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Review Article

Contemporary Strategies for Managing and Controlling Viral Outbreaks: An Overview

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Abstract: Viruses are notorious for causing a significant array of infectious diseases, rendering them a prominent contributor to global morbidity and mortality rates. Throughout history, various regions have experienced outbreaks, epidemics, and pandemics, resulting in significant mortality rates. The Influenza virus gave rise to highly fatal outbreaks that disseminated on a global scale, subsequently resulting in a pandemic during the initial decades of the 20th century. This catastrophic event led to >75 million fatalities, accompanied by a substantial incidence of illnesses. In addition to the development of efficacious treatments for viral diseases, it is imperative to establish and implement various preventive measures to mitigate the transmission of diseases within both local and global populations. Furthermore, it is critical to implement proven conventional and contemporary strategies for managing viral infections, alongside bolstered surveillance systems. Viruses employ diverse modes of transmission, encompassing respiratory, oral-fecal, blood-borne, and vector-borne pathways. Consequently, effective measures to mitigate viral dissemination must be tailored to address each distinct route of transmission. This review discusses the existing strategies employed to mitigate the transmission and containment of viral outbreaks, as well as the dissemination of the disease within a sizable population, intending to reduce their detrimental and fatal impacts on a community.

Keywords: Blood-borne viruses, Epidemic, Pandemic, Respiratory viruses, Vector-borne viruses, Viral outbreaks.

1. INTRODUCTION

Viruses belong to a distinct group of infectious agents having unique and simpler acellular organization and their way of multiplication as compared to bacterial and fungal pathogens [1]. Viruses are mainly composed of nucleocapsids comprising of the nucleic acid genome (DNA/RNA) and protein coat, while some of the viruses have an additional lipid bilayer surrounding the protein coat called the envelope. Despite their simple organization, they are one of the major causes of diseases and can infect all types of cells, including plants, animals, humans, protists, fungi, and bacteria. The International Committee on Taxonomy of Viruses (ICTV) designates about 9110 viral species and classifies them into 224 genera, 189 families, 59 orders, 39 classes, 17 phyla, 10 kingdoms, and 6 realms [2].

The convergence of infectious viral illnesses poses a significant public health obstacle in the 21st century. An emerging virus, contingent upon its capacity for human-to-human transmission has the potential to cause isolated or sporadic instances leading to a localized outbreak that necessitates public health action [3]. In the most severe situations, it may escalate into a widespread epidemic or global pandemic. Epidemics and outbreaks of infectious diseases have killed more humans in history as compared to any other cause [4]. An epidemic is the rapid and instant spread of a particular disease in a large number of individuals in a given population of a specific geographic location within a short period. When an epidemic occurs worldwide, crossing the boundaries of several countries and affecting a large population it is called a pandemic [5]. A viral infection ranges from trivial infections to smallpox and flu that altered the course of history. There have been several different emergence episodes in

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the previous twenty years. The viruses encompass both novel viruses such as the SARS and MERS coronaviruses [6, 7], and well-known reemerged epidemics such as swine- and avian-origin influenza as well as Ebola and Zika viruses [8-10]. Because of the immense variation in viruses' epidemiology, mode of transmission, and pathogenesis, there is no single magic bullet to control viral diseases.

The landmark in combating the viral infection was made in 1798 by Edward Jenner when he inoculated a boy with less virulent cowpox to form immunity against the smallpox virus [11]. For about two centuries after the first vaccination by Jenner, healthcare providers tried to limit the spread of the virus by providing effective vaccines for protection against viral infections and scientists spared no efforts in developing effective vaccines [12]. In recent decades, there has been a surge in various types of viral outbreaks ranging from influenza pandemics to emerging zoonotic diseases and COVID-19 [13, 14]. These outbreaks have required a multifaceted and dynamic response from the scientific and public health sectors. Researchers are exploring the complex mechanisms of viral pathogenesis, host-virus interactions, and the ecological factors that contribute to viral spillover. As a result, new combating strategies have been developed to detect prevent, and reduce the impact of viral outbreaks. Currently, approaches and advances are in progress to confine a virus to the place of its origin and try to stop its spread to a large population. When it comes to combating outbreaks and epidemics, it is crucial to not only focus on effective immunization and therapeutic interventions but also prioritize the implementation of preventive measures. Approaching the prevention and control of infectious diseases requires a scientific approach which involves following strict hygiene practices, maintaining high sanitation standards, implementing vector control measures, and conducting regular screenings for pathogens. These measures are crucial in reducing the occurrence and effects of infectious diseases. The scientific perspectives highlight the importance of using a comprehensive strategy that combines preventive interventions and curative measures to control the spread and impact of harmful outbreaks in different epidemiological settings [15, 16].

Factors contributing to viral emergence have been extensively studied and documented. These factors include population growth, travel, land use changes, dietary shifts, conflicts, social changes, and climate change [17]. These factors contribute to the increased interactions between humans and reservoir hosts, which in turn lead to greater exposure to zoonotic viruses and the transmission of infections to people. Additionally, these factors also facilitate the spread of emerging viruses within human populations. Understanding the intricate connections between virus ecology, host factors, and genetics that contribute to virus emergence is an incredibly intricate task, and if connections are made accurately the viral outbreaks can be controlled by applying respective mitigation strategies [4, 18, 19]. Moreover, virus genomics has been employed for many years to examine and analyze epidemics of viral diseases. The phenomenon is feasible because viruses, especially those with RNA genomes produce genetic diversity at the same rate as virus transmission. This is achieved by a combination of rapid mutation and replication processes. Therefore, it is feasible to deduce the epidemiology and emerging dynamics by analyzing virus genomes that have been sampled and sequenced during short epidemic periods. However, it is challenging to anticipate which virus will trigger the next epidemic. Therefore, it is crucial that our response is based on sound scientific knowledge, resilient strategies, and effective efficiency [20]. This review will delve into the important aspects of current viral epidemic management using contemporary approaches including preventive measures, vaccine research, antiviral treatments, and public health initiatives.

2. VIRAL DISEASES EPIDEMICS AND PANDEMIC

The emergence of microbes that are pathogenic to humans appears to be accelerating every year. Of all the pathogenic microorganisms that have been identified since the 1980s, approximately 60% spread from animal source to human, either due to interaction with vector or carrier (mosquitos, ticks, etc.) due to direct contact with microorganism, respiratory transmission (Influenza), the bite of an infected animal (rabies), or through contact with body fluids like tears, saliva, or blood [21]. Major epidemics and pandemics due to viruses worldwide from 1918 up till now are described in Table 1.

Table 1. Major outbreaks of viral diseases in the recent past (1918-2023).

