strategies for decreasing the risk of virus spillover in these areas. Many communities in these hotspots face challenges such as limited access to healthcare, sustainable livelihoods, food security, and education [27]. Improving health and economic security aligns with both local priorities and global pandemic prevention goals.

Some measures to reduce zoonotic disease risk can be relatively simple. For instance, the risk of Nipah virus transmission can be reduced by covering shaved areas of palm tree trunks and sap vessels, thereby preventing contamination by bat excrement [28]. In cases where contact with wildlife cannot be completely avoided, improved sanitary practices, such as safer methods of butchering wildlife, can help mitigate spillover risks [29]. While community-driven interventions to reduce human-wildlife contact and spillover risks have not been widely implemented, several projects demonstrate their potential. In Indonesia and Uganda, for example, such projects have successfully altered relationships between communities, forests, and wildlife [25,30]. Another project in Madagascar's Manombo Rainforest aims to implement community-designed conservation initiatives and collect data over a decade to assess impacts on biodiversity, wildlife, and human health (A. Emerson et al., unpub. data). More initiatives focused on spillover risk in disease hotspots are needed to provide proof of concept [31]. These projects should include the measurement of spillover within target communities to allow for comprehensive evaluations of their outcomes [32].

Enhancing Biosecurity in Animal Husbandry

The World Organisation for Animal Health (WOAH) defines biosecurity in animal husbandry as a set of management and physical measures aimed at reducing the introduction, spread, and establishment of diseases within animal populations. This is crucial, as several zoonotic viruses—such as avian influenza A(H5N1), pandemic influenza A(H1N1), Nipah virus, and MERS-CoV—have emerged from wildlife reservoirs into humans via commercial animal industries (5, 34–36). To improve biosecurity in animal husbandry, both management and physical measures are essential. Management measures include practices like quarantining newly introduced animals and vaccinating livestock against endemic diseases. Physical measures involve creating enclosures that separate farm animals from each other and from wildlife, reducing cross-species transmission risks (37). However, biosecurity challenges persist, particularly in backyard flocks and large-scale commercial systems. Implementing biosecurity protocols is difficult in resource-limited settings due to the lack of tailored solutions for these contexts and the need to communicate them effectively in local languages (37, 38).

Commercial industrial systems pose additional biosecurity challenges due to the density of genetically similar, single-age animals, which increases disease transmission risks. Addressing these risks often requires significant investments, particularly when animal welfare is not optimal (39). Moreover, ineffective livestock disease surveillance, driven by underfunded animal health services, and chronic household food insecurity also contribute to risky husbandry practices, such as consuming sick or dead animals (40, 41). To address these issues, global organizations such as the Food and Agriculture Organization of the United Nations (FAO) and WOAH have acknowledged the challenges and are working collaboratively with the World Health Organization and the United Nations Environment Program. This collaboration aims to optimize human, animal, plant, and environmental health through the One Health Joint Plan of Action, launched in 2022. The plan emphasizes improving prevention, detection, and response to health threats and requires the engagement of national and local agencies (42, 43).

Investing in public and private animal health services and improving the identification of animal illnesses that pose public health concerns can significantly enhance biosecurity. Such investments would not only reduce pathogen transmission between wildlife and domestic animals but also improve disease surveillance and food security (37, 40, 45). These initiatives can be integrated with community-designed interventions to reduce costs and enhance their impact, particularly in emerging infectious disease hotspots. A key component of improving biosecurity is controlling vaccine-preventable diseases in livestock. Vaccination reduces illness and mortality among domestic animals and decreases the spread of emerging infectious diseases by preventing delays in diagnosis due to overlapping clinical signs. For instance, outbreaks of highly pathogenic avian influenza can go undetected in areas with low vaccination rates for Newcastle disease, which presents similar symptoms (45, 47). Similarly, controlling African swine fever (ASF) is challenging when classical swine fever (CSF) vaccination rates are low, as the two diseases share clinical signs (48). A notable example is China's 2019 pork shortage caused by ASF, which likely led to increased consumer demand for wildlife products, raising the risk of pathogen spillover (2).

