Biological Times

Volume No. 4 | Issue No. 11 | Pages 14-15

Cross-Species Transmission of Viral Zoonoses: Threats to Animal and Human Health

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ABSTRACT

Almost 60-70 % of newly discovered infectious diseases start in animals, viral zoonotic diseases are among the biggest threats to global health. Cross-species transmission enables pathogens to move between different species and creating new reservoirs targeting outbreaks in humans and domestic animals. This process is fueled by ecological disruption, agricultural intensification, viral evolution, and wildlife trade. The mechanism allowing viral spillover are examined in this review including host-pathogen interactions, genetic adaptation and environmental interfaces involving wildlife, livestock, and humans. The complexity of transmission pathways is represented by pathogens such as, rabies, Nipah viruses, arboviruses, coronaviruses, and influenza viruses. This review also described the need for integrated surveillance systems, the increasing threats posed by urbanization and climate change and implications for One Health security. Pandemics in future caused by viral zoonoses spillover must be avoided by early detection, biosecurity, international cooperation, and immunization campaigns.

Keywords: Cross-species transmission, Zoonoses, Animal Health, Viral infections, One Health

To cite this article: Malik M, R Ahmed, FT Zahra, A Rehman & A Zahid. Cross-Species Transmission of Viral Zoonoses: Threats to Animal and Human Health. Biological Times. 2025. November 4(11): 14-15.

Introduction

Zoonotic diseases are those in which pathogens transmitted between animals and humans and have shaped the trajectory of global health for centuries. Zoonotic spillover frequency has accelerated in recent decades due to rapid social, environmental, and technological changes [1]. Viral zoonotic diseases are of particular concern due to high mutations in viruses, broad-host adaptability, and the ability to transmit rapidly across humans. HIV, H1N1 influenza, SARS in 2002, MES in 2012, Ebola, and COVID-19 pandemic emergence highlights the spillover events that transform into global crisis [2]. Transmission between species (cross-species) is not an accidental phenomenon, it is the complex interaction among viruses, host, ecosystem, and human behaviour. It is critical mechanism for developing strategies to detect, prevent, and respond to future threats of zoonoses. The review focuses on in-depth detail of the biological, ecological, and socio-economic factors spreading spillover and associated with threats to both human and animal health.

Primary Influences on Animal-to-Human Viral Transmission

Ecological and Environmental Disruption

Ecological changes, deforestation, and expansion of agricultural land driven by humans brings wildlife, livestock, and humans in contact [3]. Animal such as rodents, bats, and primates towards human settlements and increase likelihood of viral exchange pushed by deforestation. Deforestation, for example, in South Asia has been strongly linked to spillovers of Nipah virus from bats to pigs and eventually humans [4]. As natural ecosystems degrade, the buffering capacity that once separated wildlife reservoirs from human populations collapses. This increases not only direct contact but also indirect transmission through contaminated food, water, or vectors [5].

Agricultural Intensification and Livestock Production

Farmers on industrial scale creates the dense population of genetically similar livestock, by providing viruses an ideal environment to amplify, mutate, and resort [6]. In poultry and swine farmers, Influenza-A virus is classic example, where repeated mixing of viral strains can generate novel variants which are capable of infecting humans [7]. Animal markets accelerates cross-species viral movement into crowded and stressful environments. This causes to compromise the immunity of animals and increase viral shedding and forming hotspot for spillovers [8].

Urbanization and Human Population Growth

Peri-urban expansion and rural areas can increase the Animal-human interaction [9]. Urban wildlife such as bats, monkeys, and rodents thrive in densely populated cities, creating new viral interfaces. As global travel and trade intensify, viruses that spill over in one region can rapidly disseminate internationally turning localized events into global health emergencies [10].

Viral Evolution and Genetic Plasticity

Viruses, particularly RNA viruses mutate rapidly, adapting to new hosts [11]. Three key processes promote cross-species transmission including, **Mutation:** Creates genetic variants with altered host receptor binding. **Recombination:** Common in coronaviruses, enabling the exchange of genetic segments between strains. **Reassortment:** Occurs in segmented viruses such as influenza, leading to novel pandemic strains [12].

