

Perspective

Chandipura Viral Encephalitis: A Re-emerging Threat to Public Health and Regional Security in South Asia

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ABSTRACT

Background: Chandipura viral encephalitis (CHPV) has emerged as a significant public health challenge in South Asia, particularly in pediatric populations, with alarming mortality rates. **Objective:** This review synthesizes the current knowledge about the impact of CHPV on human health and healthcare systems. **Methods:** A comprehensive analysis of the published literature, outbreak reports, and clinical studies was conducted to evaluate the epidemiology, clinical manifestations, diagnostic approaches, and treatment strategies of CHPV. **Results:** CHPV has a distinct predilection for children under 15 years of age, with case fatality rates ranging from 55–70% in severe pediatric cases. Disease progression is characterized by the rapid onset of symptoms, typically evolving from initial influenza-like manifestations to severe neurological complications within 48 h. The clinical presentations include high-grade fever, altered consciousness, seizures, and various neurological deficits. Diagnostic challenges persist, particularly in resource-limited settings, despite advances in molecular detection methods. Treatment remains primarily supportive, with a focus on managing severe complications and maintaining vital organ function. Socioeconomic impacts are substantial, with catastrophic healthcare costs affecting vulnerable populations and straining healthcare systems in endemic regions. **Conclusion:** The reemergence of CHPV poses serious challenges to public health systems, particularly in resource-limited settings. Rapid progression of the virus, high mortality rates, and significant socioeconomic burden necessitate enhanced surveillance systems, improved diagnostic capabilities, and strengthened healthcare infrastructure. The priority areas for intervention include developing point-of-care diagnostics, establishing standardized treatment protocols, and implementing sustainable vector control programs.

KEYWORDS

Chandipura virus, emerging infectious disease, encephalitis, disease outbreaks, vectorborne diseases, global health surveillance

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INTRODUCTION

In recent years, various viral diseases that pose significant threats to public health, including swine flu, Nipah virus, Crimean-Congo hemorrhagic fever, Rift Valley fever, avian influenza, COVID-19, monkeypox, Ebola, Middle East Respiratory Syndrome (MERS), hantavirus, Zika virus, Lassa fever, and others, have emerged and reemerged [1–3]. Among these emerging threats, Chandipura virus encephalitis has emerged as a public health challenge in the Indian subcontinent, characterized by its rapid progression and high mortality rates, especially among pediatric populations [3]. The causative agent, Chandipura vesiculovirus (CHPV), is an enveloped RNA virus belonging to the Rhabdoviridae family that is transmitted primarily by female phlebotomine sandflies [4,5].

Although significant progress has been made in understanding the molecular characteristics and transmission dynamics of CHPV since its first identification in 1965, several critical gaps remain in our knowledge of its pathogenesis, host-pathogen interactions, and optimal therapeutic approaches. The potential for geographical expansion of this virus, coupled with the lack of specific antiviral treatments and limited diagnostic capabilities in resource-constrained settings, presents a complex challenge for public health systems. Furthermore, the socioeconomic impact of CHPV outbreaks, particularly in vulnerable communities, raises important questions about healthcare equity and resource allocation [6–8].

This comprehensive review aims to synthesize current knowledge about CHPV, examine emerging research directions, and evaluate existing control strategies. By analyzing recent outbreaks across various regions of India, including Andhra Pradesh, Gujarat, Madhya Pradesh, Maharashtra, Odisha, and Rajasthan, this review seeks to identify patterns in disease transmission, assess the effectiveness of current interventions, and propose evidence-based recommendations for improving surveillance, diagnostic capabilities, and treatment approaches. In addition, it explores the broader implications for regional health security and the importance of international collaboration in addressing this re-emerging threat.

The urgency of addressing CHPV is underscored by its high case fatality rate, particularly among children under 15 years of age, and its potential for rapid spread through vector populations. Understanding these challenges in the context of limited healthcare resources and evolving disease patterns is crucial for developing effective control strategies and protecting vulnerable populations. This review contributes to the growing body of knowledge necessary for informed policy decisions and for improving public health responses to CHPV outbreaks.

PERSPECTIVE

Historical and epidemiological

The historical trajectory and epidemiological significance of Chandipura virus (CHPV) represent a compelling narrative of emerging infectious diseases in the Indian subcontinent. Initially, isolated in 1965 from two patients in Chandipura village, Maharashtra, India, during an investigation of Dengue and Chikungunya viruses, CHPV was considered to be of minimal public health significance [1,3,9]. However, this perception dramatically shifted following its re-emergence in the early 21st century, marked by several severe outbreaks with significant mortality rates, particularly among children [10]. The virus remained relatively quiescent for nearly four decades until a major outbreak in 2003 in Andhra Pradesh, India, which recorded 329 cases with an alarming case fatality rate of 55% [8]. This outbreak served as a watershed moment in CHPV epidemiology, prompting increased surveillance and research. Subsequent investigations revealed retrospective evidence suggesting that CHPV might have been responsible for numerous unexplained encephalitis cases in central India during the intervening years, particularly in Maharashtra and Gujarat [11–13].

The epidemiological pattern of CHPV has shown characteristics that distinguish it from other viral encephalitides. The virus has a remarkable predilection for pediatric populations, with the most severe cases occurring in children aged < 15 years. This age-specific vulnerability pattern has been consistently observed across multiple outbreaks, including the 2004 Gujarat outbreak, where 78% of affected children succumbed to the infection within 48 h of onset [14]. The rapid

progression and high mortality rates have established CHPV as a significant public health threat, particularly in rural and socioeconomically disadvantaged regions. The areas affected by CHPV are shown in **Figure 1**.

