Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 12s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

Public Health Response and Control Measures for Monkeypox Virus Outbreaks." A review of past and present outbreak responses, highlighting successes, challenges, and lessons learned

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Cite this paper as: Mufakkir Aziz, Tasneem Noor Mohamad, Hafeezullah Wazir Ali, Manal Satti Awad Elsied, Aamna Shah, Muhammad Asif, Salwa M. A. Dahesh, (2025) Public Health Response and Control Measures for Monkeypox Virus Outbreaks." A review of past and present outbreak responses, highlighting successes, challenges, and lessons learned. *Journal of Neonatal Surgery*, 14 (12s), 906-917.

ABSTRACT

Monkeypox, an emerging zoonotic disease caused by the monkeypox virus, has become a major global public health concern due to its periodic outbreaks and expanding geographic reach. This review provides a comprehensive overview of public health responses to monkeypox outbreaks, focusing on the global rise in 2022 and the important 2024 outbreak. Drawing on epidemiological data, scientific literature, and public health reports, the review investigates the virus's origins, transmission dynamics, and clinical manifestations, as well as a chronological examination of its epidemiological patterns.

Data for this review were gathered from a variety of sources, including historical outbreak records from endemic regions, World Health Organization (WHO) updates, national public health reports, and peer-reviewed studies, to highlight initial response measures such as quarantine, contact tracing, and public awareness campaigns. While such approaches have had various degrees of success, newer developments, such as the return of smallpox immunizations and antiviral medications like tecovirimat, have dramatically enhanced outbreak containment efforts. Enhanced surveillance systems and data-driven techniques have proven useful in detecting and managing epidemics.

The obstacles, which ranged from vaccine inequities and misinformation to gaps in worldwide coordination, were particularly evident during the 2024 pandemic, when resource limits and public perception hampered effective control measures. Despite these challenges, important triumphs, such as community-led awareness campaigns and improved immunization regimens, are mentioned.

This review highlights the necessity of long-term global collaboration, strong public health infrastructure, and continuous vaccination and medicines development. Lessons from the 2024 outbreak highlight the importance of data-driven measures and equitable resource allocation to prevent future outbreaks and protect world health..

Keywords: *Monkeypox, Outbreak, Vaccination, Epidemiology*

1. INTRODUCTION

Monkeypox (Mpox) is a zoonotic infectious sickness caused by the monkeypox virus (MPXV), which was first identified in 1970 in rural villages in Central and West Africa's rainforests, around the same time that smallpox was eradicated. MPXV is a double-stranded DNA virus from the Poxviridae family, specifically the genus Orthopoxvirus (OPXV), which also includes the smallpox virus variola and the cowpox virus vaccinia. MPXV has two genetically distinct clades: Clade I (formerly known as the Central African, Congo Basin clade) and Clade II (formerly known as the West African clade). Clade II is further divided into two sections: IIa and IIb.

Clade I is clinically more severe, with increased interhuman transmission and mortality rates. MPXV is widely distributed, particularly in monkeys and tiny rodents, mostly in Africa. This includes squirrels, Gambian marsupial rats, dormice, nonhuman primates, and other species. [1]. Individuals with mpox have a 7 to 21-day window between exposure and the emergence of specific clinical symptoms such as fever, headache, muscle pain, back pain, chills, skin rash, and lymphadenopathy [2]. Mpox transmission in endemic countries is mostly from animals to humans by direct contact with infected animals, which occurs frequently during hunting, capture, and processing of afflicted animals or their parts and fluids. Small mammals can carry the virus, frequently without symptoms, but non-human primates can become ill and show symptoms comparable to humans [1].

In 1959, MPXV became known as the source of illness in a group of cynomolgus monkeys (Macacafascicularis) at a Danish research facility. The Mpox virus was discovered to cause smallpox-like illness in humans in the Democratic Republic of the Congo in the 1970s. The virus had been common in Africa since the 1970s, but a human case was reported in the United States in 2003 as a result of prairie dog infection [3]. Mpox is endemic in Benin, Cameroon, the Central African Republic, Côte d'Ivoire, the Democratic Republic of the Congo, Gabon, Liberia, Nigeria, Sierra Leone, and South Sudan. Cases have also been reported in countries other than Africa, including as Singapore (May 2019), Israel (September 2018), the United Kingdom (September 2018), and the United States. In 2022, a huge global outbreak occurred, particularly involving Clade IIb, triggering a public health disaster [4].

