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Nipah Virus: From Animal Reservoirs to Human Disease

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Review Article

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Abstract

Nipah virus (NiV) is a highly pathogenic zoonotic virus that continues to represent a serious public health concern in South and Southeast Asia. Fruit bats of the genus Pteropus are recognized as important natural reservoirs, while domestic animals such as pigs can contribute to viral amplification and transmission to humans. Human infection may occur through direct contact with infected animals, contaminated food, or infected individuals, with clinical disease ranging from asymptomatic or mild infection to severe respiratory illness and encephalitis. The high case-fatality associated with severe Nipah virus disease, combined with the absence of widely available licensed vaccines or specific antiviral treatments, makes early detection and prevention particularly important. Advances in molecular diagnostics, genomic surveillance, animal monitoring, monoclonal antibody research, and vaccine development are improving preparedness, but substantial challenges remain. This review discusses the ecology and transmission of Nipah virus, its pathogenesis and clinical manifestations, current approaches to diagnosis and surveillance, and emerging strategies for prevention and treatment. A coordinated One Health approach integrating human, animal, and environmental health will be essential for reducing the risk of future outbreaks.

Keywords: Nipah Virus; Zoonotic Disease; Pteropus Bats; Animal Reservoirs; Viral Pathogenesis; Encephalitis; One Health; Surveillance; Vaccine Development

Introduction

Nipah virus is an enveloped, negative-sense RNA virus belonging to the genus Henipavirus within the family Paramyxoviridae. It was first recognized during an outbreak of encephalitis and respiratory disease in Malaysia and Singapore in 1998–1999, where transmission was strongly associated with infected pigs and human contact with these animals. Since then, outbreaks have been reported mainly in Bangladesh and India, with important differences in transmission patterns between regions.

What makes Nipah virus particularly concerning is its ability to move between animal and human populations while causing severe disease in humans. Fruit bats, especially Pteropus species, are considered important natural reservoir hosts. Viral spillover can occur when humans come into contact with infected animals or materials contaminated by them. In some outbreaks, subsequent human-to-human transmission has sustained transmission within families, healthcare settings, and communities.

Nipah virus illustrates why emerging viral diseases cannot be understood solely from a human clinical perspective. The ecology of the reservoir host, changes in land use, livestock production, food practices, climate-related environmental changes, and human behavior can all influence the probability of spillover. Understanding this interconnected system is central to preventing future outbreaks.

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Animal Reservoirs and Viral Ecology

Fruit bats of the genus Pteropus are recognized as important natural hosts of Nipah virus. These bats can carry henipaviruses without developing the severe disease observed in humans. Viral shedding may occur through saliva, urine, and other biological materials, creating opportunities for transmission to other animals or humans.

The relationship between bats, domestic animals, and people is particularly important in areas where agricultural activity occurs close to natural habitats. Habitat disturbance and changes in food availability may increase interactions between bats and human-managed environments. Such ecological changes do not automatically lead to outbreaks, but they can create conditions in which opportunities for viral spillover increase.

The Malaysian outbreak demonstrated the importance of pigs as an intermediate host. In that setting, intensive pig farming and ecological changes created conditions that facilitated transmission from bats to pigs and subsequently to humans. In contrast, outbreaks in Bangladesh and India have more often been associated with direct or foodborne exposure involving fruit bats and subsequent human-to-human transmission.

These differences emphasize that Nipah virus transmission is not governed by a single pathway. Local ecological and social conditions determine how the virus moves between reservoir hosts, animals, and humans. Consequently, prevention strategies must be adapted to the specific epidemiological context of each region.

Transmission to Humans

Human Nipah virus infection can occur through several routes. Direct exposure to infected animals or their secretions represents one important pathway. Contamination of food by infected bats is another recognized route. In Bangladesh, consumption of fresh date palm sap contaminated by fruit bats has been associated with human infection.

Human-to-human transmission is also a major concern. Close contact with infected individuals can result in transmission, particularly among family members and healthcare workers caring for severely ill patients. Healthcare-associated transmission highlights the importance of infection prevention and control measures, especially when the diagnosis is not initially recognized.

The existence of multiple transmission routes makes Nipah virus particularly challenging to control. Preventing spillover requires interventions at the animal–human interface, while preventing secondary transmission requires rapid diagnosis, isolation, contact tracing, and appropriate infection-control measures.

Viral Pathogenesis and Human Disease

Nipah virus has a marked tropism for endothelial cells and the central nervous system. Following infection, viral replication and dissemination can lead to systemic disease, vascular involvement, and neurological complications. The mechanisms responsible for severe disease involve both direct viral effects and host immune responses.

The clinical presentation can vary considerably. Some infected individuals may have nonspecific symptoms or relatively mild illness, whereas severe cases can develop respiratory distress, altered consciousness, seizures, and encephalitis. Neurological disease is one of the defining features of severe Nipah virus infection.

Encephalitis may progress rapidly and can result in coma and death. Survivors may experience persistent neurological complications, and delayed or recurrent neurological manifestations have also been described. The severity of disease and the potential for rapid deterioration make early clinical recognition particularly important.

