

The Never-Ending Battle: Strategies for Infectious Disease Control in The Face of Emerging Pathogens

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1. Introduction

Both natural processes, such as the development of pathogens over time, and human behavior and behaviors may cause newly emerging infectious illnesses. Natural processes include the evolution of pathogens over time. Population expansion, migration from rural regions to urban areas, international air travel, poverty, conflicts, and detrimental ecological changes as a result of economic development and land usage are some of the factors that have led to these changes. The transmission of infectious agents from animals to people is the cause of a significant number of newly discovered illnesses (Fong & Fong, 2017). The probability that humans may come into close contact with animal species that have the potential to be hosts of an infectious agent is certain to rise as the human population grows and extends into new geographical locations. It is simple to understand that this combination creates a significant danger to human health when that element is paired with increases in human density and mobility. This combination poses a hazard to human health. As a potential contributor to the growth of infectious illnesses, climate change is becoming an increasingly pressing reason for worry. Diseases can spread into new geographical regions when the temperature of the Earth increases, and various ecosystems are changed (Baker et al., 2022; Jones et al., 2008). Certain microorganisms, such as bacteria, viruses, and others, can evolve over time and acquire resistance to the medications used to treat illnesses caused by infections. Consequently, medicines that were beneficial in the past for the purpose of illness control are no longer suitable for this purpose. Vaccine coverage that is decreasing may lead to the resurgence of disease; hence, even when there is a vaccine that is both safe and effective, an increasing percentage of individuals opt not to be vaccinated against the illness (Baker et al., 2022; Trovato et al., 2020).

The plague in the fourteenth century, the Spanish flu of 1918, and, recently, the COVID-19 pandemic are examples of threats that have not disappeared but are constantly resembling one difference: they remain deadly. They underscore the need for constant alertness and creativity in how people address the spread of infectious diseases (Mack et al., 2007). Given the availability of new pathogens, conventional approaches to combating diseases do not suffice. One of the reasons why attempts to fight this disease proved so difficult is that various factors influenced its evolution, including changes in the environment, growing international travel, and mutations of the microbes that caused the disease (Levitt et al., 2010). Technological changes such as deforestation and climate change affect ecosystems in a way that the disease-causing pathogens seek new niches to thrive on. Globalization also helps in the speedy interconnectivity of people and the carriage of goods, helping to spread diseases. However, pathogens are not stateless entities; they change, and evolution may, on certain occasions, compromise their susceptibility to treatments (Flood et al., 2024).

Solving these problems is possible only through a complex set of measures. Healthcare, prevention, and early diagnosis programs are pivotal to preventing severe epidemics. It has been

found that prevention is highly effective, and such measures are usually manifested in vaccination and health promotion. Quarantine, isolation procedures, and antimicrobial agents are used to prevent cases from getting out of hand or spreading to the community (Choudhary, 2021). However, technology and innovation play a significant role in fighting economically threatening diseases. Some diagnostic tools, data analytics, and vaccine efficacy have contributed to improved knowledge of the current threats posed by emerging pathogens. International cooperation and policy frameworks support people's cooperation at the international level and the exchange of resources and information. This chapter provides an assessment of the various approaches used in managing infectious diseases and the ever-evolving nature of the task. Mainly, the emphasis is made on considering historical and modern techniques, the technologies that play a significant role in today's world, and global collaboration in the context of controlling infectious diseases (Tabish & Nabil, 2022).

1.1. Infectious Diseases

Infectious diseases originate from pathogenic organisms, including bacteria, viruses, fungi, or parasites. When the host is infected, these can enter the body, multiply, and cause symptoms and health complications. Infectious diseases can be passed on through direct contact with an affected individual, contact with objects or articles contaminated with the disease-causing agents, consumption of contaminated food or water, and through vectors such as insects or some animals (Kapasi, 2024). Infectious diseases are sicknesses caused by pathogens; these differ in degrees of severity, ranging from simple illnesses caused by microbes to fatal diseases caused by viruses that have the potential to spread through a population and cause cases of outbreaks, epidemics, or even pandemics (Adalja et al., 2019). Some of the well-known infectious diseases are influenza, tuberculosis, malaria, HIV/AIDS, COVID-19, and so on.