MPXV is a serious developing and re-emerging zoonotic disease with a wide host range [5]. Rodents could serve as potential MPXV reservoirs because to their high host-pathogen interaction with other Orthopoxvirus members [6]. Recent Mpox outbreaks around the world have underlined the importance of improving universal health-care systems [3]. The World Health Organization closely monitors e(Room No: 710, Faculty cabin Islamiat studies, Faculty cabin economic studies)pidemics and responds by sharing information and working with member countries and partners. Between January 1, 2022 and November 30, 2023, 92,783 Mpox cases and 171 deaths were reported to WHO from 116 countries/territories/areas throughout six WHO regions [7].

The Africa Centres for Disease Control and Prevention (Africa CDC) declared mpox a public health emergency of continental security on August 14, 2024, and WHO declared mpox a public health emergency of international concern[9], both of which are powerful reminders of the impact that this disease has had and will continue to have if not controlled. With verified cases of mpox reported in at least 12 African countries, including an increasing number of children, and the first confirmed case of the clade 1 variant outside of Africa in Sweden, the global health community must now work with countries and partners to protect populations and prevent further mpox spread [10].

This review is to provide a complete examination of public health responses to previous and current monkeypox outbreaks, with a focus on identifying successes, problems, and lessons gained. By comparing historical and present control approaches, this article will investigate how shifting strategies have impacted outbreak containment and what improvements are required to manage future outbreaks efficiently.

Epidemiology and Outbreak History

Early Outbreaks (Pre-2022)

Mpox (formerly known as monkeypox), an infectious disease caused by the monkeypox virus (MPXV), was discovered in 1958 and first seen in humans in 1970. Prior to 2017, mpox was primarily found in central and western Africa, with ongoing MPXV transmission in local animal reservoirs and occasional expansion to human populations, particularly in rural areas[11]. MPXV did not cause significant outbreaks, and pre-1980s epidemiological data suggested that the reproductive number of mpox in the population was less than one, indicating a risk of extinction [12].

However, the gradual eradication of smallpox—the last smallpox incidence in the DRC was reported in 1971, and the last worldwide in 1977 [13]—marks the start of the mpox era [14]. Smallpox was declared eradicated in 1980, signaling the end of most smallpox vaccination campaigns, including those in the Democratic Republic of the Congo [15]. Following the declaration of smallpox eradication in 1980, the Democratic Republic of the Congo undertook active surveillance for human monkeypox for five years, detecting and investigating 338 more cases. Eight cases were reported passively and investigated in West Africa [16, 17]. A serological survey in three West African countries found that almost 10,000 infants under the age of five who did not have a smallpox vaccination scar showed no signs of human monkeypox infection, including no facial scarring or orthopox antibodies. This offered reassurance that human monkeypox transmission was not rising, and reports of sporadic cases persisted [18, 19]. According to the Whitehouse study, everyone born before 1980 had a smallpox vaccine. Vaccination rates were far below 100%. Given that the post-1980 birth cohort is anticipated to constitute the majority of the DRC's population [20], we must assume that only a minority of citizens have smallpox vaccine-induced immunity to monkeypox.

By 1995, researchers had gained a solid understanding of the epidemiology of human monkeypox. It was unusual to find a case of human monkeypox in persons above the age of 15, and more than 70% of cases were linked to contact with a rainforest animal—either one found sick or dead and handled by a youngster, or one brought home from the tropical forest by a hunter. Except for those without a smallpox vaccination scar, there was limited onward transmission to family members, and infection was rarely passed down to a third generation. Serological studies on children in West Africa found that community-level transmission did not occur among unvaccinated children. However, in 1996, the number of reported human monkeypox infections in the Democratic Republic of the Congo increased dramatically, and by 1997, 88 persons had been diagnosed with the disease [21]. Between 1996 and 2005, monkeypox cases rose in older uninfected communities, with <25% of infections attributed to animal interaction. Transmission persisted for up to nine generations of unvaccinated contacts, compared to three generations before 1996 [22].

In the Democratic Republic of the Congo, intensive surveillance for human monkeypox was resumed in 2006 and 2007, and

these studies revealed that transmission had increased 20-fold since the 1980s, with vaccinated people having a 5.21-fold lower risk of infection than those who had not been vaccinated [16]. Recent studies have shed more light on the role of zoonotic transmission [23]. No cases of human monkeypox were reported in Nigeria for 39 years, until 2017. One hundred twenty-two confirmed or probable cases were found, with transmission from both known zoonotic sources and from person to person, including two healthcare personnel [24]. Since then, Nigeria has reported intermittent incidents [25].