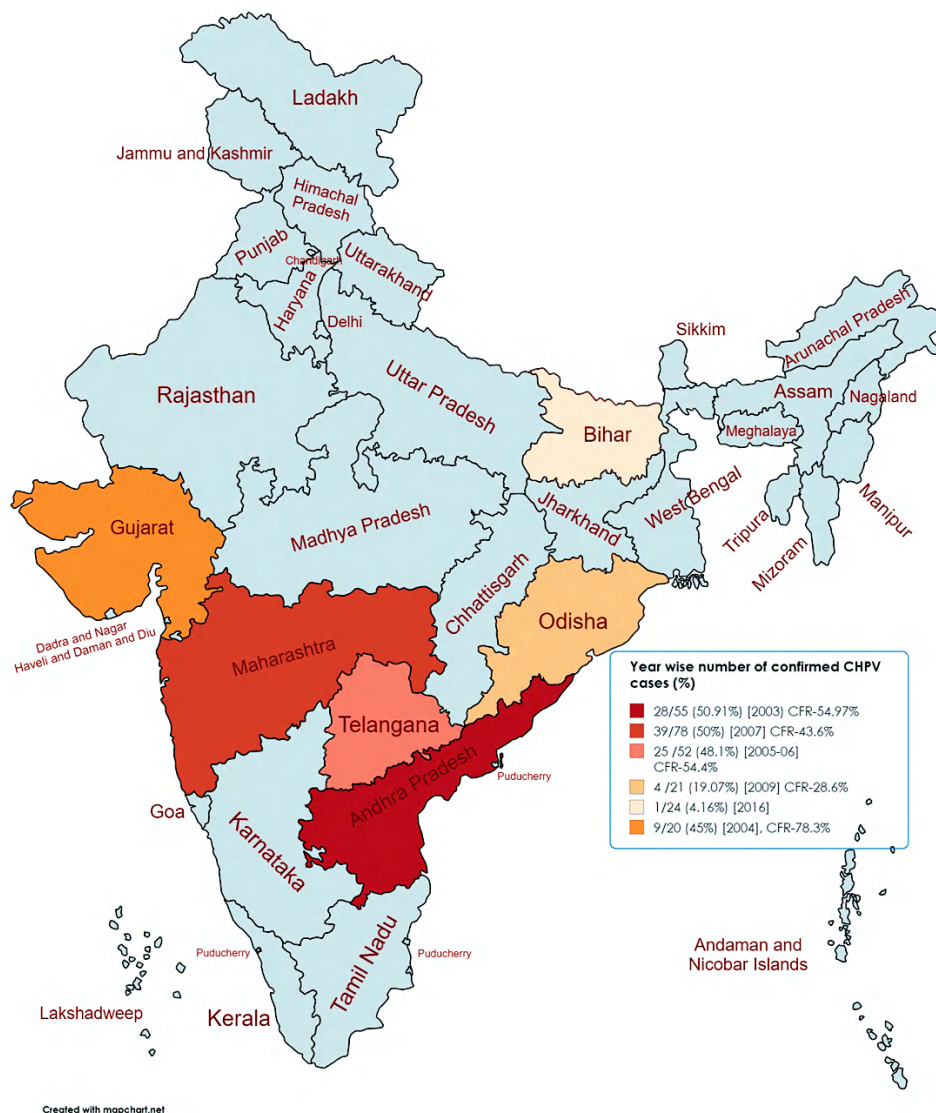


Figure 1. Spatial pattern of Chandipura virus (CHPV) in India. Remarks: The map displays the number, percentage of annual cases, and case fatality rate (CFR). A high risk of death indicates that the region must be aware of this threat. This figure was adopted from the study by Bhavesh Kanabar [14].

Recent epidemiological studies have identified several factors that contribute to the re-emergence and persistence of the virus. Environmental changes, urbanization, and altered human-vector interactions have been implicated in the expanding geographical distribution of CHPVs. The virus has been detected in multiple states across India, with evidence of silent transmission in areas previously considered nonendemic [15]. Additionally, serological surveys have revealed significant levels of CHPV antibodies in asymptomatic populations, suggesting widespread exposure and potential underreporting of cases [16]. The temporal and spatial distributions of CHPV outbreaks exhibit distinct seasonal patterns, with peak transmission occurring during the monsoon and postmonsoon periods. This seasonality correlates with the breeding cycles of *Phlebotomus* sandflies, the primary vector for CHPV transmission. Recent molecular epidemiological studies have revealed genetic variations among CHPV isolates from different geographical regions, suggesting viral evolution and adaptation [14]. These findings have important implications for understanding the pathogenicity of the virus and designing effective control strategies.

The re-emergence of CHPV has also highlighted significant gaps in public health infrastructure and surveillance systems[17]. The challenges in case detection, reporting, and laboratory confirmation have likely resulted in the underestimation of the true disease burden. Furthermore, geographical overlap with other endemic viral infections, such as Japanese encephalitis and dengue, complicates clinical diagnosis and epidemiological assessment [11]. The historical context and epidemiological significance of CHPV underscore the need for enhanced surveillance, improved diagnostic capabilities, and strengthened public health measures to address this re-emerging threat effectively [18].