2. Emerging Pathogens

Newly identified microorganisms or old disease-causing organisms that are on the rise either have recently entered a population or exist but are spreading fast. These pathogens are relatively new and present substantial threats to human health since most people have not developed immunity against them, and most cures or vaccines are still being developed (Bloom & Cadarette, 2019). New pathogens can develop through several methods, such as genetic mutation, jump species, or change within the environment, which opens other paths to spread. Some newly identified pathogens include SARS-CoV-2, which led to COVID-19, Ebola, and Zika as discussed in Table 1 (Mohapatra & Menon, 2022). Their sources could be fundamental activities like interactions between humans and animals, international and internal travel and trades, increased human encroachment into animal-inhabited areas, and environmental changes.

Table 1: Summary of pathogens with spillover, animal-to-human transmission, human-to-human transmission, or both with their interventions.

Pathogen	Mode of transmission	Intervention	References
Subcritical pathogens	Spillover	Reduction of human contact with camels Camel vaccination	(Dudas et al., 2018)
MERS			
Crimean-Congo hemorrhagic fever (CCHF)	Human-to-human (nosocomial)	Case isolation Contact precautions (PPE)	(Tsergouli et al., 2020)
Nipah	Spillover	Avoid consumption of palm sap Covers for palm sap collection vessels	(Nikolay et al., 2019)

Pathogen	Mode of transmission	Intervention	References
Avian influenza (H7N9)	"Spillover Human-to-human Both"	"Reductions in poultry exports Market disinfection Handwashing Social distancing Poultry trade regulations Health education campaigns"	(Stoto et al., 2019)
Post-elimination measles	"Spillover	Targeted vaccination of international travellers	(Hyle et al., 2019)
Monkeypox	"Spillover Both Human-to-human"	"Reduce contact with reservoir animals Smallpox vaccination Community-based interventions Improved diagnostics for early case detection Vaccinating healthcare workers"	(Reynolds & Damon, 2012)
Supercritical Pathogens			
Yellow fever	"oth Spillover Human-to-human"	"Vaccination of the general population Vector control Urban vector control"	(Ellwanger & Chies, 2018)
SARS-CoV	"Spillover Human-to-human"	"Culling civets Reducing contacts in live markets Culling civets Reducing contacts in live markets"	(Riley et al., 2003)
Ebola	" S p i l l o v e r H u m a n - t o - human"	"Avoid contact with animals found dead Vaccination of nonhuman primates Safe burial Contact precautions (PPE) Drug treatments Ring vaccination"	(Jendrossek et al., 2019)
SARS-CoV-2	" S p i l l o v e r H u m a n - t o - human "	"Market closure Social distancing Travel restrictions Contact precautions (PPE) Quarantine and isolation"	(Kraemer et al., 2020)

3. A Short History of Emerging Infectious Diseases

The establishment of human settlements and the subsequent development of agricultural practices created favorable circumstances for the creation and spread of infectious illnesses. The development of agriculture made it possible for people to remain in the exact location, and the rise in food production led to an increase in population density that was far higher than what could be maintained only by hunting and gathering. Because of this population density increase, a critical mass of individuals found it possible to maintain and transmit infectious and contagious illnesses. Additionally, some agricultural methods, notably the domestication of animals, led to a rise in the number of encounters between humans and animals and interactions between groups of animals of various species. Different species interacted with one another, creating the perfect environment for developing new infectious illnesses (Weiss & McMichael, 2004). The subsequent historical events that included migration, conflict, and commerce established a way by which disease epidemics

