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REVIEW ARTICLE

An Overview of Complexities of Ebola Virus

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Abstract:
Ebola Virus Disease (EVD), a deadly viral hemorrhagic illness, is caused by infection with a strain of the Ebola virus, belonging to the Filoviridae family. Due to globalization, the disease has emerged as a significant global health concern, particularly impacting regions with large migrant populations. Initially manifesting as nonspecific flu-like symptoms, patients progress rapidly to shock and multiorgan failure. This review provides an extensive examination of EVD, covering clinical manifestations, diagnostic criteria, treatment strategies, preventive measures, and management protocols. The disease first surfaced in 1976 near the Ebola River in what is now the Democratic Republic of Congo, leading to sporadic outbreaks primarily in African countries. Six distinct strains of the virus have been identified, with bats believed to serve as primary reservoir hosts. Human outbreaks typically stem from contact with infected forest animals, consumption of bushmeat, or exposure to contaminated bodily fluids. Human-to-human transmission occurs through direct contact with infected fluids, particularly via damaged skin or mucous membranes. EVD presents with sudden onset 'flu-like' symptoms (fever, muscle pain, chills), vomiting, and diarrhea, rapidly progressing to a severe state marked by hemorrhagic complications and multiple organ failure

Keywords: Ebola Virus Disease (EVD); Filoviridae family; Hemorrhagic illness; Variants of Concern; Multiorgan failure

1. Introduction

Ebola, previously known as Ebola Hemorrhagic Fever (EHF), is a lethal disease that predominantly affects both humans and nonhuman animals. It is caused by infection with a virus belonging to the species Ebolavirus, which is part of the Filoviridae family. Since its identification, Ebola virus diseases (EVDs) have represented a significant global public health threat. In 1976, while investigating a suspected case of yellow fever, Dr. Peter Piot first encountered the illness in Zaire, Africa. The disease was named "Ebola" after its discovery near the Ebola River in Congo. The dimensions of Ebola infections vary, with diameters ranging from 50 to 80 nm and lengths spanning between 10,000 to 14,000 nm. Virions exhibit diverse shapes, including filaments, branches, and circles, although each filovirus possesses a distinctive thread-like structure. The RNA of the Ebola virus is negative-stranded, non-segmented, and approximately 19 kilobases in length, with seven characteristic features typically observed in its genome. [1-3]

Fruit bats of the Pteropodidae family, such as Hypsignathus monstrosus, Epomops franqueti, and Myonycteris torquata, serve as the primary hosts of EBOV in Africa. Nonhuman primates may contribute to transmission by ingesting partially consumed fruits dropped from trees, which can then transmit the disease to humans. The Indian population poses a potential risk for EVD due to its native Pteropodidae bat species. The Ebola virus was initially identified in 1976 during two unrelated outbreaks in southern Sudan and northern Zaire, the present-day Democratic Republic of Congo. It was named after the Ebola River. Laboratory analysis revealed that the viruses responsible for both outbreaks were antigenically, biochemically, and virologically identical to the Zaire and Sudan ebolavirus strains. In 2014, a significant outbreak of Ebolavirus disease in Western African countries quickly spread to several other nations, resulting in a dire global situation. [2-4]

Ebola virus belongs to the Filoviridae family, which also includes the Marburgvirus variant. This family is part of the Mononegavirales group, which also encompasses members of the Bornaviridae, Paramyxoviridae, and Rhabdoviridae families. Presently, six specific strains of Ebola virus are known: Zaire (EBOV), Sudan (SUDV), Tai Forest (TAFV), Bundibugyo (BDBV), Bombala (BOMV), and Reston (RESTV). Among these, the Zaire ebolavirus strain causes Ebola Hemorrhagic Disease (EHD), which exhibits the highest mortality rate in humans (57%-90%), followed by SUDV (41%-65%) and Bundibugyo ebolavirus (40%). Tai Forest ebolavirus has been linked to only one nonfatal human infection, while Reston ebolavirus causes asymptomatic infections in humans.[5,6]

