

Ebola Virus: Global and India threats, Synergy of AI and 3D Bioprinting in Next-Generation Therapeutics, Variants, Spillover Dynamics, Cellular Tropism Mechanism, Host Models for Rapid Drug and Vaccine Discovery

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Abstract:

Ebola virus disease (EVD) is a severe, fatality-prone zoonotic infectious disease, which remains a prominent health threat around the world owing to its fast propagation, frequent occurrence, and serious repercussions on both medical and socio-economic fronts. The factors like increasing globalization, environmental alterations, and contact between humans and reservoir animals have escalated the chances of emergence and global dissemination of Ebola virus. In this review article, the focus will be on examining the taxonomy, structural biology, global and Indian threats, mutations, spillover events, cell-specific tropism, and pathophysiology associated with the Ebola virus. Moreover, the review also throws light on the expanding influence of artificial intelligence, computational biology, and 3D bioprinting in outbreak prediction, genomics-based surveillance, discovery of antiviral drugs and vaccines, and modeling of viral diseases. AI-driven tools have expedited medical research, while 3D bioprinting has facilitated a better understanding of the infection process and effectiveness of antiviral agents through bioengineered human-like samples.

Keywords: Ebola virus, Artificial Intelligence, 3D Bioprinting, Spillover Dynamics, Cellular Tropism

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1. INTRODUCTION

Ebola virus disease (EVD) is an extremely dangerous and lethal zoonosis belonging to the family Filoviridae. Since its first detection in 1976, numerous outbreaks have occurred worldwide, especially in Africa, causing considerable mortality and creating medical crises in addition to social and economic consequences. EVD features hemorrhagic fever, immunological disorders, vascular impairment, and multiple organ dysfunction. Spread of the Ebola virus takes place due to direct exposure to bodily fluids of infected people, contaminated materials, and sick animals; hence, a fast response in controlling the situation is crucial for public health protection¹.

Various factors, such as globalisation and international travel, environmental changes and deforestation, climate change, and increased contacts between humans and their environment, may result in the emergence and cross-transmission of the Ebola virus across national borders. One could only mention the West African epidemic of Ebola virus that took place from 2014 to 2016 and showed the terrible consequences this virus produces to healthcare systems, local and global economy, and preparedness of the world community to deal with such a threat. Although there are no cases of endemic occurrence of EVD in India, there are certain threats posed by the peculiarities of this state.

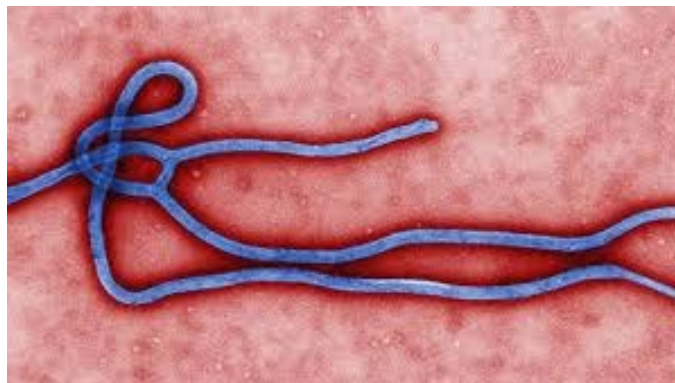


Figure 1: Ebola virus disease²

Emerging scientific discoveries concerning artificial intelligence, computational biology, regenerative medicine, and 3D bioprinting provide innovative ways for fighting with Ebola virus disease. The role of the former increases with the number of applications in outbreak prediction, genetic analysis, anti-viral medication discovery, and vaccine creation.

1.1 Background Information

The Ebola virus disease (EVD) is a serious and lethal zoonotic infection caused by viruses that fall under the classification of the genus Ebolavirus in the filovirus family. Ebola virus infections have been linked to multiple epidemics since its discovery in 1976 in Central Africa. The transmission of Ebola virus infection occurs through the direct contact with the fluids and tissues of individuals infected with the virus and results in a hemorrhagic fever, impaired immune response, and organ dysfunction. The increase in globalization, climate change, and human activity among the Ebola virus reservoir animals has led to an increased likelihood of an epidemic breakout.

