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Anticipating future global health crises: Strategies for addressing emerging infectious diseases and preparing for the next pandemic

Fahdah Mehsan Alotaibi
KSA, National Guard Health Affairs

Abdulrhman Ali Almazam
KSA, National Guard Health Affairs

Motaeb Alotaibi
KSA, National Guard Health Affairs

Arwa Mohammad Emam
KSA, National Guard Health Affairs

Naif Saad Alqahtani
KSA, National Guard Health Affairs

Ashwaq Ibrahim Alheggi
KSA, National Guard Health Affairs

Khlood Khaldan Alharbi
KSA, National Guard Health Affairs

Arwa Abdullah Alhamed
KSA, National Guard Health Affairs

Eman Ibrahim Alshaikh Ali
KSA, National Guard Health Affairs

Maram Jaafar Alnemer
KSA, National Guard Health Affairs

Nujoud Abdulrahman Almussa
KSA, National Guard Health Affairs

Muteb Abdullah Aldosari
KSA, National Guard Health Affairs

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Mahfoudh Saad Alghamdi
KSA, National Guard Health Affairs

Nasser Hamoud Mohammed Alharbi
Ministry of National Guard Health Affairs

***Abstract*---**Introduction: Despite initial optimism about controlling infectious diseases with antibiotics and vaccines, the emergence of the HIV pandemic and recent global health crises have highlighted the persistent threat of infectious diseases. The rise of antimicrobial resistance, novel viral agents like SARS-CoV-2, and bioterrorism underscore the need for ongoing vigilance. Emerging infectious diseases are those with increasing incidence or potential for increase, often stemming from zoonotic origins due to human-animal interactions and environmental changes. Aim: This article aims to review strategies for addressing emerging infectious diseases and preparing for future pandemics, emphasizing the roles of healthcare professionals and essential preparedness measures. Methods: A comprehensive review of historical and recent data on infectious disease emergence, including zoonotic pathogens and antimicrobial resistance, was conducted. The roles of physicians, pharmacists, and nurses in managing these diseases are analyzed, along with strategies for pandemic preparedness. Results: Effective strategies include strengthening global surveillance systems, investing in research and development of vaccines and treatments, improving preparedness planning, and fostering international collaboration. Key roles of healthcare professionals include diagnosis, treatment, medication management, infection control, and patient education. Conclusion: Addressing emerging infectious diseases and preparing for future pandemics require a multi-faceted approach involving enhanced surveillance, research, public health infrastructure, and global cooperation. The combined efforts of physicians, pharmacists, and nurses are crucial in managing these threats and safeguarding global health.

***Keywords*---**Emerging infectious diseases, pandemic preparedness, zoonotic diseases, healthcare roles, antimicrobial resistance, global health strategies.

Introduction

In the 1970s, with the advent of antibiotics and vaccines and the imminent eradication of smallpox, there was widespread optimism that infectious diseases would soon be relegated to history. In 1972, Nobel laureate Macfarlane Burnet prognosticated: 'If … we retain a basic optimism and assume no major catastrophes occur and that any wars are kept at the 'brush fire' level, the most likely forecast about the future of infectious disease is that it will be very dull' [1]. However, the emergence of the HIV pandemic shattered this optimism, and

infectious diseases reasserted their prominence on the global health agenda. The seminal 1992 publication *Emerging Infections: Microbial Threats to Health in the United States* marked a pivotal moment in this renewed focus [2]. Since that time, the rise of antimicrobial resistance across various pathogens, including those resistant to last-resort antibiotics, the continual emergence of primarily viral agents with the potential for human-to-human or pandemic transmission—severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and its associated disease, coronavirus disease 2019 (COVID-19), being the most recent and notable example—and the deliberate release of pathogens as bioterrorist weapons serve as persistent reminders that infectious diseases remain far from inconsequential [3].

Definitions

'Emerging infectious diseases' are characterized as those whose incidence in humans has increased over the past two decades or poses a threat of increase in the near future [4]. Emergence may occur through the spread of novel agents (including known agents with new resistance mechanisms), the detection of previously undiagnosed infections, or the recognition of an infectious origin in previously established diseases. Additionally, emergence can also refer to the reappearance (or re-emergence) of a known infection following a period of reduced incidence [5].