might be transmitted to new populations all across the globe (McNeill, 2010). Throughout human history, the distribution of infectious illnesses has occurred during societal upheaval and changes (McMichael, 2004). There is a possibility that infectious diseases were responsible for some events that occurred throughout history. An epidemic wiped out the population of ancient Greece, and the period known as the "Plague of Athens," which may have been caused by typhus, may have had a significant role in determining the result of the Peloponnesian war and the destiny of the state of Athens. Similarly, the 'Justinian Plague,' which is thought to have been caused by *Yersinia pestis*, had a significant impact on the Byzantine Empire and was responsible for the destruction of Constantinople when it occurred (Wagner et al., 2014). After fourteen centuries, the plague made its way to Europe via trade routes, which led to an exceptionally high fatality rate. The massive fall in population that occurred as a consequence throughout Europe contributed to a rise in social mobility and may have had a role in the development of changes in the political and economic structure (Alesina, 2013). Exploration and travel were other factors that contributed to the introduction of new infectious illnesses into populations that were vulnerable to them. For example, when the Spanish arrived in the Americas, they brought with them the diseases of measles and smallpox. These illnesses had a more significant effect on the native population than on the comparatively tiny troops that accompanied Cortez and Pizarro. The transmission of newly discovered illnesses was mostly one-sided, although it was not unidirectional. For instance, it is quite probable that Spanish explorers were the ones who brought syphilis to Europe (Weiss & McMichael, 2004).

Within the context of the Industrial Revolution, cities, with their quickly expanding populations, were highly influential in spreading infectious illnesses. This was especially true in Britain. As the people relocated from rural areas to urban areas to find employment in the newly constructed factories, migrants encountered overcrowding, longer working hours, and an inferior diet in comparison to their contemporaries who lived in rural communities over the same period diseases like TB, typhus, and smallpox were prevalent in urban areas. Measles, mumps, and scarlet fever were among the illnesses that contributed to the high rate of child death. Before the extensive implementation of contemporary sewage systems in the latter half of the 19th century, sewage was often responsible for directly contaminating water sources. Cholera has been abolished in the United States and the United Kingdom due to cleaner water sources; nonetheless, the spread of cholera continues to be caused by inadequate sanitation in many regions of the globe. Over the last several decades, advancements in technology and the general quality of life for certain people have resulted in new pathways for the spread of newly developing illnesses.

As a consequence of the growing number of people traveling, it is now possible for illnesses to spread from continent to continent in a matter of days rather than weeks or months. As a result, the proximity between people and infectious diseases can no longer be defined in terms of geographic distance. Furthermore, the elements responsible for the emergence of infectious diseases in one region of the globe may rapidly spread to other areas of the world. Additionally, the pursuit of natural resources and food sources has brought people into close contact with new species, increasing the likelihood of disease spillover (Daszak et al., 2000; Jones et al., 2013). This in conjunction with the ease with which both people and diseases can travel, has created an unprecedented opportunity for new diseases to emerge and spread (Polgreen & Polgreen, 2017).

3.1. Ancient and Medieval Times:

Early societies introduced measures of public health that included quarantining the infected individuals and isolation. Quarantine history could be traced back to the 14th century during what was then known as the black death; ships arriving in Venice were asked to stay in quarantine for forty days. It is stated that early attempts to control infectious diseases date back to Egypt, Greece, and China, where early cures and primary surgery by identification of herbs were mentioned (Conti, 2008).

3.2. 17th to 19th Century:

Substances that exist in large amounts but are not visible to the naked eye include microorganisms discovered by Antonie Van Leeuwenhoek in the 17th century. Thus, the development of the smallpox vaccine by Edward Jenner in 1796 provided insight into the functionality of vaccination in combating infectious ailments (Montero et al., 2024). The study carried out by John Snow identified contaminated water as the cause of cholera in London in 1854, and it stressed the significance of hygiene and cleanliness, signaling the start of epidemiology as a formal science (Tulchinsky, 2018).

3.3. Early 20th Century:

Louis Pasteur and Robert Koch helped establish germ theory that was major in managing infectious diseases by arriving at vaccines, antiseptics, and hygienic behavior. It would be best to mention that effective antibiotics appeared in the late 1940s, with penicillin being the first – and entirely revolutionized the approaches to bacterial infection treatment and the number of lives saved (Podolsky, 2015).

