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Global Health Preparedness: Lessons from COVID-19 and Future Threats

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A B S T R A C T

Emerging infectious diseases are becoming an increasing threat to global health, which has been accelerated by globalization, climate change, and the increase in human-animal interactions. The COVID-19 pandemic laid bare the vulnerabilities of healthcare systems worldwide, showing critical gaps in surveillance, healthcare infrastructure, and international cooperation. This review seeks to expound on the lessons learned from COVID-19, with an emphasis on genomic surveillance, equitable distribution of vaccines, and strong public health policies; on the other hand, it examines the rise of pathogens such as Ebola and Zika as well as the evolving challenges posed to pandemic preparedness. Addressing these issues will greatly benefit from the application of a comprehensive and multidisciplinary approach, thus linking scientific advancement, ethical arena, and policy intervention for the development of an enhanced global health security. Future preparedness must ensure that early detection and rapid response mechanisms are accompanied by equitable access to healthcare in order to limit the impact of emerging pathogens.

Keywords: Emerging Infectious Diseases, Zoonotic Transmission, Vaccine Equity, Global Health Security, COVID-19 Response.

Introduction

A major aspect of understanding trends in the emerging pathogens is a multifaceted approach concerning the emergence of new pathogens, which usually relates to the entire strategic "farm-to-fork" aspects of health. Many emerging pathogens may have existed long before their sudden prominence due to certain environmental changes and adaptability to new conditions.[1] Emerging infectious diseases tend to share some features with one another, but they mostly have different modes of transmission, degree of severity, and target affected populations. Respiratory pathogens include diseases such as SARS-CoV-2 (COVID-19) and H1N1 influenza (swine flu), which spread through the air and are capable of generating big epidemics. Conversely, there are those diseases transmitted primarily through contact or have other peculiarities that present different problems.

Predicting an outbreak's progression becomes extremely complex once it starts. It is highly unpredictable, from very general, early outbreaks that move into sporadic resurgences and that those resurgences are caused by the introduction of new variants. All of these developments were along with the evolution of public health policies and responses that were being informed by improvements in diagnostic, preventive, and therapeutic measures.

There is a lack of a clear definition of what constitutes a public health emergency or pandemic. Declaring a pandemic can trigger critical resource mobilization; on the other hand, an early declaration could severely disrupt everyday life. A late declaration, on the other hand, might delay interventions when they are most needed. The recent response to emerging infectious diseases (EIDs) echoes an inconsistent categorization of outbreaks, mostly reflecting political and social factors that affect public health response. There is, however, no doubt that a pandemic epidemic is an epidemic that transcends national or continental borders and impacts a disproportionately large number of people.[2]

Even though it is still the case that COVID-19 has become a pandemic,[3] the outburst of SARS-CoV-2, initially identified in China, followed by its spread across the world, made impressive impressions on health systems of the world and continued to threaten global economy stability.[4] The nations' and international organizations' responses in tackling the issues

are expected to have long-lasting effects in global health. The decisions that happen at national and international levels are expected to be game changers in terms of future strategies in the management of pandemics and also other broader health security issues.[5]

On the other hand, it has also been an increasing trend over the last four decades for the occurrence of global disease outbreaks and pandemics to exponentially multiply [6, 7] Thus, the understanding of the spatial and temporal patterns in which novel infectious diseases will occur remains one of the main issue and complex challenges of the 21st century.[7, 8]

This review aims to look at the effects of the emerging pathogens over global health, the effects well reflective of valid lessons from the COVID-19 pandemic in order to strategize for preparedness in the future. Also, the article aims to articulate understanding regarding facts about the emergence of pathogens, obstacles within pandemic response, and how improvements must be done especially in surveillance, health institutions, and collaboration on the global scale.

Emerging Pathogens: An Overview

Emerging infections are diseases that either are new to a population or are pre-existing ones to which the incidence increases rapidly or cover new geographic areas. In 2020, the World Health Organization (WHO) pointed out that infections rank the second and third leading causes of death worldwide.[9]

Emerging infectious diseases (EIDs) are generally split into the categories of new emerging and reemerging diseases. Newly emerging diseases are new sicknesses that come along rapidly in a large geographical area or new incidents or a case of a specific infection that appear and are spreading. In contrast to that, reemerging infections are rather due to changes or evolution in existing microorganisms, the return of historically known diseases but in new areas, or drug-resistant forms, the reinforcement of infections that are not yet dealt with properly, or conditions where diseases that were familiar to one set of people jump to another set.[10]