Zoonotic Emergence

Pathogen: There are over 1,400 known human pathogens, with the majority (approximately 60%) being zoonotic in nature, relying on an animal reservoir for their survival [6]. A smaller fraction (5–10%) is transmitted through environmental means, while the remaining pathogens are sustained solely through human-to-human transmission cycles. Among emerging infections, zoonotic diseases account for an even higher proportion (73%), highlighting the significant risk posed by the human-animal interface. Furthermore, nearly all established strictly human pathogens are believed to have zoonotic origins, having transitioned from animals to humans and undergone extensive adaptation over millennia of co-evolution with their hosts.

Human: Given that most human pathogens depend on animal or environmental reservoirs, the interactions between human populations and their ecosystems play a crucial role in determining the local pathogen spectrum. Historical shifts in human-environmental and interpopulation interactions have profoundly altered the spectrum and causes of infectious diseases within human populations. Currently, we are experiencing the fourth major historical transition, characterized by extensive human encroachment into previously uncharted areas, the globalization of economic and cultural practices, rapid and widespread communication, accelerated urbanization, and increased dependence on complex or large-scale technologies. These factors are reshaping the dynamics between humans and microbes.

The evolution of human societies has been marked by several significant transitions over time. The prehistoric transition, occurring millions of years ago, saw a shift from arboreal living to savannah habitats, accompanied by the

development of hunter-gatherer lifestyles. This was followed by historical transitions: the first, occurring approximately 5,000 to 10,000 years ago, involved the establishment of settlements and the domestication of crops and livestock. The second transition, occurring between 1,000 and 3,000 years ago, was characterized by increased military and commercial interactions within continents. The third transition, beginning in the 16th century, was defined by European exploration and imperialistic expansion. Currently, the fourth transition is underway, characterized by globalization, rapid urbanization, and climate change, which are reshaping human societies on a global scale.

The transmission of infectious agents from animals to humans, known as a species, jump, is frequently facilitated by novel or atypical physical interactions between potential pathogens and human hosts. These interactions often arise from changes in human cultural, social, behavioral, or technological practices that alter the human-animal interface. The likelihood of subsequent spread of these new infectious diseases is influenced by a variety of environmental and social factors, which collectively drive the emergence of such diseases [1]. These drivers include microbial adaptation and change, susceptibility to infection, climate and environmental conditions, economic development and land use, human demographics and behavior, technology and industry, international travel and commerce, public health infrastructure breakdowns, poverty and social inequality, war and conflict, urban decay, lack of political will, and intentional biological attacks [2]. Rather than being a singular event, the species jump is more accurately described as a transitional process comprising multiple stages [3]. This process requires the pathogen to surmount various biological barriers—inter-species, intra-human, and inter-human—to ultimately achieve sustained human-to-human transmission. Analysis of data from 1940 onwards has identified hotspots for the emergence of infectious diseases, particularly zoonotic infections originating from wildlife and domestic animals, as well as drug-resistant and vector-borne organisms [4].

To address novel infectious disease events, numerous international consortia and extensive research programs have been established with the aim of predicting, preventing, preparing for, and mitigating such occurrences. Advances in technology now allow for the rapid detection, characterization, and tracking of pathogens. Despite these advancements, experience has shown that predicting and managing the emergence of novel pathogens, such as Middle East respiratory syndrome coronavirus (MERS-CoV), Ebola, Zika virus, and even the annual re-emergence of H7N9 influenza in China, remains challenging [1]. This suggests a need for a more proactive approach, such as employing platform technologies to create vaccine and monoclonal antibody libraries that can be mass-produced when required. Although the potential for SARS-CoV-2 emergence was anticipated as early as 2005 from sequences of coronaviruses in bats, which were closely related to SARS-CoV-1 and capable of binding to known human receptors [2], many countries struggled to allocate resources effectively to prevent the virus's entry and spread in early 2020.

A pandemic is defined as an epidemic that has spread across a vast geographic area, such as multiple continents or globally. Factors such as globalization and increased air travel facilitate the rapid spread of pandemics. Historically, most

zoonotic pandemics have been caused by influenza viruses due to their rapid transmission and ability to spread from human to human, often before symptoms appear, making them exceedingly difficult to contain [3]. Since 1900, the world has experienced pandemics of varying severity, including severe (1918 H1N1), moderate (1957 H2N2, 1968 H3N2), and mild (2009 H1N1pdm09) influenza strains.