3.4. Mid to Late 20th Century:

One of the world's most significant successes in public health was the elimination of smallpox in 1980 with the help of a large-scale vaccination campaign conducted by WHO. Immunization, for instance, with the emergence of the poliomyelitis vaccine, lessens the impact of many contagious illnesses (Nathanson & Kew, 2010).

3.5. 21st Century:

New diseases such as SARS, H1N1 influenza, Ebola, Zika, and COVID-19 remain relevant assumptions for studying the possibilities of infectious disease control. Genomic sequencing, big data analytics, and artificial intelligence are new methods for managing and preventing infectious diseases (Dong et al., 2021).

4. Why is it Necessary to Focus on New and Reemerging Pathogens?

New strains of diseases present an actual and potential menace to the world's population. Several vital factors underscore the importance of addressing these threats:

4.1. Rapid Spread and Global Impact:

New pathogens possess the characteristics of epidemiology as international mobility has enhanced the ease of disease spread. An example is the COVID-19 global pandemic, which within months, affected almost all countries globally, leading to illnesses, numerous deaths, and economic disruptions. The integration of international supply networks and globalization contribute to the fact that the cases of the pandemic's outbreak in one region can negatively affect the entire world economy and health systems (Ibn-Mohammed et al., 2021).

4.2. Limited Preparedness and Response:

Emerging strains are a significant threat because the health systems may not prepare for such diseases because there is little information, few diagnostic methods, and no vaccinations or medicines available. The initial process is of utmost importance in managing new pathogens that threaten society, and this can only be done effectively if there are efficient surveillance mechanisms, quick diagnostic tools, and malleable health systems (Baquerkhani et al., 2022).

4.3. Public Health and Economic Consequences:

Disseminated things can rapidly infect a large number of people, overloading healthcare facilities and further worsening morbidity and mortality. Health centers, especially hospitals, are overburdened with patients, and normal outpatient services are likely to be affected. Pandemic

diseases are costly to the economy, resulting in health and related services expenditures, productivity loss, and economic development fluctuations. According to the World Bank the global cost of COVID-19 might be in trillions of dollars for global economies (Weiss et al., 2020).

5. Antimicrobial Resistance:

The use of antibiotics and other antimicrobial agents in the wrong or excessive quantities is a cause of resistant strains of bacteria, viruses, and other pathogens. This resistance hinders the management of infections, raising the rates of severe diseases and death. Crushing of antimicrobial resistance entails collaborative efforts worldwide and appropriate utilization and creation of further antimicrobial agents (Jani et al., 2021).

5.1 Need for Innovation and Collaboration:

Dealing with new pathogens requires constant studying, testing, and development of novel vaccines, drugs, and diagnostic techniques. This encompasses the use of the latest technology and encourages innovation in biomedical science. International cooperation must be achieved because diseases are not limited to a given country's/region's territory. It is crucial to stress that no single country can fight new threats alone; thus, international organizations, national governments, and the private sector must cooperate to share information, experience, and resources (Jones et al., 2009). Thus, the primary and secondary prevention of infectious diseases and the containment of new pathogens are vital to maintaining good health and well-being, guaranteeing economic growth, and preserving the world's stability. It is essential to look out and be ready to fight the next in a continuous struggle between man and pathogens. Emerging pathogens are new to a given population or are increasingly being identified in a population or regions of geographical distribution where they previously had negligible influence. Such pathogens are usually of new types or strains recently emerging or mutating from existing microbes. They tend to be more pathogenic, resistant to treatments, and can infect people of different species. Some of them include the coronavirus (COVID-19), the Ebola Virus, which is responsible for severe hemorrhagic fever ranging from moderate to severe in human beings, and the Zika Virus, which leads to congenital disabilities and neurological afflictions in human beings (McEntire et al., 2021). These include the H1N1 virus that caused the flu pandemic in 2009 and the MERS-CoV virus, which is widely known to cause the Middle East Respiratory Syndrome. The causes of infection re-emergence include ecological shift, climate change, movement of people and animals, goods and services, and microorganism characteristics, including drug and vaccine resistance. These changes in environmental inclinations, for instance, deforestation, urbanization, and fluctuation in climate make the interaction between humans and wildlife or between different species easier, thereby increasing the incidence of pathogens and zoonotic diseases. There are also the aspects of new pathogen creation through intensified livestock contact with people and administration of antibiotics to livestock to gain resistance strains (Harbarth et al., 2015).