Morens et al. say the pathogen adaptation moves through stages as shown in Figure 1. The first stage occurs when the microorganism infects a new host and begins adapting to new biological surroundings. After that, the infection enters the epidemic phase, in which it becomes widespread and has considerable pathogenic effects. After this stage, the disease becomes endemic to a certain population or territory. Finally, in this adapted phase, it stops being harmful and may even confer benefits to the host. The microorganism would, perhaps, be assimilated into the host microbiome or integrated into its genome, as in the case of endogenous retroviruses.[11]

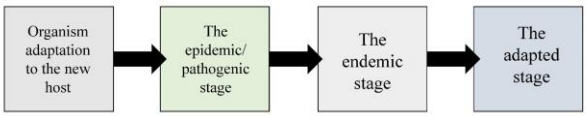

Figure 1. The hours are succeeded by phases of pathogen emergence as follows: (1) adaptation of the organism to a new host; (2) spread and disease manifestation, i.e. epidemic/pathogenic stage; (3) organism and host population, i.e. an endemic stage where the organism maintains a stable presence; and (4) adapted stage. In the adapted stage, the organism may become, or at least appear, non-pathogenic to the host, with possible benefits to it (e.g., the human microbiota) or integration into the host genome (e.g., endogenous retroviruses). Adapted from the conceptual framework proposed by Morens et al. 2013.

Human infectious diseases by translation fall into the categories of not needing the help of other creatures (non-zoonotic) or needing the help of another animal (zoonotic). Zoonotic transmission refers to the infection that is spread between human and animal directly through contact or indirectly through water, food, or environmental exposure.[10] Zoonotic diseases have a very serious health impact on the human population since they account for the 61% in the number of all infectious diseases. Among such are coronaviruses, influenza viruses, West Nile Virus, *Yersinia pestis*, and still in the plant world have been mentioned *Sporothrix brasiliensis* as examples.

Additionally, non-livestock-transmitted diseases account for the 39% of infectious diseases, which are transmitted exclusively among humans or within certain environments without any animal intervention. These are disease-causing microbes such as *Variola virus, Staphylococcus aureus, Clostridium difficile, Candida auris, Blastomyces spp., Emergomyces spp., Rasamsonia argillacea, Trichophyton indicatore, Aspergillus fumigatus*, and *Schistosoma* species.[9] Overall, zoonotic diseases represent the most significant contributors to infectious diseases affecting humans, emphasizing the importance of understanding and mitigating zoonotic transmission pathways.[12] The main drivers of the infections are a variety of factors such as zoonotic diseases, climate change, and global travel that viral infections that lead to most of the infections as shown in Figure 1.[13]

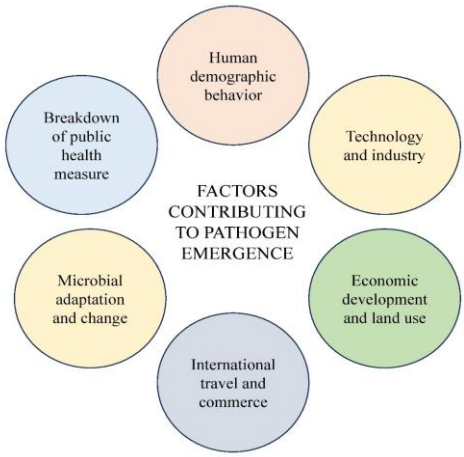

Figure 2. Several factors lead to the emergence of pathogens: the growing human population, human behavior, technological changes, economic development, international travel, microbial adaptation, and a breakdown of public health measures. The list underscores the complex interplay between human activity and infectious disease dynamics.

The COVID-19 Pandemic: A Case Study

For a long time, Coronaviruses have been known to pose a serious threat of a pandemic.[14, 15] All of the already identified human coronaviruses have zoonotic origins, and this is how they are supposed to be with the majority of human viruses. SARS-CoV-2 is similar to four endemic human coronaviruses: human coronavirus-OC43 (HCoV-OC43), human coronavirus-HKU1 (HCoV-HKU1), human coronavirus-229E (HCoV-229E), and human coronavirus-NL63 (HCoV-NL63).[16] August 2023 saw numerous epidemiological studies done that concluded Huanan Seafood Wholesale Market as one major center for early transmission of SARS-CoV-2 in Wuhan. From the findings, it was established that in December 2019, about 28% of all diagnosed cases were related to the Huanan market. Along with other local markets, about 55% of cases that month were linked to the Huanan market, with more in the first two weeks of December.[17]

On the 20th day of April year 2020, Johns Hopkins University reported to the entire world that there were 2.4 million cases of COVID-19 and 165,273 people had succumbed to death because of it. The locus of highest cases was found in the U.S.-759,766; Spain-198,674; Italy-178,972; France-154,098; Germany-145,742. A percentage case fatality spectrum stands at 3.1% in Germany.[18] Indeed, case fatality rates was overestimated as they were based on very limited testing, which includes primarily severe cases.[19] Case fatality (CF) is quite low until 60 years but rises precipitously after that. It is not yet known whether age itself or comorbidities related to age causes this rebound.