1.2 Objectives of the Review

The main objectives of this review are:

- To examine the taxonomy, structural biology, and pathogenesis of Ebola virus.
- To analyze global and Indian threats associated with Ebola virus disease.
- To evaluate spillover dynamics, zoonotic transmission, and cellular tropism mechanisms.
- To discuss viral variants and evolutionary dynamics influencing disease progression.

1.3 Importance of the Topic

The Ebola virus continues to be considered one of the deadliest diseases that have emerged due to their high mortality rate and the possibility of epidemic spread and the devastating socioeconomic impact they may cause. It becomes crucial to gain insight into such aspects as the Ebola virus structure, mode of transmission, and evolution in order to enhance the capabilities of the global health care system to address future outbreaks. In turn, innovations like artificial intelligence and computational biology, as well as 3D bioprinting, have led to the emergence of novel methods in diagnostics and prevention of such diseases.

2. EBOLA VIRUS: TAXONOMY AND STRUCTURAL BIOLOGY

Ebola virus is an extremely dangerous type of zoonotic virus which is grouped within the Filoviridae family. It is important to note that the Filoviridae is a viral family characterized by its capacity to cause hemorrhagic fever in human beings as well as other nonhuman primates. In addition, Ebola virus is considered part of the Ebolavirus genus.

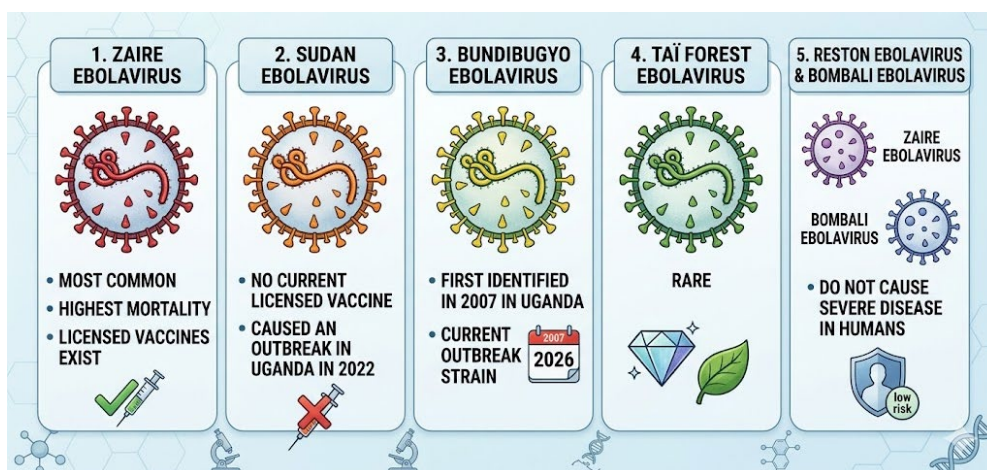


Figure 2: Species of the virus³

As previously mentioned, there are several species of the virus, all of which vary based on geographical locations as well as their level of danger. The different species of the virus include:

- Zaire ebolavirus
- Sudan ebolavirus

- Bundibugyo ebolavirus
- Tai Forest ebolavirus
- Reston ebolavirus
- Bombali ebolavirus

Among these species, Zaire ebolavirus remains the most deadly and important pathogen. This virus has been involved in almost all major epidemics, including the deadly outbreak in West Africa in 2014-2016. Zaire ebolavirus features extremely high fatality rates and immune-evasion mechanisms and stands out as one of the most dangerous human pathogens.

On the other hand, Sudan ebolavirus, which has triggered several epidemics in Sudan and Uganda, is usually less lethal than the former species. Bundibugyo ebolavirus is moderately pathogenic and has been observed to cause epidemics in Uganda. Moreover, there have been some isolated cases where Tai Forest ebolavirus was found to infect humans. Interestingly, Reston ebolavirus infects only non-human primates and pigs with very low fatality in humans. Recently, scientists identified yet another bat species, Bombali ebolavirus, but its potential to cause infection in humans is not yet confirmed⁴.

In terms of structure, Ebola virus belongs to the group of filoviruses because of its filamentous or thread-like shape. The virus particles can be either linear, branched, circular, or "U" shaped when observed under an electron microscope. Like any other envelope virus, the Ebola virus particle is enclosed in an envelope derived from the host cell upon budding. In this envelope, one finds viral glycoproteins, which play a vital role in facilitating the attachment to the host cell.