The 2017 pandemic in Nigeria was distinct from large outbreaks of clade I MPXV in Central Africa for a number of reasons. The outbreak struck a highly inhabited area, with fewer than 10% of patients reporting contact with wildlife and clustering within households. These findings indicate that the majority of cases were generated by human-to-human transmission rather than zoonotic spillover. Second, 69% of the cases were men (mostly in their twenties or thirties), and 68% of the cases under investigation had genital ulcers [26]. Although these discoveries were not widely publicized at the time, sexual interaction was hypothesized as a mode of transmission [27].Finally, Nigeria's better international air transport connections than inaccessible forest areas in Central Africa may have contributed to MPXV's increased global distribution.

2022 Outbreaks: Until 2022, rare cases identified in non-endemic nations were typically imported, with human-to-human transmission accounting for a small percentage of cases [1]. On May 6, 2022, an outbreak of monkeypox (MPX) was confirmed in the United Kingdom (UK), originating from a British resident who traveled to Nigeria, where the disease is endemic, and had symptoms consistent with those recorded on April 29, 2022. On May 4, this individual returned to the United Kingdom with the outbreak's index case [28].

As of May 21, 2022, 92 cases had been confirmed in 13 countries where monkeypox virus (MPXV) is not endemic (the United Kingdom, Australia, Belgium, Canada, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden, and the United States) [29]. As of May 22, 2022, the number of nations with confirmed outbreaks had risen to 15. On May 24, the United Arab Emirates (UAE) became the first Arab country to report an infected case [30]. So far, no deaths have been reported [29], and Belgium is the first to enforce required 21-day MPX quarantine [31].

The majority of documented cases have no travel-related connection to an endemic country, and the majority of cases involve men having sex with men, increasing the risk of sexual transmission. Monkeypox is not a sexually transmitted infection in the classic sense, yet it is easily transferred through sexual and personal contact. The virus enters skin and mucosal surfaces by direct contact, whether sexual or skin-to-skin, and can also be spread through fomites such as towels, bedding, and sex toys [32].

Outbreak 2024: On September 19, 2023, the World Health Organization released a report indicating that 90,439 mpox cases had been detected worldwide in 115 countries as of September 11, 2023, dating back to January 1, 2022. According to the data, 22 of 115 nations were newly affected within 21 days [33]. Another recent WHO report, published on October 20, 2023, stated that from January 1, 2022 to September 30, 2023, there were 91,123 confirmed cases of mpox infection in 115 countries, with 157 deaths overall. The 10 most affected countries are: the United States, Brazil, Spain, France, Colombia, Mexico, Peru, the United Kingdom, Germany, and China [33]. According to another recent WHO report, 668 cases from 29 countries had been confirmed worldwide through October 2023. The bulk of cases were reported in the Western Pacific and European regions. Aside from that, eight new cases in Africa and one in the Eastern Mediterranean have been documented. According to recent global observations, MPV infection spreads more slowly in European and American countries than in the Western Pacific and Southeast Asia. Aside from that, in the Democratic Republic of the Congo, 12,569 instances have been suspected, with 581 deaths. According to the most latest WHO data, published on December 22, 2023, approximately 92,783 confirmed cases and 171 deaths occurred between January 1, 2022 and November 30, 2023.

In November, 906 cases of mpox were reported in 26 countries. According to the study, the sickness spread rapidly in Europe and America, with 26,654 and 60,400 confirmed cases, respectively [34]. On the other hand, the CDC reported that as of February 8, 2024, the Democratic Republic of Congo had 12,569 suspected cases and 581 deaths from mpox [35]. The global mpox outbreak has been related to Clade IIb MPXV, whereas African outbreaks have historically been caused by Clade II and Clade I, with Clade I being more virulent than Clade II [36].

In 2023, in addition to an increase in mpox cases in endemic areas, the more virulent Clade I MPXV was transmitted through sexual contact for the first time in the DRC and has since been recorded in other countries in the region. At the time, Clade Ib MPXV outbreaks were primarily characterized by heterosexual transmission associated with commercial sex work, with a few modest clusters of cases among guys who have sex with men [37].