Global COVID-19 responses such as imposing lockdowns and quarantines over regions, the early days of the pandemic in Wuhan, China, witnessed other measures.[20, 21] Other countries, too, introduced travel bans and closed public facilities at the early days of the pandemic.[22-24] On the other hand, the UK and the USA, which used social distancing, school closures, and national curfews, faced bigger challenges in attempting to control the virus spread.[25, 26] Over the period, digital contact tracing (DCT) has been tried in different countries and regions, monitoring virus exposure, vaccination status, and test results.[27]

These measures lead to some challenges such as direct contact was very limited due to which people have less time with their friends and family. Travel restrictions were mostly affecting the people who used to go to the cinema, the theater, gym, eating, or traveling, lately, when they were confined, and it was harder for them. Along with all this information of the media was often opposite, and that, in turn, was puzzling and agitating the people who hence were not eager to know what was happening and what would come.[28] All key aspects of COVID-19 Pandemic are summarized in the Table I.

Table I: Key Aspects of the COVID-19 Pandemic.

Aspect	Details
Origin	SARS-CoV-2 appears to have been the result of a zoonotic virus that was cultivated in Wuhan China, in contrast to earlier strains of the virus such as SARS taking root in primates.
Initial Spread	Wuhan's Huanan market emerged as a predicted outbreak location but infection then transmigrated across globe at an alarming rate thanks to interpersonal relations.
Transmission Mode	Virus mostly disseminated through the use of respiratory droplets, aerosols, and a direct connection, along with active carriers showing a significant number of breaches during growth and development.
Public Health Impact	A considerable number of patients came flooding towards health facilities, majority of them received untimely treatment reflecting in very high death rates during the outbreak.
Mortality Statistics	In April 2020, globally 2.4 million cases of covid were reported and 165,273 deaths however the fatality was different in various parts of the globe.
Containment Strategies	Countries all across the globe had to endure methods like lockdowns, border and travel movement externalities, QCOVID testing and contract tracing, however their efficiency varied from one place to another.
Key Challenges	Vaccine inequity, misinformation, healthcare disparities, and challenges in implementing containment measures.

Lessons from COVID-19

The COVID-19 pandemic has highlighted the need for genomic surveillance, whereas attempts to integrate genomes into public health systems faced infrastructural and methodological issues

across the globe.[29] Future readiness demands foresightedness to enhance surveillance strategies such as standardization of sampling, optimizing sequencing capacity, and strengthening equitable data-sharing mechanisms. Metagenomic approaches and stratified sampling depending on research questions, for example, those concerning disease severity, can increase the utility of viral genetic monitoring. Surveillance systems have played an indispensable role in the tracking of viral variants, understanding transmission, and informing vaccine design, more particularly via collaborative and open-access data sharing.[30, 31] In turn, the pandemic provided credence to the transformative potential of mRNA in vaccine development, possessing far greater speed, flexibility, and scalability when compared to conventional vaccines based on live or inactivated pathogens. By the end of the year 2023, more than 13 billion doses of vaccine had been distributed globally; however, stark inequities persisted: only about 25% of persons in low-income countries had received their complete primary vaccine series, with booster doses administered to less than 5% of the population. [32, 33] High-income countries were further put to task for their actions during the pandemic that displayed vaccine

nationalism, having acquired doses through bilateral arrangements and through COVAX. [34] The pandemic exposed the cracks in healthcare systems that were ill-prepared to serve adult and elderly populations equitably. It helped underline integrated vaccination campaigns as well as the need for a protected and well-trained health workforce supported by participatory and community-centered programs.[35] The seven-day strategy (detect report, respond) certainly proved promising for outbreak response improvements in countries like Nigeria, Mexico, and Uganda. [36, 37] Herein lies an important aspect of public health communication; however, socioeconomic or demographic factors pose barriers to equitable access to health information and thus limit the effectiveness of outreach initiatives.[38] Finally, ethical considerations in determining resource allocation during a crisis had to follow the principles of stewardship, transparency, and accountability. The SARS outbreak of 2003 exposed serious lapses in preparedness and led, in turn, to the development of an ethical framework by the University of Toronto's Pandemic Influenza Working Group, now widely used. This framework guided responses during the COVID-19 pandemic with a view to promoting fair and just healthcare practices.

