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Updated WHO list of emerging pathogens for a potential future pandemic: Implications for public health and global preparedness

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SUMMARY

Historically, pandemics constitute a major nuisance to public health. They have a debilitating impact on global health with previous occurrences causing major mortalities worldwide. The adverse outcomes are not limited to health outcomes but ravage the social, economic, and political landscapes. The World Health Organization (WHO) stands at the front of the pandemic response, strategizing to contain and mitigate the impacts on humans and the environment. It also intervenes in regional disease outbreaks that pose a threat to global health through strategic technical guidance, resource allocations, and expert support. With emerging pathogens, and in the aftermath of the COVID-19 pandemic, discussions are currently underway on global preparedness for a potential future pandemic. The effects of previous pandemics underscore the need to improve global health preparedness for upcoming pandemics. The WHO's July 2024 updated list of emerging pathogens serves as a potential tool to foster global health readiness for a future pandemic. It represents a change in the world's approach to emerging and re-emerging pathogens, shifting focus from specific pathogens to adopting a broader family-focused approach. This new list recognizes the shortcomings of previous lists and adopts a more forward-thinking, proactive, and flexible approach to dealing with familiar and unfamiliar pandemic risks, now incorporating 'Prototype Pathogens' and 'Pathogen X' into its risk classification. The WHO has set the pace, developing tools and guidelines for practice. This updated list of high-priority pathogens seeks to gear research and development toward combating and neutralizing the virulence of these pathogens. Recent outbreaks of Cholera, Mpox, and Dengue fever in Africa, Avian influenza (H5N2) in Mexico, Nipah virus disease in Bangladesh, and Oropouche virus in the Americas necessitate intensifying regional disease surveillance Research organizations and institutions must prioritize incorporating these tools and approaches for shared learning and collective action established during the COVID-19 pandemic and other recent public health emergencies in the Preparedness and Resilience for Emerging Threats (PRET) Initiative as outlined by WHO.

Keywords: Pandemic preparedness, WHO pathogen list, pandemics, disease surveillance.

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INTRODUCTION

Global health security is a collective responsibility shared by all. This often entails early prevention, detection, and swift response to transnational infectious disease threats posing potential threats to public health and safety. It requires concerted efforts among nations, organizations, and sectors to bolster public health systems, improve disease surveillance, enhance rapid escalation, and effective emergency responses. The World Health Organization (WHO) is saddled with ensuring nations achieve all-round health safety and care [1]. They coordinate international public health actions to curb the adverse impacts of public health emergencies and events that threaten the lives of individuals globally by monitoring existing diseases and identifying novel pathogens that could trigger an outbreak [1]. These pathogens are enlisted as high priority to foster research and development of treatment regimens and increase surveillance among member countries [2]. Additionally, strategic measures are targeted at proactively preventing disease epidemics and safeguarding global health [2].

Monitoring emerging pathogens encourages early detection and timely response to health threats that could become pandemics [3]. In recent years, there has been an upsurge in the incidence of emerging and reemerging infectious disease outbreaks, spanning zoonotic viral and bacterial illnesses to airborne and water-borne diseases [3]. Transnational spread of these diseases causes atypical presentations and explosive outbreaks as a result of insufficient global and region-specific interventions [4]. Coincidentally, most outbreaks occur along with human and natural disasters, which limits effective and timely surveillance [5]. This reinforces the need for continuous monitoring of both existing and emerging pathogens, poised at understanding the disease's emergence, associated risk factors and possible interventional approach.

Pandemics have plagued the world for centuries and have dealt devastating blows to public health, economies, and global security [6]. Each outbreak has seemingly exposed flaws ingrained in regional health systems. The 1918 influenza pandemic, which claimed the lives of millions globally, highlighted global unpreparedness to manage such a crisis as of the 20th century [7]. The 2005 Hurricane Katrina in the United States and the 2010 Haiti earthquake compounded outbreaks of Leptospirosis and Cholera, respectively, affirming the consequences of this occurrence, and underscoring the challenges surrounding a double ineffective disaster management [8, 9]. Other bottlenecks such as ineffective vaccine distribution and inequitable access, as seen during the 2009 H1N1 influenza pandemic, containing a high biosafety level infection in resource-constrained areas during the 2014 Ebola virus outbreak, and the recent COVID-19 pandemic in 2020, have exposed significant gaps in emergency response during past and recent pandemics [10-12].

The first WHO priority pathogen list was published in 2017 and is updated routinely [13]. This calls attention to the ever-evolving nature of disease-causing microbes. Novel pathogens can exploit the current dents in health systems to wreak havoc on societies, while re-emerging ones may evolve to surmount disarming mechanisms of previously effective treatments and preventive measures [2]. The current priority pathogen list, updated by the WHO in July 2024 is a research community reference point to steer pandemic preparedness. Thus, updating the list of emerging pathogens is essential for maintaining an effective public health response. It provides insight into the current state of global health and guides the development of treatments and remediation strategies [13, 14]. This perspective reviews the 2024 updated WHO list of emerging pathogens, analyzes the implications for public health and global preparedness, and provides recommendations for improving response strategies in an event of a pandemic.