The Africa Centres for Disease Control and Prevention (Africa CDC) proclaimed mpox a public health emergency of continental security on August 13, 2024[8], and the WHO designated mpox a public health emergency of global concern on August 14, 2024[9]. In the present outbreak, single cases outside of Africa suggestive of MPXV clade Ib infection have been reported in Sweden [38] and Thailand [39].

According to an epidemiological update published by the European Centre for Disease Prevention and Control, or ECDC, on August 26, 2024 [39], "the total number of people with mpox due to MPXV clade I have increased in recent months, alongside a geographical expansion of mpox in African countries where it was not previously documented."More imported

MPXV clade I cases are expected to be reported by the EU/EEA and other countries [40]. Men who have sex with men (MSM), occupational sex workers, and LGBTQ people are among the groups most vulnerable to Mpox exposure or high-risk behavior. Health workers who administer smallpox vaccinations, laboratory personnel working with orthopoxvirus, and diagnostic testers are all at risk [41].

Geographical and Demographic Spread:

Prior to 2017, mpox was primarily found in central and western Africa, with continuous MPXV transmission in local animal reservoirs and occasional penetration into human populations, particularly in rural areas [42]. Human-to-human transmission has been occurring in Western Africa since 2017, with periodic exports to adjacent nations from 2018 to 2021[43]. The virus is usually conveyed from person to person through direct contact with infected lesions and bodily fluids, but it can also be transmitted through respiratory droplets or contact with fomites [42, 44]. Mpox has made headlines around the world, raising concerns of a new global pandemic. Over 110 countries from six continents have reported cases, prompting the CDC to issue a level two alert [45]. So far, the disease has affected over 85,000 people, with instances documented in 110 countries, the majority of which are not normally endemic for MPXV, and in some cases, no known travel link exists [46]. Men who have sex with men (MSM), occupational sex workers, and LGBTQ persons are among the most vulnerable to Mpox exposure or high-risk behaviors. Health workers who administer smallpox vaccinations, laboratory personnel working with orthopoxvirus, and those performing diagnostic tests are all at risk [41].

In 2023, seven African Union member states reported 14,837 cases of monkeypox, with 738 confirmed fatalities. As of April 2024, 4594 cases and 280 deaths from monkeypox had been reported in five African Union Member States: Cameroon, the Central African Republic, Congo, the Democratic Republic of Congo, and Liberia [47]. A global review of the mpox epidemiological state, as reported to WHO on May 31, 2024, found 97,745 laboratory-confirmed cases and 203 deaths [48]. As a result, continual monitoring, risk assessment, and surveillance of monkeypox in both endemic and non-endemic countries are critical to limiting global spread and lowering the direct economic impact and indirect societal consequences.

Public Health Response

Initial Response Measures

The public health response to monkeypox outbreaks has evolved substantially over time, progressing from basic containment measures in the early stages to more sophisticated tactics in recent years. Early responses to epidemics in Central and West Africa focused on basic containment strategies such as confirmed case isolation, contact quarantine, and limited contact tracing. In many remote regions, these activities were hampered by a lack of finances, limited access to healthcare, and a lack of public awareness about the condition [49]. As a result, outbreaks were frequently managed on a local basis, with little international participation or coordination.

In contrast, the 2003 outbreak in the United States resulted in a more organized response, mainly to the involvement of the Centers for Disease Control and Prevention (CDC). To keep the virus from spreading, federal and state health officials used contact tracing, quarantine, and risk communication strategies [50]. Public health measures tried to educate the public on how to prevent contact with diseased animals and recognize symptoms early on, which was crucial in managing the outbreak.

The 2022 global outbreak triggered a significantly faster and more extensive response from health officials around the world. Early containment tactics included isolating confirmed cases, conducting widespread contact tracing, and advising high-risk populations, particularly men who have sex with men (MSM), to avoid close physical contact until outbreaks were under control [51]. Many countries deployed digital technologies and networks for real-time contact tracing, which made these processes faster and more efficient than in past outbreaks.

Vaccine strategies:

In the 1950s, the Turkish Vaccine Institute in Ankara developed the chorioallantois vaccinia Ankara (CVA) strain of vaccinia [52].Next, Anton Mayr and his team at the BayerischeLandesimpfanstaltMünchen (Bavarian State Vaccine Institute in Munich) passed CVA through chick embryo fibroblasts more than 500 times to develop ModifiziertesVakziniavirus Ankara (MVA) [53]. In the 1970s, more than 120,000 people in Germany, including toddlers, elders, and those with proliferative skin conditions, were immunized against smallpox using MVA as a priming dose [54]. MVA cannot grow in human cells. MVA makes early, intermediate, and late proteins, but only immature virions exist [55]. MVA most likely works by completing an already begun replication cycle in human cells but not replicating further [52].