Year of Outbreak	Outbreak Event	Countries Affected	Pathogens	Number of Deaths	References
1918-1922	Influenza Pandemic	Worldwide	Influenza A/H1N1	50 million +	
1924-1925	Smallpox epidemic	Minnesota, US	Variola virus	500	
1940	Yellow fever epidemic	Sudan	Yellow fever virus	1,627	
1948-1952	Polio epidemic	US	Poliovirus	9000	
1957-1958	Asian flu Pandemic	Worldwide	Influenza A/H2N2	2-4 million	
1974	London Flu	US	Influenza A/H3N2	1,027	
1974	Smallpox epidemic	India	Variola virus	15,000	
1977-78	Soviet Flu	Worldwide	Influenza A/H1N1	10,000-30,000	
1981-present	AIDS	Worldwide	HIV	32,000,000 +	
1998-1999	Nipah epidemic	Malaysia	Nipah virus	105	
2000	Dengue epidemic	Central America	Dengue virus	40+	
2002-2004	SARS epidemic	Worldwide	SARS-CoV	774	
2004	Dengue outbreak	Indonesia	Dengue virus	658	
2004	Ebola outbreak	Sudan	Ebola virus	7	
2005	Dengue outbreak	Singapore	Dengue virus	27	
2006	Dengue epidemic	India	Dengue virus	50+	
2006	Dengue epidemic	Pakistan	Dengue virus	50+	
2007	Ebola epidemic	Demographic Republic of Congo	Ebola virus	187	
2007	Ebola outbreak	Uganda	Ebola virus	37	
2008	Dengue epidemic	Brazil	Dengue virus	67	
2008	Dengue epidemic	Cambodia	Dengue virus	407	
2009	Dengue epidemic	Bolivia	Dengue virus	18	
2009	Hepatitis outbreak	India	Hepatitis B virus	49	
2009-2010	Swine flu pandemic	Worldwide	Influenza A/H1N1	18,449	[13-15, 22]
2010-2014	Measles outbreak	Demographic Republic of Congo	Measles virus	4500+	
2011	Dengue epidemic	Pakistan	Dengue virus	350+	
2012	MERS outbreak	Worldwide	MERS-CoV	935	
2013-2016	Ebola epidemic	Worldwide	Ebola virus	11,323+	
2013-2015	Chikungunya outbreak	America	Chikungunya virus	183	
2015-2016	Zika virus outbreak	Worldwide	Zika virus	53	
2017	Dengue outbreak	Pakistan	Dengue virus	69	
2018	Nipah outbreak	India	Nipah virus	17	
2018-2020	Kivu Ebola epidemic	Uganda and the Demographic Republic of Congo	Ebola virus	2280	
2019-2021	Measles outbreak	Philippines	Measles virus	415	
2019-2021	Dengue epidemic	Latin America, Asia-Pacific	Dengue virus	3930	
2019-2022	COVID-19	Worldwide	SARS-CoV-2	6 million+	
2022-2023	Monkeypox	Worldwide	Monkeypox virus	100+	

3. PREVENTION AND CONTROL STRATEGIES FOR VIRAL OUTBREAKS

For every kind of viral outbreak, the concept is to break the chain of infection to mitigate its spread. The current prevention, control, and management strategies for viral outbreaks involve both pharmaceutical interventions (vaccine and drugs) and non-pharmaceutical interventions like isolation, contact tracing, vector control, hygienic practices, and case management tools that could influence the spread of infection and hence break the chain of infection. Outbreak management and control is a stepwise approach that includes surveillance, determining the reality of an outbreak, case definition and ascertainment by laboratory detection, epidemiological studies, epidemiological curve monitoring, determining the root cause of an outbreak, comparative studies, intervention, control measures, assessment of intervention for their effectiveness, and sharing of the findings with national and international healthcare bodies. Figure 1 illustrates the strategies involved in controlling the viral infection and preventing its transmission to a large population.

4. CURRENT STRATEGIES TO COMBAT RESPIRATORY VIRAL INFECTIONS

Respiratory tract infections caused by viruses are one of the leading causes of morbidity and mortality in the world, representing an enormous health and economic burden [23]. Respiratory viruses replicate and damage the respiratory tract, and shed via respiratory routes to infect other individuals. Three different routes are used by respiratory viruses to transmit from one host to another; droplet, contact (indirect or direct), and aerosol transmission. The transmission of the viruses via these routes depends upon several variables like environmental factors, overcrowding of people, and host cell receptor distribution in the respiratory tract. Respiratory infections caused by viruses or other related pathogenic agents are more common in the winter season, possibly due to the propensity of people to remain inside houses and shelters nearby [24]. The Influenza seasonality is strongly modulated by relative humidity (HR) and temperature as the virus has shown enhanced transmissibility in low temperature and humidity. A study reported the enhanced transmission rate of the virus among guinea pigs at 5 °C while inhibited at 30 °C. Similarly, dry conditions (RH of 20-35%)

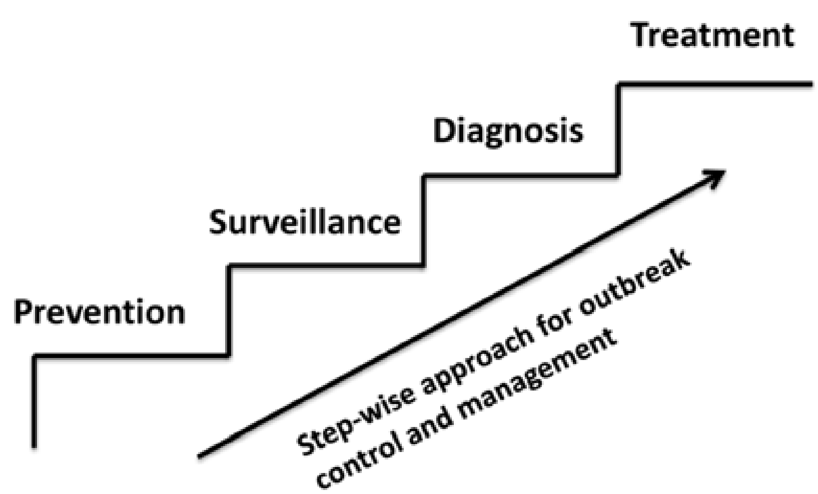

Fig. 1. Illustration of the generalized step-wise approach for the control and management of viral outbreaks. The first step toward the management and control of viral outbreaks is “Prevention” which could be brought about by education, awareness about the diseases, following occupational safety measures, proper sanitation system, and proper hygienic practices. The second step is “Surveillance” which involves the epidemiological investigation, seroprevalence, and characterization of the pathogen in the population. The third step is “Diagnosis” which involves the laboratory detection of pathogen and the last approach in control and management of viral outbreaks is the “Treatment” by using different antivirals and supportive therapies

were observed more favorable in viral transmission compared to intermediate (RH of 50%) or humid (RH of 80%) conditions [25].

Generally, respiratory tract infections are mostly non-lethal, but some people are at risk of developing severe symptoms and are more vulnerable to disease. The individuals who are more vulnerable to respiratory tract infections include old individuals, individuals with pre-existing lung infections, and immune-compromised individuals [26]. The following strategies could be adopted to prevent an outbreak or mitigate the effect of an ongoing epidemic of respiratory viral diseases

4.1. Enhanced Surveillance System

When a cluster of cases is reported in an area, an enhanced surveillance system is required to manage and limit the spread of associated diseases, enabling the public health authorities to effectively monitor and manage the potential risk of disease (Fig. 2). The main objectives of an enhanced surveillance system include the rapid testing, detection, and management of infected and suspected cases, contact tracing, implementation of effective control measures, the impact of the epidemic on healthcare systems, epidemiological trends of pathogenic organisms, and co-circulation of that pathogenic organism with other related pathogens [27]. The comprehensive national action plan for the management of viral respiratory diseases requires the adaptation and enforcement of national systems under the recommendations of the national health regulatory system of the country. Since the world has faced many respiratory viral outbreaks including influenza virus (H1N1, H7N9, and H10N8) [28], human adenovirus, and coronaviruses (SARS-CoV, MERS-CoV, and SARS-CoV-2) [29] various surveillance systems have been developed to monitor the respiratory viral outbreaks [30]. These systems include a web-based system, syndrome identification, and a system that obtains data from healthcare facilities. The Global Influenza Surveillance and Response System called Global Influenza Surveillance Network (GISN) was established in 1952 and is the classical example of global network surveillance of the disease that currently has 6 WHO Collaborating Centers and 138 National Influenza Centers [31]. Figure 2 shows the systems involved in the enhancement of valuable data on disease for the management and control of an outbreak.