The recognition of CHPV as a significant public health challenge has led to increased research focus and international collaboration. The World Health Organization has acknowledged the potential for CHPV to emerge as a broader regional threat, emphasizing the need for coordinated surveillance and control efforts across the Indian subcontinent [19]. Understanding the historical context and epidemiological patterns of CHPV is crucial for developing effective prevention strategies and improving our preparedness for future outbreaks of this emerging pathogen.

Viral characteristics

Chandipura virus (CHPV) has distinct molecular and structural characteristics that contribute to its pathogenicity and transmission. As a member of the Rhabdoviridae family and genus Vesiculovirus, CHPV shares structural similarities with vesicular stomatitis virus (VSV) but has unique genomic features that influence its virulence and host interactions. The viral particle is bullet shaped, measuring approximately 180 nm in length and 75 nm in diameter, with characteristic surface glycoprotein projections that facilitate host cell entry [6,20]. The CHPV genome consists of a single-stranded, negative-sense RNA approximately 11.1 kb in length and encodes five major structural proteins: nucleocapsid protein (N), phosphoprotein (P), matrix protein (M), glycoprotein (G), and large protein (L). The genome structure of CHPV is shown in **Figure 2**.

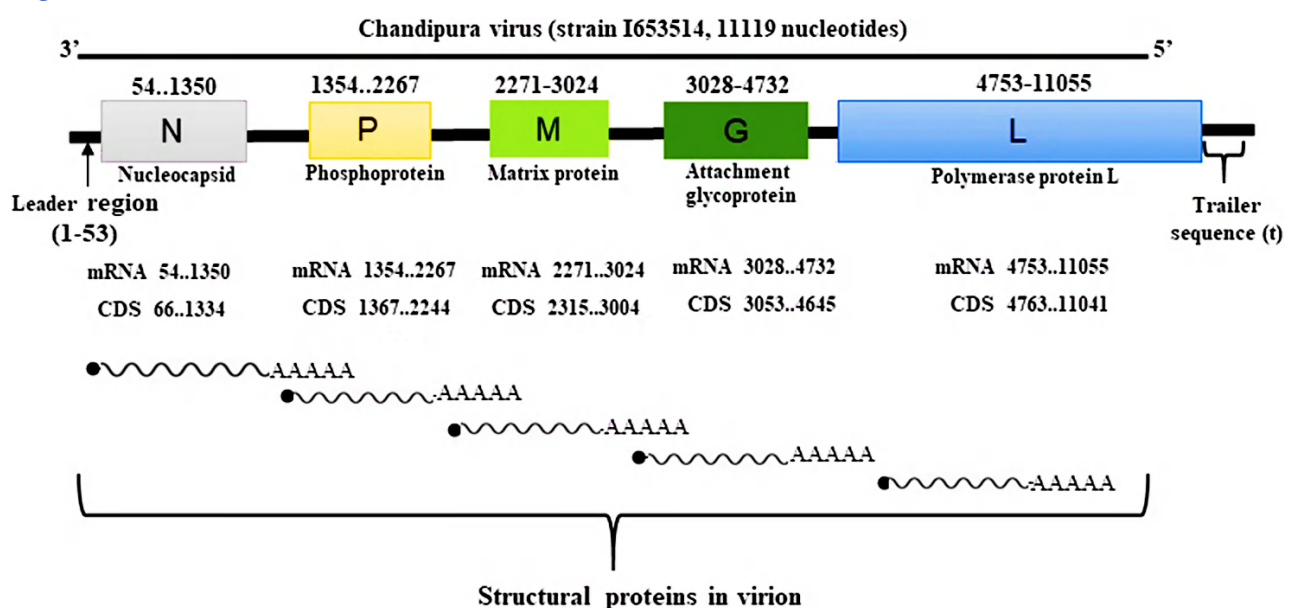


Figure 2. Genome structure of the Chandipura virus (CHPV). **Remarks:** The genomic organization of the Chandipura virus (strain I653514) exhibits a sophisticated architecture comprising 11,119 nucleotides with five distinct structural genes arranged in a precise linear sequence (3' to 5'). The genome is flanked by a leader region (1-53) and a trailer sequence containing five major coding regions: the nucleocapsid protein (N) gene spanning positions 54-1350, the phosphoprotein (P) gene at positions 1354-2267, the matrix protein (M) gene at positions 2271-3024, the attachment glycoprotein (G) gene at positions 3028-4732, and the large polymerase protein (L) gene extending from positions 4753-11055. Each gene segment contains specific messenger RNA (mRNA) and coding sequence (CDS) regions with mRNAs featuring characteristic polyadenylation signals. This highly organized genomic structure reflects the

evolutionary optimization of the genetic elements of CHPV, which are essential for its replication and virion assembly processes. This figure was adopted from a study by Sharma et al. [21].

Genomic organization follows the conserved pattern of rhabdoviruses, with genes arranged in the order 3'-N-P-M-G-L-5' [9]. The G protein, in particular, plays a crucial role in viral entry and pathogenesis and contains specific domains that mediate receptor binding and membrane fusion [22]. Recent structural analyses have revealed distinct antigenic sites on the G protein that could serve as potential targets for therapeutic interventions. The virus demonstrates remarkable efficiency in its replication cycle, which begins with receptor-mediated endocytosis facilitated by the G protein. Following entry, the viral ribonucleoprotein complex is released into the cytoplasm, where transcription and replication occur. CHPVs effectively utilize the host cell machinery, with the P protein serving as an essential cofactor for viral RNA-dependent RNA polymerase (L protein). The M protein coordinates viral assembly and budding while also playing a crucial role in suppressing host antiviral responses [9,14]. The CHPV display and assembly mechanism are shown in **Figure 3**.