HISTORICAL PANDEMICS AND EPIDEMICS: BURDEN AND EMERGING PATHOGENS

The world has experienced devastating pandemics in the last years and centuries not limited to the Athenian Plague in 430 BC, the Antonine Plague in 165-180 AD, and the Black Death between 1346-1353 [15]. It was thought that wartime overpopulation was the source of the Athenian Plague, which killed about 25% (5 million) of Athenians, sweeping across the Roman Empire. The Antonine plague caused an estimated 5 million deaths during the period [15]. The Mediterranean and European regions each lost approximately 60% of their population due to the Black Death, commonly re-

ferred to as the bubonic plague and called after the Byzantine ruler Justinian [16]. In 1817, a fatal cholera pandemic struck and brought with it millions of mortality with dehydration and severe diarrhea scourging victims [17]. An estimated 50 million deaths were recorded globally between 1918 and 1919 due to the Spanish Flu pandemic caused by the H1N1 influenza virus. Over one-third of the global population was infected with the impact felt across sectors [18, 19]. The aftermath of World War I exacerbated poor hygiene, limited health services, and overall inefficiency in health systems observed as immediate outcomes of the pandemic [18]. The return of the H1N1 influenza virus in 2009 and 2010 brought with it the swine flu pandemic, although comparatively with low death rates [21]. Similarly, the H2N2 influenza virus caused the 1957-1958 Asian Flu pandemic, claiming over a million lives in China [20]. Since its first diagnosis in 1981, the HIV/AIDS epidemic has remained a threat to public health, claiming millions of lives, and is still highly prevalent around the world. Although antiretroviral medication aids in illness management, a cure is still unattainable [16].

The 2002-2003 global SARS-CoV pandemic caused severe respiratory symptoms and 774 fatalities [16]. Apart from respiratory virus, hemorrhagic fevers have also registered troubling epidemics. Between 2013 and 2016, the Ebola virus epidemic emerged, affecting most West African states, and is now causing transnational spread claiming thousands of lives [22]. The SARS-CoV-2, responsible for COVID-19, emerged in 2019 and was declared a global pandemic in 2020. From minor respiratory illnesses to serious consequences like acute respiratory distress syndrome (ARDS) and multi-organ failure across various organ systems, symptoms and complications vary widely [23]. The recent multi-country outbreak of 2022 monkeypox in non-endemic nations, recently declared a public health emergency of international concern by WHO now tops the list of potential triggers for the next pandemic [24, 25]. Zika in the southern Americas, Chikungunya in the Caribbean, the 2009 H1N1 influenza pandemic, and other infectious disease outbreaks remained prominent in global health. Initially causing outbreaks in Africa, Asia, Europe, and the Pacific islands, the Chikungunya virus continues to spread rapidly to the Caribbean, Central America, and South America, infecting approximately 2 million people [26, 27].

Hepatitis A, B, C, D, and E are the five hepatotropic viruses that cause viral hepatitis, which affects hundreds of millions of people globally. The two most prevalent types, hepatitis B and C, account for a considerable percentage of fatalities and caused 1.4 million deaths in 2017, 90% of which were associated with cirrhosis and hepatocellular cancer [28]. Antibiotic-resistant pathogens have now emerged as a global health concern, with multidrug-resistant tuberculosis (MDR-TB) affecting over half a million people worldwide [29]. Emerging and reemerging microbes continue to perturb global health balance. Notable pathogens such as those causing community-acquired pneumonia (CAP) include *Streptococcus pneumoniae*, *Mycoplasma pneumoniae, Staphylococcus aureus, Legionella pneumophila*, and Enterobacteriaceae (Table 1) [30].

Table 1 - Cases of some emerging and re-emerging infectious diseases infecting humans.

Infectious Disease	*Pathogen*	*Emerging/Reemerging*	*Primary transmission*
Virus			
West Nile fever	West Nile virus	Reemerging	Vector-borne
Hantavirus pulmonary syndrome	Hantavirus	Emerging	Zoonotic
Dengue fever	Dengue virus	Reemerging	Vector-borne
Zika virus disease	Zika virus	Reemerging	Vector-borne
Yellow fever	Yellow fever virus	Reemerging	Vector-borne
Japanese encephalitis	Japanese encephalitis virus	Reemerging	Vector-borne
Marburg hemorrhagic Fever	Marburg virus	Reemerging	Zoonotic
Rift Valley fever	Rift Valley fever virus	Reemerging	Vector-borne