Shutting Down or Strictly Regulating Wildlife Markets and Trade

Both legal and illegal wildlife markets pose significant risks for zoonotic pathogen transmission, as seen with mpox virus, SARS-CoV-1, and likely SARS-CoV-2 (2, 3, 5). The wildlife trade, driven by demand for animals as food, pets, and for use in traditional medicine and ornaments, creates opportunities for pathogen spillover. Live and freshly butchered wild birds and mammals represent the highest risk. Efforts to prevent zoonotic spillover should target commercial wildlife markets and trade while prioritizing the rights of Indigenous Peoples and Local Communities (IPLCs), who depend on wildlife for food and livelihoods. Addressing these risks requires investments in four key areas. First, policy reform is essential to restrict or close legal commercial wildlife markets and trade. This includes introducing new legislation and amending existing laws to ban the sale of live and freshly butchered wild birds and mammals for commercial purposes, aligning with the World Health Organization's 2021 recommendations (49). Several countries have already taken action. For instance, in February 2020, China banned farming, hunting, trading, and consuming terrestrial wildlife in response to the COVID-19 pandemic (50). Similarly, Gabon prohibited the sale and consumption of pangolins and bats in March 2020 (51).

Second, stronger legislation and enforcement are needed to combat illegal wildlife markets and trade. Law enforcement agencies, judicial bodies, and other mandated institutions must be adequately resourced, with sufficient budgets for staffing, training, equipment, and enforcement. These agencies must also have the legal authority to employ all available investigative approaches and maintain high integrity standards to prevent corruption. Although the legality of wildlife in trade does not influence pathogen spillover, efforts to tackle wildlife trafficking are crucial to mitigating risk. Third, programs aimed at local communities and the rural poor are necessary to reduce their dependence on wildlife trade for income. Partnerships between local communities and governments can help create sustainable income alternatives, reducing reliance on wildlife markets. These partnerships are vital in providing viable economic options that do not involve the exploitation of wildlife.

Fourth, government leaders and experts must spearhead efforts to change consumer behavior to reduce the demand for live wild birds and mammals. Applying principles from behavioral science, psychology, economics, and social marketing can help shift public perceptions and reduce the desirability of wildlife products. Public institutions, in collaboration with civil society and academia, should lead large-scale behavior change initiatives. In many countries, wildlife consumption in urban areas is not driven by food security concerns but by luxury, status, or perceived health benefits. For instance, in China, wildlife prices are two to five times higher than pork, the most common source of animal protein, with prices even higher for exotic or endangered species (52, 53). Reducing urban demand for wildlife can alleviate pressure on IPLCs by reducing economic incentives to supply the trade, ensuring that more wildlife is available for subsistence needs. To ensure the success of these strategies, it is critical to recognize and support IPLC rights while preventing these rights from being exploited as a pretext for continuing commercial wildlife trade.

Expanding Pathogen Surveillance at Human-Domestic Animal-Wildlife Interfaces

Effective pathogen surveillance at the interfaces between humans, domestic animals, and wildlife relies on coordinated multisectoral efforts. Surveillance platforms for monitoring pathogen emergence involve both active and passive data collection systems that track exposures and infections across human and animal populations, observe the severity of diseases, and detect evolving microbes in natural reservoirs and additional hosts (54, 55). These integrated systems offer valuable insights into zoonotic pathogens like Ebola virus in their ever-changing reservoirs and provide crucial data on spillovers into domestic animals and humans, informing pandemic prevention, preparedness, and response strategies (56, 57). For instance, over 25 years of data on Hendra virus spillovers from bats to horses revealed that such events increase during times of environmental stress, suggesting that forest restoration could serve as an ecological countermeasure to reduce future spillovers (58).

Implementing systematic wildlife surveillance will require a robust veterinary medical capacity and a significant strengthening of multisectoral and decentralized laboratory networks to support molecular and serologic testing of both animal and human samples. These laboratory networks should be equipped with pathogen-specific diagnostic assays and unbiased high-throughput screening technologies (59, 60). With the growing availability of whole-genome sequencing platforms and near real-time genomic sequencing, investments in bioinformatics for analyzing genomic data will be increasingly important in tracking viral evolution and epidemiology.

Human pathogen surveillance can be enhanced by extracting data from primary sources such as health information systems, sentinel surveillance sites, and repeated household surveys. Extending these systems to include wild and domestic animal populations will provide a broader understanding of pathogen emergence. In many low-income countries, febrile illnesses often go undiagnosed because they do not reach the healthcare system, resulting in many viral infections never being properly evaluated (61, 62). Improving routine diagnostic systems, especially for traditionally undiagnosed illnesses, could be achieved by expanding pathogen libraries from wild and domestic animal populations.