Contrary to earlier beliefs that coronaviruses like SARS-CoV-1 and MERS-CoV posed a lower pandemic threat due to limited pre-symptomatic and asymptomatic transmission, early 2020 reports of significant proportions of SARS-CoV-2-infected individuals remaining asymptomatic or exhibiting delayed symptoms indicated that SARS-CoV-2 would lead to a markedly different epidemic from its predecessors. This realization marked a moment of profound impact, akin to the September 11, 2001, attacks on the New York City World Trade Center [4].

While zoonotic pathogens capture significant attention, they are not the sole concern in infectious disease emergence. There is a 'slow pandemic' of antimicrobial resistance affecting bacteria and other pathogens, threatening the effectiveness of treatments for HIV, malaria, tuberculosis, and various hospital- and community-acquired infections caused by common Gram-positive and Gram-negative bacteria. This issue is recognized as a global public health emergency, necessitating worldwide efforts to enhance awareness, enforce regulations, and develop new antibiotics or alternative prevention and treatment methods [5].

Failures in vaccination programs, driven by negative publicity or religious beliefs, can lead to the re-emergence of highly infectious viruses such as those causing measles or rubella in developed countries, as observed in the USA and Europe. Additionally, global food production and distribution networks can facilitate the spread of foodborne infections and bacteria with new resistance mechanisms. In the Asia-Pacific region, despite the focus on avian influenza, hand, foot, and mouth disease caused by various non-polio enteroviruses leads to significant morbidity, including severe complications and a mortality rate of approximately 0.1%, highlighting that emerging infections can also stem from human sources [6].

A selection of important emerging infectious diseases since 2003:

- **2020:** SARS-CoV-2
- **2016:** Plasmid-mediated colistin resistance in Enterobacteriaceae (mcr-1)
- **2015:** Zika virus
- **2013:** Ebola virus in West Africa, Influenza virus A/H7N9, Candida auris invasive hospital-acquired infections
- **2012:** MERS-CoV
- **2011:** Escherichia coli O104
- **2010:** New Delhi metalloprotease-associated carbapenem resistance in Enterobacterales, Huaiyangshan virus (severe fever and thrombocytopenia syndrome)
- **2009:** Influenza virus A/H1N1pdm09

- **2008:** Artemisinin-resistant Plasmodium falciparum, Plasmodium knowlesi, Lujo virus
- **2006:** Extensively drug-resistant Mycobacterium tuberculosis
- **2005:** Human retroviruses HTLV-3 and HTLV-4
- **2004:** Re-emergence of influenza virus A/H5N1
- **2003:** SARS-CoV

The Role of Physicians, Pharmacists, and Nurses in Managing Emerging Infectious Diseases

The emergence of new infectious diseases and the re-emergence of known pathogens present complex challenges to healthcare systems worldwide. The roles of physicians, pharmacists, and nurses are critical in addressing these challenges through prevention, diagnosis, treatment, and management of such diseases. Each of these healthcare professionals plays a unique yet complementary role in the fight against emerging infectious diseases.

Physicians

Physicians are at the forefront of diagnosing and managing emerging infectious diseases. Their role encompasses several key areas:

1. **Diagnosis and Assessment:** Physicians are responsible for identifying symptoms and providing accurate diagnoses of emerging infectious diseases. This involves a thorough understanding of the disease's clinical presentation, which can often be atypical or overlap with other conditions. Physicians must remain vigilant and updated on the latest disease patterns and diagnostic criteria, which may involve collaborating with infectious disease specialists and utilizing advanced diagnostic tools.
2. **Treatment and Management:** Once a diagnosis is confirmed, physicians devise and implement treatment plans tailored to the individual patient. This may include prescribing appropriate antiviral or antibiotic medications, managing symptoms, and addressing complications. Physicians must also consider emerging drug resistance patterns and adapt treatment protocols accordingly. For example, in the case of COVID-19, treatment protocols have evolved as more information about the disease has become available.
3. **Public Health and Prevention:** Physicians play a crucial role in public health by implementing preventive measures and advising on vaccination strategies. They contribute to outbreak surveillance and reporting, which helps in tracking and controlling the spread of infectious diseases. Physicians also engage in educating patients and the community about preventive measures, such as hygiene practices and vaccination.
4. **Research and Policy:** Physicians often participate in research efforts to better understand emerging infectious diseases and develop new treatment approaches. They may contribute to clinical trials and studies that inform public health policies and guidelines. Their insights are valuable in shaping responses to outbreaks and improving healthcare practices.