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Infectious Disease	*Pathogen*	*Emerging/Reemerging*	*Primary transmission*
Ebola hemorrhagic fever	Ebola virus	Reemerging	Zoonotic
Lassa fever	Lassa virus	Reemerging	Zoonotic
Hendra virus infection	Hendra virus	Emerging	Zoonotic
Nipah virus infection	Nipah virus	Emerging	Zoonotic
Highly pathogenic avian influenza	H5N1, H7N9 influenza virus	Emerging	Zoonotic
Severe acute respiratory syndrome	SARS-CoV-1	Emerging	Respiratory (person-to-person)
Middle East Respiratory Syndrome	MERS-CoV	Emerging	Zoonotic
COVID-19	SARS-CoV-2	Emerging	Respiratory (person-to-person)
2009 Pandemic influenza	Swine-origin H1N1 influenza virus	Emerging	Respiratory (person-to-person)
Oropouche Fever	Oropouche Virus	Emerging	Bite of infected midges
Borealpox	Borealpox Virus	Emerging	Zoonotic
Nipah Virus	Nipah virus	Emerging	Zoonotic
Akhmeta Virus	Akhmeta virus	Emerging	Zoonotic
Bacteria			
Lyme disease	Borrelia spp.	Emerging	Vector-borne
Cholera	Vibrio cholerae	Reemerging	Waterborne
Plague	*Yersinia pestis*	Reemerging	Vector-borne
Bartonellosis	*Bartonella* spp.	Emerging	Zoonotic
Methicillin-Resistant Staphylococcus aureus (MRSA)	*Staphylococcus aureus*	Reemerging	Direct contact with contaminated objects
Vancomycin-Resistant *Staphylococcus aureus* infections	*Staphylococcus aureus*	Reemerging	Person-to-person
Pathogenic *Escherichia coli* infections	Pathogenic *E. coli* strains (O157:H7 & O104:H4)	Emerging	Foodborne
Diphtheria	*Corynebacterium diphtheriae*	Reemerging	Respiratory (person-to-person)
Typhoid fever	*Salmonella typhi*	Reemerging	Foodborne, waterborne
Multidrug-resistant tuberculosis infections	*Mycobacterium tuberculosis*	Reemerging	Respiratory (person-to-person)
Clostridioides difficile infection	Clostridioides difficile	Reemerging	Feco-oral route
Carbapenem-resistant Enterobacteriaceae (CRE)	Klebsiella pneumoniae, Escherichia coli	Emerging	Direct contact with infected subjects
Gonorrhea	Neisseria gonorrhoeae	Emerging	Sexual contact with an infected person
Legionnaires' disease	Legionella pneumophila	Reemerging	Inhalation of contaminated aerosolized droplets
Acinetobacter baumannii	Acinetobacter baumannii	Emerging	Direct contact with contaminated surfaces
Shigellosis	Shigella species	Reemerging	Feco-oral route
Parasite			
Cyclosporiasis infections	Cyclospora cayetanensis	Emerging	Foodborne, waterborne
Drug-resistant malaria	Plasmodium spp.	Reemerging	Vector-borne

IMPACT OF PANDEMICS ON GLOBAL HEALTH SYSTEMS

Pandemics have severely strained global health systems, overwhelming already-burdened infrastructure, particularly in the initial stages [31]. They have challenged healthcare personnel, medical facility usage, and essential medical supply availability. Pandemics have disrupted equitable access to healthcare services, especially in resource-limited settings, due to direct effects and immense pressure on health systems [32]. These crises have revealed underlying weaknesses in health systems, interrupting preventive and curative services for both communicable and non-communicable diseases. Essential services are delayed, with patients missing follow-ups and acute care due to fear and uncertainty [33]. Pandemics also cause indirect morbidity and mortality from other preventable and treatable conditions due to service disruptions. Critical gaps or reductions in services during pandemics are often due to reallocating healthcare workers, canceling planned treatments, decreasing public transport, loss of income, and reduced healthcare facility use [32].

Pandemics have had catastrophic impacts on global health, decimating populations as seen during the Black Death in Europe, the Spanish Flu, the COVID-19 pandemic, and the ongoing HIV/AIDS epidemics [15, 18, 34]. These crises have increased morbidity and mortality rates, particularly in low- and middle-income countries. Individuals in their extreme ages are disproportionately affected due to their lower immunity. Pandemics lead to a substantial increase in years of life lost and exacerbate existing health issues, with long-term effects such as those seen with the Zika virus [35]. Economically, pandemics cause severe short-term fiscal shocks and long-term growth problems. Economic downturns result from behavioral changes, such as avoiding public places and jobs due to fear. Mitigation strategies further disrupt social and economic order [36]. In nations with weak institutions and unstable political environments, pandemics exacerbate political pressures and tensions, often inciting violence and escalating conflicts between the public and government [36]. Contemporary pandemics cause worry, social isolation, and economic suffering, while historical ones lead to population disruptions. The 2014 West African Ebola outbreak highlighted how pandemics can aggravate pre-existing issues [37].