Ebola viral RNA is a negative-sense, single-stranded RNA measuring 19 kb in size. As a result, it is not possible for the viral RNA to translate directly into proteins within the host. Therefore, first, it should undergo transcription to produce positive-sense RNA using the viral RNA-dependent RNA polymerase. The viral genome encodes a total of seven essential proteins, which facilitate viral survival and replication in the host.

Table 1. Structural Proteins and Functions of Ebola Virus⁵

Viral Protein	Major Function
Glycoprotein (GP)	Host-cell attachment and membrane fusion
NP	Encapsidation of viral RNA
VP24	Interferon antagonism
VP35	Immune suppression
VP30	Transcription regulation
VP40	Viral assembly and budding
L Protein	RNA polymerase activity

The glycoprotein (GP) plays a critical role in cellular entry and immune evasion, making it a major therapeutic and vaccine target.

Table 2. Summary of Previous Literature on Ebola Therapeutics, Artificial Intelligence, and 3D Bioprinting Applications

Author(s) & Year	Title of the Study	Methodology/Focus	Major Findings
Skariyachan et al. (2026) ⁶	<i>Integrative computational approaches in the quest for novel Ebolavirus therapeutics</i>	Computational biology, AI, molecular docking	AI and bioinformatics approaches accelerated Ebola therapeutic discovery and target prediction.
Lu et al. (2019) ⁷	<i>Ebola therapeutic study and future directions</i>	Review of antiviral and therapeutic strategies	Monoclonal antibodies, antivirals, and vaccines showed promise, but challenges in efficacy and accessibility remained.
Sweiti et al. (2017) ⁸	<i>Repurposed therapeutic agents targeting the Ebola virus: A systematic review</i>	Systematic review of repurposed drugs	Drug repurposing offered rapid and cost-effective therapeutic options for Ebola management.
Derakhshanfar et al. (2018) ⁹	<i>3D bioprinting for biomedical devices and tissue engineering</i>	Review of 3D bioprinting technologies	3D bioprinting improved tissue engineering, disease modeling, and biomedical research applications.
Kong & Zhao (2023) ¹⁰	<i>3D bioprinting for biomedical applications</i>	Biomedical applications of bioprinting	Bioprinted tissues and organoids supported personalized medicine and advanced therapeutic testing.

From the literature review, it can be seen that the advancement in the fields of artificial intelligence, computational biology, drug repurposing, and 3D bioprinting has greatly impacted the research related to Ebola and the development of medicines for Ebola. While AI-based techniques helped in faster discovery of drugs and the study of mutations, drug repurposing enabled quick treatment during the outbreak of the virus. The research on 3D bioprinting emphasized the significance of bioprinting in Ebola research.

2.1 Global and Indian Threats of Ebola Virus

Ebola virus disease (EVD) is one of the deadliest infectious zoonotic diseases that are posing significant challenges to global public health due to their highly deadly nature, fast spread, and adverse effects on healthcare. Globalization, international travel, environmental changes, and increasing contact between humans and wildlife have transformed the Ebola virus from a local

disease to a global public-health problem. Significant outbreaks like the West African outbreak of 2014-16 have highlighted the challenges posed by Ebola to healthcare facilities, the economy, and social order¹¹.

Even though Ebola is not endemic to India, the country is still vulnerable to an EVD outbreak. Issues like crowded hospitals, lack of BioSafety Level 4 labs, and uneven emergency response capabilities might increase the chances of a breakout. The Indian government has taken several steps to ensure adequate preparation against potential EVD outbreaks in the country. These include increased airport screening, improved quarantine, enhanced molecular diagnostics, surveillance, and infection control measures.

2.2 Global Threats

The Ebola virus continues to pose a significant danger to global health due to its high infectivity, high pathogenicity, and fast transmission capability. Spread from human to human takes place when people come into direct contact with body fluids of infected patients and contaminated materials. Delayed diagnosis can further worsen the situation since it leads to faster spread of the disease within communities and hospitals. Weak healthcare facilities in the affected areas further contribute to the high levels of mortality rates since diagnostic labs, isolation rooms, and healthcare professionals lack sufficiently in these areas. Moreover, increased international travels and globalization pose threats to non-endemic nations.