Diagnostic testing limitations are not exclusive to low-income countries. For example, the United States faced significant challenges during the COVID-19 pandemic and mpox epidemic due to testing shortages (63, 64). This demonstrates the global need for more accessible diagnostic testing to enhance pathogen detection and response capabilities. Mounting evidence suggests that zoonotic spillovers happen more frequently than previously understood. A study on batborne SARS-related coronaviruses estimated that approximately 66,000 people are infected with SARS-related coronaviruses annually in South and Southeast Asia (65). Similar high rates of pre-COVID-19 SARS-related coronavirus exposure have been observed in Sierra Leone (66). These findings highlight the urgent need to strengthen surveillance systems for zoonotic pathogens with pandemic potential. Expanding pathogen surveillance across human, domestic animal, and wildlife interfaces is a crucial step in mitigating future pandemics.

Discussion

COVID-19 and mpox have starkly revealed the inadequacies in current domestic and global pandemic approaches, exposing significant gaps in prevention efforts. A narrow window for reform exists before the next zoonotic-origin pandemic takes hold (14, 15). Historical trends suggest that future pandemics will most likely result from the spillover of novel viruses from wildlife to humans or through domestic animals (1). Therefore, it is imperative to address the underlying drivers of pathogen spillover to prevent outbreaks. We propose a non-exhaustive set of interventions to reduce spillover risks, emphasizing the global imperative of pandemic prevention. While high-income countries continue to fund bilateral aid programs, no single nation should bear the cost of global pandemic prevention alone. Programs such as the US Agency for International Development (USAID) Emerging Pandemic Threats PREDICT program (2009–2020) have played a crucial role in transforming zoonotic disease prevention by strengthening local capacities to detect and respond to known and unknown viral threats (67). Currently, USAID is investing in spillover prevention in priority countries, focusing on building a One Health workforce through university networks in Asia and Africa and developing interventions to mitigate spillover at high-risk human-animal interfaces.

Despite these efforts, such programs remain vulnerable to changes in government priorities and lack the necessary funding to fully address the global threat. An integrated global pandemic prevention (prespillover) and preparedness (postspillover) strategy would require approximately \$20–\$50 billion annually, a small fraction of the trillions of dollars lost and millions of lives impacted by COVID-19 (14, 68, 30). Research indicates that prespillover initiatives alone can be achieved for approximately \$20 billion per year globally, a cost far outweighed by the savings in both human lives and financial resources. Addressing the drivers of zoonotic spillover will yield broader benefits beyond pandemic prevention, including mitigating climate change, preventing biodiversity loss, enhancing human health, upholding human rights, and promoting sustainable development (10). As international initiatives such as the World Bank Pandemic Fund and the World Health Assembly pandemic accord take shape, these interventions must be incorporated (13). Additionally, the UN's commitment to ending deforestation in more than 100 countries by 2030 presents a promising opportunity, with health outcomes prioritized to ensure impactful results.

On-the-ground compliance and community engagement are critical for the success of these initiatives. Communities must believe that the proposed measures will positively affect their lives. In practice, the One Health approach, often applied reactively after spillover events, needs to be expanded. To prevent future waves of outbreaks and pandemics, the global community must broaden its use of One Health strategies and embrace preventive measures (69). A comprehensive One Health approach to pandemic prevention requires coordination, collaboration, and significant new resources distributed across human health, animal health, environmental, and food safety agencies (70). Preventing spillover is also a matter of equity. Focusing only on postspillover interventions sends the message that the global community is willing to tolerate outbreaks in resource-limited settings as long as they do not escalate into epidemics or pandemics. Prioritizing preventive measures will save lives in the most vulnerable regions and ensure equitable health benefits.

A robust research agenda is needed to examine the causal links between the proposed interventions and reductions in spillover events. While current evidence suggests these interventions can meaningfully reduce spillover risks (5), few large-scale programs have focused on evaluating their effectiveness. Scaling up these programs will help build a stronger evidence base to demonstrate the impact of addressing spillover drivers. Nevertheless, the Precautionary Principle dictates that we must act now, given what we already know about the risks and solutions (https://unesdoc.unesco.org/ark:/48223/pf0000139578). Humanity's broken relationship with nature heightens the risk of zoonotic pandemics. The actions outlined in this proposal will not only reduce spillover risks but also address pandemics, climate change, biodiversity loss, and inequity. The evidence for these actions existed before COVID-19, yet little action was taken. As we emerge from the current pandemic, we have a responsibility to act decisively to prevent the next one. While we cannot undo the past, we must learn from it and do better in the future.