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2. Background

2.1. History

The initial documented outbreak of Ebola took place in 1976, with simultaneous occurrences in Yambuku, northern Zaire (now the Democratic Republic of the Congo, DRC), and Southern Sudan. The name "Ebola" was derived from the Ebola River in Zaire. In 1994, an ethnologist fell ill after encountering a deceased monkey at Ivory Coast's Tai National Park. This infection was distinct from those associated with outbreaks in the DRC and Sudan, thus termed Tai Forest ebolavirus. In 1990, an outbreak of an enigmatic illness occurred in Reston, Virginia, USA, among cynomolgus macaque monkeys imported from the Philippines. This was later identified as Reston ebolavirus, an Asian variant of the Ebola virus. In 2007, a new strain of Ebola emerged in the Bundibugyo district of Western Uganda, leading to the confirmation of a fifth strain known as Bundibugyo ebolavirus. The most severe Ebola outbreak in West Africa took place between 2013 and 2015. [7] Originating in Guinea in March 2014 but ultimately traced back to late 2013, this outbreak marked the first instance of sustained human-to-human transmission of an Ebola virus strain for an extended period. Bombala ebolavirus (BOMV) was first identified in Sierra Leone in 2018, although it remains uncertain whether it causes illness in animals or humans. Major cases and outbreaks of Ebola virus disease in humans are chronologically listed thereafter [8]

2.2. Mode of transmission

The primary routes of transmission include close physical contact with patients during the acute phases of illness and exposure to the bodily fluids of the deceased. Traditional burial practices in African nations involve direct handling of deceased individuals, contributing to disease dissemination. In the 2014 EVD outbreak in Guinea, the high-risk traditional burial method accounted for 68% of infected cases. [9] EBOV RNA can persist for up to a month in rectal, conjunctival, and vaginal secretions, while semen samples may test positive for infection for up to 90 days, indicating viral presence in recovered individuals. Cases of physically transmitted EVD have been documented between recovering patients and close relatives. Additionally, a male patient who had recovered from EVD tested positive for Ebola virus antigen in his sperm sample approximately 90 days after onset of illness.

Initial beliefs that EBOV carriers played an insignificant role in EVD outbreaks, based on field studies in West Africa, were challenged by the documentation of a single asymptomatic carrier case during the 1996 North African pandemic. EBOV has been detected in various bodily fluids such as blood, saliva, sperm, and breast milk, while RNA has been found in sweat, tears, feces, and samples from the genital and rectal areas, suggesting that exposure to infected bodily fluids and substantial secretions is the primary mode of transmission. Consumption of undercooked meat from infected animals, such as bats or chimpanzees, significantly contributes to oral transmission of EVD, particularly in African regions. The identification of the disease in pigs in the Philippines in 2008 raised concerns about a wide range of potential animal hosts. Hospital-acquired infections have also been implicated in the spread of EVD, especially in areas with inadequate sanitation. Contaminated needles were identified as the source of the 1976 EVD epidemic in Sudan and Zaire, while poor sanitation and sterilization were key factors in the 1967 Yambuku EVD outbreak. Transmission through inanimate objects containing infected bodily fluids (fomites) is possible, although it remains unclear whether the illness can spread via airborne or droplet infection. [10]

3. Ebola Virus Disease (EVD)

3.1. Trasmission

The specific hosts and reservoirs of the Ebola virus remain elusive. However, there are indications suggesting that primates such as humans, chimpanzees, gorillas, and monkeys serve as primary hosts. Fruit bats of the Pteropodidae family are believed to be the primary reservoirs of the Ebola virus. Other animals, including duikers, non-human primates, cats, foxes, pigs, porcupines, pronghorns, and rodents, are considered to be intermediate or accidental hosts of the Ebola virus. Unlike bats, these animals typically experience severe and often fatal illnesses upon infection. [11] They can asymptomatically spread the virus and excrete it in their bodily fluids, potentially contaminating individuals who come into contact with them during hunting or handling of bushmeat. Research suggests that the virus can persist in human tissues and bodily fluids such as urine, sperm, sweat, aqueous humor, and breast milk of individuals recovering from the illness. This circumstance could lead to recurrence of Ebola infection in individuals who have recently recovered from EVD. [12]