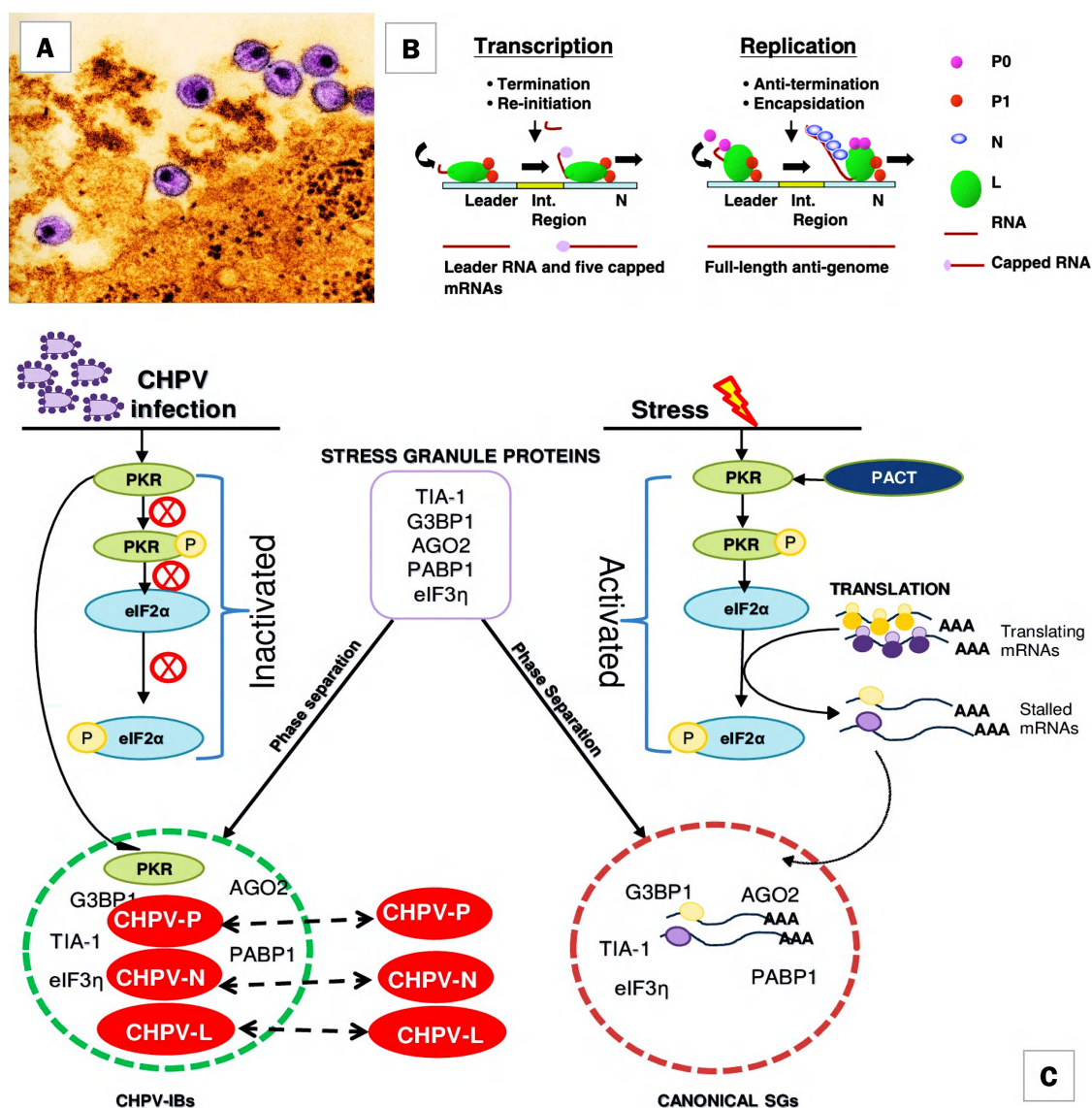


Figure 3. Cross-sections of a virus obtained from a patient infected with Chandipura virus (a), the RNA synthesis process of Chandipura virus (b), and the mechanism of CHPV formation and assembly (c). **Remarks:** Explanation of part C, the schematic illustration delineates the divergent molecular pathways governing the formation of stress granules (SGs) and Chandipura virus-induced inclusion bodies (CHPV-IBs), highlighting fundamental differences in their assembly mechanisms. In the CHPV infection pathway (left), the process notably circumvents the

conventional PKR/eIF2 α phosphorylation cascade, as indicated by inhibition markers (X), demonstrating the ability of the virus to establish cytoplasmic compartments through an alternative mechanism. The central region identifies key stress granule proteins TIA-1, G3BP1, AGO2, PABP1, and eIF3 η , which participate in both pathways through phase separation processes. In contrast, the cellular stress response pathway (right) follows a canonical mechanism, where PACT-mediated PKR activation leads to eIF2 α phosphorylation, resulting in translation inhibition and accumulation of stalled mRNAs. This process ultimately culminates in the formation of canonical stress granules containing the aforementioned protein components along with stalled mRNA complexes. The CHPV-IBs (bottom left) incorporate the viral proteins N, P, and L, which colocalize with cellular factors in distinct compartments, whereas canonical SGs (bottom right) maintain their characteristic composition of RNA-binding proteins and translationally repressed mRNAs. This mechanistic divergence reveals the sophisticated strategy of CHPV to establish virus-specific compartments while potentially evading host stress responses, providing crucial insights into viral pathogenesis and potential therapeutic targets. This figure was reproduced by Sarkar et al. [23] and Basak et al. [24].