The enhanced surveillance system involves the collection of integrated data from primary care centers, hospitals, and diagnostic labs. The data collection of cases from private practitioners and residential facilities like an orphanage, daycare centers, and sports centers also need to be considered in the surveillance. Event-based surveillance and participatory surveillance can be

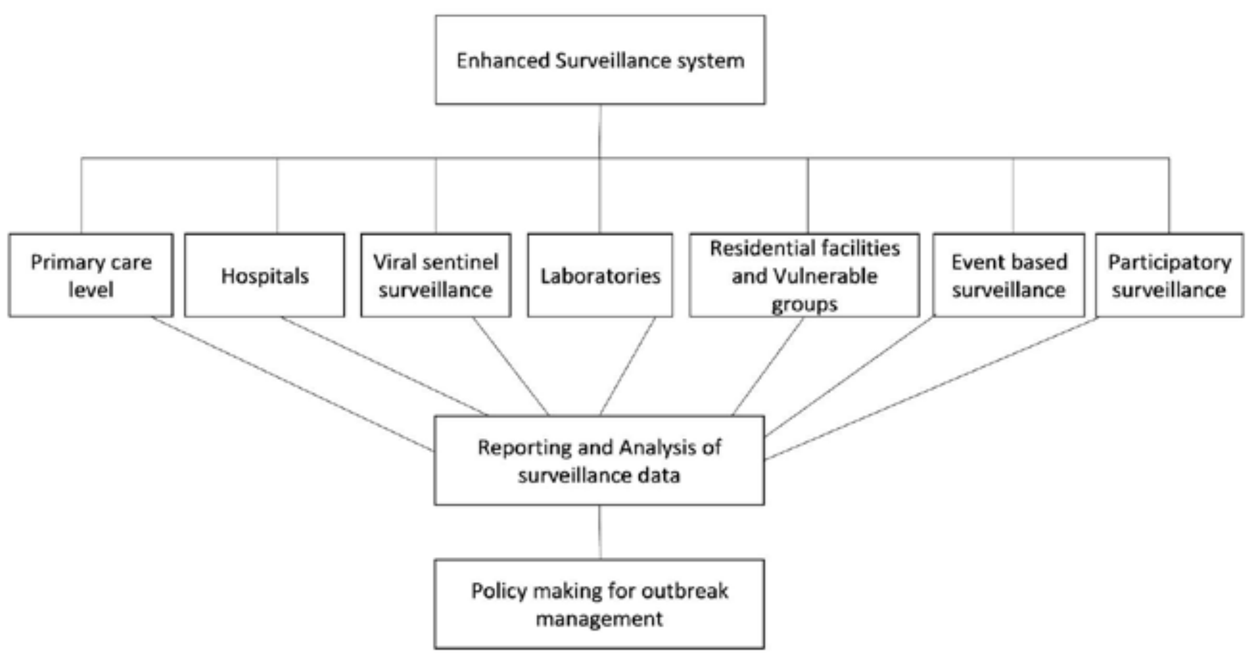

Fig. 2. Enhanced surveillance system for rapid detection and management of viral outbreaks.

included in the enhanced surveillance system to determine the incidence of disease in a particular area. The collective data will then be analyzed and policies to control the outbreak can be made by governments easily, as it can give detailed accounts of the geographic locations and vulnerable groups. The policies should be based on the assessment of existing research, public communication capacity, and community understanding including demographics, socioeconomic status, literacy level, and ethnicity followed by coordination of different related departments. The policymakers then can construct an emergency plan that captures previously reported cases and develop plans to control the newly emerging cases.

Several global surveillance systems have been developed for predicting, monitoring, and determining possible threats of outbreaks to public health. This surveillance system includes Program for Monitoring Emerging Diseases (proMED), the CDC's Global Disease Detection Network (GDD), WHO's Global Outbreak Alert and Response Network (GOARN), U.S Department of Defense's Global Emerging Infections Surveillance and Response System (GEIS), a joint network by WHO, World Organization for Animal Health (OIE) and Food and Agriculture Organization (FAO) of Global Early Warning System for Major Animal Diseases including zoonosis (GLEWS), and USAID's Emerging Pandemic Threat Program (EPT) [31].

4.2. Prompt Isolation after Diagnosis and Social Distancing

If the patient is diagnosed with a respiratory infection caused by viruses, he/she needs to be isolated from other family members or hospital patients. The caretaker of the patients should follow the safety measures. Use of personal protective equipment (PPE) in the patient's room and removal of PPE before leaving the room, and washing hands after providing care to the patients need to be ensured. Other members of the family and staff should monitor themselves daily for symptoms associated with that particular viral infection. It should be made sure other members suffering from the same symptoms are provided with medical care immediately to prevent the further spread of the disease.

The strategy for the isolation can be either centralized (imposition of the lockdown by governments), de-centralized (social distancing by removal of social networks), or hybrid (centralized and decentralized) both strategies. The results of the study conducted by Topîrceanu et al. show that the hybrid strategy (including both centralized and decentralized isolation policy) is the most effective isolation strategy in moderating the speedy spread of respiratory viral diseases (COVID-19) and has the potential to reduce the peak of incidence to <10% of initial values. The study also describes that stronger social distancing (75% cutting of social relations) can reduce the burden of an outbreak by 87% for hybrid (centralized and decentralized) strategy, 75% for centralized, and 33% for decentralized isolation [32]. Wilasang et al. report a drop in the reproduction number of COVID-19 in the countries that employ prompt isolation after case detection policy [33].

Whenever there is an epidemic or outbreak of contagious diseases like COVID-19, Influenza, and other respiratory diseases, maintaining social distancing is a reliable method of controlling the infection. A safe distance should be kept and visits to infected persons should be restricted. A minimum social distance of about 1-2 meters should be maintained during physical contact [34]. Social distancing is one of the major factors in the prevention of transmission of respiratory viruses [35]. For example, if the persons who are asymptomatic carriers of a virus meet a couple of people and sit in the gatherings, they spread the virus more frequently as they sneeze or cough in the gatherings. Khataee et al. reported the effect of mitigating COVID-19 transmission due to social distancing and the imposition of the lockdown [36]. Several studies describe the reduction in the incidence of COVID-19 cases as a "flattening of the curve" due to social distancing [36, 37]. The ultimate goal of social distancing in the respiratory viral outbreak is to mitigate its effect by limiting the spread of the disease. The study conducted in Italy reported that the use of masks and observance of social distancing could reduce the potential transmission of COVID-19 by 1000 times [38]. Physical distancing measures were found to be more effective if a phased return to work is followed; it is predicted to reduce the median number of infections by >92% (IQR 66-97) and 24% (13-90) in mid-

2020 and by the end of 2020 respectively [39].