Preventive Techniques:

Infectious diseases can be effectively controlled and prevented through a variety of strategies that target both the pathogen and its means of transmission. One of the most critical techniques is vaccination, which strengthens the immune system by providing immunity against specific pathogens before exposure occurs. Widespread immunization programs have dramatically reduced the incidence of many life-threatening diseases, such as measles, polio, and influenza. Vaccines work by introducing a weakened or inactive form of the pathogen into the body, prompting the immune system to develop antibodies and prepare for future encounters with the actual pathogen. Ensuring high vaccination coverage in populations, especially for children and at-risk groups, is a cornerstone in preventing outbreaks and safeguarding public health.

Another important method for preventing infectious diseases is practicing good hygiene, particularly handwashing with soap and water. Many infectious diseases, including respiratory infections and gastrointestinal illnesses, are transmitted through contact with contaminated surfaces or direct person-to-person contact. Proper hand hygiene, especially after using the restroom, before eating, and after coughing or sneezing, can greatly reduce the spread of germs. In healthcare settings, strict adherence to infection control protocols, including the use of personal protective equipment (PPE) and regular sanitization of surfaces, helps prevent healthcare-associated infections. Similarly, safe food handling practices and proper sanitation systems are essential in reducing the spread of waterborne diseases.

Environmental control measures also play a vital role in the prevention of infectious diseases. Vector control, such as mosquito management, is crucial in limiting the spread of vector-borne diseases like malaria, dengue, and Zika virus. These measures include eliminating breeding grounds for mosquitoes, using insecticides, and promoting the use of insecticide-treated bed nets in affected areas. Additionally, promoting clean water access and improving waste management systems help prevent diseases like cholera and typhoid, which thrive in unsanitary conditions. Addressing environmental factors that contribute to the spread of infectious diseases can significantly reduce their incidence, especially in low-resource settings.

Public health surveillance and early detection systems are another key element of infectious disease prevention. These systems monitor for signs of emerging infectious threats and facilitate rapid responses to contain outbreaks before they escalate. Effective surveillance relies on coordinated efforts between governments, healthcare systems, and international organizations, allowing for timely identification of new diseases, tracking of known pathogens, and assessment of potential risks. When outbreaks do occur, quarantine measures, isolation of affected individuals, and contact tracing are employed to limit the spread of the disease. These interventions, along with public health campaigns that raise awareness about disease symptoms, prevention, and treatment, ensure a swift and organized response to infectious threats.

Role of Paramedics, Nursing, and Health Informatics:

In the context of controlling and preventing infectious diseases, **paramedics**, **nurses**, and **health informatics** professionals play vital and collaborative roles, each contributing uniquely to mitigating the spread and managing outbreaks.

Paramedics are often the first point of contact with patients suffering from infectious diseases, especially in emergency situations. Their ability to quickly assess, isolate, and provide pre-hospital care for patients with infectious diseases like COVID-19, influenza, or emerging diseases is crucial in preventing transmission. Paramedics are trained in infection control protocols, including the use of personal protective equipment (PPE), decontamination processes, and the safe transport of contagious patients. They also play a role in early detection and reporting of potential outbreaks by communicating signs and symptoms to healthcare facilities, allowing for timely intervention.

Nurses are central to infection prevention and control (IPC) efforts within healthcare settings. They educate patients on hygiene practices, administer vaccines, and are often responsible for implementing and monitoring infection control procedures such as hand hygiene, sterilization, and isolation protocols. In outbreak scenarios, nurses lead efforts in patient care and prevention measures, including the use of PPE, proper waste disposal, and ensuring that infection control guidelines are followed in hospitals and clinics. Nurses also engage in public health education, promoting community awareness about disease prevention practices like vaccination, handwashing, and proper sanitation. Their role is particularly significant in controlling healthcare-associated infections (HAIs), reducing transmission within healthcare facilities.

Health informatics professionals enhance infectious disease control by leveraging technology to track, analyze, and predict disease patterns. They develop and maintain surveillance systems that collect and analyze data on infectious disease outbreaks, helping public health officials and healthcare providers respond more effectively. Health informatics can assist in the early detection of emerging diseases by integrating data from multiple sources, such as hospitals, labs, and public health agencies. These systems enable real-time reporting and monitoring, providing essential information for decision-making during outbreaks. Informatics also supports telemedicine, electronic health records (EHRs), and digital communication platforms that facilitate remote consultations, reducing the risk of infection in healthcare settings.

Together, paramedics, nurses, and health informatics professionals form an essential network in the early detection, prevention, and control of infectious diseases. Their collaboration ensures timely responses, reduces the spread of infections, and enhances the overall capacity of healthcare systems to handle epidemics and pandemics.