Molecular studies have revealed that CHPV possesses sophisticated mechanisms for evading host immune responses. The P protein antagonizes interferon signaling by inhibiting STAT1 phosphorylation, whereas the M protein suppresses host gene expression through multiple pathways. These immune evasion strategies contribute to the rapid replication and severe pathogenicity of the virus, particularly in neuronal cells [25]. Recent investigations using advanced imaging techniques have provided insights into the neurotropism of the virus, demonstrating its ability to efficiently cross the blood-brain barrier and establish infection in neural tissues [26].

Genetic analyses of CHPV isolates from different geographical regions and time periods have revealed evolutionary patterns and potential determinants of virulence. Comparative genomic studies have identified specific mutations in the G and P proteins that correlate with increased pathogenicity in strains from recent outbreaks. These molecular changes may partially explain the virus's re-emergence and increased virulence observed in contemporary outbreaks [27]. Additionally, the virus shows remarkable stability under various environmental conditions, contributing to its persistence in nature and successful transmission through vector populations.

Clinical manifestations and disease progression

The clinical manifestations and disease progression of CHPV infection present a complex spectrum of symptoms characterized by rapid onset and potentially severe neurological complications. The disease typically manifests in three distinct phases, prodromal, encephalitic, and convalescent, with significant variations in severity and outcomes among different age groups. Initial symptoms often emerge following an incubation period of 3–8 days post infection, although this timeline can vary considerably depending on host factors and the viral load [28].

The prodromal phase is characterized by the abrupt onset of influenza-like symptoms, including high-grade fever (typically >39°C), severe headache, myalgia, and gastrointestinal disturbances, such as vomiting and abdominal pain. This initial phase typically lasts 24–48 h, during which patients may also experience photophobia, generalized weakness, and altered consciousness. Clinical observations have shown that the progression from these initial symptoms to neurological manifestations can be remarkably rapid, particularly in pediatric patients [8]. The encephalitic phase represents the most critical period of infection and is characterized by the development of severe neurological complications. Patients frequently exhibit altered sensorium, seizures, and various degrees of impaired consciousness, ranging from confusion to coma. Neurological examinations during this phase often reveal signs of meningeal irritation, including neck stiffness and a positive Kernig's sign. Serial neurological assessments have documented the progression of focal neurological deficits, including cranial nerve palsies, abnormal reflexes, and motor dysfunction [26].

A particularly concerning aspect of CHPV infection is its marked predilection for rapid deterioration in children aged < 15 years. Clinical studies have reported that approximately 55–

75% of pediatric patients progress to severe encephalitis within 48 h of symptom onset. This age-dependent severity pattern suggests unique pathophysiological mechanisms in the developing nervous system, although the exact factors that determine this vulnerability remain unclear [29]. Laboratory findings during the acute phase typically reveal leukocytosis with predominant neutrophilia, although some patients may present with normal white blood cell counts. Cerebrospinal fluid (CSF) analysis usually reveals moderate pleocytosis with lymphocytic predominance, elevated protein levels, and normal glucose levels. Neuroimaging studies, particularly magnetic resonance imaging (MRI), have demonstrated various patterns of brain involvement, including diffuse cerebral edema, focal lesions in the basal ganglia, and brainstem abnormalities [5].

The convalescent phase, when reached, showed significant variability in recovery patterns and outcomes. While some patients experience complete recovery, others may develop persistent neurological sequelae, including cognitive impairment, behavioral changes, and motor deficits. Long-term follow-up studies have indicated that survivors, particularly children, may experience developmental delays and various degrees of neurological disability, highlighting the significant long-term impact of severe CHPV infections [30,31]. Several prognostic indicators have been identified in clinical studies, with poor outcomes associated with factors such as young age, rapid progression to unconsciousness, the presence of status epilepticus, and the development of respiratory failure. The case fatality rate varies significantly across different outbreaks and age groups, with some studies reporting mortality rates as high as 55–70% in severe pediatric cases [3,11].

Transmission dynamics

The transmission dynamics of the Chandipura virus (CHPV) represent a complex interplay between vectors, hosts, and environmental factors, with significant implications for disease epidemiology and control strategies. The primary transmission cycle involves *Phlebotomus* sand flies as vectors, although multiple species of sand flies have been identified in different geographical regions. These vectors demonstrate varying degrees of competence in viral transmission, with *P. argentipes* showing particularly high infection rates and efficient viral replication [15]. The virus exhibits a unique temporal and spatial distribution pattern, which is strongly influenced by environmental conditions. The seasonal peaks in transmission typically coincide with monsoon and postmonsoon periods, when vector populations reach their highest density. Studies have demonstrated that temperature and humidity significantly affect vector survival and viral replication within the vector, with optimal conditions occurring between 25–30°C and a relative humidity above 60% [14,16,26]. This environmental dependence helps explain the geographical clustering of cases and the seasonal nature of outbreaks.

Vector competence studies have revealed important aspects of virus-vector interactions. CHPV can successfully replicate within sandfly vectors, achieving high titers in the salivary glands, which facilitates efficient transmission during blood feeding [32–34]. Transovarial transmission has also been documented in vector populations, suggesting a mechanism for viral persistence during unfavorable environmental conditions [35]. This vertical transmission pathway may contribute to the maintenance of viral reservoirs between epidemic seasons [36,37]. The role of vertebrate hosts in CHPV transmission cycles remains unclear. Although humans are considered dead-end hosts, several species of small mammals, particularly rodents and insectivores, have been identified as potential reservoir hosts. Serological surveys have detected CHPV antibodies in various domestic and wild animals, suggesting a broader host range than initially recognized. However, the relative contributions of different host species to viral maintenance and amplification in nature require further clarification [5].