Transmission of Ebola to humans can occur through contact with infected animals' blood, organs, or other bodily fluids. The first recorded case of Ebola virus illness during the West African outbreak from 2014 to 2016 was linked to exposure to bats. Besides bats, cases of EVD have been documented in individuals who have handled infected gorillas, chimpanzees, and even wild gazelles in Gabon, the Republic of the Congo, and Cote d'Ivoire, whether dead or alive. Possible entry points for the virus into the body include mucous membranes, cuts, wounds, eyes, ears, nose, mouth, and open wounds. Transmission through sexual intercourse with an Ebola patient in recovery or convalescence has been documented. All bodily fluids from individuals with EVD, such as blood, feces, urine, sweat, tears, saliva, semen, and other natural fluids, can harbor the Ebola virus. Reuse of contaminated needles

and medical equipment without proper sterilization can also transmit the Ebola virus. The virus can persist for weeks on surfaces such as doorknobs, light switches, beds, clothing, furniture, and utensils that have been contaminated by bodily fluids. [13]

3.2. Pathophysiology

The central focus of Ebola infection lies within the intricate phagocytic network. The Ebola virus can enter target monocytes, macrophages, and dendritic cells through the skin or mucous membranes, where these cells serve as crucial vectors for viral dissemination. Initially, the Ebola virus spike glycoprotein impedes the virus's entry into dendritic and macrophage cells, a pivotal stage in the progression of the disease. This disruption leads to deficiencies in the adaptive immune response, including the inability to stimulate chemokines, up-regulate the major histocompatibility complex (MHC), and induce cell dissociation. Interferon production is also hindered. The later stages of Ebola Virus Disease (EVD) are characterized by multiple organ dysfunction syndrome (MODS), which results from persistent and severe underlying vascular inflammation, evident through phenomena such as edema, capillary leakage, and generalized increased capillary permeability. Changes in capillary permeability, alterations in blood flow dynamics, the formation of microthrombi, and disturbances in microvascular equilibrium collectively contribute to organ dysfunction observed in MODS [14]

3.3. Signs and Symptoms

Individuals affected by Ebola virus disease (EVD) present a diverse range of clinical symptoms. Typically, it takes anywhere from two to twenty-one days for symptoms to manifest following infection. Initial signs of EVD include fever, chills, headaches, body aches, and fatigue. Subsequently, gastrointestinal symptoms such as nausea, vomiting, constipation, and abdominal pain often follow these initial effects. As the illness progresses, patients may experience severe weakness, profound fatigue, and dehydration, which can lead to complications like low blood pressure, shock, and multi-organ failure. In severe cases, individuals with EVD, also known as Ebola hemorrhagic fever, may suffer from significant external and internal bleeding. Moreover, neurological symptoms such as confusion, seizures, and unconsciousness can also occur as a result of EVD. The manifestation and severity of symptoms may vary among patients, with some not experiencing every symptom. However, those who exhibit symptoms are highly contagious during the acute phase of the illness, underscoring the importance of early detection and isolation to prevent further spread of the virus. [15]

Following exposure to the Ebola virus, symptoms may appear within a range of 2 to 21 days, typically averaging between 8 to 10 days. As the illness progresses, symptoms typically transition from "dry" symptoms like fever, body aches, and fatigue to "wet" symptoms such as diarrhea and vomiting. Common symptoms and indicators of an Ebola infection include severe headache, muscle and joint pain, weakness and fatigue, sore throat, loss of appetite, gastrointestinal issues like stomach pain, diarrhea, and vomiting, unexplained bleeding, and swelling. Additional symptoms may include red eyes, skin rash, and hiccups. It's important to note that symptoms of Ebola virus infection can resemble those of other common illnesses such as influenza, malaria, or typhoid fever. Ebola virus is a complex and often fatal disease. Recovery depends on the patient's robust immune response and consistent medical care. Studies have shown that survivors of ebolavirus illness have detectable antibodies in their blood for up to ten years post-recovery, indicating protective immunity against the ebolavirus strains responsible for the illness. [16]