Besides causing public health challenges, Ebola outbreaks also create numerous negative consequences that include trade reduction, economic hardships, mental stress, stigmatization of infected individuals, and mistrust of the local population towards healthcare providers. The evolution of the virus can have an impact on the transmissibility, immune evasion, and efficacy of developed vaccines. Healthcare workers are the most vulnerable to the effects of Ebola outbreaks because of their high levels of exposure. Global health institutions suggest several key steps in enhancing preparedness.

2.3 Indian Threats and Preparedness

The threat of Ebola virus infection is persistent in India due to a number of factors. India has a dense population living in metropolitan cities that could help in the quick spread of infections during an epidemic outbreak.



Figure 3: Ebola haemorrhagic fever¹²

Enhanced international connections increase the likelihood of importing infections from affected areas. Secondly, the disparities in the availability of health services in urban and rural areas can result in late detection and control measures. Lastly, there are no adequate BSL-4 centers for containing infections by Ebola in the country.

Some major risks posed by Ebola in India are:

- Dense urban population
- International travel connectivity
- Healthcare inequalities
- Limited high-containment facilities
- Risk of imported infections

India is employing several surveillance and precautionary measures to improve national preparedness. Screening procedures for travelers at airports include thermal scans and history checks to isolate suspicious cases that may have traveled from affected areas. Hospitals have also adopted isolation and quarantine procedures to avoid human to human transmission.

Table 3. Comparative Analysis of Global and Indian Ebola Threats¹³

Parameter	Global Perspective	Indian Perspective
Endemicity	Present in Africa	Non-endemic but vulnerable
Transmission Risk	High	Imported case risk
Healthcare Preparedness	Variable	Improving
Biosafety Facilities	Advanced in developed regions	Limited BSL-4 facilities
Population Vulnerability	Moderate to high	Extremely high

Molecular diagnostic laboratories, including those used for RT-PCR testing, have been established in order to increase the speed of viral identification and surveillance. Emergency outbreak preparation programs that include medical personnel training, rapid response, and public education campaigns have been instituted to increase preparedness in case of an Ebola epidemic.

3. VARIANTS AND EVOLUTIONARY DYNAMICS

The level of variation at the genetic level has great significance in terms of the virulence, transmission efficacy, and treatment of the Ebola virus. Being a type of RNA virus, the Ebola virus tends to accumulate mutations as it replicates. This could have an impact on the virus's virulence or its characteristics when it causes outbreaks¹⁴.

Newly emerging mutations could:

- Viral infectivity
- Immune escape mechanisms
- Vaccine efficacy

- Host adaptation
- Antiviral resistance

Mutations in viral proteins, especially the glycoprotein (GP), may increase viral infectivity and help the virus evade host immune responses. Certain genetic changes may also reduce the effectiveness of vaccines and antiviral drugs. In addition, viral evolution can improve adaptation to human hosts and increase the risk of future outbreaks.

Table 4. Major Ebola Virus Species and Characteristics¹⁵

Ebola Species	Pathogenicity	Human Infection
Zaire ebolavirus	Very high	Yes
Sudan ebolavirus	High	Yes
Bundibugyo ebolavirus	Moderate	Yes
Reston ebolavirus	Low	Rare

With advances in technology, AI-driven systems have become an important part of genomic surveillance systems that monitor changes in the genome of Ebola virus. The use of artificial intelligence and machine learning can make it easier to analyze, understand, and track mutations.

3.1 Spillover Dynamics and Zoonotic Transmission

Spillover involves the transfer of disease-causing agents from animals to humans. The ebola virus is one such zoonotic agent, and its natural hosts are fruit bats that are capable of carrying the virus without exhibiting serious symptoms. Human infection is likely to occur due to interaction with infected animals or their biological components.

Human infection takes place due to:

- Wildlife exposure
- Bushmeat consumption
- Contact with infected body fluids
- Occupational exposure
- Nosocomial transmission

Individuals involved in the hunting, butchery, and handling of infected animals are more vulnerable to infection. Transmission from one person to another is primarily by direct exposure to blood, saliva, vomit, urine, and other infected bodily fluids. Hospital-related infections can result due to poor infection control and lack of appropriate protective gear.