OVERVIEW OF THE 2024 UPDATED WHO LIST OF EMERGING PATHOGENS FOR PANDEMIC PREPAREDNESS

The WHO 2024 updated list of emerging pathogens is a proactive step mirroring global health preparedness for future pandemics, shifting from reacting to specific pathogens to a broader family-focused approach. The new list released in July 2024 reflects a shift in health priorities, acknowledging previous lists' limitations and adopting a more adaptive approach to addressing both familiar and novel pandemic risks [38]. The 2017 and 2018 lists ranked specific pathogens according to their potential to trigger a Public Health Emergency of International Concern (PHEIC) [39]. Although these lists guided research and development (R&D) initiatives, they overlooked the dynamic nature of pathogens, potentially leaving the global community vulnerable to unforeseen threats [40, 41].

The 2024 update addresses this by examining all families and acknowledging that any family, currently viewed as low risk, could trigger a future pandemic. This recognizes that evolutionary changes could turn low-risk families into major threats due to genetic alterations or environmental shifts [38]. A notable advancement in the 2024 compilation is the inclusion of *Prototype Pathogens* (Table 1). These pathogens, chosen from families known for their potential to cause public health emergencies, serve as research models for their respective families [42]. The selection criteria for *Prototype Pathogens* included their pathogenic significance, understanding of their replication and disease mechanisms, and the availability of animal models for human disease research [38]. Studying *Prototype Pathogen*s allows researchers to develop broadly applicable medical countermeasures (MCMs) that are versatile and quickly adaptable to various pathogens within the same family, including new emerging threats [43]. This proactive approach contrasts with developing MCMs tailored to specific pathogens, which often proves inadequate during rapidly evolving pandemics like COVID-19 [44]. Emphasizing preparedness, the 2024 plan introduces the concept of *Pathogen X*, representing a potential future pandemic threat [38, 41]. This placeholder underscores the need for continuous global monitoring, fundamental research, and

Table 2 - Priority pathogens and prototype pathogens (WHO, 2024).

Family	*Priority Pathogens (High PHEIC risk)*	*Prototype pathogen*
Adenoviridae	No Priority pathogen proposed	*Mastadenovirus blackbeardi* serotype 14, Recombinant Mastadenovirus
Anelloviridae	No Priority pathogen proposed	No Prototype pathogen proposed
Arenaviridae	*Mammarenavirus lassaense* (Lassa Fever)	*Mammarenavirus juninense* (Junin virus), *Mammarenavirus lassaense*, *Mammarenavirus lujoense*
Astroviridae	No Priority pathogen proposed	*Mamastrovirus virginiaense*
Bacteria	*Vibrio cholerae* (O139), *Yersinia pestis*, *Shigella dysenteriae* serotype 1, *Salmonella enterica* non-typhoidal serovars, *Klebsiella pneumoniae*	No Prototype Pathogen proposed
Bornaviridae	No Priority pathogen proposed	*Orthobornavirus bornaense*
Coronaviridae	Subgenus *Sarbecovirus* (SARS-CoV-2), Subgenus *Merbecovirus* (MERS-CoV)	Subgenus *Merbecovirus*, Subgenus *Sarbecovirus*
Filoviridae	*Orthoebolavirus zairense* (Ebola Virus), *Orthoebolavirus sudanense*, *Orthomarburgvirus marburgense*	*Orthoebolavirus zairense*
Flaviviridae	*Orthoflavivirus denguei*, *Orthoflavivirus flavi*, *Orthoflavivirus zikaense*, *Orthoflavivirus encephalitidis*, *Orthoflavivirus nilense*	*Orthoflavivirus denguei*, *Orthoflavivirus zikaense*, *Orthoflavivirus nilense*, *Orthoflavivirus encephalitidis*
Hantaviridae	*Orthohantavirus hantanense*, *Orthohantavirus sinnombreense*	*Orthohantavirus sinnombreense*
Hepadnaviridae	No Priority pathogen proposed	*Orthohepadnavirus hominoidei* genotype C
Hepeviridae	No Priority pathogen proposed	*Paslahepevirus balayani* genotype HEV-3
Herpesviridae	No Priority pathogen proposed	No Prototype pathogen proposed
Nairoviridae	*Orthonairovirus haemorrhagiae*	*Orthonairovirus haemorrhagiae*
Orthomyxoviridae	*Alphainfluenzavirus influenzae* H1, H2, H3, H5, H6, H7, H10	*Alphainfluenzavirus influenzae* (H1N1), *Alphainfluenzavirus influenzae* (H5Nx)
Papillomaviridae	No Priority pathogen proposed	No Prototype pathogen proposed
Paramyxoviridae	*Henipavirus nipahense*	*Henipavirus nipahense*
Parvoviridae	No Priority pathogen proposed	*Protoparvovirus carnivoran*
Peribunyaviridae	No Priority pathogen proposed	*Orthobunyavirus oropoucheense*
Phenuiviridae	*Bandavirus dabieense*	*Bandavirus dabieense*, *Phlebovirus riftense*
Picobirnaviridae	No Priority pathogen proposed	*Orthopicobirnavirus hominis*
Picornaviridae	*Enterovirus coxsackiepol* (Enterovirus A71, Enterovirus D68)	*Enterovirus alphacoxsackie* 71, *Enterovirus deconjucti* 68
Pneumoviridae	No Priority pathogen proposed	*Metapneumovirus hominis*
Polyomaviridae	No Priority pathogen proposed	No Prototype pathogen proposed
Poxviridae	*Orthopoxvirus variola*, *Orthopoxvirus monkeypox*	*Orthopoxvirus monkeypox*, *Orthopoxvirus vaccinia*
Retroviridae	*Lentivirus humimdef1*	*Lentivirus humimdef 1*
Rhabdoviridae	No Priority pathogen proposed	Genus *Vesiculovirus*
Sedoreoviridae	No Priority pathogen proposed	Genus *Rotavirus*
Spinareoviridae	No Priority pathogen proposed	*Orthoreovirus mammalis*
Togaviridae	*Alphavirus chikungunya*, *Alphavirus venezuelan*	*Alphavirus chikungunya*, *Alphavirus venezuelan*