Conclusion

Preventing the next pandemic requires a shift from reactive, post-spillover strategies to proactive approaches that address the root causes of zoonotic disease transmission. The EMS response to infectious disease outbreaks should not only focus on managing post-exposure scenarios but also include preemptive interventions that mitigate the risk of spillover. The interconnectedness of human, animal, and ecosystem health—embodied in the One Health framework—demands that we view pandemics through a broader lens, where forest conservation, community health, and biosecurity play pivotal roles. Deforestation and habitat degradation, particularly in tropical and subtropical regions, bring humans, domestic animals, and wildlife into closer contact, increasing the likelihood of pathogen transmission. Reducing deforestation incentives, improving the health and economic security of communities in disease hotspots, and enhancing biosecurity measures in animal husbandry are critical interventions that could significantly lower the risk of new zoonotic diseases emerging. Furthermore, the regulation or closure of wildlife markets—especially those involved in the sale of live wild birds and mammals—can prevent the direct transmission of zoonotic pathogens to humans. The lessons learned from recent pandemics, such as COVID-19, demonstrate that relying solely on vaccine development and healthcare system strengthening is inadequate. Vaccine shortages, logistical challenges, and public misinformation can severely limit the effectiveness of post-spillover interventions. Instead, a combination of preemptive measures, community-based initiatives, and stronger legislative frameworks are necessary to address both the environmental and socioeconomic factors driving spillover events. By adopting these integrated strategies, we can improve pandemic preparedness and create more resilient systems to prevent future infectious disease outbreaks.

References

1. Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, et al. Global trends in emerging infectious diseases. *Nature.* 2008;451:990–3. 10.1038/nature06536
2. Lytras S, Xia W, Hughes J, Jiang X, Robertson DL. The animal origin of SARS-CoV-2. *Science.* 2021;373:968–70. 10.1126/science.abh0117
3. Zimmer, C., Mueller, B., & Buckley, C. (2021). First known COVID case was vendor at Wuhan market, scientist says. *New York Times.*
4. Dash, S. P., Dipankar, P., Burange, P. S., Rouse, B. T., & Sarangi, P. P. (2021). Climate change: how it impacts the emergence, transmission, resistance and consequences of viral infections in animals and plants. *Critical reviews in microbiology*, *47*(3), 307-322.
5. Alimi Y, Bernstein A, Epstein J, Espinal M, Kakkar M, Kochevar D, et al. Report of the scientific task force on preventing pandemics [cited 2021 Nov 1]. https://cdn1.sph.harvard.edu/wp-content/uploads/sites/2343/2021/08/PreventingPandemicsAug2021.pdf
6. Daszak P, Amuasi J. das Neves CG, Hayman D, Kuiken T, Roche B, et al.; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Workshop report on biodiversity and pandemics.
7. Loh EH, Zambrana-Torrelio C, Olival KJ, Bogich TL, Johnson CK, Mazet JA, et al. Targeting transmission pathways for emerging zoonotic disease surveillance and control. *Vector Borne Zoonotic Dis.* 2015;15:432–7. 10.1089/vbz.2013.1563
8. Plowright RK, Reaser JK, Locke H, Woodley SJ, Patz JA, Becker DJ, et al. Land use-induced spillover: a call to action to safeguard environmental, animal, and human health. *Lancet Planet Health.* 2021;5:e237–45. 10.1016/S2542-5196(21)00031-0
9. Faust CL, McCallum HI, Bloomfield LSP, Gottdenker NL, Gillespie TR, Torney CJ, et al. Pathogen spillover during land conversion. *Ecol Lett.* 2018;21:471–83. 10.1111/ele.12904
10. Keesing F, Ostfeld RS. Impacts of biodiversity and biodiversity loss on zoonotic diseases. *Proc Natl Acad Sci U S A.* 2021;118:e2023540118. 10.1073/pnas.2023540118
11. United Nations Office on Drugs and Crime. Combating wildlife and forest crime. Global Pramme for Combating Wildlife and Forest Crime annual report 2020. https://www.unodc.org/documents/Wildlife/Annual_Report_GPWLFC 2020.pdf
12. Marani M, Katul GG, Pan WK, Parolari AJ. Intensity and frequency of extreme novel epidemics. *Proc Natl Acad Sci U S A.* 2021;118:e2105482118. 10.1073/pnas.2105482118