Pharmacists:

Pharmacists play an essential role in the management of emerging infectious diseases through their expertise in medication management and patient care:

1. **Medication Management:** Pharmacists are responsible for ensuring the safe and effective use of medications. In the context of emerging infectious diseases, this includes selecting appropriate antiviral or antimicrobial agents, monitoring for adverse effects, and managing drug interactions. Pharmacists must stay informed about new medications and treatment guidelines to provide accurate recommendations.
2. **Drug Resistance and Stewardship:** Pharmacists contribute to combating antimicrobial resistance by promoting responsible drug use. They participate in antimicrobial stewardship programs that aim to optimize the use of antibiotics and other antimicrobials. This involves educating healthcare providers and patients about appropriate drug use and monitoring prescription patterns to prevent misuse.
3. **Patient Education:** Pharmacists educate patients about their medications, including how to take them correctly, potential side effects, and the importance of adherence to prescribed regimens. In the case of emerging infectious diseases, pharmacists provide crucial information on new treatments and preventive measures.
4. **Supply Chain Management:** Pharmacists are involved in managing the supply chain for medications and vaccines. During an outbreak, they ensure the availability and distribution of essential drugs and vaccines. They work with healthcare systems and regulatory bodies to address shortages and ensure that medications are accessible to those in need.

Nurses:

Nurses are integral to the management of emerging infectious diseases, providing direct patient care and supporting broader healthcare efforts:

1. **Direct Patient Care:** Nurses are responsible for providing hands-on care to patients with emerging infectious diseases. This includes monitoring vital signs, administering medications, and implementing infection control measures. Nurses play a key role in managing symptoms, providing comfort, and ensuring patient safety.
2. **Infection Control:** Nurses are vital in implementing infection control practices to prevent the spread of infectious diseases within healthcare settings. This includes adhering to protocols for personal protective equipment (PPE), hand hygiene, and isolation procedures. Their role in maintaining a sterile environment and preventing cross-contamination is critical to controlling outbreaks.
3. **Patient and Family Education:** Nurses educate patients and their families about the nature of the disease, treatment options, and preventive measures. They provide support and counseling to help patients cope with the emotional and psychological aspects of illness. Effective communication is essential in ensuring that patients and families understand and adhere to treatment and prevention strategies.
4. **Coordination and Advocacy:** Nurses coordinate care among different healthcare providers and advocate for patients' needs. They play a role in

managing complex cases and ensuring that patients receive comprehensive care. Nurses also contribute to public health efforts by participating in vaccination campaigns and health promotion activities.

5. **Surveillance and Reporting:** Nurses contribute to disease surveillance by documenting and reporting cases of emerging infectious diseases. This information is crucial for monitoring the spread of diseases and implementing timely interventions. Nurses collaborate with public health authorities to provide data that informs outbreak responses and policy decisions.

In managing emerging infectious diseases, the roles of physicians, pharmacists, and nurses are interdependent and essential. Physicians lead in diagnosis, treatment, and public health efforts; pharmacists manage medication use and resistance; and nurses provide direct care, implement infection control measures, and educate patients and families. Together, these healthcare professionals form a comprehensive response team, working collaboratively to address the challenges posed by emerging infectious diseases and safeguard public health. Their combined expertise and efforts are crucial in mitigating the impact of these diseases and preparing for future health threats.

Strategies for Addressing the Next Infectious Pandemic:

Preparing for the next pandemic involves a multifaceted approach that combines various strategies to enhance readiness and response capabilities. Here are some of the most common and effective strategies:

1. Surveillance and Early Detection

- **Global Surveillance Systems:** Strengthening global and national surveillance systems to monitor and detect emerging pathogens early. This includes enhancing reporting mechanisms, laboratory capabilities, and data sharing among countries.
- **Sentinel Surveillance:** Utilizing sentinel sites and networks to detect outbreaks of new infections, especially in high-risk areas such as wildlife markets and regions with high zoonotic disease prevalence.

