

REVIEW ARTICLE

Advances in monkeypox-related research: India's strategic response and scientific contributions

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Abstract

The resurgence of mpox (formerly known as monkeypox), caused by the mpox virus, has emerged as a global health concern, extending beyond its endemic regions and affecting countries such as India since 2022. Although less severe than smallpox, mpox shares clinical similarities with smallpox, complicating clinical diagnosis and reporting. Its rapid transmission, coupled with the absence of targeted vaccines and antiviral therapies, underscores the urgent need for focused research and public health preparedness. This review synthesizes findings from over 350 publications originating from Indian institutions, highlighting progress in epidemiology, clinical characterization, genomic analysis, vaccine development, and public health strategies. It discusses breakthroughs in diagnostics, molecular studies, and therapeutic approaches, while identifying key challenges and future priorities. The World Health Organization's declaration of mpox as a public health emergency of international concern in 2022 has catalyzed research efforts in India. Indian scientists have responded with a surge in publications, exploring viral pathogenesis, host interactions, and the development of novel diagnostic tools and vaccines. The review also emphasizes the role of computational biology, artificial intelligence, and traditional medicine in shaping India's response. India has made significant progress in mpox-related research, particularly in diagnostics, clinical management, and epidemiology. However, the absence of specific vaccines and antiviral treatments remains a critical gap. Continued investment in research, international collaboration, and policy innovation will be essential for developing effective containment and treatment strategies. With sustained efforts, India is well-positioned to make a meaningful contribution to global mpox control and preparedness.

Keywords: Monkeypox; Mpox virus; Zoonotic diseases; India public health response; Mpox virus research in India

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1. Introduction

The global health landscape, still recovering from the COVID-19 pandemic, now faces a renewed challenge: the emergence and spread of mpox (formerly known as monkeypox), a zoonotic viral disease caused by the mpox virus (MPXV). MPXV is transmitted through close contact with infected animals or humans, including respiratory droplets, skin-to-skin contact, sexual transmission, and contaminated fomites.¹ There is growing concern that MPXV may occupy the ecological niche once held by the eradicated smallpox virus.^{2,3}

Mpox is often misdiagnosed and underreported due to its clinical resemblance to other pox-like illnesses.⁴ Human infections typically arise from direct contact with infected animals (e.g., bites, scratches, or handling during slaughter) or exposure to contaminated fomites from infected individuals.^{2,3,5} The 2022 outbreaks in non-endemic regions have elevated mpox to a pressing global public health concern. Notably, higher mpox infection rates among travelers and workers in the Middle East may be linked to the transit of African travelers through major international airports in the region, which act as critical hubs for disease transmission.⁶

Clinically, mpox manifests with symptoms including fever, headache, fatigue, lymphadenopathy, and a characteristic rash that evolves from macules to pustules and crusts.^{7–11} In severe cases, complications may involve the cardiac, neurological, renal, and respiratory systems.¹² Vulnerable groups include infants, young children, pregnant women, and immunocompromised individuals.¹³

Historically, MPXV was first identified in laboratory monkeys (*Macaca fascicularis*) in Denmark in 1958,¹⁴ with subsequent outbreaks reported in the United States.^{14,15} The first documented human case occurred in the Democratic Republic of Congo in 1970.¹⁶ Since then, MPXV has become endemic in Central and West Africa, comprising two distinct clades: the more virulent Central African (Clade I) and the less severe West African (Clade II).^{17,18} The virus has subsequently spread to countries across the Americas, Europe, Asia, the Middle East, and Australia, with over 85,000 cases reported globally by 2023.^{18–26}

International travel, asymptomatic carriers, and potential viral mutations have collectively contributed to MPXV's geographic expansion and enhanced transmissibility. Recent global analyses underscore the role of major international transit hubs, particularly in the Middle East, in facilitating mpox dissemination, highlighting the urgent need for innovative prevention and control strategies.²⁷ MPXV is classified as a risk-group 4 (RG4) pathogen due to its potential for aerosol

transmission and life-threatening outcomes.²⁴ In addition, recent studies have identified transmission risks in personal service establishments, such as tattoo parlors and spas, where inadequate hygiene practices may facilitate viral spread.²⁸

India and other developing nations face unique challenges in controlling MPXV, particularly in implementing effective sterilization protocols, enhancing diagnostic capacity, and raising public awareness. In July 2022, the World Health Organization declared MPXV a public health emergency of international concern,²⁹ prompting global biosafety and vaccination initiatives. The Centers for Disease Control and Prevention recommends handling MPXV under biosafety level 2 (BSL-2) conditions with appropriate personal protective equipment,^{30,31} and endorses the JYNNEOS™ vaccine for high-risk laboratory personnel.³²

Vaccination continues to be a cornerstone of mpox prevention. The JYNNEOS™ vaccine (also known as MVA-BN, Imvanex, or Imvamune) provides approximately 85% effectiveness.^{33,34} Additional vaccines, including ACAM2000 and APSV, are approved for use in high-risk populations.^{35,36} However, cold chain logistics and cost barriers hinder equitable distribution, particularly in low-resource settings.³⁷ Novel approaches, such as mRNA-based vaccines, are currently under development.³⁸

India's response to mpox has accelerated since the first confirmed case in 2022. Indian researchers have actively engaged in genomic comparisons, epidemiological surveillance, and public health interventions. This review aims to consolidate India's scientific contributions to mpox research, encompassing epidemiology, clinical manifestations, diagnostics, molecular insights, vaccine development, and policy strategies.