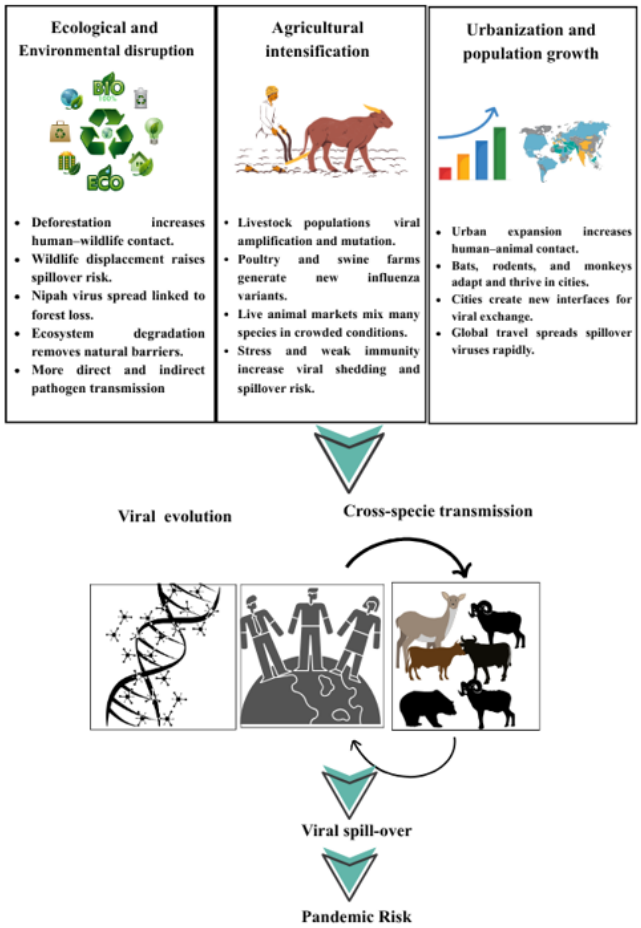

Fig. 1: Pathways to pandemic risk: Environmental disruption, agricultural intensification, and urbanization drive viral evolution and cross-species transmission, ultimately leading to viral spillover and increased pandemic potential., make this caption short.

Mechanisms and Dynamics of Cross-Species Viral Spillover

Viral spillover in cross-species involves a series of biological and ecological transition that allow a pathogen to establish infection in a new host [13]. Molecular barriers such as, receptor compatibility, cellular entry mechanisms, and host innate responses help overcome virus. Many viruses,

specifically RNA virus possess high mutation rates that enable rapid adaptation to new type of receptors, changes in tissue tropism, and evasion of host antiviral pathways [14]. Spillover is also shaped by ecological interactions, contaminated environments, vectors such as mosquitoes and ticks, or viruses often move from wildlife to humans through intermediate host. Host such as camels, pigs, or civets can increase viral dose and accelerate adaptation. Human behavior, including hunting, livestock intensification, and wildlife trade, creates repeated exposure events that increase the probability of successful spillover. Once a virus enters a susceptible host, sustained transmission depends on viral fitness, opportunities for human-human transmission, and shedding dynamics [15].

Major Viral Zoonoses and Their Impact on Global Health

There are some families of viruses that optimize the consequences of cross-species transmission. Influenza A virus in aquatic birds, routinely move into pigs and humans through genetic reassortment, generating pandemics strains such as H1N1 [16]. Bat origin coronaviruses including SARS, MERS, and SARS-COV2 demonstrate the ability to adapt via intermediate animal hosts and cause large-scale outbreaks [17]. Rabies viruses thrive in various wildlife reservoir and demonstrate the severe health stress that originate from repeated cross-species exposure [18]. Environmental disruption and livestock interfaces of Nipah virus allow highly lethal virus spillover into humans. West Nile, Zika, Dengue, and other arboviruses highlight the role of vectors in bridging viral movements in birds, primates, livestock, and humans. The zoonoses collectively disrupts the public health, causing economic loss through livestock mortality, reduce biodiversity, and reshaping global disease landscape [19].

Approaches for Prevention, Surveillance, and One Health Preparedness

Viral zoonoses prevention requires a coordinated global effort using One Health framework that integrates animals, humans, and environmental health [20]. One Health surveillance should include monitoring of wildlife and screening of livestock, genomic sequencing, and molecular detection tools to identify an emerging virus before wide transmission has occurred [21]. Biosecurity on farms, regulation of live animal markets, and vaccination in animals, especially rabies can be controlled by reducing spillover risk [22]. Similarly, investments in universal or broad-spectrum vaccines have improved antiviral therapies, and intranasal vaccine offering promise for reduction of viral transmission at mucosal entry sites. Public engagement, community behavior change, food safety education, and responsible wildlife-human interaction practices complement these technological interventions [23]. It is important in the mitigation of climate change and land-use planning because environmental stability reduces contact rates between humans, livestock, and wildlife.

Conclusion

Cross-species viral transmission is a defining global health challenge to face the ecological disruption, viral evolution, human expansion, and environmental change. Interactions between humans, humans, and livestock increasingly interconnected, opportunities for viral spillover are growing. Host jump mechanisms, identification high-risk ecological interfaces, and strengthening surveillance and biosecurity system understanding is key factor to prevent the next pandemic. One Health approach offer a best path to minimize the threats of zoonotic diseases that unites scientific innovation with public policy and community practices. Future of global health depends on the active investment, collaboration across sectors, and sustained commitment to manage viral zoonotic diseases.

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