3.4. Diagnosis

Diagnosing Ebola infection early in its course can be challenging. Initial symptoms such as fever, headache, and weakness are not specific to ebolavirus infection and may also be observed in individuals with other common illnesses like typhoid fever and gastrointestinal diseases. To consider Ebola infection as a potential diagnosis, a combination of symptoms resembling those of Ebola and potential exposure to an ebolavirus within the 21 days preceding symptom onset is necessary. Exposure may involve contact with. If an individual displays symptoms of Ebola virus and has a history of exposure, they should be isolated from others and reported to public health authorities. Diagnosis can be confirmed through blood tests obtained from the patient, which can detect the presence of Ebolaviruses once symptoms develop. However, the infection may not be detectable until three days after symptoms begin. Polymerase chain reaction (PCR) is a commonly used diagnostic method for Ebola virus due to its ability to detect low concentrations of the virus. PCR techniques can identify even a few virus particles in small blood samples, though accuracy improves with higher viral loads. However, PCR may not be effective if viral levels are insufficient at the time of testing. Another method for confirming ebolavirus susceptibility and infection is detecting antibodies. A positive test result from the laboratory confirms the presence of an ebolavirus. Public health professionals will conduct a comprehensive health assessment to identify and verify any potential unrecognized connections [17]

3.5. Treatment

At present, there is no specific antiviral medication or vaccine available for treating Ebola Virus Disease (EVD). The primary focus of the management protocol is to provide supportive and symptomatic treatment. General health strategies emphasizing contact tracing, quarantine measures, and epidemiological surveillance are recommended to contain the spread of EVD. Supportive treatment for EVD patients includes rehydration, adequate nutrition, pain relief, and blood transfusions. Intravenous fluids and oral rehydration solutions are essential for replenishing electrolytes and maintaining intravascular volume. Antiemetics and antidiarrheal

medications are administered to manage persistent vomiting and diarrhea. Prophylactic antibiotics, such as third-generation intravenous cephalosporins, are prescribed to address suspected cases of secondary bacterial infections and septicemia. Additionally, concurrent parasitic coinfections may occur, necessitating prompt investigation and management. Numerous clinical trials are underway to develop vaccines, antibody therapies, and other potential treatments for EVD. Various vaccine candidates are being tested using different platforms, including recombinant viral vectors (the most advanced vaccine candidate), DNA vaccines, inactivated viral particles, subunit proteins, recombinant proteins, and virus-like particles. Viral vectors expressing ebolavirus glycoproteins, such as recombinant simian adenovirus (cAd3), recombinant vaccinia virus, recombinant human adenovirus (Ad26), and live vesicular stomatitis virus, are being evaluated either alone or in combination as prime-boost regimens. However, the glycosylated surface proteins of the Ebola virus and its selective targeting of immune cells pose challenges to the development of an effective vaccine [18]

4. Challenges for developing EVD vaccines

4.1. Selection of immunogens

In the development of viral vaccines, whole microorganisms (either live or inactivated) or their surface protein subunits, along with polysaccharides, are utilized in combination with adjuvants to enhance and stimulate the immune response. The primary approach for selecting antigens for Ebola vaccination involves both humoral pathways (which activate killer antibodies) and cell-mediated mechanisms (involving lymphocyte function). Identifying suitable antigens for Ebola vaccine development poses a significant challenge due to antigen complexity. Transmembrane glycoproteins are frequently employed as immunogens to prevent and assist in the recovery from infection in non-human primates, by neutralizing immunoglobulins or through the use of antagonistic monoclonal antibodies such as ZMapp. The humoral immune response of the host body targets the highly glycosylated glycoprotein spike of the Ebola virus (EBOV-GP-1,2). In preclinical trials, sheep were immunized with recombinantly produced EBOV-GP ectodomain (EBOV-GP1,2ecto) expressed in mammalian cells, resulting in a robust immune response and the generation of high titers of potent monoclonal antibodies [19]

