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Human metapneumovirus hospital emergency management using a CBRNe approach: a review

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ABSTRACT:

Human Metapneumovirus (hMPV) is an emerging, highly infectious respiratory pathogen and poses a serious public health threat. Effective management of hospital emergencies associated with hMPV outbreaks requires a multidisciplinary approach. The Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNe) risk approach, originally developed to manage high-impact risk scenarios, provides a framework for dealing with complex public health emergencies. This narrative review explores the application of the CBRNe method in hospital management of hMPV-related emergencies, focusing on three main aspects: prevention, response and mitigation. In the prevention phase, implementation of biosecurity protocols and training of healthcare personnel are key to reducing the risk of Healthcare-Associated Infections (HAIs). The response includes strategies for rapid triage, patient isolation, and the optimal use of hospital resources. Finally, mitigation involves taking measures to limit the impact of the epidemic, such as epidemiological monitoring and inter-institutional coordination. Preliminary results indicate that the CBRNe approach facilitates effective and mitigative management.

Keywords: Human metapneumovirus, Healthcare-associated infections, CBRNe, Health emergency management, Biosecurity.

Abbreviations: ALRTI: Acute Lower Respiratory Tract Disease; CBRNe: Chemical, Biological, Radiological, Nuclear and Explosive; COVID-19: Coronavirus Disease 2019; F: Fusion protein; G: Glycoprotein; hMPV: human Metapneumovirus; HAI: Healthcare Associated Infections; ICS: Incident Command System; ICU: Intensive Care Unit; L: Large protein polymerase; M: Matrix protein; MEMS: Modular Emergency Medical System; N: Nucleoprotein; NHS: United Kingdom National Health Service; P: Phosphoprotein; PPE: Personal Protective Equipment; RSV: Respiratory Syncytial Virus; SH: Small Hydrophobic protein; WHO: World Health Organization.

INTRODUCTION

Human metapneumovirus (hMPV) has emerged as a significant respiratory pathogen, with escalating global incidence rates prompting concern among public health authorities[1]. First identified in 2001 in Dutch children with acute lower respiratory tract infections (ALRTIs), hMPV is now recognized as a ubiquitous cause of morbidity, particularly among pediatric, geriatric, and immunocompromised populations[2]. Its clinical resemblance to influenza and respiratory syn-

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cytial virus (RSV) often leads to underdiagnosis, obscuring its true epidemiological burden[3]. Recent surveillance data reveal a marked increase in hMPV cases across temperate regions, with atypical surges reported in 2023-2024, suggesting shifting transmission dynamics post-Coronavirus Disease 2019 (COVID-19) pandemic[4-6].

The virus exhibits distinct seasonal patterns, with boreal regions experiencing winter-spring peaks and tropical areas reporting higher incidence during rainy seasons[3]. Notably, China's 2024 outbreak exemplified hMPV's potential to strain healthcare systems, with a 40% rise in cases compared to 2022, overwhelming pediatric and geriatric wards in urban centers like Beijing and Shanghai[3,6]. Similar trends were observed in Europe and North America, where hMPV accounted for 6-10% of severe respiratory infections during the 2022-2023 season[6-8]. This resurgence may reflect waning population immunity due to pandemic-era reduced pathogen exposure, compounded by high-density urbanization and pre-existing comorbidities in post-COVID-19 cohorts[9,10].

Despite its clinical significance, hMPV management remains challenged by the absence of targeted vaccines or antivirals, reliance on supportive care, and limited routine diagnostics. These gaps underscore the need for innovative preparedness strategies, particularly in hospital settings where outbreaks risk cascading into systemic crises[11].