2. Biological features of monkeypox virus

The MPXV is a large, enveloped, brick-shaped virus measuring approximately 200 × 250 nm.³⁹ It belongs to the genus *Orthopoxvirus* within the family Poxviridae. The MPXV genome is a linear double-stranded DNA molecule of approximately 200 kb,⁴⁰ flanked by inverted terminal repeats and containing over 190 open reading frames (ORFs).⁴¹ These ORFs encode proteins involved in viral replication, host immune evasion, and virulence, although many remain functionally uncharacterized. Key ORFs and their functional roles are summarized in [Table 1](#), providing insight into viral replication and immune evasion mechanisms.

Replication of MPXV occurs entirely in the cytoplasm of host cells—a unique feature among DNA viruses. The

Table 1. Key open reading frames in the mpox virus genome and their functional roles

Open reading frames	Number of amino acids	Function
F8L	1,006	DNA polymerase
A11L	891	Major virion core protein p4a
E5R	785	Nucleic acid-independent nucleoside triphosphatase, required for DNA replication
I4L	771	Single-stranded DNA-binding P-protein interacts with the R1 subunit of ribonucleotide reductase
A50R	554	DNA ligase
A19R	492	DNA helicase, post-replicative negative transcription elongation factor
F1L	479	Poly (A) polymerase and catalytic subunit
C16L	439	Encoding serine/threonine protein kinase 2 and regulation of virion morphogenesis
C2L	375	Synthesis of serine protease inhibitor (SPI-3) prevents cell fusion
I7L	423	Virion core protein, DNA topoisomerase II homolog
I1L	312	Virosomal protein needed for virus multiplication
A34L	300	DNA packaging into the virion and nucleoside triphosphates-binding motif A
I3L	269	Single-stranded DNA-binding P-protein, which interacts with the R2 subunit of ribonucleotide reductase
F4L	259	RNA polymerase, 30-kDa subunit, virus intermediate transcription factor (VITF-1)
D5R	242	Zinc-binding, virulence factor, and inhibition of ultraviolet-induced apoptosis
H5R	213	Virosome-associated, late gene transcription factor, (VLTf-4), Ca ²⁺ -binding motif
A13L	190	Virion core protein
F3L	153	Double-stranded RNA binding inhibits double-stranded RNA-dependent protein kinase and 2-5A-synthetase
C8L	151	Deoxyuridine triphosphatase production
G4L	124	Virion-associated glutaredoxin, required for disulfide bonds and assembly
P1L	117	Secretion of virulence factor
Q2L	108	Virion-associated glutaredoxin
C23R	101	Virion core DNA-binding phosphoprotein
F9R	95	Protein disulfide bond-forming enzyme
G6R	63	RNA polymerase, 7-kDa subunit

viral entry process involves three key steps: adsorption, membrane fusion, and core invasion. The entry fusion complex, composed of proteins such as A21L, A16L, G3L, and O3L, facilitates membrane fusion and viral entry. Several virulence factors have been identified, including BR-203 (which inhibits host cell apoptosis), BR-209 (which binds interleukin-1 β to suppress lymphocyte proliferation), and COP-C3L (which inhibits complement cascade reactions).

In addition, MPXV encodes a natural killer cell inhibitor that acts as a natural killer group 2, member D antagonist, impairing innate immune responses.⁴² During replication, MPXV produces two types of infectious particles: intracellular mature virus (MV) and extracellular enveloped virus (EV).⁴³ MV is released on host cell lysis and is stable in the external environment, facilitating animal-to-animal transmission. EV, released through exocytosis, is wrapped in a lipid membrane derived from the Golgi apparatus or endosomes and plays a role in human-to-human transmission. Despite being the final product of the morphogenetic pathway, EVs constitute less than 1% of total progeny virions.⁴⁴

The structural morphology and the genomic organization of MPXV are illustrated in [Figures 1 and 2](#), respectively. These figures provide visual context for understanding the virus's architecture and genetic complexity, which are crucial for identifying vaccine and drug targets.

Clinically, the prodromal phase of mpox includes fever, headache, lethargy, myalgia, and lymphadenopathy within 0–5 days (20%).¹⁸ This is followed by a rash that begins in the oral mucosa and spreads to the face, extremities, palms, soles, and genitalia. The most commonly affected sites are the face (98%), palms and soles (95%), oral mucosa (70%), genitalia (28%), and conjunctiva (20%).