Deliberate travel and transporting goods and services have created more chances for people to move across the globe, thus creating more authoritative chances for diseases to move across continents. Through today's means of transportation, viruses can quickly spread from one country to another; the globalization of the wildlife trade means that new strains of pathogens can be brought directly to human populations, as was the case with the SARS-CoV-1 virus outbreak concerning wild animal markets (Leite Junior et al., 2020). These factors are further compounded by microbial adaptation and resistance when it comes to the control of emerging pathogens. The genetic changes in the pathogen can also increase its virulence capacity to bypass the host's defence mechanisms or resist the effects of drugs. Horizontal gene transfer enables bacteria to use genes resistant to other bacteria, forming multi-drug-resistant organisms. The regular use of antibiotics and other antimicrobial substances puts pressure on the exertion of success of the existing strains of microorganisms (Emamalipour et al., 2020).

6. Surveillance and Early Detection

6.1. Significance of Surveillance Systems

Surveillance systems form the base of most public health interventions and are critical in controlling epidemics of infectious diseases. Interpretation and management of the surveillance enable the early detection of the events, the trends of diseases and the effects of the interventions. Surveillance is an organized and structured means of assembling, studying, and using operative health information to drive community decisions. They help in the early institution of control measures, thus preventing the spread of contagious illnesses and their effect on society. Surveillance systems also support cooperation and information sharing regarding international health threats, which are mandatory since the hazards are not confined to local or regional areas (Caballero-Anthony, 2006).

6.2. Modern Technologies in Diseases Diagnosis

Modern technology has boosted the vigour of disease detection, sharpening up the methodology of surveillance. Technologies of the present age offer effective ways of diagnosing and monitoring diseases and their spread long before they gain epidemic proportions.

6.2.1 Genomic Sequencing

Genomic sequencing is a modern innovation that involves the analysis of the total DNA or RNA of the pathogen and provides a clear view of the pathogen's genes. This information is invaluable for several reasons: This information is invaluable for several reasons:

6.2.2. Identification and Characterization: Molecular characterization aids in the proper type and description of the agents; they determine the pathogen's propensity to cause disease, how it spreads, and the drugs it can evade (Procop, 2007).

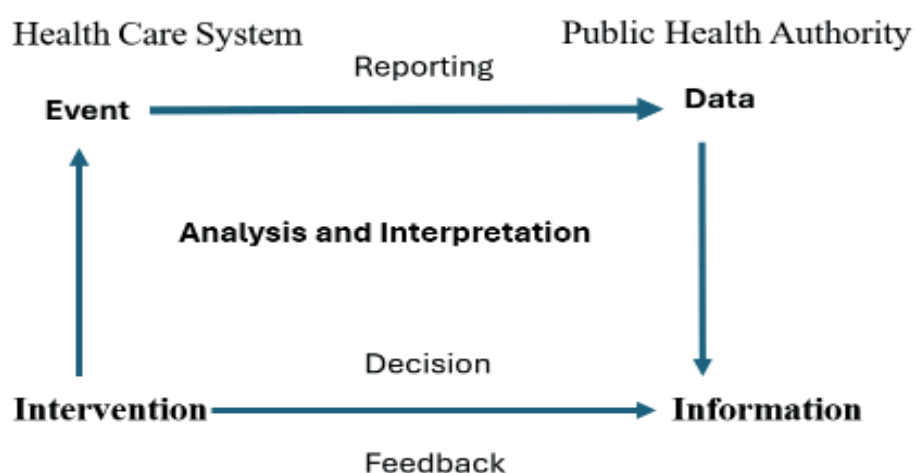
6.2.3. Tracking and Monitoring: By comparing sequences of the genes from various samples, the researchers can monitor the spread of pathogens or their evolution in the shortest time possible. This capability is beneficial in tracking the roots of the incidents and assessing the impact of new strains (Pybus & Rambaut, 2009).