13. Ellwanger, J. H., & Chies, J. A. B. (2021). Zoonotic spillover: Understanding basic aspects for better prevention. *Genetics and Molecular Biology*, *44*(1 Suppl 1), e20200355.
14. G20 High Level Independent Panel. A global deal for our pandemic age [cited 2021 Nov 1]. https://pandemic-financing.org/report/foreword
15. Sirleaf EJ, Clark H. Report of the Independent Panel for Pandemic Preparedness and Response: making COVID-19 the last pandemic. *Lancet*. 2021;398:101–3. 10.1016/S0140-6736(21)01095-3
16. Hotez P, Batista C, Ergonul O, Figueroa JP, Gilbert S, Gursel M, et al. Correcting COVID-19 vaccine misinformation: Lancet Commission on COVID-19 Vaccines and Therapeutics Task Force Members. *EClinicalMedicine*. 2021;33:100780. 10.1016/j.eclinm.2021.100780
17. World Health Organization. Joint Tripartite and UNEP Statement: Tripartite and UNEP support OHHLEP's definition of "One Health" 2021. Dec 1 [cited 2021 Dec 1]. https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health
18. Nepstad D, McGrath D, Stickler C, Alencar A, Azevedo A, Swette B, et al. Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. *Science*. 2014;344:1118–23. 10.1126/science.1248525
19. Nepstad D, Soares-Filho BS, Merry F, Lima A, Moutinho P, Carter J, et al. Environment. The end of deforestation in the Brazilian Amazon. *Science*. 2009;326:1350–1. 10.1126/science.1182108
20. West TAP, Fearnside PM. Brazil's conservation reform and the reduction of deforestation in Amazonia. *Land Use Policy*. 2021;100:105072. 10.1016/j.landusepol.2020.105072
21. Food and Agriculture Organization of the United Nations. Forest governance by indigenous and tribal peoples https://www.fao.org/americas/publicaciones-audio-video/forest-gov-by-indigenous/en
22. European Union. European Green Deal: Commission adopts new proposals to stop deforestation, innovate sustainable waste management and make soils healthy for people, nature and climate https://ec.europa.eu/commission/presscorner/detail/en/ip_21_5916
23. Catanoso J. COP26 Glasgow Declaration: salvation or threat to Earth's forests? Mongabay 2021. Nov 3 [cited 2021 Dec 1]. https://news.mongabay.com/2021/11/cop26-glasgow-declaration-salvation-or-threat-to-earths-forests
24. Grima N, Singh SJ, Smetschka B, Ringhofer L. Payment for Ecosystem Services (PES) in Latin America: analysing the performance of 40 case studies. *Ecosyst Serv*. 2016;17:24–32. 10.1016/j.ecoser.2015.11.010
25. Jones IJ, MacDonald AJ, Hopkins SR, Lund AJ, Liu ZY-C, Fawzi NI, et al. Improving rural health care reduces illegal logging and conserves carbon in a tropical forest. *Proc Natl Acad Sci U S A*. 2020;117:28515–24. 10.1073/pnas.2009240117
26. Allen T, Murray KA, Zambrana-Torrelio C, Morse SS, Rondinini C, Di Marco M, et al. Global hotspots and correlates of emerging zoonotic diseases. *Nat Commun*. 2017;8:1124. 10.1038/s41467-017-00923-8