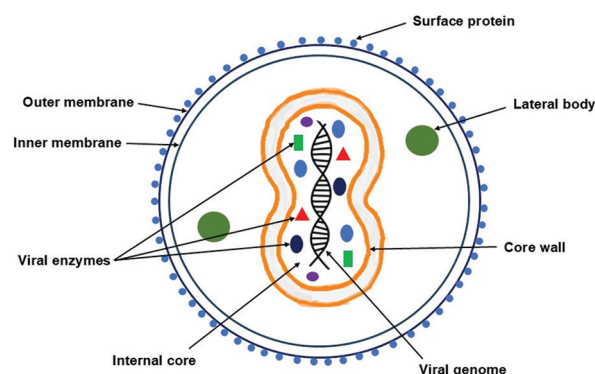


Figure 1. Schematic representation of the mpox virus structure, highlighting key components such as the viral envelope, core, and surface proteins involved in host cell entry. Adapted from Stilpeanu *et al.*⁴⁵

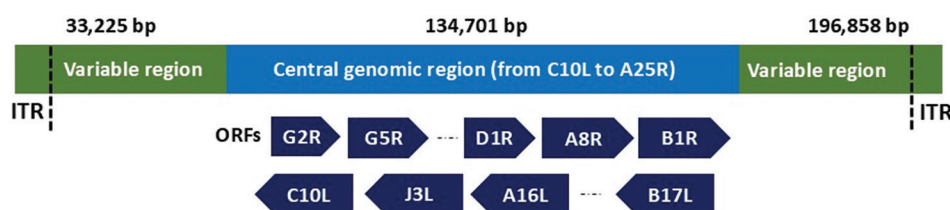


Figure 2. Genomic architecture of the mpox virus, showing the conserved central region and variable terminal regions with ITRs, ORFs, and regulatory elements

Abbreviations: ITR: Inverted terminal repeat; OTR: Open reading frame.

Monkeypox virus can be cultured *in vitro* using cell lines such as A549, Vero, RK-13, HeLa, and HAP1.⁴⁶⁻⁴⁹ In addition to cell culture systems, MPXV exhibits broad cellular tropism in human hosts. The virus can enter through respiratory or cutaneous routes. In the respiratory tract, ciliated cells and airway epithelial cells are particularly vulnerable. On skin inoculation, MPXV infects keratinocytes, fibroblasts, Langerhans cells, and antigen-presenting cells, such as dendritic cells and macrophages. These infected antigen-presenting cells may migrate to draining lymph nodes, thereby facilitating lymphatic dissemination. MPXV primarily targets lymphoid tissues, including the lymph nodes, thymus, spleen, and tonsils, often resulting in lymphopenia. Within these tissues, activated T-cells, B-cells, dendritic cells, and monocytes/macrophages have been identified as susceptible cell types, indicating their role in systemic viral spread and immune modulation.^{50,51}

In vivo, MPXV infects various small animals, including mice, rabbits, squirrels, rats, prairie dogs, and non-human primates.^{52,53} The prairie dog model is widely used in research^{54,55} for disease characterization, while *Cynomolgus* and *Rhesus macaques* serve as models for vaccine and antiviral research. MPXV is sensitive to heat (inactivated at 56°C for 30 min) and organic solvents such as methanol, phenol, formaldehyde, chloroform, and sodium dodecyl sulfate.

Table 1 summarizes key ORFs in the MPXV genome identified through computational analysis. Among over 190 predicted ORFs, those listed in Table 1 share over 90% sequence identity with orthologs in other orthopoxviruses, highlighting their conserved and functional relevance. Functional details are adapted from Shchelkunov *et al.*⁴¹

3. Monkeypox virus research: Indian scenario

3.1. Epidemiological profile of monkeypox virus in India

The first confirmed case of mpox in India was reported on July 14, 2022, in the Kollam district of Kerala, followed by

additional cases from Kannur and Malappuram districts in the same state within 48 h.⁵⁶ Shortly thereafter, a case was reported in Delhi, the national capital, on July 25, 2022, followed by two more cases in Thrissur and Malappuram, indicating ongoing viral transmission during that period. In response, the Indian government and scientific community swiftly initiated preventive public health measures, including isolation protocols and contact tracing. Simultaneously, Indian biologists began comparative genomic studies using *in silico* methods and global datasets to understand the viral lineage and mutation patterns.⁵⁷

As of the latest reports, 10 confirmed cases (eight males and two females) have been documented, with 23 suspected cases across other states, including Bihar (Nalanda and Patna), Uttar Pradesh (Auraiya, Ghaziabad, and Gautam Buddha Nagar), and Telangana (Khammam).⁵⁸ Alarmingly, all confirmed cases were individuals under 35 years of age, and most had a recent travel history to the United Arab Emirates (UAE) or Nigeria within the preceding 21 days.^{56,59,60} However, on July 24, 2022, a locally transmitted case was reported at Lok Nayak Hospital, Delhi. The patient, a middle-aged male, had no recent travel history abroad but had attended a social gathering in Himachal Pradesh. The origin of transmission in this case remains unknown. Although this raised concerns about possible local circulation, community transmission was not officially confirmed by government health authorities.⁶¹ India reported its first mpox-related death on July 31, 2022, from the Thrissur district of Kerala.⁶² However, the limited number of reported cases and the absence of widespread community surveillance raise concerns about underreporting and the potential for undetected transmission chains. Therefore, there is a need for systematic seroprevalence studies and enhanced syndromic surveillance to better understand the true burden and transmission dynamics of mpox in India. Furthermore, the lack of data on asymptomatic or subclinical infections represents a significant gap in the current epidemiological understanding.