In 1998, the Institute of Molecular Virology, a branch of the Research Center for Environment and Health (GSF, Munich), sent one vial of MVA (at passage 582) to Bavarian Nordic GmbH in Martinsried, Germany [56]. Bavarian Nordic A/S expanded on that isolate; calling it MVA-BN.
An analysis of case data from the 2022 global outbreak reveals that the MVA-BN vaccine is efficacious in preventing mpox, validating the decision to administer these immunizations during outbreaks [57].

In 2024, the prevalence of MPXV clade I in the DRC has increased. This is problematic since MPXV clade I disease has a higher case fatality rate than MPXV clade IIb disease. This clinical and epidemiologic state needs intensive primary

prevention efforts in the Democratic Republic of the Congo and other similar settings [58]. Despite the effectiveness of these immunization programs, challenges remain in providing equal access to vaccines, especially in resource-constrained settings. The global demand for vaccines during the 2024 outbreak far exceeded supplies, leaving numerous countries with insufficient doses to protect their people.

Treatment and Supportive Care

Several antiviral drugs, including tecovirimat, brincidofovir, and cidofovir, may be effective in treating MPXV infection. Despite human dose studies, the efficacy of these drugs has not been adequately established [50].

Tecovirimat (TPOXX, ST-246), which inhibits the orthopoxvirus VP37 envelope-wrapping protein, is used to treat human VARV in adults and children weighing at least 3 kg [59, 60]. Tecovirimat can be administered orally via capsules or intravenously for 14 days [61].

Brincidofovir (BCV) was licensed by the US Food and Drug Administration for the treatment of human VARV illness under the Animal Rule in June 2021 [62]. BCV is a long-acting, orally accessible broad-spectrum antiviral that inhibits viral DNA synthesis mediated by orthopoxvirus DNA polymerase. It is an analog of the injectable medicine cidofovir that may be safer and cause less kidney damage [63].

VIGIV is an FDA-approved medication used to treat complications associated with vaccinia immunization. However, it is not licensed for the treatment of MPXV. The CDC allows the use of stockpiled VIGIV to treat orthopoxvirus, including MPXV, during an outbreak [64].

Two intravenous VIGIV preparations (cangene and Dynport) have been approved for the treatment of patients with progressive vaccinia, eczema vaccinatum, severe generalized vaccinia, broad body surface involvement, or periocular implantation due to unintentional inoculation [65].
Many patients with MPXV infection recover without the need for treatment, only requiring symptomatic supportive care [66]. This includes a variety of active care treatments, pain management, adequate hydration and nourishment, and protection for sensitive areas such as the eyes and genitals. Furthermore, it is crucial to prevent and treat subsequent bacterial infections and other issues while improving overall patient care [67].

Surveillance Systems:

Building robust systems is critical. Establishing robust laboratory networks and timely reporting to the WHO improves outbreak detection [68]. Using sensitive case definitions, such as fever and particular skin lesions, was also demonstrated to increase surveillance accuracy [69].

2. CHALLENGES IN CONTROL MEASURES

Resource Limitations:

The LAMP-based assay is a useful tool in resource-constrained contexts where access to a thermo cycler, a continuous electrical supply, and temperature control are limited. Despite their simplicity, many traditional LAMP-based assays need a laboratory setup and include complex primer and probe design. Advances in isothermal technologies, such as combining recombines polymerase amplification (RPA) with clustered repeatedly interspaced short palindrome repeats (CRISPR)-based technologies, simplify procedures while increasing test sensitivity [70]. A recent study that combined RPA-CRISPR-cas12a technology with lateral flow assay (LFA) readouts showed potential for using this technique as a true POCT [71].

Misinformation and Public Perception:

The proliferation of personalized feeds tailored to each social media user has made it considerably more difficult to identify and counter misinformation on social media [72]. Research on the impact of social media on attitudes and behaviors during the mumps outbreak demonstrates the presence of prejudices and assumptions. One study revealed that stigmatizing beliefs toward mpox can inhibit persons from implementing recommended procedures like as vaccination, hand washing, and social distancing [73]. While similar beliefs about COVID-19 impeded adherence to social distancing measures, the stigma associated with mpox may exacerbate the situation by fostering negative stereotypes or supporting conspiracy theories. Zenone and Caulfield [74] found 11 types of conspiracy theories about the smallpox outbreak in short-form social media films.