27. Garchitorena A, Sokolow SH, Roche B, Ngonghala CN, Jocque M, Lund A, et al. Disease ecology, health and the environment: a framework to account for ecological and socio-economic drivers in the control of neglected tropical diseases. *Philos Trans R Soc Lond B Biol Sci*. 2017;372:20160128. 10.1098/rstb.2016.0128
28. Khan SU, Gurley ES, Hossain MJ, Nahar N, Sharker MAY, Luby SP. A randomized controlled trial of interventions to impede date palm sap contamination by bats to prevent nipah virus transmission in Bangladesh. *PLoS One*. 2012;7:e42689. 10.1371/journal.pone.0042689
29. Wolfe ND, Switzer WM, Carr JK, Bhullar VB, Shanmugam V, Tamoufe U, et al. Naturally acquired simian retrovirus infections in central African hunters. *Lancet*. 2004;363:932–7. 10.1016/S0140-6736(04)15787-5
30. Augeraud-Véron, E., Fabbri, G., & Schubert, K. (2021). Prevention and mitigation of epidemics: Biodiversity conservation and confinement policies. *Journal of Mathematical Economics*, *93*, 102484.
31. Bloomfield LSP, McIntosh TL, Lambin EF. Habitat fragmentation, livelihood behaviors, and contact between people and nonhuman primates in Africa. *Landsc Ecol*. 2020;35:985–1000. 10.1007/s10980-020-00995-w
32. Salerno J, Ross N, Ghai R, Mahero M, Travis DA, Gillespie TR, et al. Human-wildlife interactions predict febrile illness in park landscapes of western Uganda. *EcoHealth*. 2017;14:675–90. 10.1007/s10393-017-1286-1
33. World Organisation for Animal Health, Office of Innovation and Entrepreneurship. Terrestrial animal health code glossary 2018. [cited 2021 Nov 1]. https://www.oie.int/fileadmin/Home/eng/Health_standards/tahc/2018/en_glossaire.htm
34. Brockwell-Staats C, Webster RG, Webby RJ. Diversity of influenza viruses in swine and the emergence of a novel human pandemic influenza A (H1N1). *Influenza Other Respir Viruses*. 2009;3:207–13. 10.1111/j.1750-2659.2009.00096.x
35. Gambotto A, Barratt-Boyes SM, de Jong MD, Neumann G, Kawaoka Y. Human infection with highly pathogenic H5N1 influenza virus. *Lancet*. 2008;371:1464–75. 10.1016/S0140-6736(08)60627-3
36. Han H-J, Yu H, Yu X-J. Evidence for zoonotic origins of Middle East respiratory syndrome coronavirus. *J Gen Virol*. 2016;97:274–80. 10.1099/jgv.0.000342
37. Otte J, Rushton J, Rukambile E, Alders RG. Biosecurity in village and other free-range poultry—trying to square the circle? *Front Vet Sci*. 2021;8:678419. 10.3389/fvets.2021.678419
38. Bagnol B, Naysmith S, Bruyn JD, Wong J, Alders R. Effective animal health programming requires consideration of and communication with those at the human-animal interface. *Perspect Agric Vet Sci Nutr Nat Resour*. 2016;11:1–7. 10.1079/PAVSNNR201611030
39. Moore TC, Fong J, Rosa Hernández AM, Pogreba-Brown K. CAFOs, novel influenza, and the need for One Health approaches. *One Health*. 2021;13:100246. 10.1016/j.onehlt.2021.100246
40. Wong JT, Bagnol B, Grieve H, da Costa Jong JB, Li M, Alders RG. Factors influencing animal-source food consumption in Timor-Leste. *Food Secur*. 2018;10:741–62. 10.1007/s12571-018-0804-5

41. Food and Agriculture Organization of the United Nations. Hunger and food insecurity https://www.fao.org/hunger/en
44. Rulli MC, D'Odorico P, Galli N, Hayman DTS. Land-use change and the livestock revolution increase the risk of zoonotic coronavirus transmission from rhinolophid bats. *Nature Food*. 2021;2:409–16. 10.1038/s43016-021-00285-x
45. Alders RG, Bagnol B, Young MP. Technically sound and sustainable Newcastle disease control in village chickens: lessons learnt over fifteen years. *Worlds Poult Sci J*. 2010;66:433–40. 10.1017/S0043933910000516
46. Ayala AJ, Yabsley MJ, Hernandez SM. A review of pathogen transmission at the backyard chicken–wild bird interface. *Front Vet Sci*. 2020;7:539925. 10.3389/fvets.2020.539925
47. Miller PJ, Torchetti MK. Newcastle disease virus detection and differentiation from avian influenza. In: Spackman E, editor. Animal influenza virus. New York: Springer; 2014. p. 235–9.
48. Smith D, Cooper T, Pereira A, Jong JBDC. Counting the cost: The potential impact of African Swine Fever on smallholders in Timor-Leste. *One Health*. 2019;8:100109. 10.1016/j.onehlt.2019.100109
49. World Health Organization. Reducing public health risks associated with the sale of live wild animals of mammalian species in traditional food markets https://www.who.int/publications/i/item/WHO-2019-nCoV-Food-safety-traditional-markets-2021.1
50. Koh LP, Li Y, Lee JSH. The value of China's ban on wildlife trade and consumption. *Nat Sustain*. 2021;4:2–4. 10.1038/s41893-020-00677-0
51. McCall R. Eating bats and pangolins banned in Gabon as a result of coronavirus pandemic. Newsweek. 2020. Apr 6 https://www.newsweek.com/eating-bats-pangolins-gabon-coronavirus-pandemic-1496329
52. Xiao L, Lu Z, Li X, Zhao X, Li BV. Why do we need a wildlife consumption ban in China? *Curr Biol*. 2021;31:R168–72. 10.1016/j.cub.2020.12.036
53. Xiao X, Newman C, Buesching CD, Macdonald DW, Zhou Z-M. Animal sales from Wuhan wet markets immediately prior to the COVID-19 pandemic. *Sci Rep*. 2021;11:11898. 10.1038/s41598-021-91470-2
54. Berthe FCJ, Bouley T, Karesh WB, Le Gall FG, Machalaba CC, Plante CA, et al. One Health: operational framework for strengthening human, animal, and environmental public health systems at their interface. Washington: World Bank; 2018.
55. Watsa M; Wildlife Disease Surveillance Focus Group. Rigorous wildlife disease surveillance. *Science*. 2020;369:145–7. 10.1126/science.abc0017
56. Machalaba CC, Salerno RH, Barton Behravesh C, Benigno S, Berthe FCJ, Chungong S, et al. Institutionalizing One Health: from assessment to action. *Health Secur*. 2018;16(S1):S37–43. 10.1089/hs.2018.0064
57. Kuisma E, Olson SH, Cameron KN, Reed PE, Karesh WB, Ondzie AI, et al. Long-term wildlife mortality surveillance in northern Congo: a model for the detection of Ebola virus disease epizootics. *Philos Trans R Soc Lond B Biol Sci*. 2019;374:20180339. 10.1098/rstb.2018.0339
58. Ellwanger, J. H., & Chies, J. A. B. (2021). Zoonotic spillover: Understanding basic aspects for better prevention. *Genetics and Molecular Biology*, *44*(1 Suppl 1), e20200355.