6.2.4. Vaccine and Therapeutic Development: Knowing the relatedness of pathogens helps develop the best vaccine and ways of treating pathogen-related sicknesses. For example, quick sequencing of the virus SARS-CoV-2 paved the way for the fast development of COVID-19 vaccines (Riley & Blanton, 2018).

6.2.5. Outbreak Response: Sequencing offers essential information for public health interventions and includes elements of contact tracing, quarantining, and travel bans. In the years following COVID-19, human genomic data has depended on it to detect new strains and apply necessary preventive measures (Hill et al., 2021; Hoque et al., 2020). Therefore, the role of surveillance systems and capturing the opportunities with the latest technologies like genomic sequencing remain paramount in combating infectious diseases. These tools are essential because they help identify disease outbreaks early and the correct intervention to take and manage them, ensuring people's health worldwide.

Table 2: Challenges of current surveillance strategy

Type	Challenges	Suggestion
"Scarce international cooperation"	"(i) Current surveillance sources are not well-allocated around the world. (ii) Some countries are unwilling to share pathogen materials."	"Establishing a global effective surveillance system under the frame of WHO, through integrating current surveillance systems among various countries."
Technical shortage	"(i) Data analysis is lacking accuracy. (ii) Lacking sufficient capability of real-time and automatic surveillance. (iii) Lack of specificity and reliance on chief complaint data. (iv) Insufficiency in detecting unknown pathogen"	"(i) Using the big data technique based on multiple stream information for accurate surveillance. (ii) Using automatic biosensing detection techniques, combined with modern networking and communication technology. (iii) Interdisciplinary integration in high techniques including internet, big data and molecular detection. (iv) Developing multiplexed detection methods and novel gene sequencing techniques."
"Fragments in management"	Lacking enough coordinate and interoperability across agency borders to share data to meet the surveillance requirement	"Establishing well-integrated surveillance across different departments."
Others	(i) Privacy of protected health information	(i) Legislation to regulate surveillance activities.

**Figure 1.** Framework for surveillance and response measures for emerging infectious disease.

6.3. Preventive Measures

6.3.1. Vaccination

Development and Deployment of Vaccination occupies one of the critical approaches to preventing infectious diseases. Vaccine development also goes through different phases: exploratory/research, pre-clinical/animal studies, clinical trials, and Regulatory approval. Once a vaccine is developed, especially once it goes through the process of being tested and trials to prove that it is safe for administration and effective in the war against a particular disease, it is produced and circulated in the community. These include using national immunization days, EPI sad calendar, and

unique target group campaigns. Vaccination campaigns have been proven to work, and smallpox has been completely eradicated. In contrast, polio has nearly been eradicated, and incidences of other diseases such as measles, mumps, and rubella have reduced significantly. Despite the accomplishments, vaccination programs present the following challenges. Lack of trust and false information can work against the nation's immunization programs. There are various challenges, like the cold chain problem and distribution of vaccines in hard-to-reach areas. These challenges were brought to light by the COVID-19 pandemic but, at the same time, proved economical and fast vaccine development and delivery. Measures like worldwide cooperation and progressive approaches like mRNA vaccines introduced new standards in vaccinology, which underlines that considering these problems is critical for attaining immunization coverage.