4.2. Immunization

Several vaccines have undergone phase 1 trials and clinical studies. The two most promising initial Ebola vaccine candidates are live-replicating vesicular stomatitis virus (rVSV) and attenuated chimpanzee adenovirus 3 (ChAd3). To achieve successful and timely vaccination, the identification and isolation of infected individuals, along with the inoculation of potential contacts with an experimental Ebola vaccine, are crucial. Consequently, the United States Food and Drug Administration (FDA) authorized clinical trials for an effective Ebola vaccine known as V920 (rVSVΔG-ZEBOV-GP or rVSV-ZEBOV), which elicited a rapid immune response within 14 days after a single dose. The fundamental principles for effective vaccines should prioritize durability and serve as a primary defense for long-term protection. The preventative vaccination strategy focuses on high-risk populations, particularly healthcare workers and frontline workers, to assess the durability of immunity; however, limited data or records were available one year post-vaccination. Additionally, the speed of immune response induction is a critical factor in determining the overall efficacy of a vaccine in the context of ring vaccination. Consequently, clinical trials of Ebola vaccines reported no instances of viral illness following vaccinations in randomized trials [1-3]

4.3. Cross-Defence Resistance

The use of infected individual plasma exchange for vaccination significantly impacts the development of antibodies against common viral infections. Despite serological cross-reactivity, the identification of cross-species protective vaccines has not hindered the progress of countermeasures against Ebola virus (EBOV). Non-human primates exhibited cross-protective immunity following administration of a recombinant adenovirus serotype 5 boost and DNA vaccination. Moreover, a recombinant vesicular stomatitis vaccine vector provided protection to non-human primates during and after exposure challenge trials. Although there are several potential vaccine candidates, the factors contributing to EBOV disease protection remain unclear. There is potential to enhance vaccines to be as robust as post-exposure treatments or vaccines that provide cross-protection against the four African strains of EBOV by integrating existing vaccine candidates with investigations into immune responses and the utilization of genomic approaches [2,6]

4.4. Quality assurance

The evaluation identified five distinct strains of Ebola virus, and specific vaccines only conferred protection against particular strains, making a multi-strain viral vaccination approach currently challenging. Implementing broad vaccinations targeting multiple strains is logistically challenging, costly, and requires extensive regulatory approval. The lack of cross-protection provided by existing vaccines against genetically divergent strains implies that forthcoming vaccines may not confer immunity against newly emerging Ebola virus variants. Given the unpredictable and rapid nature of viral outbreaks, individuals at risk should receive a vaccine offering long-term protection. [4,16]

Research focusing on the extended efficacy of vesicular stomatitis virus (VSV)-based vaccines (VSVG/EBOVGP) in rodent models (mice and guinea pigs) has demonstrated a robust barrier against Ebola virus infection and has provided consistent results in non-human primate studies. A delayed two-stage investigation evaluating the effectiveness of Ebola vaccination via respiratory and sublingual (SL) adenovirus in non-human primates found robust protection from a single dose in monkeys with varying levels of Ebola GP-specific CD4+ lymphocytes, though the process proved to be temperamental. [5,7]