4.3. Hand Hygienic Practices

In an epidemic of respiratory diseases, the WHO and CDC recommend washing hands regularly and sanitizing to prevent getting infected [40]. The enveloped viruses are highly susceptible to alcohol-based hand sanitizers as alcohol targets the lipids envelope of viruses but their efficacy reduces against non-enveloped viruses. The efficacy of the ethanol solution can be enhanced by adding acids to the ethanol solution against the viruses that are resistant to ethanol solution alone. For any contagious infection, hand washing with soap and water after contact with the potentially infected objects, surfaces or persons can effectively protect one and others from getting infected. The CDC in a recent pandemic of COVID-19 recommended hand-washing with soap and water for at least 20 seconds frequently a day or the use of hand sanitizer having 60% alcohol [41].

4.4. Occupational Safety Measures

Occupational safety measures by using PPE like medical masks, gloves, gowns, and eye protection are necessary to prevent transmission while working with the pathogen or dealing with the infected person. Improper occupational safety measures can result in a large number of hospital-acquired infections. Vaccination of healthcare workers is of utmost priority in reducing hospital-acquired infections and disease burden, as these workers are at higher risk of acquiring infections [42]. Nosocomial infection during an outbreak or epidemic is a major threat to hospital staff and hospitalized patients. Horcajada et al. reported the nosocomial outbreak of the Influenza A virus in a period without an Influenza outbreak concluding that the hospital setting and improper safety measures could spread the infection to other healthy individuals [43]. Several studies reported the transmission of COVID-19 in the hospital setting due to a lack of occupational safety measures [44]. Schwierzeck et al. report about forty-eight COVID-19 cases in its nosocomial outbreak [45].

4.5. Vaccination

Vaccination provides immunity to the individual and is one of the key parameters in the control of viral epidemics. The specific group of the population in a specific season may be targeted depending on the national vaccination program, access to vaccination, and effectiveness of the vaccine [46].

For a respiratory virus like the influenza virus, three types of vaccines are available; live attenuated influenza vaccine, inactivated influenza vaccine, and recombinant vaccine. Conventionally, live attenuated and inactivated influenza vaccines have been produced to protect against three different types of influenza virus (trivalent vaccine). The trivalent vaccine contains one of the two influenza B lineage viruses, Influenza A (H1N1) and Influenza A (H3N2) [47]. As trivalent vaccines contain only one influenza B lineage strain, the seasonal vaccines were improved by including both lineage strains of influenza B. Thus, resulting quadrivalent influenza vaccines respond more effectively in controlling the global influenza epidemiology [48]. Most influenza vaccine elicits an immune response against viral surface proteins including neuraminidase and hemagglutinin but influenza vaccines need to be updated regularly due to antigenic drift in surface proteins [49]. For other respiratory viruses like rhinovirus, effective vaccine development is challenging for scientists, as they have many serotypes and there is little or no cross-protection between their serotypes [50, 51]. The development of a vaccine against the respiratory syncytial virus (RSV) has also faced challenges like the enhancement of vaccine-induced disease in infants. Efforts are being made to develop effective vaccines against RSV that elicit age- age-appropriate immune responses in the target population [52, 53]. Due to the effectiveness of the vaccine like smallpox vaccines and polio vaccines, the world is now relying on the vaccination program to control the recent pandemic of COVID-19 and the struggle for vaccine development started immediately with its spread. The current most important and widely used vaccines to control respiratory viral infections are summarized in Table 2.

4.6. Treatment and Biochemical Prevention

Biochemical prevention is an alternative approach to antiviral drugs and vaccines, used for the control of viral infection when vaccines or drugs cannot be generated or are ineffective for the control of

Table 2. Treatment and vaccination for respiratory diseases caused by viruses.

Pathogen	Vaccine type (Commercial names)	Treatment	Reference
Influenza A virus	Inactivated vaccine (Fluzone Quadrivalent, Vaxigrip Tetra, Afluria Quandrivalent) Quadrivalent Recombinant vaccine (Flublok Quadrivalent)	Oseltamivir, Zinamivir, Baloxavir, Amantadine, and Rimantadine	[59-61]
Respiratory syncytial virus	No approved vaccine	Palivizumab and Ribavirin	[62]
Measles virus	Live attenuated vaccine (Measles-mumps-rubella vaccine)	Ribavirin, Vitamin A, Ibuprofen	[63, 64]
Mumps virus	Live attenuated vaccine (Measles-mumps-rubella vaccine)	No specific antiviral drugs, acetaminophen, and Ibuprofen used to ease symptoms	[65]
Adenovirus	Live oral adenoviral vaccine type 4 and 7 (for military personnel only)	Brincidofovir	[66, 67]
Rhinovirus	No approved vaccine	No specific treatment	[68]
SARS-CoV-2	mRNA-based vaccine (Pfizer-bioNtech, Moderna), Viral vector vaccine (AstraZeneca, Sputnik V), Inactivated vaccine (Sinovac, Sinopharm), Protein subunit vaccine (Novavax)	Remdesivir, Paxlovid, Molnupiravir, Dexamethasone, and other supportive care	[69-71]

viral infections [54]. The most successful approach for treating respiratory syncytial virus infection has been the use of anti-viral antibodies relying on biochemical prevention. In 1996, RespiGam™ globulin (REV-IG) was offered for use in children aged < 2 years and was found to be an effective way to control respiratory diseases caused by the respiratory syncytial virus (RSV) [55]. Similarly, Palivizumab serves as primary medical care for RSV prevention and is shown to reduce the infection risk by 55% in infants [56].

Human rhinovirus causes more than 80% of the common cold infections during the winter season and developing a vaccine against these viruses is unfeasible due to 115 antigenic-ally different serotypes [54]. In rhinovirus infection, around 90% of human rhinovirus serotypes use a receptor called ICAM-1 for the attachment of the virus and their subsequent entry. Administration of soluble monoclonal antibodies against ICAM-1 in clinical trials has shown a decrease in the severity of symptoms of the disease but cannot prevent the occurrence of the disease completely [57]. The randomized control trials of combination therapy of Bamlanivimab and Etesevimab have shown the reduction of viral load of SARS-CoV-2 on the 11th day in patients with mild to moderate COVID-19 infection [58].

5. MEASURES IN MANAGING AND CONTROLLING GASTROINTESTINAL VIRAL OUTBREAKS

The first epidemiological investigation for the disease transmitted via the fecal-oral route was performed by John Snow in 1848-54 and reported the association between drinking water and deaths due to cholera. He compared the mortality rate due to cholera in the Soho district with different water supplies and revealed that the mortality rate was higher among the people who drink water supplied by Southway Company [72]. He concluded that cholera was spread by contaminated water through fecal-oral routes [73].