adaptive R&D strategies. Recognizing *Pathogen X* necessitates shifting from a reactive pathogen-focused approach to understanding evolutionary trends and the potential for interspecies transmission (Table 2) [38].

For the 2024 list, scientists initially assessed 28 viral families and one core group of bacteria, totaling 1,652 pathogens. The Prioritization Advisory Committee (PAC) then reviewed evidence from eight DNA virus families, 19 RNA virus families, and five bacterial families [38]. Consequently, the final 2024 list includes at least 27 viral families and five bacterial families. Experts initially compiled viral families identified by the International Committee on Taxonomy of Viruses, focusing on those linked to human pathogens capable of causing outbreaks (Figure 1). They then removed families posing no epidemic or pandemic risk [38]. For the remaining families, experts evaluated each pathogen based on transmission patterns, virulence, availability of MCMs, and potential to evolve into a future threat, termed *Pathogen X* [45]. This assessment included a questionnaire addressing the pathogen's spread, disease severity, available treatments, and outbreak potential. The selection criteria targeted those posing a risk of sparking a PHEIC, considering both current knowledge and future developments (Figure 1). Thus, the WHO's evolving approach to updating the list of emerging pathogens shows increased risk awareness and a shift towards preparedness (Table 3) [46].

CURRENT STATE OF GLOBAL HEALTH PREPAREDNESS

Predicting which organisms will cause future epidemics or pandemics is challenging. Therefore,

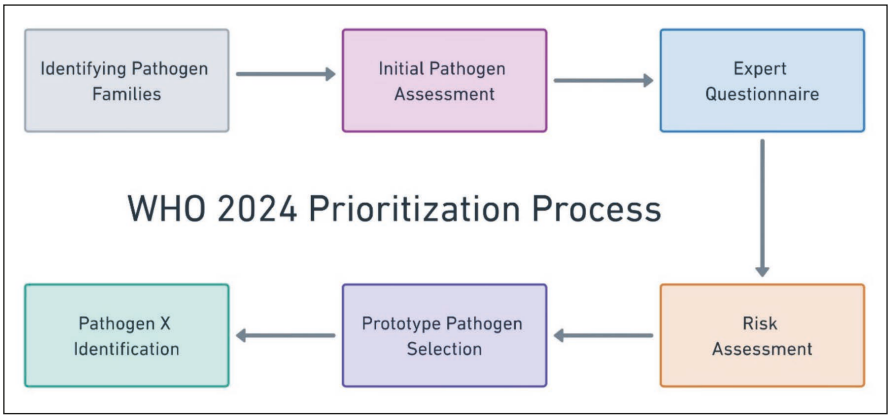

Figure 1
WHO 2024 Prioritization Process.

Table 3 - Changes in the WHO priority pathogen list: 2017/2018 to 2024.

2017/2018 List	*2024 List*	*Rationale for Updates*
Focus on individual pathogens (e.g., Crimean-Congo haemorrhagic fever virus)	Transition to a Family-centric approach (e.g., prioritising research across the entire Nairoviridae family).	Focuses on creating knowledge and strategies that can be applied to viruses in a family, improving readiness for dangers and changes in viruses.
Limited inclusion of Prototype Pathogens	Introduction of Prototype Pathogens as representative viruses for research within each prioritised family.	Seeks to speed up the development of MCMs by using knowledge obtained from examining well-characterized viruses to quicken the study of potentially more dangerous viruses, in the same group.
Less emphasis on Pathogen X	Explicit inclusion of Pathogen X as a category representing the potential for future, currently unknown threats emerging from within known viral families.	Highlights the need for continuous surveillance, basic research, and adaptable research platforms to rapidly respond to novel viral threats, recognising the limitations of focusing solely on known pathogens.