Since the inception of the first Ebola vaccine, which primarily aimed to neutralize the virus, in vivo animal model tests or trials have presented various phases of genome, protein, or viral vaccine designs. Pre- and post-exposure treatment strategies encompass a range of approaches, including DNA vaccination, RNA interference, polymeric delivery systems, virus-like particles (VLPs), Venezuelan equine encephalitis virus replicons (VEEV RPs), serotypes, attenuation, and replication-competent viral vectors, such as human parainfluenza virus 3 (HPIV3) and recombinant vesicular stomatitis virus (rVSV). Virus replication during infection is instrumental in eliciting strong, durable immune responses in hosts. Conversely, numerous genetically modified antigenic particles, such as subunit DNA plasmids or proteins, have often exhibited poor immunogenicity, despite being presumed generally safe (depending on the adjuvant). Similarly, in human primate models, the previously mentioned vaccines have demonstrated high immunogenicity at threshold levels of antibody production following a single dose and have elicited a reduction in white blood cell immunity. Non-human primates (NHPs) were shown to be protected against Ebola virus following exposure through administration of purified sheep antibodies in contradiction to antigen, i.e., EBOTAb. Additional clinical investigations have explored passive transfer using human convalescent sera. Furthermore, EBOV typically induces acute illness, which is more frequently controlled by antibodies, whereas chronic infections are typically better managed by cytotoxic white blood cells. Vaccine regulatory approval benefits from the identification of strategies ensuring the safety and efficacy of prospective vaccines. The World Health Organization recommends a strategy for directing resources towards EBOV pathogen zero-testing and molecular inquiry. As bioassays are utilized in these processes, having access to reference materials is crucial for accurate diagnosis and data supplementation, as well as for facilitating comparison of test outcomes over time or between laboratories.[2,3,19]

5. Monitoring and Management

5.1. Early monitoring and treatment

Effectively managing outbreaks requires the coordination of clinical services, encompassing early detection, tracing contacts of Ebola-exposed individuals, providing treatment for those exposed to the virus, and administering vaccines to frontline healthcare workers and vulnerable populations. In certain Ebola-affected countries, phased and multisectoral initiatives have been implemented to contain the spread of the disease. These initiatives involved collaboration across various sectors, not limited to healthcare services but also involving all levels of government. This comprehensive approach allowed nations to enhance their preparedness in combating the outbreak from multiple angles and addressing the diverse factors contributing to its escalation. [20]

Reflecting on and extracting lessons from successful strategies employed during these outbreaks could prove valuable in planning for future occurrences and enhancing our ability to control them. By adopting a similar phased and multisectoral approach, we may bolster our response efforts and mitigate the impact of future Ebola outbreaks. Public education funded by the government on this deadly disease is also crucial for preventing its transmission. Vigilant monitoring of airports and other public venues with a high risk of disease transmission is essential. Individuals exhibiting symptoms should be monitored for at least 21 days to prevent further spread. Healthcare workers must adhere to stringent protective measures, including wearing protective clothing such as suits, gloves, face masks, goggles, and respirators, and implementing infection control measures. Diagnostic samples should be handled under Biosafety Containment Level 4 conditions and transported with utmost care. Monitoring and regulating the consumption of bushmeat and its illicit export to developing countries are critical, as it has been identified as a significant and potentially lethal source of diseases. Encouraging safe sex practices among recovered individuals and administering approved vaccines to frontline workers and high-risk individuals are recommended preventive measures [8, 12]

5.2. Antibody therapy

The One Health (OH) program is a collaborative approach aimed at preserving the well-being of humans, animals, and the environment. Historically, animal research has significantly influenced human medicine. While there was once a strong connection between human and animal medicine, this link gradually weakened during the Modern Revolution due to increased specialization. However, over the past three decades, it has become evident that most novel and emerging pathogens capable of transmitting from animals to humans originate in animal species, particularly wildlife. [3,4,7]

Human activities such as changes in land use, ecosystem disturbances, urbanization, global travel, and trade are significant drivers of these emerging diseases. Studies have demonstrated a correlation between recent deforestation events and an increased risk of Ebola Virus Disease (EVD) outbreaks in specific regions. To effectively respond to and manage each newly emerging zoonotic

disease, a collaborative, multidisciplinary approach involving animal, human, and environmental health is necessary to understand the biology of each infection and conduct thorough risk assessments. The One Health approach emphasizes the impacts, responses, and evaluations implemented at the interfaces between animals, humans, and ecosystems. This approach is especially crucial for addressing emerging and endemic zoonoses, which pose a more severe health threat in developing countries and have a significant socioeconomic impact in resource-limited areas. [11,14]