6.3.2. Public Health Campaigns

Hygiene and Sanitation Personal and environmental hygiene and sanitation are critical measures to prevent the spread of infectious diseases. Through education and improved sanitation, hand washing, food preparation, and other hygiene practices, the rates of diarrhea, cholera, and hepatitis A illness have significantly declined. The infrastructure includes a clean water supply and proper sewage systems. Indeed, health departments often initiate displays when epidemics occur to remind the audience of the potential consequences of insolent germs. Education and awareness programs and campaigns are crucial in the fight against diseases as they help change people's behavior and attitudes toward preventing the spread of diseases. Through these campaigns, awareness messages on the symptoms, mode of spread, and prevention methods of the diseases are transmitted through different media stations. Awareness is created through programs in schools and communities to have correct knowledge and practice to prevent disease spread. Efficient campaigns such as the HIV/AIDS campaign or the anti-smoking campaigns capture the essence of education in enhancing the population's health.

6.3.3. Measures Used in Quarantine and Isolation

Quarantine and isolation are essential to control contagious diseases, particularly during epidemics. To mean effective quarantine, people who may have been in contact with or are infected with the disease are isolated and cannot move around. Isolation, on the other hand, includes taking the already affected individuals from the larger population and putting them in isolation. These practices have been in existence for many years, from the times of epidemics such as that of the black death to the recent ones such as the COVID-19 virus. Implementing quarantine and isolation entails proper communication, facilities, and support structures for people in quarantine. Although these measures may inconvenience the public, they are very effective if implemented at the right time and properly to curb the spread of diseases. Thus, immunization, raising the population's awareness and education, and measures related to quarantine and isolation are among the crucial strategies to eliminate the threat of infectious diseases. These strategies limit the occurrence and transmission of diseases and the general ability of health frameworks.

6.4. Treatment Strategies

6.4.1. Antimicrobial Therapies: Broad categories in the treatments are antibiotics, which sub-treat bacterial infections; Antifungals, which treat fungal infections; and antiparasitic, which treat parasitic infections. It engages through either the extermination of the pathogens or the prevention of their growth.

6.4.2. Addressing Antibiotic Resistance

This is an emerging health problem of global proportions whereby bacteria change their structure and ability to be killed by antibiotics. Addressing antibiotic resistance involves multiple strategies: Educating patients and their caregivers to improve their understanding of the dangers of over-prescription of antibiotics using health facilities to install antibiotic stewardship programs

to enhance proper usage of the drugs, strengthening global surveillance to detect rising trends of AMR and characterize prevalent resistant strains (Harikumar & Krishanan, 2022) and increasing adherence to infection control measures in health facilities and communities to reduce the emergence and transmission of resistant organisms. Thus, the management strategies for infectious diseases include antiviral and antimicrobial medications, research for more therapeutic options, and combating drug-resistant bacteria. It is essential to control the present emergent diseases and anticipate and look forward to the challenge of new and re-emerging pathogens (Avershina et al., 2021).

6.4.3. Biotechnology Advancements

There are tremendous improvements that have been made by biotechnology in the diagnosis, treatment, and control of infectious diseases. Key areas of progress include:

6.4.3.1. Genomic Sequencing: Molecular biology techniques/western blotting techniques like next-generation sequencing (NGS) can be used to analyze many pathogen sequences simultaneously. This capability is extremely important for diagnosing and typing new pathogens, epidemiological surveillance, and studying and differentiating strains. Genomic sequencing played a crucial role in COVID-19 when new virus variants were discovered (Benito-Vicente et al., 2018).

6.4.3.2. Monoclonal Antibodies: Monoclonal antibodies are substances produced in the laboratory to resemble the human body's immune system when combating dangerous pathogens. These are employed in managing numerous infectious ailments such as COVID-19, Ebola, and respiratory syncytial virus (RSV). Antibody therapies have proven to be very effective in eliminating disease-causing agents and lowering the disease's severity (Mokhtary et al., 2022).

6.4.3.3. mRNA Technology: Lockdowns and mRNA technology, which has been hailed for having a role in developing a vaccine for COVID-19, is a breakthrough in developing vaccines. Currently, mRNA vaccines are introduced into the organism's mRNA, which are cells that produce the protein that causes an immune response and protects the organism against the virus. This technology presents a fast and efficient method to create vaccines against several diseases affecting humankind (Deering et al., 2014).