There are various environmental factors that lead to Ebola spillover, including:

- Deforestation
- Climate change
- Mining activities

- Agricultural expansion
- Wildlife habitat destruction

These environmental disturbances increase human interaction with wildlife and disrupt natural ecosystems, thereby raising the risk of zoonotic transmission. Climate change may also influence animal migration patterns and viral circulation¹⁶.

AI-based ecological surveillance systems are increasingly used to monitor spillover risks. Artificial intelligence analyzes climate data, wildlife migration patterns, satellite imagery, and geographic information systems (GIS) to identify high-risk regions and support early outbreak prediction.

3.2 Cellular Tropism and Pathogenesis

The Ebola virus has wide cellular tropism since it can infect many cell types within the human body. The Ebola virus infects mainly immune cells and vascular cells. This leads to significant illness due to immune system dysfunction¹⁷.

Target cells include:

- Macrophages
- Dendritic cells
- Hepatocytes
- Endothelial cells
- Fibroblasts
- Adrenal cells

The Ebola infection process involves several stages:

1. Viral attachment
2. Membrane fusion
3. Cytoplasmic replication
4. Immune suppression
5. Systemic dissemination

Glycoprotein is the component of the virus that attaches to the host cell and enters by means of membrane fusion. The virus then replicates rapidly within the cytoplasm before spreading to several organs. The Ebola virus interferes with host immune responses, thus hindering effective replication of the virus.

Table 5: Major Cellular Targets and Pathological Effects¹⁸

Cell Type	Pathological Effect
Macrophages	Cytokine storm

Dendritic cells	Immune suppression
Endothelial cells	Vascular leakage
Hepatocytes	Coagulation disorders
Adrenal cells	Electrolyte imbalance

Infected macrophages and dendritic cells release excessive inflammatory cytokines, leading to a cytokine storm. This severe immune reaction contributes to vascular leakage, coagulation abnormalities, tissue damage, shock, and multi-organ failure, which are major causes of mortality in Ebola virus disease

4. METHODOLOGIES AND FINDINGS

The study of the Ebola virus in modern times employs multidisciplinary approaches such as molecular biology, genomics, artificial intelligence, tissue engineering, immunology, and epidemiology. The use of modern techniques has greatly enhanced our knowledge on the evolution, mode of transmission, pathogenesis, surveillance, and treatment options for the Ebola virus infection. Molecular techniques are particularly useful in the identification of mutations and for treatment purposes¹⁹.

4.1 Genomic Methodologies

Genomic techniques have proven vital for studying Ebola virus because they enable researchers to analyze virus structure, mutations, genetic differences, and routes of transmission. Such genomic analysis provides important insight into how the virus changes through the course of an outbreak and affects its pathogenicity and treatability.

Some genomic techniques are:

- Whole-genome sequencing
- RT-PCR
- Transcriptomics
- Proteomics

Whole-genome sequencing is commonly used as an approach to analyzing all genes present within the Ebola virus. The approach assists in determining the existence of mutations, tracing viral evolution, comparing genomes from various outbreaks, and mapping out transmission paths of the virus. Whole-genome sequencing was instrumental for tracking the spread of the virus during the largest outbreaks and identifying new variants. RT-PCR is a technique of paramount importance for diagnosing Ebola virus infections. Reverse transcription polymerase chain reaction enables conversion of viral RNA into complementary DNA, followed by amplification of genomic segments of interest. The technique has a high degree of sensitivity and accuracy and is therefore crucial for the detection of viruses.

The term transcriptomics refers to the study of mRNA transcription during infection. Transcriptomics allows for examining changes in gene expression in hosts infected with the virus. These alterations may involve inflammatory processes and immune response

mechanisms. Proteomics implies the large-scale analysis of proteins expressed during infection. Proteomic analysis is used for identifying viral proteins as well as protein expression in the host's cells during infection²⁰.

Findings

These genomic methodologies have produced several important findings in Ebola research, including:

- Identification of mutation hotspots
- Improved outbreak tracking
- Better diagnostic sensitivity

There is evidence from genomic studies that certain mutations act as hot spots for adaptation, transmission, and immune evasion. Sequencing methods have enabled researchers to effectively track viral transmission and evolution during outbreaks. RT-PCR technology along with advances in molecular diagnostics has enhanced the sensitivity of the detection process greatly²¹.