countries develop protocols to reduce morbidity, mortality, and socio-economic impacts. The COVID-19 pandemic revealed unexpected disparities between the responses of developed and low-income countries to pandemics and potential PHEIC. According to the Global Health Security Index (GHSI), the US, UK, and the Netherlands ranked highest in pandemic preparedness, yet their responses did not reflect this ranking [47]. Various initiatives have historically assessed global preparedness for emerging pathogens. The International Health Regulations (IHR), a legally binding instrument in 196 countries, aims to detect and report global public health emergencies [48]. IHR mandates that countries must detect, assess, report, and respond to PHEIC. When an event of concern arises in a WHO member country, it must assess the risk within 48 hours and report to WHO within 24 hours [48]. The International Health Regulations Monitoring Tool (IHRMT) ranks countries based on pandemic preparedness. Countries self-report annually on eight parameters, including legislation policy, coordination, surveillance, response, preparedness, risk communication, human resource capacity, and laboratories [49]. The IHR monitoring and evaluation framework assists in measuring a country's health security capacity through mandatory States Parties Self-Assessment Annual Reporting (SPAR) and optional Joint External Evaluations (JEE), After Action Reviews, and Simulation exercises [48]. Global readiness for a potential pandemic remains debatable. WHO has launched initiatives targeted at reforming international health regulations and developing a new pandemic treaty [50]. Considering the challenges faced in the last pandemic, pertinent issues that must be addressed ahead of future pandemics include those surrounding global health equity – how medicine, vaccines, and similar pandemic reliefs can be equitably distributed across the global north and south [50]. Effective information dissemination sits at the core of the pandemic response, and current preparedness is geared toward rapid information generation and circulation [50]. Amendments are targeted at the modification and effective use of the WHO Conventions and Agreements, and the WHO Regulations. In the concluding phase of the 77th World Health Assembly, the first WHO investment rounds were initiated, aimed at mobilizing resources to drive global health activities for the next four years (2025 - 2028). Although pandemic preparedness is not explicitly itemized in its seven core targeted activities – increasing vaccine delivery to priority countries, enabling health access to over 150 million humanitarian health service portals across 30 countries, solar electrification for 10,000 healthcare settings, increasing education and employment of 3.2 million healthcare workers across 55 countries, accelerating malaria and mother-to-child HIV transmission eradication, fostering accessibility to health data, and prequalifying about 400 medicines, healthcare devices and similar products per year – these development is set to pitch global health preparedness for another pandemic [51].

The Global Health Security Agenda (GHSA), launched in February 2014, employs multisectoral partnerships among over 70 countries and organizations to prioritize infectious disease prevention, early detection, and rapid response [52]. GHSA promotes global safety against infectious diseases and aims to accelerate compliance with International Health Regulations [52]. It integrates human, animal, and environmental health under the One Health framework [53]. Additionally, the 2015 Sendai Framework for Disaster Risk Reduction (SFDRR), adopted by 187 UN members, focuses on risk assessments for health, including pandemics and epidemic risk reduction, and emphasizes biological and natural hazards. It aims to develop institutions and mechanisms to enhance resilience during hazards, with specific goals and actions for managing future threats [49, 54].

CHALLENGES

Global preparedness against emerging pathogens faces significant challenges, which are not limited to potential inaccuracy from insufficient quality assurance during data collection. The IHR relies on self-reported data from government agencies, this predisposes it to data quality strains.

Policies relying on data quality stand a chance of being flawed [47]. Also, WHO evaluations are executed by experts, often from high-income countries, and funded by major intergovernmental organizations. This creates a problem when evaluators lack diversity, leading to a narrow perspective on challenges and solutions [47]. Without equal representation from developing countries, nuanced perspectives may be overlooked due to un-

familiarity. Additionally, the GHSI ranks countries on preparedness but fails to account for their unique circumstances, potentially resulting in harmful policy changes [47]. Furthermore, robust clinical research projects are limited before pandemics, as core clinical trials typically occur during outbreaks. Developing and maintaining pre-clinical trials and protocols can reduce the time needed to develop interventions during an outbreak.

SELECTED CASE STUDIES OF CURRENT OUTBREAKS INVOLVING EMERGING PATHOGENS

A new strain of Mpox was detected in the Democratic Republic of Congo and declared a PHEIC in August 2024. Over 2000 confirmed cases and 13 fatalities across 12 African countries (Burundi, Cameroon, Central African, Republic, Congo, Cote d'Ivoire, DRC, Kenya, Liberia, Nigeria, Rwanda SA, Uganda) have been reported [55]. Mpox is a zoonotic disease caused by Orthopoxviruses and can spread from human to human via bodily fluids, skin lesions, and internal mucosal surfaces [56]. Symptoms usually begin 1 week after exposure, with fever, muscle aches, sore throat, lymphadenopathy, and varying levels of skin lesion. WHO has initiated funding for affected countries to facilitate control measures and began emergency use listing for vaccines in nations lacking national approval. Key public health responses include the National Mpox Incident Management Team, surveillance, and contact tracing [55, 57]. The Mpox vaccine is recommended for high-risk individuals, including healthcare workers, close contacts of diagnosed patients, homosexual men, and sex workers. Both pre-exposure and post-exposure vaccinations are available, with post-exposure vaccination advised within 4 days of contact [58]. Despite availability in over 70 countries, no African country had received the vaccine as of August 26, 2024. The imminent arrival of the first batch in Africa underscores health inequality, as the hardest-hit countries have yet to receive the vaccine [59]. The JYNNEOS vaccine, licensed by the US Food and Drug Administration (FDA), is the most used for Mpox prevention [60].