The gastrointestinal tract is the susceptible organ to infection, which comes in contact with pathogenic microorganisms, mainly via the oral-fecal route. Gastrointestinal infections range from mild to more severe forms of inflammation or may cause direct damage to the epithelial lining of the gastrointestinal tract resulting in nausea, vomiting, and diarrhea. Gastroenteritis is responsible for 2-3 million deaths each year [74]. Children in developing countries and immune-compromised individuals mostly suffer from viral gastroenteritis [75]. The viruses including rotavirus, norovirus, and Hepatitis A virus enter via the fecal-oral route in contaminated water and food causing a large number of infections worldwide. These viruses after entry, replicate in the cells of the gastrointestinal tract and cause gastroenteritis. Viruses pathogenic to humans had already been described since 1901, but the viral gastroenteritis caused by norovirus was first identified in 1972 in the outbreak of diarrhea in Norwalk, US [76]. After the discovery of Norovirus, several other gastroenteritis-causing viruses were identified and are summarized in Table 1 with their epidemic history.

The prevention of outbreaks of gastrointestinal viruses has been challenging because the outbreaks that start with a single common exposure to contaminated water or food can rapidly spread in a community due to similar food or water sources. Investigating and tracking the outbreak requires the isolation of the virus from secondary cases in which the transmission route might be different from the primary one. Knowledge about the chain of disease transmission to common exposure like contaminated food, water, or oysters can identify the associated virus [77]. Sequencing the virus in a specific epidemic can identify the specific strain of the virus that is linked with the outbreaks, monitoring its evolution and spread could help the public health worker to establish the policy against that particular strain [78]

5.1. Sanitation and Hygienic Practices

Many of the viral outbreaks can be prevented by a proper sanitation system that does not have any source of food or water contamination by human or animal feces. Preventing the secondary spread of the gastrointestinal virus via contaminated environmental surfaces such as cruise ships, hospital wards, canteens, person-to-person contact, etc. can stop the chain of the outbreak. Enforcing public hygienic practices including not allowing ill food handlers to remain on the job until clear the infection and strict personal hygiene for food handlers can prevent the spread of the disease [79]. A study conducted by Belliot et al. demonstrated the *in vitro* inactivation of infectious norovirus by ethanol and isopropanol in mice infected with norovirus [80].

5.2. Laboratory Detection

A rapid detection system by the public health department should be launched as soon as there is a cluster of cases observed in a specific region. Assays that can detect the presence of gastrointestinal viruses in contaminated water and food need to be prepared and adapted for routine screening of water and food [81]. Considerable efforts by governments and healthcare departments need to update the conventional approaches to identify infectious agents and development of methods for the detection, identification, and elimination of viruses from contaminated sources to prevent large epidemics [82].

5.3. Vaccination and Treatment

Effective vaccines against some of the enteric viruses have been developed and their use reduces the large outbreaks and epidemics worldwide. Rotarix vaccine, first licensed in 2004, has effectively prevented the infection from Rotavirus and is used across 123 countries [83]. Poliomyelitis, a crippling disease that results from infection with any of the 3 related poliovirus types can be prevented by using one of the two types of vaccines such as inactivated polio vaccine and oral polio vaccine. The use of the polio vaccine effectively eradicated viruses from all around the world except Afghanistan and Pakistan, where wild-type polio cases are being reported. The treatment and vaccination against enteric viruses are described in Table 3.

6. VECTOR-BORNE VIRUSES

Arthropods are considered the main vector that transmit pathogens from reservoirs to hosts or from one host to another. Arthropods are capable of transmitting the disease in two ways. Firstly by mechanical vectors in which the passive transport of pathogens on the arthropod's body or feet occurs and when the insects make contact with food, capable of transmitting the pathogen to food that another host can consume and become infected. The second method of transmission is biological transmission which is an active process. In biological vectors, the arthropod bites an infected animal or person taking a meal along with a potential pathogen. The pathogen reproduces in the vector's gut and will ultimately migrate to salivary glands. The vector is thus capable of injecting the pathogen in healthy individuals by biting or taking a blood meal [90]. The most endemic and common viral vector-borne diseases include Dengue, Chikungunya, Zika,

Table 3. Treatment and vaccination for gastrointestinal infections caused by viruses.

Pathogen	Vaccine type (Commercial name)	Treatment	References
Rotavirus	Live attenuated vaccine (Rotarix, Rotateq)	Antidiarrheal, Antiemetic, Thiazolides	[84, 85]
Norovirus	No approved vaccine (P particle and virus-like particle-based vaccine under clinical trials)	Interferon alpha	[86]
Hepatitis A	Inactivated vaccine Avaxim, Biovac A, Havrix)	Acetaminophen, Paracetamol	[87, 88]
Poliovirus	Live attenuated oral polio vaccine (OPV, Orimune, Sabin) Inactivated polio vaccine (Salk vaccine)	Pain relievers, Ventilators, and supportive care	[89]

Yellow fever, Japanese encephalitis, Rift Valley fever, tick-borne encephalitis, West Nile, and Crimean Congo hemorrhagic fever. The common vectors for Dengue and Chikungunya are *Aedes aegypti* and *Aedes albopictus* mosquitoes while the *Culex* mosquito transmits the West Nile virus from one individual (infected) to another (healthy) [91]. Rabies is transmitted by an animal host like dogs, raccoons, cats, foxes, and skunks to humans and the Crimean Congo hemorrhagic virus is a tick-borne disease transmitted to humans by Hyalomma tick [92, 93].

6.1. Mechanical Control Measures for Vector-Borne Outbreaks

Mechanical control measures have been adopted and practiced for centuries in several countries since they are cost-effective and easy methods for the control of vectors like mosquitos and ticks. Mechanical control measures involve the removal of unwanted stored water and the covering of water-containing utensils, as these are the primary sites of mosquito breeding [94]. Streets, buildings, and housing units must be properly cleaned. Wearing long-sleeved shirts and trousers and use of arthropod repellents on exposed skin can protect from being bitten by mosquitos, ticks, or sandflies. Installation of window screens at workplaces and homes can keep mosquitos outside, therefore reducing the risk of exposure. In tick-infested areas luggage, clothing, and other belongings should be examined carefully to remove any ticks. If tick-infested on the skin, it should be removed from the skin using tweezers, and applying disinfectant at the surface can reduce the risk of transmission of pathogens [95].

6.2. Chemical Control Measures for Vector-Borne Outbreaks

Chemical control measures include the use of chemicals like organochloride, pyrethroids, thiacloprid, and organophosphorus that primarily target the nervous system of the vector [96]. The use of fogging and spraying with insecticides has been adopted in outdoor environments to control the vector's population. Repellents like N, and N-Diethyl-meta-toluamide (DEET) need to be used in households to prevent mosquito irritation at home. Rodriguez et al. compared the efficacy of different mosquito repellent sprays and reported the highest efficacy of DEET and p-methane-3,8-diol against mosquitos [97]. A similar study reported that insect growth regulators (IGRs) like Pyriproxyfen are effective in reducing the immature *Aedes* population [98]. An essential approach for managing arbovirus outbreaks, such as dengue involves the utilization of synthetic pesticides that rapidly eliminate adult vectors through space spraying [99]. Most of the insecticides that are advised belong to the pyrethroid chemical class. However, this poses difficulties in preventing the selection of mosquito populations that are susceptible to these insecticides, as well as controlling mosquitoes that are resistant to pyrethroids [100]. When it comes to managing the population of arbovirus vectors, particularly *A. aegypti*, controlling the larvae has been suggested and put into practice as the main technique which involves using chemical and microbial larvicides, and IRGs.