Viral transmission in India has been linked to close or intimate physical contact, including sexual transmission,

and exposure to contaminated items such as bedding, clothing, and/or personal items, which are recognized as mpox risk factors. High-risk groups include pregnant women, infants, children under 8 years old, the elderly, immunocompromised individuals, and malnourished tribal or ethnic minorities.⁶ In late June 2022, the World Health Organization declared mpox a global health threat, citing the rapid rise in cases worldwide.⁶³ However, distinguishing MPXV from other poxvirus infections remains challenging due to overlapping clinical features and limited awareness of the disease. Accurate diagnosis relies on serological and molecular assays capable of detecting MPXV-specific markers.

Initially, the National Institute of Virology (NIV), Pune, served as the sole testing facility for mpox in India.⁶⁴ To expand diagnostic capacity, the Indian Council of Medical Research (ICMR) trained and designated 15 additional laboratories across the country for early detection of the virus and monitoring the infection: Sher-e-Kashmir Institute of Medical Sciences, Srinagar; All India Institute of Medical Sciences, New Delhi; B.J. Medical College, Ahmedabad; Kasturba Hospital for Infectious Diseases, Mumbai; Government Medical College, Guwahati; Gandhi Medical College, Secunderabad; All India Institute of Medical Sciences, Nagpur; SMS Medical College, Jaipur; Government Medical College, Amritsar; King George's Medical University, Lucknow; National Institute of Cholera and Enteric Diseases, Kolkata; Bangalore Medical College and Research Institute, Bangalore; The King Institute of Preventive Medicine and Research, Chennai; NIV Field Unit, Kerala; and Government Medical College, Trivandrum.⁶⁵

The Department of Health Research and ICMR urged researchers and the pharmaceutical industries to accelerate the development of diagnostic tools and vaccines. In response, the NIV developed the IMDX Mpox Detection reverse transcription-polymerase chain reaction Assay, a rapid test kit using the loop-mediated isothermal amplification technology for efficient detection.⁶⁶ The Central Drugs Standard Control Organization approved the manufacturing of domestically developed mpox diagnostic kits validated by ICMR, which target two distinct regions in the viral genome, covering both clade I and clade II variants, ensuring broad detection.^{66,67}

On the vaccine front, the Serum Institute of India (SII) has announced plans to collaborate with Novavax to produce mRNA-based vaccines for mpox. In addition, SII is pursuing a technology transfer agreement to manufacture Bavarian Nordic's MVA-BN[®] vaccine for the Indian market.⁶⁸ These initiatives are supported by the Union Cabinet's BioE3 policy, which aims to boost

biomanufacturing through an INR 10,000 crore investment, potentially accelerating India's vaccine production capacity and bioeconomy.⁶⁹

Monkeypox virus infection can lead to serious complications, including encephalitis, pneumonia, and vision loss. If the MPXV infection is acquired during pregnancy, it can lead to stillbirth or birth defects. While such complications have been reported in Central and West Africa, no similar outcomes have been documented in India to date.⁷⁰⁻⁷² Furthermore, official reports from the ICMR, National Centre for Disease Control (NCDC), and Ministry of Health and Family Welfare (MOHFW) confirm the absence of these complications in Indian cases.

To manage confirmed cases, the NCDC and MOHFW implemented protocols including home or hospital isolation, rehydration therapy, nutritional support, and symptom alleviation as essential principles in the management of mpox cases in India. Over time, Indian investigators made significant contributions to the mpox literature. The trend of MPXV-related publications from Indian institutions indexed in PubMed is illustrated in [Figure 3](#). This upward trend highlights the growing scientific interest in mpox in India, particularly following the 2022 outbreak. [Table 2](#) presents the selected Indian research institutions and investigators contributing to MPXV studies, including their areas of expertise and relevant publications. The table highlights the breadth of institutional involvement and thematic scope in India's mpox research landscape.

Together, these epidemiological insights and institutional efforts have laid the groundwork for more in-depth molecular investigations. The following section explores how Indian researchers applied genomic and proteomic tools to characterize MPXV strains, track viral evolution, and identify potential therapeutic targets.