2. Research and Development

- **Vaccine Development:** Investing in research and development of vaccines for potential pathogens. Developing platform technologies that allow rapid adaptation of vaccines to new pathogens can accelerate response times.
- **Antiviral and Therapeutic Research:** Conducting research to discover and develop new antiviral drugs and treatments. This includes exploring novel drug candidates and improving existing therapies.
- **Diagnostic Tools:** Developing and validating rapid and accurate diagnostic tests for new pathogens. Ensuring that these tests can be deployed quickly in the event of an outbreak.

3. Preparedness Planning

- **Pandemic Preparedness Plans:** Developing and updating comprehensive pandemic preparedness and response plans at national and institutional levels. These plans should include protocols for outbreak detection, response, and recovery.

- **Simulation Exercises:** Conducting regular simulation exercises and drills to test and refine pandemic response plans. These exercises help identify gaps and improve coordination among different agencies and sectors.

4. Public Health Infrastructure

- **Strengthening Healthcare Systems:** Enhancing the capacity and resilience of healthcare systems to handle surges in patients during an outbreak. This includes expanding hospital capacity, ensuring adequate supplies of medical equipment, and training healthcare workers.
- **Emergency Response Teams:** Establishing and maintaining rapid response teams that can be deployed to outbreak sites to provide assistance and support.

5. Global Collaboration

- **International Cooperation:** Fostering collaboration between countries, international organizations (e.g., WHO), and non-governmental organizations to share information, resources, and best practices. Coordinated efforts can improve the effectiveness of response measures.
- **Information Sharing:** Promoting transparency and information sharing regarding outbreaks and response efforts. This includes sharing data on pathogen characteristics, spread patterns, and response strategies.

6. Public Communication and Education

- **Public Awareness Campaigns:** Running public education campaigns to inform people about preventive measures, such as hygiene practices, vaccination, and recognizing symptoms of emerging diseases.
- **Clear Communication:** Providing clear, accurate, and timely information to the public during an outbreak to prevent misinformation and panic.

7. Stockpiling and Resource Management

- **Medical Supplies:** Stockpiling essential medical supplies, including vaccines, antiviral drugs, personal protective equipment (PPE), and diagnostic tests.
- **Resource Allocation:** Ensuring efficient allocation of resources, including funding, medical supplies, and personnel, based on need and urgency.

8. Addressing Antimicrobial Resistance

- **Antimicrobial Stewardship:** Implementing antimicrobial stewardship programs to combat the rise of drug-resistant pathogens. This involves promoting appropriate use of antibiotics and other antimicrobial agents.
- **Resistance Monitoring:** Monitoring and tracking patterns of antimicrobial resistance to inform treatment strategies and prevent the spread of resistant infections.

9. Zoonotic Disease Monitoring

- **Wildlife Surveillance:** Monitoring wildlife populations for signs of zoonotic diseases that could potentially jump to humans. This includes studying interactions between wildlife and humans in high-risk areas.
- **Regulation of Wildlife Trade:** Implementing regulations and controls on wildlife trade and markets to reduce the risk of zoonotic disease transmission.

10. Policy and Governance

- **Health Policies:** Developing and enforcing policies that support pandemic preparedness and response, including regulations for vaccine distribution, travel restrictions, and public health interventions.
- **Funding and Support:** Securing adequate funding and support for pandemic preparedness initiatives, including research, infrastructure improvements, and emergency response capabilities.

By combining these strategies, governments, healthcare systems, and international organizations can enhance their ability to prepare for and respond to the next pandemic effectively, ultimately reducing the impact on global health and society.