Future Threats and Preparedness

The last ten years have seen the rise of at least a number of animal viruses that have enhanced the perception of the potential dangers that are posed by previously unknown and disregarded pathogens, the latter of which, several diseases and may even get out of control and pose significant risks to global health. The fact that even by the most optimistic estimation there are around 1.7 million viruses out there that we have not yet figured out what kind they are that live in a natural

Table II: Future Threats and Strategies for Preparedness.

Threat	Description	Preparedness Strategies
Emerging Pathogens	Unseen agents of infection with pandemic potential (for example, "Disease X").	Develop global frameworks for effectively managing outbreaks at all levels.
		Create international systems for monitoring and detecting pathogens of emerging concern.
Zoonotic Spillovers	Frequent Contacts between Human and Animal Increase the Risk of Zoonoses.	Reduce contact between humans and animals by improving agricultural practices and urban planning.
		Monitor wildlife for early signs of disease.
Climate Change	Bring Suitable Environmental Changes Needed by Pathogens to Survive and Transmit.	Embed climate risk assessments into public health strategies.
		Prepare health systems for climate-related health threats (such as those introduced by mosquitoes).
Bioterrorism	Deliberate release of pathogens, possibly engineered for harm.	Draft international agreements that prevent and monitor bioterrorism threats.
		Increase funding for rapid response mechanisms (including diagnostics, treatments, and vaccines).
Global Vaccine Inequity	Unequal Access to Vaccines, like During COVID-19, Compounds Global Health Inequities.	Build equitable distribution systems (such as COVAX initiatives).
		Complete global manufacturing capabilities to reduce dependency on wealthier nations.
Inadequate Healthcare	Weak Health Systems in Low- and Middle-Income Countries Grabbing on Timely Detection and Response.	Train and strengthen healthcare systems for health professionals.
		Identify emergency funding for pandemic responses in poor regions.
Data Gaps in Surveillance	Lack of Sufficient Genomic and Epidemiological Information Impeding Early Outbreak Detection.	Create standardized protocols in data sharing.
		Utilize technology for real time disease tracking.

environment, refer to them as the "global virome".[39] The threat of Disease X that the world is facing invites the question of prevention. It is estimated that "Disease X" will probably be a zoonotic disease, an RNA virus, which arises in certain environmental and social areas where the chances of a continuous spread among humans are higher.[40] Although the situation is quite difficult, there are a number of measures that can be taken to lessen the possibility of such pathogens and subdue the spread of these pathogens. Early detection, preparedness, and response are key activities in the control of epidemic and pandemic programs.[41] Effectively functioning warning and communication systems are imperative for these response efforts under regular conditions, as well as in pandemic cases.[42] There are various other threats that are listed, in Table II, along with the strategies that can help in pandemic preparedness.

Role of WHO in Pandemic Preparedness

The WHO has a great role to play against the global health travails, especially in the area of prevention, detection, and response to outbreaks. According to its constitution, the WHO is the primary institution dealing with the coordinate actions concerning health, and really the WHO is the one coordinating health sector issues globally. To this effect, the 73rd World Health Assembly passed a resolution calling upon the Director-General to start a comprehensive, impartial, and independent evaluation, under the auspices of the Member States, to review experience and lessons learned from the pandemic WHO international response to COVID-19. The evaluation should assess and/or make recommendations on the effectiveness of WHO's existing mechanisms, and give recommendations that would enhance global pandemic prevention, preparedness, and response, including, where necessary, the strengthening of WHO's Health Emergencies Program.

Conclusions

In light of the global pandemic COVID-19, serious ramifications from the perspective of emerging pathogens and global health preparedness have been borne even harsher. Several advances have been made in genomic surveillance and vaccine development, while misinformation, healthcare inequities, and lagging policy interventions remain. It shall be of utmost import to fortify healthcare infrastructures, synergize cross-border efforts, and invest in the technologies for early detection to avert the next outbreak. The international commitment and ethical framework to safeguard a proactive science-based approach will be instrumental in designing a resilient strengthened global health system apt for the emerging infectious disease challenges. The experiences from COVID-19 should be an anchor point for the sustainable long-term amelioration of pandemic preparedness and response.

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