59. Epstein JH, Anthony SJ. Viral discovery as a tool for pandemic preparedness. *Rev Sci Tech.* 2017;36:499–512. 10.20506/rst.36.2.2669
60. Br A, Dovih P, Ramakrishnan U, Liang E, Mendenhall I, Hong DLW, et al. Evidence of filovirus and henipavirus in bats and bat harvesters, India. *Int J Infect Dis.* 2019;79:60. 10.1016/j.ijid.2018.11.156
61. Wong EB, Olivier S, Gunda R, Koole O, Surujdeen A, Gareta D, et al.; Vukuzazi Team. Convergence of infectious and non-communicable disease epidemics in rural South Africa: a cross-sectional, population-based multimorbidity study. *Lancet Glob Health.* 2021;9:e967–76. 10.1016/S2214-109X(21)00176-5
62. Maze MJ, Bassat Q, Feasey NA, Mandomando I, Musicha P, Crump JA. The epidemiology of febrile illness in sub-Saharan Africa: implications for diagnosis and management. *Clin Microbiol Infect.* 2018;24:808–14. 10.1016/j.cmi.2018.02.011
63. Shear MD, Goodnough A, Kaplan S, Fink S, Thomas K, Weiland N. The lost month: how a failure to test blinded the U.S. to Covid-19. The New York Times. 2020. Mar 28. https://www.nytimes.com/2020/03/28/us/testing-coronavirus-pandemic.html
64. Oladoye, M. J. (2021). Monkeypox: a neglected viral zoonotic disease. *Electronic Journal of Medical and Educational Technologies*, *14*(2), em2108.
65. Platto, S., Zhou, J., Wang, Y., Wang, H., & Carafoli, E. (2021). Biodiversity loss and COVID-19 pandemic: The role of bats in the origin and the spreading of the disease. *Biochemical and biophysical research communications*, *538*, 2-13.
66. Borrega R, Nelson DKS, Koval AP, Bond NG, Heinrich ML, Rowland MM, et al. Cross-reactive antibodies to SARS-CoV-2 and MERS-CoV in pre-COVID-19 blood samples from Sierra Leoneans. *Viruses.* 2021;13:2325. 10.3390/v13112325
67. McKinsey & Company. Not the last pandemic: Investing now to reimagine public-health systems. 2021. [cited 2021 Nov 1]. https://www.mckinsey.com/industries/public-and-social-sector/our-insights/not-the-last-pandemic-investing-now-to-reimagine-public-health-systems
68. Gruetzmacher K, Karesh WB, Amuasi JH, Arshad A, Farlow A, Gabrysch S, et al. The Berlin principles on one health - Bridging global health and conservation. *Sci Total Environ.* 2021;764:142919. 10.1016/j.scitotenv.2020.142919
69. Alders RG, Chadag MV, Debnath NC, Howden M, Meza F, Schipp MA, et al. Planetary boundaries and veterinary services. *Rev Sci Tech.* 2021;40:439–53. 10.20506/rst.40.2.3236