Conclusion

The ongoing threat of emerging infectious diseases and pandemics necessitates a comprehensive and proactive approach to global health preparedness. The historical perspective shows a recurring pattern of optimism followed by setbacks due to new infectious threats, such as HIV and SARS-CoV-2. This highlights the need for constant vigilance and adaptation in our strategies. Strengthening global surveillance systems is fundamental for early detection and rapid response to emerging pathogens. This involves enhancing reporting mechanisms, laboratory capabilities, and international data sharing. Sentinel surveillance and targeted monitoring in high-risk areas are also crucial to identify outbreaks early. Research and development play a critical role in preparing for future pandemics. Investing in vaccine development and platform technologies that allow rapid adaptation to new pathogens can significantly improve response times. Similarly, advancing antiviral and therapeutic research, along with developing accurate diagnostic tools, is essential for effective management of emerging diseases. Preparedness planning, including the development of comprehensive pandemic response plans and regular simulation exercises, is vital to test and refine response strategies. Strengthening public health infrastructure to handle patient surges and ensuring the availability of medical supplies and emergency response teams are also crucial components of an effective preparedness strategy. Global collaboration enhances the effectiveness of pandemic response by fostering information sharing and resource pooling among countries, international organizations, and non-governmental organizations. Transparent communication and public awareness campaigns are necessary to prevent misinformation and promote adherence to preventive measures. Addressing antimicrobial resistance through stewardship programs and resistance monitoring is imperative to combat the slow pandemic of drug-resistant pathogens. Additionally, monitoring zoonotic diseases and regulating wildlife trade help mitigate the risk of new infectious threats originating from animal reservoirs. The roles of healthcare professionals—physicians, pharmacists, and nurses—are interdependent and vital in managing emerging infectious diseases. Physicians lead in diagnosis and treatment, pharmacists manage medication use and resistance, and nurses provide direct care and implement infection control measures. Their collaborative efforts ensure a comprehensive response to infectious disease threats. In summary, a multi-faceted strategy involving surveillance, research, preparedness planning, public health infrastructure, global cooperation, and professional roles is essential for effectively addressing emerging infectious diseases and preparing for future

pandemics. The combined expertise and efforts of healthcare professionals, along with robust preparedness and response strategies, are key to safeguarding global health and mitigating the impact of future health crises.

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استشراف الأزمات الصحية العالمية المستقبلية: استراتيجيات التعامل مع الأمراض المعدية الناشئة والاستعداد للجائحة القادمة

الملخص:

المقدمة :على الرغم من التفاؤل الأولي بشأن السيطرة على الأمراض المعدية من خلال المضادات الحيوية واللقاحات، فإن ظهور جائحة الإيدز والأزمات الصحية العالمية الأخيرة قد سلط الضوء على التهديد المستمر للأمراض المعدية. تبرز زيادة مقاومة المضادات الحيوية، والعوامل الفيروسية الجديدة مثل فيروسSARS-CoV-2 ، والإرهاب البيولوجي الحاجة إلى يقظة دائمة. الأمراض المعدية الناشئة هي تلك التي تتزايد معدلاتها أو التي قد تزداد في المستقبل، وغالباً ما تنبع من أصول حيوانية بسبب التفاعل بين الإنسان والحيوان والتغيرات البيئية.

الهدف :يهدف هذا المقال إلى مراجعة الاستراتيجيات الخاصة بالتعامل مع الأمراض المعدية الناشئة والاستعداد للجائحات المستقبلية، مع التركيز على أدوار المتخصصين في الرعاية الصحية والتدابير الأساسية للاستعداد.

الأساليب :تم إجراء مراجعة شاملة للبيانات التاريخية والحديثة حول ظهور الأمراض المعدية، بما في ذلك العوامل المسببة للأمراض الحيوانية والمقاومة للمضادات الحيوية. تم تحليل أدوار الأطباء والصيادلة والممرضين في إدارة هذه الأمراض، بالإضافة إلى استراتيجيات الاستعداد للجائحات.

النتائج :تشمل الاستراتيجيات الفعالة تعزيز نظم المراقبة العالمية، والاستثمار في البحث والتطوير للقاحات والعلاجات، وتحسين التخطيط للاستعداد، وتعزيز التعاون الدولي. تشمل الأدوار الرئيسية للمتخصصين في الرعاية الصحية التشخيص، والعلاج، وإدارة الأدوية، ومراقبة العدوى، وتعليم المرضى.

الخاتمة :يتطلب التعامل مع الأمراض المعدية الناشئة والاستعداد للجائحات المستقبلية اتباع نهج متعدد الأوجه يتضمن تعزيز المراقبة، والبحث، والبنية التحتية للصحة العامة، والتعاون العالمي. تعتبر الجهود المشتركة بين الأطباء والصيادلة والممرضين ضرورية في إدارة هذه التهديدات وحماية الصحة العالمية.

الكلمات المفتاحية :الأمراض المعدية الناشئة، الاستعداد للجائحات، الأمراض الحيوانية المنشأ، أدوار الرعاية الصحية، مقاومة المضادات الحيوية، استراتيجيات الصحة العالمية.