Similarly, the Mexican IHR National Focal Point on the 23rd of May reported a confirmed case of avian influenza A (H5N2) in Mexico [61] This was the first lab-confirmed case of the virus worldwide, with similarities to earlier viral strains identified in birds in March 2024 in Texcoco state, Mexico. Although a low-risk pathogen, the contact mode raises concerns about a possible high-risk evolution [61]. The Centre for Disease Control has recently confirmed outbreaks of the highly pathogenic avian influenza A virus (HPAI) in regions of the world including the United States and the United Kingdom. As of October 2024, approximately 20 human cases of H5 bird flu have been reported in the United States for the year 2024, with 12 confirmed as H5N1 [62], and 6 cases reported in the UK between October 2023 and March 2024 [63]. Avian Influenza A virus usually presents as mild to severe upper respiratory tract infections, although fatalities have been recorded among patients with other comorbidities. Sporadic human cases are expected in case of contact with infected poultry. WHO now advises constant investigations and contact tracing of identified cases due to the rapid evolution of influenza viruses.

Oropouche virus disease, caused by the re-emerging Oropouche virus, has recently seen a significant rise in cases in traditional areas and new countries, provoking international concern [64]. The virus has spread to multiple countries in the Americas, with over 8,000 cases reported, and has been identified among travelers globally. Brazil reported the first two fatalities in nearly 70 years and multiple cases of fetal anomalies potentially linked to the virus. The Pan American Health Organization raised the risk level from moderate to high, while the WHO assessed a high regional risk and moderate global risk. Oropouche fever is transmitted by the bite of *Culicoides paraensis* and presents with symptoms that complicate diagnosis; severe cases may lead to neurological and hemorrhagic symptoms [64]. There is no confirmed treatment or vaccine. Regional epidemiological alerts and molecular testing are in place, and both the Pan American Health Organization and WHO are aiding the region to control the infection's spread.

In Gaza, polio virus was detected in July 2024 after a 25-year absence [65]. The Gaza Strip had a good level of vaccination before the Israeli/Palestine conflict, but routine immunization has dropped to less than 90% in the first quarter of 2024 due to the impact of the conflict [66]. Gaza's health ministry has declared a polio epidemic

owing to Israel's military attacks, which caused constant population displacement, destruction of health systems, malnutrition, and improper sewage disposal, increasing the risk of this infection. Plans are now underway to deliver over 1.6 million doses of nOPV2 to curb further spread in the Gaza Strip [66].

Rwanda's first Marburg virus outbreak, announced on September 27, 2024, has resulted in 8 confirmed cases and 13 deaths as of early October 2024, primarily affecting healthcare workers especially those in intensive care units [67]. The Marburg virus, related to Ebola, is an RNA virus causing hemorrhagic fever with a high fatality rate. The Rwandan government is responding with extensive contact tracing, testing, and deploying experimental vaccines and treatments [68]. Although the outbreak is currently under control with stringent health measures, the virus's potential spread is significant due to the lack of an approved vaccine or treatment [68]. Health officials believe it is unlikely to become a pandemic given current containment efforts, but the high transmission rate and deadly history of African outbreaks make it a concern. Vaccine and treatment testing continues as the global scientific community remains vigilant

On June 14, 2024, the Ministry of Health and Medical Education (MoHME) of Iran reported the first cases of locally acquired Dengue fever. Iran previously recorded about 20 imported cases annually. Dengue fever is caused by the Dengue virus and is primarily transmitted by Aedes mosquitoes. WHO has classified the dengue fever risk as high and of public health importance due to the presence of the vector and conducive climate. While most dengue cases are asymptomatic, severe instances can induce shock, severe bleeding, and multiple organ failure [69]. Bangladesh currently faces seasonal Nipah virus (NiV) outbreaks. On February 7, 2024, the Bangladesh Focal Point for International Health Regulations reported the second NiV case within a month, unrelated to the first case detected on January 30. Both cases involved the consumption of raw date sap. NiV, a zoonotic disease transmitted by infected animals such as bats and pigs or their bodily fluids, causes severe respiratory distress and encephalitis with an incubation period of 4 to 14 days. Although some antivirals are in development, no confirmed treatment or vaccine exists for NiV. The Bangladesh government and WHO have initiated public health measures, including health promotion, risk communication, surveillance, and collaboration with One Health organizations [70].