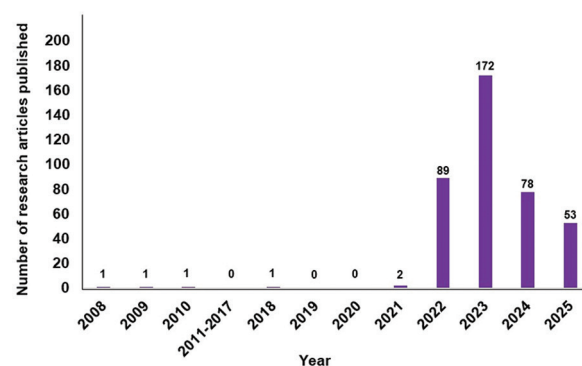


Figure 3. Annual trend of peer-reviewed publications on mpox virus research from Indian institutions indexed in PubMed (up to August 2025), illustrating increasing national research activity

Table 2. Selected Indian research institutions and investigators contributing to mpox virus studies, including their areas of expertise and relevant publications

Institute	Principal investigator	Department/area of interest	Location	References
ICMR-NIV	Pragya D. Yadav	Virology and molecular biology	Pune	59,73-76
CSIR-IGIB	Vinod Scaria	Computational approaches for genome studies	New Delhi	77,78
IISc	Perumal Arumugam Desingu	Skin disease viruses and viral pathogenesis	Bengaluru	79-81
ICAR-IVRI	Kuldeep Dhama	Division of Pathology	Uttar Pradesh	12,82,83
AVVU	Deepak Chandran	Veterinary sciences and animal husbandry	Coimbatore	82-84
SPEIDC	Anuja Elizabeth George	Dermatology	Trivandrum	59,85
ICMR-NIRRH	Rahul Gajbiye	Strategies for addressing mpox infection	Mumbai	86
GADVASU	Om Prakash Choudhary	Veterinary microbiology	Bathinda	87
SIMATS	Saravanan Sekaran	Department of Prosthodontics	Chennai	88
MAHE	Sanjay Pattanshetty	Department of Global Health Governance/data visualization and global mpox policy	Manipal	89-92
FPCHS	Chandrakant Lahariya	Public health surveillance and the health system	New Delhi	93-95
Al-Falah University	Ashish William	Department of Microbiology	Faridabad	58
AIIMS	Tanya Singh	Department of Community Medicine and Family Medicine	Jodhpur	56
RBDCH	Ramandeep Singh Gambhir	Department of Public Health Dentistry	Mohali	96
MU	Ravindra B. Malabadi	Applied Botany and Herbal Medicine	Mangalagangothri	97
AIIMS	Ramashankar Rath	Public health and tourism	Gorakhpur	98,99

Abbreviations: AIIMS: All India Institute of Medical Sciences; AVVU: Amrita Vishwa Vidyapeetham University; CSIR: Council of Scientific and Industrial Research; DST: Department of Science and Technology; FPCHS: Foundation for People-Centric Health Systems; GADVASU: Guru Angad Dev Veterinary and Animal Sciences University; ICAR: Indian Council of Agricultural Research; ICMR: Indian Council of Medical Research; IGIB: Institute of Genomics and Integrative Biology; IISc: Indian Institute of Science; IVRI: Indian Veterinary Research Institute; MAHE: Manipal Academy of Higher Education; MU: Mangalore University; NIRRH: National Institute for Research in Reproductive and Child Health; NIV: National Institute of Virology; RBDCH: Rayat Bahra Dental College and Hospital; SPEIDC: State Prevention of Epidemic and Infectious Diseases Cell; SIMATS: Saveetha Institute for Medical and Technical Sciences.

3.2. Genomic and proteomic aspects of the monkeypox virus

Research on the genomic and proteomic aspects of MPXV in India has grown significantly since the first confirmed cases in 2022. These studies have provided valuable insights into viral evolution, transmission dynamics, and potential therapeutic targets. The NIV conducted whole-genome sequencing of MPXV samples from Kerala and Delhi, identifying the A.2 lineage of clade IIb as predominant in India.^{59,76} Phylogenetic analysis revealed three sub-clusters, with seven sequences (Delhi: $n = 2$; Kerala: $n = 5$) showing high similarity to MPXV_USA_2022_FL001.⁷⁴ This work laid the foundation for understanding the genetic diversity of Indian MPXV strains.

Complementing this, researchers at the Institute of Genomics and Integrative Biology (IGIB), New Delhi, identified 16 distinct genetic variations in Indian MPXV isolates, including nonsynonymous, synonymous, and stopgain mutations, along with a 3-amino acid deletion in the *OPG174* gene.⁷⁷ Their *in silico* analysis also evaluated the impact of these mutations on polymerase chain reaction (PCR) primer efficacy, generating a heatmap of

oligo frequencies and thermodynamic parameters to guide diagnostic accuracy.⁷⁸

Further genomic investigations by the Indian Institute of Science (IISc), Bangalore, revealed insertion/deletion events ranging from 500 bp to 2 kb in outbreak strains. These strains were closely related to the West African clade responsible for the 2017–2018 outbreak in Nigeria.⁸¹ The study highlighted genomic gaps, frameshift mutations, tandem repeats, and *APOBEC3* mutations, indicating ongoing viral evolution and adaptation.^{79,80} Despite these advances, functional validation of the identified mutations remains limited. The biological significance of the observed deletions and non-synonymous mutations, particularly in genes such as *OPG174*, remains to be fully elucidated. Future studies should focus on correlating these genomic changes with clinical severity, transmissibility, and potential for immune evasion to inform vaccine and therapeutic development.