Besides traditional repellents, spatial repellents are specifically created to emit volatile chemicals into a given area, to alter insect behavior to minimize interaction between insects and humans, therefore reducing the transmission of pathogens [101]. The spatial repellent product category is now under Stage 3 of the Vector Control Advisory Group (VCAG) assessment method, where it is being evaluated for proof-of-principle efficacy through clinical trials [102].

6.3. Biological Control Measures for Vector-Borne Outbreaks

The alternative approaches of chemical use against mosquitoes have been exploited by using biocontrol agents like bacteria, fungi, and plants against the growth and propagation of the mosquito population. In 1976, *Bacillus thuringiensis* (Bt) was isolated and characterized to be toxic against mosquito larvae. Since then, Bt-based insecticides have spread to the global market. Bt-based insecticides are target-specific and produce specific delta-endotoxin by the time of sporulation that is toxic to mosquito larvae and other related flies [103]. Sterile insect techniques and incompatible insect techniques can be used to control the population of mosquitos. Sterile insect techniques involve the release of sterile mosquitos in a wild environment, these sterile mosquitos compete with other wild mosquitos to mate with females. The mating of sterile males and females does not produce offspring, reducing the population of the next generation. The incompatible insect technique involves the mating of *Wolbachia*-infected males and wild-type females that cannot produce offspring [104]. Incompatible insect techniques using intracellular bacteria *Wolbachia* have also been used as bio-pesticides to control the population of mosquitoes [105]. The *Wolbachia* method is an innovative and self-sustaining strategy for the biological management of Aedes-borne diseases. It involves genetically modifying Kales aegypti mosquitoes by introducing the Wolbachia bacterium into their cells, resulting in a decreased ability to transmit diseases [106]. Pinto et al. reported that the intervention of Wolbachia (wMel strain) was related to a reduction of 37%, 56%, and 69% in the incidence of Zika virus, chikungunya virus, and dengue virus, respectively [107].

Moreover, biological mosquito larvae control also involves strategies to augment the effectiveness of natural adversaries by adding bio-control agents such as fishes (*Gambusia spp*)and copepods, or by facilitating the colonization of isolated water bodies by natural predators through the excavation of connecting ditches [108]. The predatory native copepods (*Macrocyclops albidus)* can be cultivated and transferred into artificial containers. Once introduced, they proliferate and effectively decrease the population of mosquito larvae and have proven strong efficacy against *Aedes* mosquitoes, but only moderate efficacy against *Culex* species [109]. Similarly, fungal species like *Beauveria bassiana* and *Metarhizium anisopliae* have biocontrol properties against mosquitoes [110].

The treatment and vaccination strategies have also been developed for vector-borne diseases due to viruses and are listed in Table 4. The live attenuated vaccine called Dengvaxia and the Yellow fever virus vaccine have been approved and are used worldwide to prevent the spread of Dengue and YFV infections respectively [111,

Table 4. Treatment and vaccination for common vector-borne diseases caused by viruses.

Pathogen	Vaccine type (Commercial name)	Treatment	References
Dengue Virus	Live attenuated vaccine (Dengvaxia)	Chloroquine, Corticosteroids, and Iminosugars	[111, 114, 115]
West Nile Virus	No approved vaccine (Live attenuated chimeric vaccine 'ChimeriVax-WN02" under clinical trials)	Interferon alpha and Favipiravir	[116, 117]
Yellow fever Virus	Live attenuated yellow fever virus vaccine (YF-VAX®)	Ribavirin, Pyrazoline compounds, Tiazofurin, Interferon, and Carboxamide,	[112, 118]
Chikungunya Virus	No approved vaccine	Ribavirin, Anti-rheumatic drugs (DMARDs) and Non-steroid anti-inflammatory drugs (NSAIDs)	[113, 119]
Nipah Virus	No approved vaccine	Ribavirin, Supportive care	[120]

112]. The treatment strategies to prevent the Chikungunya virus (CHIKV) and Dengue virus (DENV) infections involve fluid balance along with other supportive care like NSAIDs for CHIKV and corticosteroids respectively [113, 114].

7. APPROACHES IN CONTROL OF BLOOD-BORNE VIRAL OUTBREAKS

Blood-borne viruses such as Human Immunodeficiency Virus (HIV), Hepatitis B virus, and Hepatitis C virus are considered a major public health threat, responsible for millions of deaths annually. It was estimated that in 2014, about 1.2 million infected individuals died of HIV with about ~40 million individuals being infected chronically worldwide [121]. Infections caused by HBV, HCV, or HEV can cause hepatitis that subsequently leads to liver cirrhosis, fibrosis, and hepatocellular carcinoma. It is estimated that 240 million people are chronically infected with HBV with ~780,000 annual deaths. The risk of developing chronic infections varies with the age of the individual infected. About 90% of toddlers and 25-50% of children aged 1-5 years can remain chronically infected with the Hepatitis B virus, however, approximately 95% of adults can eliminate the viral infection [122]. HCV infections account for 58 million people with chronic infections and 1.5 million new cases per annum worldwide [123]. The major route of transmission of blood-borne viruses involves the parenteral routes via blood and other body fluids.

Prime prevention strives to avoid the occurrence of infection by decreasing the risk factor in uninfected individuals. It involves the strategies that are useful before the disease or infection. Primary interventions or prevention involve a reduction in viral exposure, prophylaxis, and vaccination, awareness about the disease, disinfection, safety of blood products, and good hygienic practices. Secondary prevention strategies involve the surveillance and identification of infected individuals and the treatment of infected individuals with appropriate medical drugs

7.1. Awareness of Disease

Successful prevention of viral diseases requires the awareness of infected people about the transmission and spread of the disease as well as complete awareness among society and healthcare experts. Public campaigns and educating people about the disease can reduce the risk of the spread of the disease if they start adopting the prevention strategies or guidelines by health care professionals [124]. Wide-ranging and frequent education of healthcare professionals is the precondition and increasing awareness about care, prevention, and treatment on World Disease Day like 28th July as World Hepatitis Day, and 1st December as World AIDS can enhance the knowledge and expertise of social and medical professionals. The updated guidelines by the World Health Organization (WHO) and the Center for Disease Control and Prevention (CDC) need to be followed and implemented by every country that is at risk of acquiring the epidemic or outbreak of a particular viral infection [125, 126].

7.2. Screening of Blood and Blood Products

Since the last decade, the screening of blood products has significantly reduced the burden of blood-borne diseases around the globe. Nucleic acid amplification tests such as polymerase chain reaction (PCR), enzyme-linked immunosorbent assay ELISA, and rapid diagnostic tests such as lateral flow assay have been successfully developed for the detection of HBV, HCV, and HIV, thus reducing the risk of transmission in transfusion of blood and blood products to healthy individuals [127].