4.2 AI and Computational Methodologies

Computational approaches and artificial intelligence are now of great importance to the contemporary study of Ebola because of their ability to process data rapidly²². This helps to achieve the discovery of new treatments, monitoring of outbreaks, genomics, and predictive modeling at faster speeds. Artificial intelligence can be used by researchers to eliminate the costs and time required for conventional experimentation.

Key AI and computational approaches are:

- Machine learning
- Deep learning
- Molecular docking
- Predictive epidemiology

These ML algorithms are used for analyzing large biomedical datasets and detecting hidden correlations related to virus spreading, mutations, and therapeutic efficacy. Such systems may assist in predicting disease progression, developing new drugs, and improving the monitoring of outbreaks. The next-generation approach based on AI technology is deep learning that utilizes neural networks for processing highly complicated biomedical data. Such systems allow scientists to analyze genomes of viruses, detect specific mutation patterns, and enhance diagnostic imaging and predictive analysis during the course of an outbreak²³.

The molecular docking refers to computer-assisted modeling of interactions between viral protein complexes and possible drug substances. Using molecular docking, it is possible to discover antiviral substances able to interact with Ebola viral proteins and inhibit viral replication²⁴. The application of molecular docking greatly facilitates the process of discovering new drugs and applying existing drugs for novel applications. The field of predictive epidemiology utilizes AI along with statistical models and demographic data to

predict future trends and risks of epidemics. It allows analyzing climate conditions, migration flows, population distribution, and health care infrastructure.

Findings

AI and computational methodologies have produced several important findings in Ebola research, including:

- Faster drug discovery
- Improved outbreak prediction
- Enhanced mutation analysis

Through AI, the process of discovering antiviral drugs and therapeutic targets has been sped up, thus decreasing the amount of time needed to develop new drugs. Prediction modeling on the epidemic has enhanced outbreak predictions and early warning systems, which have aided public health organizations to intervene in the process in good time²⁵.

4.3 3D Bioprinting Methodologies

The use of three-dimensional bioprinting techniques can be considered an innovative approach in the study of Ebola virus infections since they allow creating tissue models that reproduce the physiological properties of human organs. This technique is based on using methods of tissue engineering, biomaterials, living cells, and computer systems to build artificially created biological systems for the study of viral infection, interaction between hosts and pathogens, and therapy reactions. In comparison with classical cultures, bioprinting makes it possible to create models that are more similar to humans²⁶.

The most common methods of 3D bioprinting include²⁷:

- Extrusion bioprinting
- Inkjet bioprinting
- Organoid engineering
- Organ-on-chip technology

The first mentioned method is widely used in tissue engineering. It presupposes extrusion of biological ink that includes living cells and biomaterial. Extrusion bioprinting allows creating various complex tissue models that are suitable for studying the process of Ebola virus infection and the effect of drugs on its replication. Inkjet bioprinting is based on droplet technology, according to which the process of deposition of materials is carried out in layers²⁸.

Inkjet technology allows obtaining high-quality printed structures and is used for creation of small-scale tissue models and infection models. Organoid engineering presupposes the creation of miniature organisms that replicate some of the physiological characteristics of human organs. Such models are used to conduct experiments related to studying processes in the course of infection of liver, lungs, blood vessels, and other human organs²⁹.

Table 6. Major Methodologies and Findings³⁰

Methodology	Major Findings
Genomic Sequencing	Emerging variant identification
AI Modeling	Rapid outbreak prediction
Molecular Docking	Potential antiviral compounds
3D Bioprinting	Realistic tissue simulation

The process of creating organ chips uses the combination of microfluidics and tissue engineering techniques for the development of miniaturized models of organs. It is possible to study infections such as those caused by the Ebola virus using organ chips³¹.

5. DISCUSSION

The discussion section provides critical analysis of the key findings associated with the Ebola virus biology, spillover mechanisms, cell tropism, evolution of viruses, as well as advancements in artificial intelligence and 3D bioprinting technologies³². The selected articles illustrate that the Ebola virus is still one of the major threats to global public health due to high mortality rate, possible transmission from animals, and fast spread of outbreaks. Modern scientific developments in bioinformatics, genomics, regenerative medicine, and tissue engineering allowed obtaining substantial data on viral pathogenesis and developing new approaches to drug development. In addition to evaluating scientific significance of the discussed results, this section also explores the current limitations and future perspectives in this field³³.