Building on genomic insights, proteomic studies have also made significant progress. IISc researchers found high mutation rates in proteins such as envelope glycoproteins, ankyrin repeat proteins, DNA polymerase,

and interferon- α receptor-like glycoproteins, which may influence viral entry, replication, and immune evasion.¹⁰⁰ In addition, a systems biology study by Adamas University, Kolkata, identified 250 differentially expressed host genes during MPXV infection. Eight genes were upregulated (e.g., *PMAIP1* and *HIST1H2BJ*), and 16 were downregulated (e.g., *HOXA9* and *CDK19*), offering insights into host–pathogen interactions and potential therapeutic targets.¹⁰¹ The genomic and proteomic insights gained from these studies have not only enhanced our understanding of MPXV biology but also laid the foundation for the development of accurate diagnostics and targeted therapeutics. These translational applications are discussed in the next section.

3.3. Diagnostics, treatment, and antiviral drugs for monkeypox virus

The lack of well-developed diagnostic techniques, licensed drugs, vaccines, and antiviral therapeutics has contributed to the rise in MPXV cases in India. Although diagnostic capacity has gradually improved, significant gaps remain in accessibility and standardization. Current diagnostic methods include laboratory culture, immunohistochemistry, PCR, electron microscopy, and antigen-specific tests such as enzyme-linked immunosorbent assay, plaque reduction neutralization test, Western blot, and electrochemiluminescence assay.^{102–105} PCR remains the gold standard, with real-time assays capable of differentiating MPXV from other orthopoxviruses and between clades.^{106,107} A meta-analysis by the Postgraduate Institute of Medical Education and Research (PGIMER), Chandigarh, identified sore throat and oral lesions as the predominant symptoms of MPXV infection.¹⁰⁸ In clinical settings, anesthetic precautions—including equipment disinfection and pre-anesthetic assessment—are critical to prevent transmission, especially during procedures involving mucosal exposure.¹⁰⁹ Researchers at IGIB conducted *in silico* evaluations to improve primer efficacy and guide healthcare professionals in selecting optimal oligos.⁷⁸

To address limitations in conventional diagnostics, innovative approaches have emerged across India. Investigators from Dr. A. P. J. Abdul Kalam University, Indore, proposed artificial intelligence (AI)-assisted lesion detection using deep learning models such as InceptionV3, ResNet50, convolutional neural networks, VGG19, and GoogLeNet.^{110,111} These tools aim to support rapid screening, especially in resource-limited settings. However, the clinical validation of these AI-based tools in real-world settings is currently lacking. There is a pressing need for multicentric trials to assess their diagnostic accuracy, usability, and integration into existing healthcare workflows.

In addition, the regulatory framework for approving such digital health tools in India remains underdeveloped, posing a barrier to their widespread adoption. The All India Institute of Medical Sciences, New Delhi, initiated clinician training programs to improve awareness and response to mpox.¹⁸ Despite these advancements, knowledge gaps among healthcare professionals remain a concern. A study from Rayat and Bahra Dental College, Mohali, revealed that one-fourth of dental students lacked awareness about mpox.⁹⁶ In contrast, medical students and practitioners in cities such as Pune, Nagpur, Bangalore, Chennai, Vijayawada, Kolkata, Siliguri, and Kerala showed satisfactory knowledge levels.^{112–114} Investigators at Dr. D.Y. Patil Vidyapeeth, Pune, emphasized the role of dentists in early detection through signs, such as fragile blisters, aphthous ulcers, and facial rashes.^{60,115} These findings underscore the importance of targeted education and training to improve mpox recognition and response among healthcare providers.

Expanding the clinical spectrum, ophthalmic complications have also been documented. Work at Dr. Om Parkash Eye Institute, Amritsar, described mpox-related ophthalmic disease (mpoxROD), with symptoms such as redness, ocular pain, photophobia, and vision problems.¹¹⁶ The dermatological evolution of India's first mpox case was studied by the State Prevention of Epidemic and Infectious Diseases Cell, Trivandrum, revealing co-infection with herpes simplex virus and elevated markers such as lactate dehydrogenase, C-reactive protein, and erythrocyte sedimentation rate.^{59,85}

In parallel, Indian researchers have actively explored antiviral strategies. A team from PGIMER, Chandigarh, listed potential drugs including N-MCT, KAY-2-41, NIOCH-14, C-ca3-Ado, C3-Npc A, HPMA, and ANO. Drugs such as cidofovir, ribavirin, and tiazofurin are already available in Indian markets.^{117,118} Although brincidofovir (CMX001) and tecovirimat (TPOXX) are approved internationally, their efficacy in Indian cases remains under investigation.^{119,120} Tecovirimat is administered orally twice daily for 2 weeks and has shown promise in animal models.