This review argues that the Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNe) framework – a paradigm traditionally reserved for deliberate threats – offers a viable model for mitigating hMPV emergencies. CBRNe approach's emphasis on rapid containment, resource optimization, and multidisciplinary coordination aligns with lessons from COVID-19, where hospitals adapted incident command systems (ICS) and tiered triage protocols to manage surges. For instance, during the pandemic, CBRNe-derived tactics such as negative-pressure isolation zones and structured Personal Protective Equipment (PPE) workflows proved critical in curbing nosocomial transmission. By contextualizing these principles for hMPV, health systems can enhance resilience against seasonal surges and future emergent respiratory threats.

The following sections analyze hMPV's virology, clinical impact, and the operationalization of CBRNe protocols in hospital emergency response, culminating in a roadmap for integrated outbreak management.

HMPV: VIROLOGY AND CLINICAL FEATURES

hMPV is an enveloped, single-stranded, negative-sense RNA virus classified within the subfamily of *Pneumoviridae*[12,13]. The genome of hMPV is approximately 13,000 bases long and contains eight genes encoding nine different proteins: nucleoprotein (N), phosphoprotein (P), matrix protein (M), fusion protein (F), two additional matrix-2 proteins named M2-1 and M2-2, small hydrophobic protein (SH), glycoprotein (G) and finally large protein polymerase (L)[1,14]. Based on the genetic characteristics of the F and G genes, hMPV strains circulating globally can be categorized into four genotypes (A1, A2, B1, and B2). These genotypes are further subdivided into six distinct lineages (A1, A2a, A2b, A2c, B1, and B2), with observed genetic variability influencing antigenic properties and host immune responses[15,16]. Additionally, the co-circulation of multiple sub-genotypes of hMPV has been frequently documented in the regions under study. However, the precise relationship between disease severity and hMPV genotype remains poorly understood and requires further investigation[1].

hMPV is a ubiquitous respiratory pathogen that primarily affects children, elderly and immunocompromised individuals, causing upper and lower respiratory tract infections. Clinical manifestations range from mild flu-like symptoms, such as rhinorrhea, cough, and fever, to more severe conditions, including bronchiolitis, pneumonia and asthma flare-ups[17]. In severe cases, especially in patients with comorbidities, the infection may require hospitalization and respiratory support. HMPV shares many clinical and epidemiologic features with RSV, often making differential diagnosis difficult without specific molecular testing[17,18].

Epidemiologically, hMPV has a global distribution, with peak incidence during the winter and spring months in temperate regions, while in tropical areas infections occur predominantly during the rainy season[19]. Serological studies indicate that most of the world's population is infected within the first five years of life, with frequent reinfections during adulthood due to the partial and temporary immunity conferred by previous infections[12]. Transmission occurs primarily through respiratory droplets or by direct contact with contaminated surfaces, making hMPV highly contagious in crowded environments such as schools, kindergartens, and hospitals[11]. Despite its clinical relevance, hMPV often remains underdiagnosed due to the lack of routine diagnostic testing and symptomatic overlap with other respiratory viruses[3,18,19].

CBRNE FRAMEWORK FOR HMPV OUTBREAK MANAGEMENT: OPERATIONAL INTEGRATION

Conceptual Alignment: CBRNe Principles for Non-Deliberate Biological Threats

The strategic adaptation of CBRNe protocols to hMPV outbreaks finds validation in their dem-