5.1 Interpretation and Analysis of the Findings

Based on the results of this review, Ebola virus continues to be a critical global health problem because of its high rate of mortality, transmission speed, and regular outbreaks³⁴. Virus mutations, spillover, and methods of evading the immune system affect the severity of the disease and therapy³⁵. Genomic monitoring is essential due to these factors. Environmental conditions, including deforestation and climate change, raise the probability of zoonotic transmission of the virus through closer contact between humans and the host species³⁶. Moreover, this review proves the effectiveness of AI in predicting outbreaks, analyzing mutations, finding drugs and vaccines, and 3D bioprinting technology in Ebola research.

5.2 Implications and Significance

The findings from this review have significant implications for public health around the world, infectious diseases research, and biomedical technology innovations³⁷. The study of evolutionary patterns of the Ebola virus and spillover events is critical towards enhancing outbreak preparedness and surveillance efforts. Artificial intelligence is central in outbreak prediction, genomic surveillance, discovery of antiviral drugs, precision medicine, and optimizing vaccines, therefore, hastening therapeutic advancements and interventions in emergencies³⁸. Furthermore, bioprinting and organoid technologies serve as more advanced human-based models for the study of viral infections and treatment efficacy, enabling personalized medicine through the reduction of animal experiments. Also highlighted in this

review is the requirement for a multidisciplinary approach towards preparation for future zoonotic infections in highly populous countries like India³⁹.

5.3 Research Gaps

Even with the considerable developments achieved, there remain critical research gaps in Ebola virus research, especially in terms of healthcare facilities, genome tracking, and Biosafety Level-4 laboratories available in the areas where outbreaks commonly occur⁴⁰. Gaps such as inadequate studies on patients who have survived Ebola virus, lack of enough data required by AI systems, and the complexities involved in using 3D bioprinting techniques still impede scientific research. In the future, there is a need to concentrate on research on AI-assisted treatments, vaccines against Ebola virus, real-time genome tracking, organoids, bioprinting techniques, and antivirals.

6. CONCLUSION

The conclusions drawn from this review article are a summary of the important facts associated with the biology of the Ebola virus, spillover dynamics, tropisms, evolution of the virus, and the latest advancements in technologies including artificial intelligence and three-dimensional bioprinting. It becomes evident from the available data that the Ebola virus is still regarded as a global health risk due to its highly pathogenic nature and ability to cause frequent outbreaks through zoonosis. The recent advancements in genomics, bioinformatics, regenerative medicine, and tissue engineering technology have contributed significantly towards enhancing knowledge on the viral mechanism and development of vaccines and drugs.

6.1 Summary of Main Insights

In this review, various aspects of Ebola virus biology, the dangers posed globally and in India, the evolution of Ebola, mechanisms of spillover events, the cell tropism of the virus, and recent advances in technology based on artificial intelligence and 3D bioprinting have been covered extensively. The findings from this literature review suggest that Ebola virus is a very deadly zoonotic disease, owing to the high mortality rate associated with it, its fast transmission capabilities, ability to evade the host immune system, and frequent outbreaks. Factors like deforestation, climate change, and human encroachment on the natural habitat of the animal reservoirs are responsible for initiating spillover and outbreak situations.

6.2 Importance of the Review

Importance of the paper can be explained by the fact that it encompasses different areas ranging from virology, epidemiology, computational biology, use of artificial intelligence, regenerative medicine, and outbreak preparedness. The paper points out the importance of the use of artificial intelligence technology and bioprinting in the development of effective measures against Ebola virus disease. It is important for people to understand how viral evolution, ecological disturbance, and technology advancement are interrelated and how they can prepare the world against any future outbreaks and reduce the impacts of zoonotic pandemics. Another reason why the paper is important includes India which faces challenges due to increased globalization.

6.3 Recommendations

1. Strengthening genomic surveillance and outbreak detection mechanisms for effective response.
2. Establishment of more BSL-4 laboratories in at-risk areas to enhance diagnosis.
3. AI-enabled advancements in drug discoveries and treatments for better Ebola disease control and management.
4. Utilizing 3D bioprinting techniques and other disease modeling methods for better antiviral tests.
5. Ecological surveillance to detect virus spillover into human communities.
6. Strengthened collaboration efforts in international research and health care.

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