Furthermore, Anoop and Sreelakshmi studied Reddit comments and discovered that, while some posts provided beneficial information regarding symptoms, transmission risk, and travel precautions, others revealed stigmatizing prejudices motivated by fear of the unknown [75].

Global Coordination Issues:

Strategic storage and distribution of medical countermeasures are critical components of Mpox pandemic preparedness and response programs. Adequate preparation requires ensuring the availability of vital medical supplies, such as antivirals and personal protective equipment (PPE), in order to effectively mitigate the impacts of outbreaks [76, 77]. National and

international collaboration is necessary to ensure the prompt purchase, stockpiling, and delivery of medical countermeasures. Health agencies at both levels should work together to assess current stockpile levels, identify gaps, and coordinate procurement activities to meet anticipated need during outbreaks.

Furthermore, techniques for rapidly deploying medical supplies should be developed to ensure a fast response to outbreaks. This includes developing distribution plans, establishing communication channels for stakeholder participation, and implementing protocols for obtaining and delivering medical countermeasures in affected areas[78]. Coordinated international solutions are urgently needed, and the PHEIC declaration will hopefully draw global attention and provide motivation for their implementation. Public health specialists can swiftly compile a comprehensive list of items and resources to strengthen public health control strategies [79].

Research Challenges with Mpox:

To better understand the dynamics of Mpox transmission and control, operational research is currently hampered by a lack of resources for intensive case investigations and contact follow-up in affected areas. A lack of adequate diagnostic facilities in the laboratory is a major concern. The lack of laboratory diagnosis capacity and availability, as well as the difficulties of diagnosing Mpox, make it difficult to determine any underlying etiology [84].

The persistent challenges of global coordination underline the importance of better international frameworks for managing zoonotic diseases such as monkeypox. A more coordinated and fair strategy for resource distribution, surveillance, and public health measures is required to guarantee that future outbreaks are better handled and that all countries have the tools they need to protect their citizens.

Successes in Public Health Responses

Successful Containment Cases

Several regions have successfully managed monkeypox outbreaks through effective public health initiatives and collaboration. One notable example is the management of the 2003 monkeypox outbreak in the United States. The outbreak, which was triggered by the importation of infected animals, was quickly stopped using a combination of public health measures including quarantine of exposed individuals, contact tracing, and education initiatives aimed at preventing further transmission. The Centers for Disease Control and Prevention (CDC) played an important role in coordinating these efforts, resulting in the outbreak being confined without further transmission [80]. The Centers for Disease Control and Prevention (CDC) recommends smallpox inoculation within two weeks, preferably within four days, after a substantial, unprotected encounter with a diseased animal or a confirmed human case [81]. Data from African outbreaks show that previous smallpox immunization gives 85% protection against monkeypox virus infection. The efficacy of immunization was demonstrated to be extended, with protection observed even several years after vaccination, and the prevalence of sequelae decreased [82]. Despite the limits of antiviral treatments for mpox, smallpox immunization can prevent epidemics (about 85.0% successful in eradicating mpox) [83].

Lessons Learned and Future Directions

Key Takeaways

The years of experience managing monkeypox epidemics have given us significant insights into successful public health responses. One of the most important takeaways is the value of global collaboration. The success of containment efforts during the 2003 U.S. outbreak and recent global responses to monkeypox has highlighted the importance of coordinated action among international health organizations, governments, and local populations [80, 85]. Effective communication and teamwork allow for the sharing of resources, knowledge, and expertise, which is critical for controlling outbreaks quickly and efficiently [86].

Another crucial point is the importance of having rapid response procedures in place. The rapid efforts performed during the 2022 global outbreak, including the deployment of vaccines and the implementation of public health campaigns, were critical in limiting the virus's spread. This emphasizes the importance of preparedness plans that include pre-established epidemic management measures, such as stockpiling vaccinations and antiviral medications, as well as promptly mobilizing healthcare resources [87].