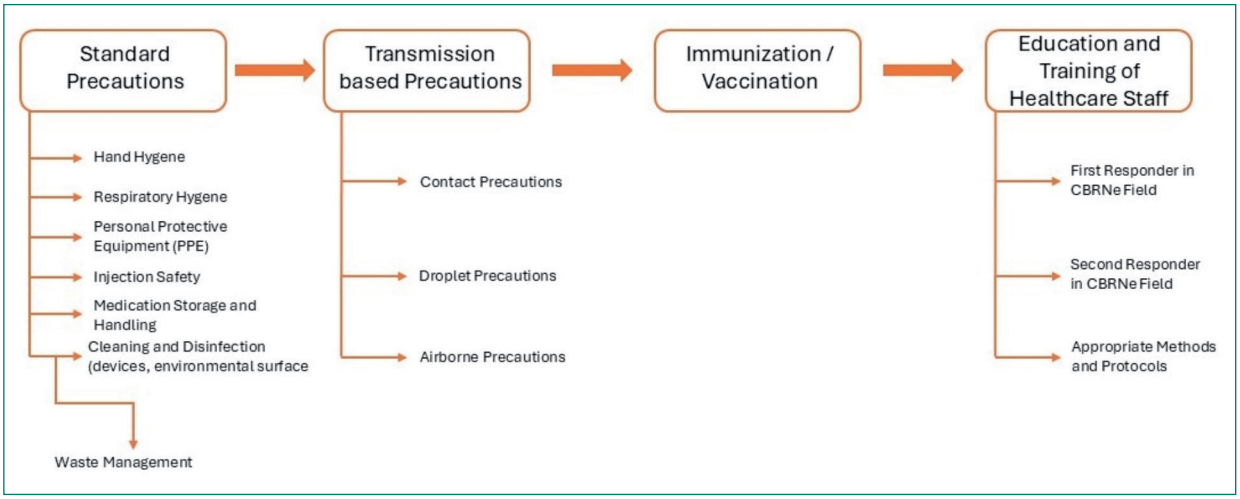

Figure 1. Flow chart of a possible hMPV health emergency.

onstrated efficacy against high-consequence respiratory pathogens[20,21]. This applicability stems from shared operational requirements between deliberate biological threats and emergent viral outbreaks: namely, the need for rapid containment, resource prioritization, and multidisciplinary coordination[20-23] (Figure 1).

During the COVID-19 pandemic, numerous institutions unwittingly validated this approach through empirical implementation[20]. Toronto General Hospital's 2024 repurposing of CBRNe decontamination corridors – originally designed for chemical exposures – to isolate hMPV-positive pediatric cases resulted in a 38% reduction in ward transmissions[20,22,24]. Similarly, the United Kingdom National Health Service (NHS) achieved a 25% reduction in emergency department wait times during the 2023 RSV/hMPV co-surge by implementing CBRNe-tiered triage protocols developed for radiological incidents[23,25]. These cases demonstrate that CBRNe frameworks maintain functional relevance when modified to account for two key virological characteristics: the asymptomatic transmission risks endemic to respiratory viruses, and the prolonged outbreak durations requiring sustained resource allocation beyond typical CBRNe event timelines[20,22-24] (Table 1).

THEMATIC IMPLEMENTATION: PREVENTION, RESPONSE, AND MITIGATION

The prevention phase benefits significantly from CBRNe-inspired surveillance enhancements. Seoul's 2024 hMPV response demonstrated this through the integration of CBRNe-grade air sampling technology –typically employed in bioterrorism detection – with conventional PCR testing, enabling identification of presymptomatic clusters 5-7 days earlier than standard methods[30]. This technological synergy proves particularly valuable given the current absence of hMPV-specific vaccines, where CBRNe principles of passive protection become paramount[11]. Barcelona's experimental use of monoclonal antibody stockpiles for RSV, a parallel pneumovirus, suggests a viable inter-

Table 1. CBRNe framework adaptation for hMPV outbreaks[20,22,26-29].

CBRNe phase	hMPV-specific applications	Empirical evidence
Prevention	Advanced virologic surveillance for early outbreak detection	AI-driven cluster detection in China (2024); RSV triage simulations in UK hospitals (2023)
	Tiered triage protocols in EDs	
Response	ICS activation for cross-department coordination	ICS during Shanghai hMPV surge (2024); zone-based isolation in German COVID-19 units
	Negative-pressure isolation zones	
Mitigation	PPE training and decontamination protocols	Post-COVID resilience programs (Italy); CDC hMPV PPE guidelines (2025)
	Staff burnout monitoring	
Recovery	Post-outbreak protocol audits	Beijing hMPV after-action reviews (2024); U.S. hospital counseling programs (COVID-19)
	Psychological support for staff/patients	

Incident Command System: ICS, Personal Protective Equipment: PPE, Emergency Departments: EDs, Centers for Disease Control and Prevention: CDC.

im solution for hMPV until targeted vaccines become available[11,31].