7.3. Biosafety and Hygienic Practices

Good microbiological practices, hygienic practices, and disinfection of possible contaminated sources can help in reducing viral transmission. To prevent occupational transmission, prevention, and control measures involve the implementation of standard primary barriers including personal protective equipment (gloves, eyewear, gowns, etc.), minimal manipulation of sharp instruments (needles, surgical blades), and discarding of sharp instruments into the proper leak-proof container after experiments. Furthermore, the sterilization of dental and medical equipment in addition to the disinfection of contaminated surfaces can reduce the spread of disease. The non-sterile setting and contaminated instruments in tattoo and piercing can increase the risk of transmission of the virus [128].

Sexual transmission can be a key risk factor and preventive measures have been applied to reduce the spread of viruses. Behavioral interpolations like the use of condoms have revealed a reduction in the incidence of HBV, HCV, and HIV [129]. Moreover, medical male circumcision has shown a reduction in transmission of HIV by the venereal route and new interference including rectal and vaginal microbiocides are under development to reduce the risk of transmission [130, 131]. Intravenous drug use is another major risk factor for the transmission of blood-borne diseases, due to sharing of virus-contaminated syringes and their preparation environment. The use of harm reduction measures like opiate substitution therapy and needle/syringe programs (NSP) effectively reduce the risk of viral transmission and hence prevent further spread [132].

7.4. Prophylaxis

In some cases, prophylaxis can be achieved either due to pre-exposure (PrEP) or post-exposure (PEP) to the virus. Pre and post-exposure prophylaxis have shown promising results in controlling viral transmission in certain risk groups. Pre-exposure prophylaxis is the administration of antivirals to the possible viral exposures of an individual. Pre-exposure prophylaxis has shown a reduction in the occurrence of HIV infections in individuals which is also recommended by CDC [133]. Post-exposure prophylaxis (PEP) is the immediate intervention with antivirals after exposure to the potential pathogen to prevent the infection. It is recommended to use post-exposure prophylaxis immediately following high-risk practices like sex with HIV-infected individuals, needle stick injury during processing of infected blood, and intravenous drug use. For HIV, post-exposure prophylaxis should be no later than 48-72 hours [134]. Several studies have reported the use of antiretroviral therapy in anticipation of potential infection by HIV either as pre-exposure prophylaxis in high-risk factor exposure or as post-exposure prophylaxis [135]. Oral pre-exposure prophylaxis like tenofovir disproxil fumarate/emtricitabine has shown great potential against HIV infections [136]. The administration of zidovudine has been reported to be effective prophylaxis in mothers and newborns, resulting in the reduction of perinatal transmission of HIV [137]. Similarly, acyclovir is used to prevent the dissemination of the Herpes simplex virus and Varicella zoster virus in immunocompromised and immunologically normal individuals [138, 139]. Oral valganciclovir is an effective oral regimen used as universal prophylaxis to prevent cytomegaloviral infections after lung transplantation [140]. Ganciclovir also serves as a prophylactic antiviral that could effectively suppress the dissemination of CMV after engraftment [141]. Similarly, post-exposure prophylaxis is also significant in preventing lethal infections. WHO recommends the administration of two doses of immunoglobulin and three doses of HBV vaccine as PEP [142].

7.5. Vaccination

Effective vaccination programs for the public contribute efficiently to the eradication and prevention of viral outbreaks. The safe and effective vaccine against the Hepatitis B virus has been available since late 1982 and vaccination programs have successfully been implemented in 47 European countries with good results [143]. The Recombivax vaccine is highly effective in preventing HBV infection in individuals who are frequently exposed to blood and other body fluids such as health care professionals and patients receiving dialysis or multiple transfusions [144]. The enforcement of stringent vaccination programs has resulted in a global decline in the occurrence of this disease. However, this may have also triggered the creation of viral variants that are capable of evading the immunity provided by the hepatitis B surface antibody [145]. Due to the increase in escape mutagens, the concern for transmission of these variants is on the rise even in vaccinated individuals [146]. Therefore, there is a need for an active surveillance system and the introduction of novel vaccination strategies such as combination vaccines (multi-epitope/ subunit) and therapeutic vaccination [147, 148].

For other blood-borne viruses like HCV, HDV, HEV, and HIV, the vaccine is not available and is in the process of developing to reduce the disease burden of blood-borne infection worldwide.

7.6. Treatment

Antiviral therapeutics prevent transmission by either reducing the viral load or by decreasing the number of infected persons in the population. Combination therapy is used to treat AIDS patients by using highly active antiretroviral therapy (HAART), in which a cocktail of drugs like nucleoside reverse transcriptase inhibitors (NRTIs), non-nucleoside reverse transcriptase inhibitors (NNRTIs), protease inhibitors (PIs), integrase strand transfer inhibitors (INSTIs), Fusion inhibitors (FIs), and chemokine receptor antagonists (CCR5 antagonist) were used for limiting multiplication of HIV [149]. Some of the notorious viruses transmitted via blood or other body fluids with their treatments and vaccination are listed in Table 5.

8. ZOONOTIC VIRAL DISEASES AND STRATEGIES TO CONTROL VIRAL OUTBREAKS

Zoonotic diseases are naturally transmitted from animals to humans, with or without an intermediate arthropod host. It is reported that approximately 75% of the newly emerged human infectious diseases are zoonotic [112]. Due to the increased interdependence of humans on animals and their products and the close association between them, the newly emerged and reemerged zoonotic viral diseases have increased over the last three decades. Zoonoses are thus considered one of the critical risk factors for human health and infectious disease. The eradication programs for the control of zoonotic-borne viral diseases are majorly focused on breaking the transmission chain in which three controlling factors are involved including neutralization of reservoirs, decreasing the potential contact between reservoirs and susceptible hosts, and increasing the host resistance [154].

The neutralization of the reservoir involves preventing the spread of viral infections by removing the infected or susceptible animals from the reservoir or by manipulating the habitat of reservoirs. The removal of infected individuals can be achieved by employing vaccination, mass therapy, or the testing and slaughter of infected animals. For example, arboviral infections are endemic in wildlife reservoirs, the control strategies should be based on vector control, limiting direct animal contact, and mass vaccination of people and domestic animals [155]. The cross-species transmission of viral diseases from animals to humans is common as seen in different cases like cross-species transmission of H7N9 influenza virus from poultry, rabies virus from infected cats, dogs, or wild animals, potential transmission of COVID-19 from wildlife, swine flu from infected pigs, and Nipah virus from fruit bats [156]. The decrease in potential contact between reservoirs and susceptible hosts by prohibiting the eating and transport of wildlife animals can prevent these transmissions. Increasing host resistance can also reduce the burden of zoonotic-borne viral diseases and it could be achieved by herd immunization, such as that which happened with rabies immunization of dogs.

Besides the close contact between humans and animals, other factors also contribute to cross-species transmission of infectious agents. So, it is critical to establish effective mechanisms for collaboration and coordination between animal, human, and environmental health sectors before the emergence of another threat like COVID-19 by bringing different sectors together to cope with endemic zoonotic viral diseases of public health concerns. For the prevention and control of zoonotic diseases, researchers and international organizations have adopted a concept called the One Health concept. The concept describes the

Table 5. Treatment and vaccination for blood-borne diseases caused by viruses.