Zoonoses account for up to 60% of newly reported infectious diseases. Effective strategies to respond to EVD epidemics must consider the complex interconnectedness between humans, animals, and the environment. The global economy has facilitated the rapid movement of people, animals, plants, and agricultural products worldwide, leading to increased outbreaks of zoonotic diseases in vulnerable populations. Sectors must collaborate more effectively to address the current disease ecology. The response to epidemics underscores the importance of strong institutional coordination efforts, as well as proficient and effective specialized tactics, diagnostic tools, and disease prevention systems. The One Health strategy acknowledges the interconnectedness of human, animal, and environmental well-being, emphasizing the inadequacy of a singular approach in combating diseases like Ebola. For instance, the Ebola outbreak in West Africa between 2014 and 2016 largely resulted from increased interaction between humans and wildlife due to agricultural activities and deforestation. [15,16]

Adopting the One Health approach enables scientists and public health authorities to better understand the biology of Ebola and its transmission between animals. With effective coordination, this strategy can identify and address underlying factors contributing to disease emergence and transmission, as well as promote targeted intervention measures to limit its spread. Overall, the One Health strategy is a valuable tool for addressing emerging diseases like Ebola, offering the opportunity to prevent further outbreaks. Current vaccine development for the Ebola virus includes nucleic acid antigens, viral vector-based vaccines, and protein-based vaccines. Live attenuated vaccines have some drawbacks compared to multi-epitope vaccines, which are considered safer. Using an immune informatics approach to develop multi-epitope vaccines against EBOV is now seen as a promising strategy for designing safer drugs. These vaccines possess desired features such as solubility, high antigenicity, and non-allergenicity. However, future vaccine development should focus on providing protection against all major strains of the virus, as intraspecies variations may affect vaccine efficacy. Plant-based vaccines against Ebola are also being explored, with some undergoing clinical trials. Key aspects requiring attention for plant-based vaccine production include consistent molecular activity, plastid expression, and viral-vector-mediated transient expression. Additionally, various repurposed compounds have shown potential as anti-Ebola agents. In-depth analysis of their pathogenesis and role in Ebola Virus Disease (EBVD) is expected to elucidate the host-microbe interaction and, if necessary, facilitate vaccine development [2,4,9]

6. Conclusion

Since approximately 1976, EVD has been acknowledged, but its severity, notably its highly contagious nature, and its classification as a pandemic in 2014-2015 have raised concerns among healthcare professionals and policymakers. The emergence of Ebola as a threat has spurred efforts to develop reserves for combating similar diseases using interdisciplinary and collaborative approaches that extend beyond national boundaries. This presents a valuable opportunity to address the EVD epidemic through the creation and dissemination of cutting-edge tools and strategies for collaborative diagnosis, as well as the enhancement of internationally viable surveillance, monitoring, and coordination frameworks, and identification of animal reservoirs. Successful prediction, containment, and control of Ebola infection areas highlight the need for strengthened coordination across animal, human, and environmental health sectors, along with defined roles and responsibilities. Progress in Ebola vaccine development has been significant in both preclinical and clinical stages, with numerous candidates advancing, particularly those in advanced phases. However, challenges related to the adequacy, efficacy, durability, and cost-effectiveness of Ebola vaccines must be addressed. Despite previous efforts, ongoing vaccine development requires a personalized approach based on individuals' immunological responses, epidemiological data, and early clinical findings regarding vaccine effectiveness. Building upon these foundations, potential vaccines can be developed and deployed to combat emerging infectious diseases that could trigger future Ebola outbreaks. This strategy underscores the critical importance of readiness, recognition, analysis, and preparedness among experts, epidemiologists, vaccine-producing pharmaceutical companies, and global funders.

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