The primary laboratory diagnostic for mpox is the detection of viral DNA using PCR. The most accurate diagnostic specimens are acquired directly from lesion material (skin, fluid, or crusts) retrieved by forceful swab. If there are no lesions, oropharyngeal or rectal swabs can be used, depending on the clinical presentation and exposure. A positive oropharyngeal or rectal sample, on the other hand, indicates mpox, whereas a negative test does not rule out MPXV infection. It is not recommended to have blood tests. Antibody detection methods can be used to classify instances retrospectively, but not to diagnose them. During the global outbreak, mpox became a notifiable disease in numerous countries, and the World Health Organization now recommends it for all countries [88].

Strengthening Public Health Infrastructure

Improved Surveillance Systems:

Implementing and improving mpox surveillance and laboratory testing would improve monitoring of the mpox burden, accelerate outbreak response, and better characterize populations that require further disease control measures, such as preventative immunization. Furthermore, comprehensive continuing data collection during vaccine distribution is essential to assess the efficacy, safety, and impact of mpox immunization schemes [89].

Faster Vaccine Deployment: Mpox vaccinations should be made available to at-risk children under 18 years old through regulatory permission or an emergency use mechanism. It would need huge immunization initiatives to return the mpox genie to its bottle [90].

Enhanced Public Communication: Public health authorities should collaborate with community leaders, religious organizations, and other stakeholders to develop and disseminate culturally appropriate educational materials and messages. Community-based organizations can act as dependable sources of information and assist in reaching marginalized or difficult-to-reach persons, hence boosting the effectiveness of risk communication efforts [91–92]. Furthermore, engaging communities in a two-way discourse fosters trust, alleviates anxieties, and promotes active participation in epidemic response. Research shows that involving community members in decision-making processes and soliciting feedback on intervention choices might improve community acceptance and compliance with recommended interventions [93, 94].

Research and Development

Understanding the Virus: The focus of research should be on better understanding Mpox epidemiology, transmission dynamics, and host-pathogen interactions. International collaboration enables the dissemination of research findings, data analysis, and multicenter study coordination in order to close knowledge gaps and guide evidence-based decisions [95].

Enhancing laboratory capacity: Improving laboratory diagnostics and surveillance abilities is crucial for early detection and confirmation of Mpox cases. International collaboration can help to establish laboratory networks, educate employees, and purchase diagnostic reagents and equipment. [97]

Providing assistance in epidemic response efforts: International partners can assist affected nations in deploying rapid response teams, establishing isolation and treatment facilities, and implementing control measures such as case detection, contact tracing, and vaccine campaigns [98].

Developing New Treatments: While antiviral medications like tecovirimat have shown promise, additional study is needed to determine their efficacy for monkeypox and to investigate other treatments. Expanding research into therapeutic possibilities will aid in the management of severe patients and mitigate the effects of outbreaks [99]. By tackling these issues, the global community will improve its ability to manage and prevent future monkeypox outbreaks and other emerging infectious illnesses. Investing in public health infrastructure, increasing research efforts, and encouraging worldwide collaboration is critical for developing a more robust response to future health crises.

Conclusion: The evaluation of public health responses to monkeypox outbreaks indicates both successes and ongoing challenges. Successful interventions, such as those witnessed in the 2003 U.S. outbreak and recent experiences in Nigeria, demonstrate the value of quick, coordinated responses that include quarantine, vaccine, and community participation. However, persistent obstacles such as resource scarcity, misinformation, and global coordination issues have hampered progress, particularly in low- and middle-income nations. The lessons from these outbreaks highlight the importance of improving public health infrastructure, surveillance, and vaccine deployment. Going forward, continued vigilance, worldwide collaboration, and investment in public health infrastructure and research are critical. Effective communication tactics for combating misinformation and stigma are also essential. Global collaboration and equitable resource distribution are vital to managing future outbreaks and protecting public health on a worldwide scale.

Data Source: Google Scholar and PubMed were used as primary data sources, including keywords like "asthma," "liposomal formulations," and "advanced drug delivery systems." To guarantee thorough coverage of the topic, the search included meta-analyses, randomized controlled trials, clinical trials, and review papers. The authors separately examined the abstracts to find articles relevant to the objectives of this review. Articles deemed possibly relevant were retrieved in full-text format and then evaluated for inclusion based on relevance and quality. The authors painstakingly read selected publications and rigorously validated the accuracy of the retrieved data to ensure the review's integrity.

Funding

This study received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest

The authors declare no conflicts of interest.

Human and Animal Rights and Informed Consent

This article contains no studies with human or animal subjects performed by authors.

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