Pathogen	Vaccination (Commercial name)	Treatment	References
Hepatitis B virus	Subunit vaccine (Recombivax, Engerix-B)	Pegylated interferon, Nucleotide analogs (Tenofovir, Adefovir) and Nucleoside analogues (Entecavir, Lamivudine, Telbivudine,)	[150, 151]
Hepatitis C virus	No vaccine available	Protease inhibitors (Boceprevir, Telaprevir, Daclatasvir), Nucleotide analog (Sofosbuvir), Ribavirin, and Pegylated interferon	[152]
HIV	No vaccine available	Highly active antiretroviral therapy (HAART)	[153]

relationship among animals, humans, and the environment. It encourages collaborations among veterinarians, microbiologists, wildlife biologists, biomedical engineers, physicians, ecologists, and agriculturists to cope with global health challenges and to ensure good health for humans, animals, and environment [157]. The multi-sector partnerships should start with the identification of priority zoonotic-borne viral diseases, improvements in surveillance and data sharing among these sectors, enhancement of laboratory diagnosis and outbreak response capacities, and research for the preparation of vaccines and medicine for the management of the disease [154].

9. APPRAISAL AND FUTURE PERSPECTIVES

A combination of traditional and latest strategies to combat the challenge of viral epidemics and associated risks to human life has helped reduce the global burden of viral diseases, nevertheless, still far from achieving significant success. Diagnostic capabilities, surveillance, and monitoring systems, as well as forecasting systems, are poor in many developing countries, while the availability of adequate healthcare facilities including vaccination remains a serious challenge in such communities. An infrastructure improvement has been witnessed in the case of COVID-19, nevertheless, they still need to go a long way.

Standard hygienic practices may control water and foodborne viral illnesses. Developed countries have been successful in reducing the burden of viral enteric illnesses by improving sanitary and hygienic conditions. Little success has been achieved in developing countries where the provision of clean water is one of the biggest challenges. Improved sanitary and hygiene standards, as well as clean drinking water, may greatly reduce the morbidity and mortality of viral diseases. The mass media campaign has been witnessed in the response to COVID-19 across the globe with fruitful outcomes. Public awareness about viral diseases and preparedness to respond to epidemic situations remain better established in the industrialized world as compared to poor nations. Future efforts need to be directed at public awareness at the individual level in electronic and print media, schools, social media, etc. Social distancing and the use of appropriate personal protective equipment should be encouraged to be practiced in public places, schools, workplaces, etc.

Vaccines have saved millions of lives from the most significant viral diseases of humans such as smallpox, polio, measles, hepatitis B, rotavirus, influenza virus infections, yellow fever, etc. The current COVID-19 pandemic has reiterated the dire need for technological advancements in vaccine development capabilities to rapidly respond to such global threats that humans may face at any time. Traditional methods of vaccine development are safer and more effective but are time-consuming and require prolonged protocols that may be further improved by incorporating the cutting-edge techniques of molecular medicine and computational biology. Currently used vaccines against COVID-19 are employing both classic techniques of vaccine development as well as modern vaccines like recombinant protein-based vaccines, adenovirus-based vaccines, and mRNA-based vaccines. Mass vaccination with COVID-19 vaccines has helped reduce the prevalence of cases. Nevertheless, continuous surveillance and monitoring of their safety and efficacy are required. To date, 10 vaccines developed by different companies have been approved by WHO.

Similarly, the management of zoonotic disease may also require the vaccination of animals, which is a serious economic challenge, especially when it comes to vaccinating wild animals or small animals like bats. Unfortunately, vaccinating masses of such animals as bats by spraying or aerosols is not possible. Nevertheless, improved vaccination strategies for humans, animals, and poultry may be considered by both developing and developed countries. Tremendous efforts have been made to develop antiviral drugs and a number of antiviral drugs are available in the market. Nonetheless, the treatment of viral diseases using antiviral drugs has been a challenge. So, advances in the research of antiviral drugs are required to treat the reemerged and emerging viral diseases.

There is a need for the establishment of a global consortium to combat such global threats that may emerge in any part of the world. No country can fight this war alone without utilizing the experiences of other institutions across the world. Despite massive efforts by global stakeholders in the past, eradication of viral diseases has always been a nightmare. Still, many viral diseases including COVID-19, AIDS, dengue fever, yellow fever, Crieamen Congo hemorrhagic fever, hepatitis, influenza, measles, etc. cost millions of lives globally. Global, integrated networks need to be established/ strengthened with the ultimate goal of control and prevention of such diseases. Lessons learned in different countries may be utilized by people working in other countries.

Moreover, besides traditional approaches, certain modern media tools like digital twins can play a significant role in combating viral outbreaks by improving monitoring, reaction capabilities, and predictions [158]. Digital twins have the capability to replicate the transmission of epidemics through the creation of virtual representations of the impacted population. These models take into account several elements including mobility, interactions, and healthcare infrastructure [159]. Digital twins have the ability to accurately reproduce and continuously monitor the current condition of healthcare facilities, equipment, and resources in real time. This aids in the identification of regions that may experience overwhelming conditions or require supplementary assistance during an outbreak. These solutions offer a comprehensive perspective on the changing situation by combining data from several sources, including wearable devices, IoT sensors, and healthcare records. Predictive analytics, enabled by digital twins helps in predicting the path of an epidemic, allowing authorities to make well-informed decisions on the allocation of resources and implementation of preventive measures. Furthermore, digital twins can also amalgamate data from many sources including social media, healthcare records, and geographic information systems (GIS) to offer a holistic perspective on the effect and dissemination of the pandemic [160].

10. CONCLUSIONS

Pandemics are the consequence of viral outbreaks and epidemics that have expanded across international borders. It is necessary to implement effective preventive measures to restrict the disease's spread to a greater number of communities to reduce morbidity and mortality, as well as the community's social and economic burden. Besides medical interventions, the primary strategy involved in controlling an outbreak is to break the chain of infection by implementing control measures against the risk factors. The route of transmission of viruses is important in developing preventive measures. For instance, the transmission of respiratory viruses could be prevented by isolation, social distancing, and hand hygiene practices. Similarly, vector-borne viral infection could be prevented by using effective strategies to control the spread of vectors like mosquitos, ticks, and mites. Gastrointestinal infection and blood-borne infections caused by viruses could be prevented by proper hygienic practices and screening of blood products before transfusion respectively. There is an urgent need for the implementation of these kinds of strategies to minimize the lethal effects of viral outbreaks, especially in developing countries where the emergence and re-emergence of viral load are high. To provide a more thorough understanding of issues and potential solutions, the complexity of health and environmental difficulties needs to be assessed in an integrated and holistic manner. It's crucial to make coordinated efforts in the paradigm shift away from silo-based health systems and toward the One Health concept. The One Health approach should be used by decision-makers responsible for disease prevention and control in order to plan for and prevent illness, hospitalization, death, and the financial burden associated with disease epidemics. An early warning system to prevent epidemics is typically put into place right away in any public health disaster. Response networks cooperate with institutions and networks to pool their technical and human resources to combat outbreaks, such as the Global Outbreak Alert and Response Network. In a quickly changing environment with little or biased information available, the crucial choice to launch a disease response is frequently reactive and urgently required. The data in traditional surveillance systems are updated often. However, these systems are retrospective and delayed by nature, which limits their usefulness for rapid response to epidemics.

11. CONFLICT OF INTEREST

The authors declared no conflict of interest.

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