The immune response to Nipah virus remains an active area of research. Understanding how innate and adaptive immune responses influence disease severity could help identify biomarkers of progression and support the development of targeted therapies. Antibody responses, particularly those directed against viral surface glycoproteins involved in attachment and membrane fusion, are of considerable interest for vaccine and therapeutic development.

Diagnosis and Surveillance

Early diagnosis is essential for managing suspected Nipah virus infections and limiting secondary transmission. Molecular testing, particularly reverse-transcription polymerase chain reaction (RT-PCR), is an important diagnostic approach during acute infection. Serological methods can also contribute to diagnosis and surveillance by identifying antibodies generated following infection.

However, laboratory diagnosis can be challenging in regions where specialized testing facilities are limited. Strengthening diagnostic capacity in areas where Nipah virus is known or suspected to circulate should therefore be an important component of preparedness.

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Genomic surveillance provides another valuable tool. Sequencing viral genomes can help identify transmission patterns, distinguish introductions from sustained local transmission, and monitor viral evolution. Integrating genomic information with epidemiological and ecological data could improve understanding of how spillover events occur and help identify populations or locations where intervention should be prioritized.

Surveillance should not be restricted to human populations. Monitoring bat populations, domestic animals, and environmental factors can provide important information about viral circulation before human outbreaks occur. This is where the One Health approach becomes particularly valuable.

One Health and Prevention

Nipah virus is a clear example of why human health, animal health, and environmental health must be considered together. A human-only approach is unlikely to prevent spillover because the virus is maintained within an ecological system that includes wildlife reservoirs and environmental factors.

One Health surveillance can combine wildlife sampling, veterinary monitoring, human disease surveillance, genomic sequencing, and environmental assessment. Such integrated systems may improve the early recognition of changes in viral circulation and identify situations where the risk of spillover is increasing.

Community education is equally important. People living in areas where fruit bats, livestock, and humans interact should receive practical information about reducing exposure to potentially contaminated materials. Safe food practices, appropriate handling of sick animals, and infection-control measures in healthcare facilities can reduce transmission opportunities.

Importantly, prevention strategies should be designed in collaboration with local communities. Interventions that ignore local economic practices or cultural traditions are unlikely to be sustainable. Effective One Health programs should therefore combine scientific evidence with community participation and locally appropriate solutions.

Vaccines and Therapeutic Research

The absence of a widely available licensed human vaccine remains an important gap in Nipah virus preparedness. Several vaccine approaches are being investigated, including viral-vector, subunit, nanoparticle, and other platform technologies. Much of this work focuses on the viral attachment and fusion proteins because antibodies targeting these proteins can interfere with viral entry into host cells.

Monoclonal antibodies have also attracted considerable attention. Experimental studies have identified antibodies capable of neutralizing Nipah virus and protecting against disease in animal models. Such approaches may eventually provide therapeutic or post-exposure options for individuals at high risk.

Antiviral research is another important area. Because Nipah outbreaks are relatively infrequent and geographically concentrated, conducting large conventional clinical trials can be difficult. This makes investment in platform-based research, animal models, preparedness trials, and internationally coordinated research particularly important.

Future medical countermeasures will need to address more than efficacy alone. They should also be rapidly deployable, scalable, affordable, and accessible in regions where outbreaks are most likely to occur.

Future Challenges and Research Priorities

Several priorities should guide future Nipah virus research. First, surveillance capacity needs to be strengthened at the animal–human interface. Better understanding of viral circulation in reservoir populations could improve risk assessment and early warning.

Second, genomic surveillance should be integrated into outbreak investigations. Rapid sequencing and data sharing can help researchers understand transmission dynamics and identify changes in viral populations.

Third, vaccine and therapeutic development requires sustained investment even during periods when no major outbreak is occurring. Research programs that disappear between outbreaks risk losing valuable expertise and infrastructure.

Finally, preparedness must become increasingly multidisciplinary. Virologists, immunologists, veterinarians, epidemiologists, ecologists, clinicians, and public health authorities all contribute different perspectives that are necessary to understand Nipah virus emergence.

Conclusion

Nipah virus demonstrates how an animal-associated pathogen can become a serious human health threat when ecological, agricultural, and social factors create opportunities for zoonotic transmission. Fruit bats remain central to the ecology of the virus, but the pathways from

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wildlife reservoirs to humans differ across geographic settings. This variation makes locally informed surveillance and prevention essential.

Progress in molecular diagnostics, genomic surveillance, vaccine research, monoclonal antibodies, and One Health approaches provides important opportunities to improve preparedness. Nevertheless, the most effective response to Nipah virus will not come from a single technology or intervention. Sustained surveillance, community engagement, stronger laboratory capacity, and international collaboration must work together.

The greatest opportunity may be to identify and reduce spillover risk before human outbreaks occur. Treating Nipah virus preparedness as a continuing priority rather than an emergency response will be critical for protecting vulnerable communities and strengthening global readiness for future zoonotic diseases.

Author Contributions

The author conceived the topic, reviewed the relevant literature, prepared the manuscript, and approved the final version.

Ethical Approval

Not applicable, as this review is based on previously published literature and does not involve human participants or animals.

Data Availability

No new datasets were generated or analyzed for this article.

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