INSIGHTS FROM ANALYSIS AND IMPLICATIONS FOR PUBLIC HEALTH

With the identification of new priority pathogens by WHO, assessing current preparedness levels is crucial for mitigating potential outbreaks and should involve periodic risk assessments. These assessments should consider factors such as transmissibility, virulence, population immunity, and social determinants of health. High-risk pathogens like Influenza strains (H1-3, H5-7, and H10), Marburg, Mpox, and Nipah viruses should be prioritized in preparedness planning. The updated list of priority pathogens is vital for shaping global and national strategies against future pandemics. Despite advancements since the COVID-19 pandemic, significant disparities in preparedness persist across regions [71]. High-income countries typically have better surveillance systems and healthcare infrastructure, enabling quicker responses to emerging threats. In contrast, low- and middle-income countries grapple with limited resources, inadequate healthcare infrastructure, and underdeveloped monitoring systems [71]. There is a need to reassess global public health policies. Governments of WHO member states and independent observers should update or create policies to enhance surveillance, reporting, and response capabilities for emerging threats across developing nations. The inclusion of these pathogens underscores the necessity of aligning current guidelines with the latest scientific insights and risks, potentially requiring the development or adjustment of strategies and programs. Efforts may include consistent vaccination campaigns, public education, and improved screening and monitoring initiatives [72].

Regional health systems should update their preparedness and response plans, involving the training of healthcare workers, establishment of protocols, and formation of specialized response teams. These new priority pathogens highlight the need for international cooperation, through effective and timely information sharing, resource allocation, and strategies provision. Additionally, public health practices must evolve, incorporating im-

proved screening procedures, robust vaccination strategies, and more effective communication. Focusing on priority pathogens necessitates reallocating resources to targeted research, including those geared at fostering an understanding of pathogenic biology, epidemiology, and potential interventions, prevention, and control measures.

STRATEGIES FOR IMPROVING EARLY DETECTION AND SURVEILLANCE

Monitoring requires enhanced surveillance systems that can detect outbreaks early and provide real-time data to inform public health responses. Enhancing these systems, especially across LMICs is vital for timely outbreak detection and containment. Global collaboration through data-sharing platforms and international networks is pivotal for tracking pathogen spread and coordinating cross-border responses. Significant improvements in healthcare infrastructure are required, including developing specialized response units and upgrading laboratory facilities. Investment in workforce training is equally important to equip healthcare professionals with the much-needed skills to utilize new detection methods and respond to emerging threats [73]. Global health authorities should create adaptable policies that quickly address evolving threats, such as the recent Preparedness and Resilience for Emerging Threats Initiative (PRET) by WHO for pandemic planning [74]. Strengthening healthcare infrastructure and expanding workforce training are essential for building resilient systems to withstand future pandemics [75]. Community engagement is also key, fostering public awareness and compliance with health measures during outbreaks [76]. Public health campaigns should educate communities about emerging pathogen risks and protective measures. International collaboration and data sharing among member states must be prioritized for a coordinated global response to emerging pathogens.

RECOMMENDATIONS

The effects of previous pandemics underscore the need to align plans to foster global preparedness for future pandemics. The WHO has set the pace, developing tools and guidelines to guide practice. The updated list of high-priority pathogens seeks to gear research and development toward combating and neutralizing the virulence of these pathogens. Research organizations and institutions must integrate the tools and approaches developed during the COVID-19 pandemic and other recent public health emergencies into the PRET Initiative, as outlined by WHO [74]. Policy developers should rapidly translate scientific evidence on the epidemiology of emerging pathogens into policies. International collaboration with early and effective stakeholder involvement in policy-making, translation, and enforcement is essential to control infection transmission across borders. Increased stakeholder involvement and funding for research on emerging pathogens are necessary to build a pandemic-resilient health system [77]. A comprehensive view of Global Health Security, which includes universal health coverage, non-communicable diseases, sustainable development, and human rights, must remain the cornerstone of pandemic preparedness [78, 79]. Global health partners should support WHO in securing stable funding and financing mechanisms for both emergency response and long-term preparedness. Robust regional public health institutions with experienced international experts are needed for technical support, guidance, and coordination in monitoring emerging pathogens. Ensuring diverse voices, especially from LMICs, participate meaningfully in policy development and processes is crucial for cooperation and collaboration in addressing future pandemics [80]. Accelerated research in vaccine development, clinical trials, and priority distribution to regions bearing the most brunt of outbreaks is imperative to mitigate the devastating effects of pandemics.

CONCLUSIONS

The WHO priority pathogen for potential pathogens has emerged as a resourceful tool to support global preparedness for pandemics. Lessons learned from historic pandemics have laid a framework for health systems strengthening and preparedness. The updated list introduces *Prototype Pathogens* as key research models for their respective families, and Pathogen X as a placeholder to guide research and development. By adopting a broader family-focused approach than the specific pathogens previously used, public health becomes better positioned and prepared to react to a poten-

tial trigger. With the recent upsurges in emerging and reemerging diseases around the world and the recent declaration of the Mpox virus as a PHEIC, there is a call to intensify and improve disease monitoring while strengthening existing surveillance systems. Recommendations are in line with the alignment of plans with those set by the WHO for a robust pandemic response. In addition to providing flexible and handy funds to foster preparedness, equitable distribution of resources, expertise, and information is a necessity.

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All authors contributed equally to the writing of this manuscript, and I've read and approved the final draft.

Conflicts of interest
None to declare

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