Beyond conventional antivirals, innovative therapies are being explored. Researchers from the Central University of Punjab, Bathinda, proposed target-based therapies, including biomarkers and silver nanoparticles.¹²¹ Computational studies by Maharishi Markandeshwar University, Haryana, identified phytochemicals, such as 4-dimethoxybenzamide and *N*-(2-allylcarbamoyl-4-chlorophenyl)-3, from *Allophylus serratus* with binding affinity to MPXV proteins.⁸² Other compounds, such as oleanolic acid, ursolic acid, and silibinin, have demonstrated antiviral responses.¹²² A cryptic binding

pocket in the P37 envelope protein was identified through molecular dynamics simulations.¹²³ In addition, Mangalore University listed over 60 Ayurvedic plants with potential antiviral activity; however, further *in vitro* and *in vivo* validation is needed.¹⁰⁵ While these diagnostic and therapeutic advancements are promising, their successful implementation depends heavily on robust public health infrastructure and policy support.

3.4. Public health strategies and policy framework for mpox in India

Building on the scientific advancements in diagnostics, therapeutics, and genomic surveillance, India's public health system mobilized a comprehensive response to the mpox outbreak. This section outlines the key strategies, institutional roles, and policy measures that have shaped the national response. Institutions such as the Surat Municipal Institute of Medical Education and Research emphasized the need for preparedness and rapid action.¹²⁴ The MOHFW issued guidelines recommending patient isolation (either at home or in a hospital), symptom alleviation, and hygiene practices such as wearing triple-layer masks and covering lesions. Isolation was advised until complete resolution of all lesions and scab shedding.⁵⁶ As of November 2025, no official reports have confirmed the distribution of mpox vaccines in India, and the country has not issued specific vaccination advisories for mpox.⁵⁷ This lack of formal guidance poses a challenge in protecting high-risk groups, including healthcare workers, laboratory personnel, and travelers to endemic regions. Without a clear national policy or established supply chain for mpox vaccines, vaccine uptake and coverage remain undocumented, and proactive immunization efforts are limited.

In addition, vaccine hesitancy may be a concern, particularly in rural and underserved populations, due to limited awareness, misinformation, and the absence of targeted communication strategies. Addressing these gaps through policy formulation, public education, and stakeholder engagement is essential for effective outbreak preparedness and response. The absence of a national vaccination strategy for mpox, despite global availability of vaccines such as MVA-BN®, highlights a critical policy gap. Comparative analyses with countries implementing targeted vaccination campaigns, such as the United States and the United Kingdom, suggest that early immunization of high-risk groups can significantly curb transmission. India's reliance on reactive rather than proactive measures underscores the need for a more anticipatory public health framework.

In parallel with these policy gaps, several institutions have taken the initiative to strengthen operational responses

at the local level. Prathima Institute of Medical Sciences, Telangana, proposed isolated systems for suspected cases, regular screening of travelers, public hygiene education, and dissemination of official instructions through central and state health departments and ICMR websites.¹²⁵ The central and state governments responded with expert teams, task forces, standard operating procedures, contact tracing, testing, isolation, treatment, and workforce training initiatives.

However, the outbreak also revealed vulnerabilities in specific populations. Studies noted increased mpox prevalence among men who have sex with men, often without travel history to endemic regions.^{107,125} Researchers from the Manipal Academy of Higher Education, Manipal, studied mpox policies among G20 nations and identified factors influencing vaccine uptake. They emphasized the need for adult vaccination policies, particularly for the LGBTQ+ community, and called for stigma-free communication strategies.^{89,91,92} Community-level awareness efforts were led by institutions such as the Saveetha Institute for Medical and Technical Sciences, Chennai, which focused on training health workers, combating misinformation, and addressing stigma surrounding mpox as a "gay disease."^{88,126,127} In addition to public health messaging, the institute proposed the use of cholesterol-lowering drugs—such as proprotein convertase subtilisin/kexin type 9 inhibitors, fenofibrates, and statins—as potential adjuvant therapies.^{128,129}

To further reduce stigma and promote inclusivity, the Centers for Disease Control and Prevention India issued messaging clarifying that mpox can affect anyone, regardless of sexual orientation. National Institute of Mental Health and Neurosciences, Bengaluru, highlighted the psychological impact of mpox-related stigma on LGBTQ+ individuals and called for integrated mental health support systems.¹³⁰ Meanwhile, Guru Angad Dev Veterinary and Animal Sciences University, Bathinda, prioritized public health risk assessment and vaccination strategies, proposing a ring vaccination approach for healthcare workers and close contacts of infected individuals.^{87,131-137} They also raised concerns about possible interactions between mpox infection and immunodeficiency conditions prevalent among gay and bisexual men, warranting further investigation.