Human-to-human transmission has not been definitively documented; however, the possibility of direct transmission through close contact with infected bodily fluids cannot be completely ruled out. The primary mode of human infection occurs through the bite of infected sandflies, with the risk of exposure being particularly high in rural and peri-urban areas, where vector density is substantial. Occupational and behavioral factors that increase exposure to vector habitats have been identified as significant risk factors for infection. Recent studies using

mathematical modeling approaches have provided insights into the spatial and temporal patterns of CHPV transmission. These models identify the key factors that influence transmission intensity, including vector density thresholds, host population dynamics, and environmental variables. Such analyses have proven valuable for predicting outbreak potential and optimizing control strategies in endemic regions [18].

Diagnostic approaches and challenges

The diagnostic landscape for Chandipura virus (CHPV) infection encompasses various methodological approaches, each presenting unique advantages and limitations in clinical settings. Accurate and timely diagnosis of CHPV infection remains crucial yet challenging, particularly in resource-limited settings, where the disease is most prevalent. Current diagnostic strategies incorporate a combination of clinical assessment, molecular techniques, serological testing, and virus isolation methods, although each approach presents distinct challenges in terms of sensitivity, specificity, and practical implementation [38].

Molecular diagnostic techniques, particularly reverse transcription polymerase chain reaction (RT-PCR), are the gold standard for CHPV detection during the acute phase of infection. Real-time RT-PCR assays targeting conserved regions of the N gene or P gene have demonstrated high sensitivity and specificity in detecting viral RNA from clinical specimens [22,39]. However, the effectiveness of these molecular methods is heavily dependent on the proper timing of sample collection because viral RNA may be detectable only during the early stages of infection. Additionally, the requirement for sophisticated laboratory infrastructure and trained personnel often limits the widespread implementation of these techniques in endemic regions [5].

Serological testing, including enzyme-linked immunosorbent assay (ELISA) and immunofluorescence assay (IFA), provides valuable tools for detecting CHPV-specific antibodies. IgM capture ELISA has proven particularly useful for diagnosis, especially when molecular testing is not feasible or during later stages of infection [40]. However, serological approaches face challenges related to cross-reactivity with other vesiculoviruses and the temporal dynamics of antibody development. The interpretation of serological results requires careful consideration of the patient's immunological status and potential exposure to related viruses [41].

When considered definitive for diagnosis, virus isolation presents significant practical challenges in routine clinical settings. This process requires specialized facilities with appropriate biosafety levels, skilled personnel, and extended time periods for virus cultivation. Furthermore, the success rate of virus isolation can be significantly affected by sample quality, storage conditions, and the timing of collection relative to disease onset. Despite these limitations, virus isolation remains valuable for research purposes and strain characterization studies [27].

Recent advances in diagnostic technologies have led to the development of rapid diagnostic tests and point-of-care devices. These innovations aim to address the need for rapid and reliable diagnostics in resource-limited settings. Loop-mediated isothermal amplification assays and lateral flow devices have shown promise in preliminary studies, although further validation is needed before widespread implementation. The development of multiplex assays capable of simultaneously detecting CHPV and other common causes of viral encephalitis represents another important advancement in diagnostic approaches [8]. Neuroimaging studies, which are not specific for CHPV infection, play a crucial role in patient assessment and management. Magnetic resonance imaging can help differentiate CHPV encephalitis from other neurological conditions and provide valuable prognostic information. However, the availability and cost of advanced imaging modalities often limit their routine use in many endemic areas [42–45].

Treatment strategies

Supportive care remains the cornerstone of CHPV treatment, with an emphasis on managing severe complications and maintaining vital organ function. The therapeutic approach adopts the "ABC" principle (airway, breathing, circulation) with a focus on respiratory support through oxygen therapy and mechanical ventilation when necessary. This includes intensive monitoring of neurological status, respiratory support when necessary, and careful fluid management. In cases of severe encephalitis, the management of increased intracranial pressure through

appropriate interventions is crucial. The implementation of standardized treatment protocols has improved outcomes in several clinical settings, particularly when it is initiated early in the disease course [29].

Recent advances in therapeutic approaches have focused on targeting specific pathophysiological mechanisms of CHPV infection. Experimental studies have investigated various antiviral compounds, including ribavirin and interferon-alpha, although their clinical efficacies remain to be evaluated. Some promising results have been reported in in vitro studies, suggesting potential therapeutic applications, but large-scale clinical trials are still needed to establish their effectiveness in human patients [4,5,31,46]. The management of neurological complications requires particular attention, given their significant impact on patient outcomes. Treatment strategies often include anticonvulsant therapy for seizure control, appropriate sedation protocols, and measures to prevent secondary complications. The use of neuroprotective agents has been explored in some cases, although evidence of their efficacy remains limited. Regular neurological monitoring and timely intervention for complications are essential components of the treatment approach [26].