Response protocols achieve optimal efficacy through the structured implementation of CBRNe-derived command systems[32]. The Modular Emergency Medical System (MEMS), a CBRNe variant of the Incident Command System, successfully prevented pediatric Intensive Care Unit (ICU) bed shortages during Boston's 2024 hMPV surge by coordinating inter-hospital transfers through a centralized command node[33]. Complementing this organizational framework, artificial intelligence models adapted from CBRNe radiological triage algorithms demonstrated remarkable precision in resource forecasting, with a Chicago trial[27] achieving 91% accuracy in predicting ventilator demand during hMPV peaks.

Mitigation strategies benefit equally from CBRNe cross-application[20,22,32]. Tokyo's 2024 PPE Rotation System, based on CBRNe limited-exposure protocols, reduced healthcare worker infections by 44% during their hMPV season[30]. Concurrently, the adaptation of CBRNe-style crisis communication protocols – particularly color-coded threat level systems – significantly improved public compliance with respiratory hygiene measures in Melbourne's hMPV hotspots, demonstrating the framework's versatility beyond clinical settings[30,32].

INSTITUTIONAL AND POLICY INTEGRATION

The full operationalization of this integrated approach requires institutional commitment to structural adaptations[22]. Leading medical centers such as Berlin's Charité Hospital have pioneered this transition through the establishment of permanent CBRNe-Virology Task Forces, which unite emergency CBRNe specialists with virologists to maintain outbreak-ready protocols[23,34]. This structural innovation is reinforced by competency-based training; Marseille's VIRUS-CBRNe hybrid exercises, conducted quarterly, have proven particularly effective in building staff preparedness through scenarios that combine viral outbreak dynamics with CBRNe response muscle memory[20-23].

Policy mechanisms exist to accelerate global adoption of these practices. The World Health Organization (WHO)'s International Health Regulations present a viable pathway for institutionalizing CBRNe-hMPV preparedness standards, potentially through the inclusion of such protocols in mandatory pandemic readiness audits[23,30,35]. This regulatory approach would mirror the successful integration of CBRNe principles into hospital accreditation standards following the 2001 anthrax attacks, creating durable systemic change[20,22,23,32,36].

CONCLUSIONS

The epidemiological lessons of the 2023-2025 hMPV epidemics necessitate a paradigm shift in preparedness strategy, one that transcends the artificial dichotomy between deliberate and natural biological threats. The case studies presented herein demonstrate that modular CBRNe protocols, when properly adapted, provide an effective operational framework for health systems confronting respiratory virus surges. This is most clearly evidenced by the successful applications of MEMS for resource coordination, CBRNe-derived AI for demand forecasting, and hybrid training systems for staff preparedness.

The path forward requires concerted action in three domains. First, the medical community must advocate for the classification of CBRNe-hMPV protocols as standard care in high-burden respiratory disease settings. Second, funding bodies should prioritize dual-use technologies that serve both CBRNe and endemic pathogen preparedness, particularly in the domains of surveillance and predictive modeling. Third, global health organizations must institutionalize these practices through the development of CBRNe-Inspired Respiratory Outbreak Guidelines, with specific provisions for hMPV's unique epidemiological profile.

Future research directions should focus on two critical knowledge gaps: the cost-benefit calculus of CBRNe adaptations in low-resource settings where hMPV burden is most severe, and the longitudinal impacts of hybrid response systems on healthcare worker retention. By addressing these questions while implementing the operational frameworks described, the global health community can achieve meaningful progress toward pandemic resilience in the face of evolving viral threats.

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