Public awareness campaigns were recommended using frequency-modulation radio, television, community meetings, and targeted messaging to disseminate accurate information and counter misinformation. Innovative suggestions included integrating mpox vaccination status and immunocompromised status into dating app profiles to promote safe practices and public health compliance. Special

populations, such as pregnant women and newborns, also received focused attention. The ICMR–National Institute for Research in Reproductive and Child Health, Mumbai, emphasized mpox preparedness in maternal and neonatal care. Their recommendations included training accredited social health activists, forming multidisciplinary teams comprising neonatologists, dermatologists, obstetricians, anesthetists, and psychiatrists, and strengthening both public and private healthcare systems.^{86,138} Finally, the All India Institute of Medical Sciences, Gorakhpur, explored the broader impact of mpox on medical tourism and regional economies. Their findings highlighted the need for infrastructure modernization, diagnostic facility upgrades, and strategic healthcare investment to mitigate the economic burden posed by re-emerging communicable diseases.^{98,99}

4. India's mpox response: Bridging the gaps and paving the way for global leadership

India's response to the mpox outbreak has been dynamic and evolving, marked by swift public health actions and growing scientific engagement. However, several critical gaps remain, necessitating urgent and coordinated attention to transform reactive measures into long-term resilience. A top priority is the comprehensive decoding of MPXV's genomic and proteomic architecture, using both biological and computational approaches. Institutions such as NIV, IGIB, and IISc have made notable contributions, yet further research is essential to unravel viral evolution, host–pathogen interactions, and mutation-driven shifts in virulence and transmissibility. Nevertheless, the current body of Indian research is heavily skewed toward descriptive epidemiology and genomic surveillance, with a limited focus on mechanistic studies and clinical trials. There is a need to transition from observational studies to hypothesis-driven research that can unravel the molecular underpinnings of MPXV pathogenesis and inform targeted interventions.

Equally crucial is the development of scalable, cost-effective diagnostic platforms. While PCR remains the diagnostic gold standard, India must invest in point-of-care technologies tailored for rural and resource-constrained settings. Innovations such as AI-assisted lesion detection, rapid antigen tests, and mobile diagnostic units can revolutionize early detection. Moreover, primer/probe validation in the context of emerging mutations is vital in maintaining diagnostic accuracy. The lack of targeted antivirals and vaccines remains a significant challenge. Indian researchers have begun exploring phytochemicals, nanomedicine, and repurposed drugs, but these efforts must be accelerated through clinical trials and translational research. The Jamal Vaccine Research

Center in Tiruchirappalli, in collaboration with the Emory Vaccine Center, has been involved in initiatives aimed at indigenous vaccine development. In addition, target-based therapies, biomarker-guided interventions, and silver nanoparticle formulations require rigorous validation and testing.

Compared to global efforts, India's response to mpox has demonstrated strengths in genomic surveillance and diagnostic innovation. For instance, while the United States and United Kingdom rapidly deployed the MVA-BN[®] vaccine and implemented ring vaccination strategies for high-risk groups, India has not yet initiated a national vaccination campaign or issued formal advisories for mpox immunization.^{33,35,137} Although the SII has announced plans for mRNA-based vaccine production and technology transfer for MVA-BN[®], these efforts remain in early stages.^{68,69} Furthermore, while India has developed indigenous diagnostic kits and AI-based lesion detection tools,^{66,110} the absence of large-scale clinical validation and regulatory pathways limits their deployment. Public health communication in India has also lagged in addressing stigma, particularly among LGBTQ+ populations, compared to targeted messaging campaigns in countries such as Canada and the United Kingdom.^{89,130} These comparisons highlight the need for India to adopt a more proactive, inclusive, and globally aligned approach to mpox preparedness.

Beyond biomedical innovation, interdisciplinary research is crucial for understanding mpox-associated inflammation across various organ systems, as well as its socioeconomic and behavioral dimensions. This includes mental health assessments, stigma reduction strategies, and community-based interventions, especially for vulnerable populations such as LGBTQ+ individuals, pregnant women, and tribal communities. Policy frameworks must be adaptive, inclusive, and evidence-driven, reflecting the diversity and complexity of India's public health landscape. Strategies such as ring vaccination, traveler screening, and integrating mpox awareness into existing health campaigns are key to containment and prevention. To sustain these efforts, India's major research bodies—the University Grants Commission, ICMR, the Ministry of Ayush, the Department of Biotechnology, and the Department of Science and Technology—must collaborate to ensure long-term funding, infrastructure development, and regulatory support. With synergistic efforts across academia, industry, and government, India is uniquely positioned to lead global innovation in mpox research and response. By bridging scientific gaps and fostering inclusive public health strategies, the nation can transform the mpox challenge into a model for managing emerging infectious diseases worldwide.

5. Conclusion

India's response to the mpox outbreak has demonstrated a commendable blend of scientific agility, public health preparedness, and collaborative research. From rapid diagnostic development and genomic surveillance to the formulation of national guidelines and indigenous vaccine research, India has positioned itself as a proactive contributor to global mpox knowledge. However, sustained investment in One Health surveillance, cross-sectoral data integration, and translational research is essential to mitigate future zoonotic threats. Strengthening regional collaborations and fostering innovation in diagnostics and therapeutics will be pivotal in shaping India's long-term strategic preparedness against emerging infectious diseases.

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