Critical care management plays a vital role in severe CHPV cases, particularly in pediatric patients, who often present with rapid disease progression. This includes careful attention to respiratory support, hemodynamic management, and prevention of secondary infections. The implementation of evidence-based critical care protocols adapted to resource-limited settings has shown promise in improving patient outcomes. Regular monitoring of vital parameters and appropriate adjustment of supportive measures are essential aspects of critical care management [8]. Emerging therapeutic strategies increasingly focus on immunomodulatory approaches, considering the significant role of host immune responses in disease pathogenesis. Research on the use of targeted immunotherapy and novel therapeutic agents continues, although these approaches remain experimental. The development of treatment algorithms incorporating both conventional supportive care and newer therapeutic options represents an important advancement in CHPV management [1].

Prevention and control

CHPV prevention and control strategies encompass a multifaceted approach that targets both vector management and human protection measures. Vector control remains paramount, particularly in endemic regions of the Indian subcontinent, where human exposure to *Phlebotomus* vectors is significant. The implementation of integrated vector management (IVM) strategies has demonstrated efficacy in reducing vector populations and subsequent disease transmission risks [47–49].

The cornerstone of prevention encompasses several evidence-based interventions. Personal protective measures include the utilization of long-lasting insecticide-treated nets (LLINs) and the application of EPA-registered insect repellents containing DEET, picaridin, or IR3535. These interventions have shown significant effectiveness in reducing vector-human contact, particularly during periods of peak vector activity. Environmental management strategies focus on eliminating vector breeding sites through proper drainage systems, vegetation control, and the environmental modification of areas conducive to sandfly proliferation. Community-level interventions play crucial roles in the prevention of disease. These include the implementation of systematic indoor residual spraying (IRS) programs using appropriate insecticides in high-risk areas, regular environmental surveillance to identify and eliminate vector breeding sites, the enhancement of community awareness through educational programs on vector biology and transmission dynamics, and the strengthening of healthcare infrastructure for early detection and response to disease outbreaks [42,48].

Research has demonstrated that, compared with singular interventions, integrated approaches that combine chemical vector control with environmental management and community participation yield superior results. The strategic implementation of these measures requires coordination between public health authorities, local communities, and healthcare providers. In healthcare settings, standard precautions and infection prevention protocols are essential, particularly for managing confirmed cases. These include the implementation of proper hand

hygiene practices using alcohol-based hand rubs or soap and water, the utilization of appropriate personal protective equipment (PPE) when handling potentially infectious materials, the safe disposal of contaminated materials, the proper decontamination of medical equipment, and the regular training of healthcare workers in infection prevention and control measures [50].

Furthermore, surveillance systems play a vital role in prevention and control strategies. Enhanced surveillance mechanisms, including both passive and active surveillance, are crucial for the early detection of cases and the implementation of timely control measures. This includes regular monitoring of vector populations and their resistance patterns to insecticides, systematic collection and analysis of epidemiological data, implementation of rapid response protocols when cases are detected, and strengthening of laboratory capacity for quick and accurate diagnosis [34].

The development of predictive models incorporating environmental and climatic factors has emerged as a valuable tool for forecasting potential outbreak risks, enabling the proactive implementation of control measures. Additionally, research on novel vector control technologies, including biological control methods and genetic approaches, shows promise for future integration into existing control strategies. While individual protective measures remain important, the sustainability of control programs depends on broader public health approaches, such as strengthening health system capacity for disease surveillance and response, developing evidence-based guidelines for vector control and case management, enhancing laboratory diagnostic capabilities, and promoting research into innovative control strategies and interventions [1,42].

The success of prevention and control measures relies heavily on sustained political commitment, adequate resource allocation, and effective coordination between the various stakeholders involved in public health interventions. Continuous monitoring and evaluation of implemented strategies ensures their effectiveness and allows for necessary modifications on the basis of emerging evidence and changing epidemiological patterns. This comprehensive approach to prevention and control, incorporating both individual- and population-level interventions, represents the most effective strategy for managing CHPV transmission and reducing its public health impact in endemic regions.

Socioeconomic impact and policy Implications

The socioeconomic impact of CHPV encephalitis extends far beyond its immediate health consequences, creating substantial ripple effects throughout affected communities and healthcare systems. The disease burden predominantly affects rural and economically disadvantaged populations, exacerbating existing socioeconomic disparities and placing significant strain on limited healthcare resources. Understanding these impacts is crucial for developing comprehensive policy responses and implementing effective intervention strategies [42].

The economic burden of CHPV infection manifests at multiple levels, from individual households to national health care systems. Direct medical costs associated with hospitalization, intensive care, and long-term rehabilitation can be catastrophic for affected families, particularly in regions with limited healthcare coverage [51]. Studies have estimated that the average cost of treating a severe CHPV case can exceed several months of median household income in affected areas, pushing many families into financial hardships or debts. Furthermore, indirect costs such as lost productivity, caregiving responsibilities, and reduced educational opportunities for affected children compound the economic impact on households [8].

The disease's predilection for pediatric populations has significant societal implications. The high mortality rates among children and potential long-term neurological sequelae in survivors can devastate families and communities. Educational disruptions, both for affected children and their siblings, who may need to contribute to household income or caregiving, can perpetuate cycles of poverty and limited opportunities. Research has documented significant psychological impacts on families affected by CHPV, including increased rates of depression and anxiety among caregivers [29].

Healthcare system impacts are equally substantial, particularly in endemic regions, where resources are often already thin. The need for specialized care facilities, trained personnel, and

diagnostic capabilities places an additional burden on healthcare infrastructure. Seasonal outbreaks can overwhelm local healthcare facilities, potentially compromising the quality of care for both patients with CHPV and those with other medical conditions. The cost of maintaining surveillance systems, vector control programs, and emergency response capabilities represents a significant ongoing expense for public health systems [29].

The policy implications of the socioeconomic impact of CHPV necessitate a multisectoral approach to disease control and management. Current policy frameworks often focus predominantly on medical interventions while potentially overlooking broader social determinants of disease transmission and impact. The evidence suggests that integrated approaches incorporating healthcare strengthening, poverty reduction, and environmental management may be more effective in reducing the disease burden. Recent policy analyses have emphasized the need for sustainable financing mechanisms to support long-term disease control efforts and provide financial protection for affected households [5]. The role of international collaboration and support in addressing the socioeconomic impact of CHPVs has gained increasing recognition. Cross-border coordination in surveillance, research, and resource mobilization can help strengthen the regional capacity for disease control. Policy frameworks that facilitate knowledge sharing, technology transfer, and capacity building across affected regions may help optimize resource utilization and improve outbreak response capabilities [48].

Regional collaboration and global health security

The regional collaboration and global health security dimensions of the Chandipura virus (CHPV) present complex challenges that necessitate coordinated international responses and robust cross-border partnerships. The emergence and re-emergence of CHPV in the Indian subcontinent highlights the critical importance of collaborative approaches in disease surveillance, research, and control strategies. This regional health security challenge requires integrated efforts that transcend national boundaries while considering the unique epidemiological and sociocultural contexts of the affected areas [8].

International surveillance networks have emerged as crucial components for monitoring the spread and evolution of CHPVs. These networks facilitate real-time data sharing, standardized reporting protocols, and coordinated response mechanisms among participating countries. The establishment of regional reference laboratories and standardized diagnostic protocols has increased the capacity for rapid detection and characterization of CHPV cases across borders. However, significant disparities in surveillance capabilities and reporting systems among different countries continue to pose challenges for comprehensive regional monitoring [5]. Cross-border research collaborations have proven instrumental in advancing our understanding of CHPV epidemiology and pathogenesis. Joint research initiatives have enabled the sharing of expertise, resources, and technical capabilities between institutions across the region. These collaborative efforts have led to important discoveries on viral evolution, transmission dynamics, and potential therapeutic approaches. Furthermore, such partnerships have facilitated the development and validation of standardized protocols for diagnosis and clinical management [5].

The World Health Organization's Southeast Asia Regional Office (WHO-SEARO) has played a pivotal role in coordinating regional responses to CHPV threats. Through various initiatives, the WHO-SEARO has supported capacity building, technical assistance, and policy harmonization among member states. The organization's efforts have been particularly crucial in strengthening laboratory networks, enhancing surveillance systems, and promoting evidence-based interventions across the region. Regular regional consultations and workshops have provided platforms for knowledge exchange and strategy development. Capacity-building initiatives represent a critical aspect of regional collaboration for CHPV control. Programs focused on training healthcare workers, laboratory personnel, and public health officials have helped strengthen local capabilities while promoting standardized approaches to disease management and control. These efforts have been particularly important in resource-limited settings where technical expertise and infrastructure may be limited. Regional training centers and exchange programs have facilitated knowledge transfer and skill development across borders [1,3].

The integration of CHPV surveillance and control measures into broader global health-security frameworks has gained increasing attention. Recognition of the virus's potential for geographical expansion and its impact on vulnerable populations has led to its inclusion in regional and global disease monitoring systems. This integration has facilitated access to international resources and expertise while highlighting the importance of addressing CHPV as part of comprehensive regional health security strategies [8,29].

CONCLUSIONS

Chandipura virus encephalitis represents a significant emerging threat to public health security on the Indian subcontinent, with profound implications for regional healthcare systems and vulnerable populations. The distinctive characteristics of the virus—rapid progression, high mortality rates, particularly among children, and complex transmission dynamics through *Phlebotomus* sandflies necessitate an integrated approach to disease management and control. Recent advances in molecular diagnostics and clinical protocols have improved case detection and management; however, significant challenges persist in implementing effective interventions across resource-limited settings. The socioeconomic impact of CHPV infection coupled with the potential for geographical expansion underscore the urgent need for enhanced regional collaboration and sustainable control strategies. Critical priorities include strengthening surveillance networks through standardized reporting protocols, developing point-of-care diagnostics suitable for resource-limited settings, and establishing sustainable vector control programmes. Additionally, investment in research focused on antiviral therapeutics and vaccine development combined with capacity building for healthcare systems is essential. The implementation of comprehensive public health measures, supported by international collaboration and adequate resource allocation, will be crucial for addressing this emerging threat and protecting vulnerable populations.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

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ABBREVIATIONS

CHPV, Chandipura Vesiculovirus; RNA, Ribonucleic Acid; VSV, Vesicular Stomatitis Virus; CSF, Cerebrospinal; MRI, Magnetic Resonance Imaging; RT-PCR, Reverse Transcription Polymerase Chain Reaction; ELISA, Enzyme-Linked Immunosorbent Assay, IFA, Immunofluorescence Assay; LAMP, Loop-Mediated Isothermal Amplification; IVM, Integrated Vector Management; LLINs, Long-Lasting Insecticide-Treated Nets, IRS, Indoor Residual Spraying; PPE, Personal Protective Equipment; DEET, N,N-Diethyl-meta-toluamide, IR3535, Insect Repellent 3535; and EPA, Environmental Protection Agency, N, Nucleocapsid, P, Phosphoprotein; M, Matrix; G, Glycoprotein; L, Large protein.

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