6.4.4. Big Data and AI in Disease Control

Big Data is the accumulation of an immense volume of data that is processed to uncover relationships, correlations, or tendencies, and this is mostly applied to studying the tendencies and patterns of diseases and people's behavior. In disease control, big data is used to: Epidemiological Surveillance: Track the disease occurrences by collecting and analyzing data from different sources, including health facilities, social media conversations, and mobile applications (Fung et al., 2015). Determine future incidences of the disease and areas that may experience high prevalence through movement information, climate, and other factors.

6.4.5. Artificial Intelligence (AI): The use of AI technologies such as machine learning and natural language processing improves the control of diseases by:

6.4.5.1. Early Detection: AI can also help diagnose diseases since one can feed the system with data and then group areas with symptoms characteristic of a particular disease, thus allowing officials to contain the disease quickly (Zeng et al., 2021).

6.4.5.2. Diagnostic Tools: A self-diagnosis auto system can be designed to analyze medical images, laboratory results, patient clinical details, and other related parameters so doctors and surgeons can diagnose infectious diseases aptly and speedily (Alqaissi et al., 2023; Asiri, 2024).

6.4.5.3. Public Health Interventions: AI can be used to design intervention strategies and assess the efficiency of intervention plans in containing the spread of diseases of particular interest in public health (Agrebi & Larbi, 2020). Therefore, in the contemporary world, technology and

innovation are significant determinants of healthcare as they increase disease prevention strategies' availability, effectiveness, and impact. Telemedicine, biotechnology, and applying big data and AI in diagnosing, treating, and preventing infectious diseases positively impact health and the healthcare system's capacity (Dogheim & Hussain, 2023).

6.5. Vector Control Strategies

Control measures are instrumental in eradicating vector-borne ailments, diseases that affect both man and animals and are passed on by agents like mosquitoes, ticks, fleas, and flies. The promotion of vector control aims to decrease or at least minimize these diseases' occurrence by addressing the vectors or their breeding grounds (Lobo et al., 2018). Here are some key strategies:

6.5.1. Vector Surveillance: Surveillance of the vectors is done by evaluating their population density, distribution, behavior, and ability to develop insecticide resistance. This proves helpful in planning and executing control measures in the fight against diseases (Fournet et al., 2018).

6.5.2. Habitat Modification: Modifying or eradicating the breeding place of vectors. These could mean emptying the water in which mosquitoes lay their eggs, cutting vegetation on which ticks like to feed, or better disposing of food waste that attracts flies (Takken & Knols, 2009).

6.5.3. Use of Insecticides: Insecticide spraying to eliminate adult vectors (adulticiding) and or their larvae (larviciding). This approach calls for a proper mode of insecticide selection, considering the efficiency, effects on the surrounding environment, and measures to counteract cases of resistance (Britch et al., 2019).

6.5.4. Biological Control: Release the natural enemies, parasites, or diseases of the vector species to control their populations and, for instance, use fish to eat mosquito larvae in water bodies to check their multiplication (Hajek & Eilenberg, 2018).

6.5.5. Community Engagement and Education: To create awareness of vectors and vector-borne diseases for the public and how to prevent them. Involving the communities in vector control efforts may improve the chances of observing control measures, making them sustainable (Rivera et al., 2023).

6.5.6. Integrated Vector Management (IVM): The proposed vector control method entails adopting multipronged strategies derived from the vector ecology of a given locality and disease epidemiology. IVM also underlines objective interventions and integration of interactions from different sectors (like health, environment, agriculture, etc.) (Dusfour et al., 2019). Vector control is, therefore, not one man's affair, and it should involve public health departments, environmental conservation departments, non-governmental organizations, and the general community. It is crucial in decreasing the rates of vectors and diseases affecting the populace's health and well-being (Wilson et al., 2020).

7. Emerging pathogens difficulties in their study and management

New diseases are dangerous for global health since they can evolve quickly, spread easily, and pressure countries' health services. It is equally important to note the following challenges as they are vital to formulating critical strategies in managing infectious diseases.

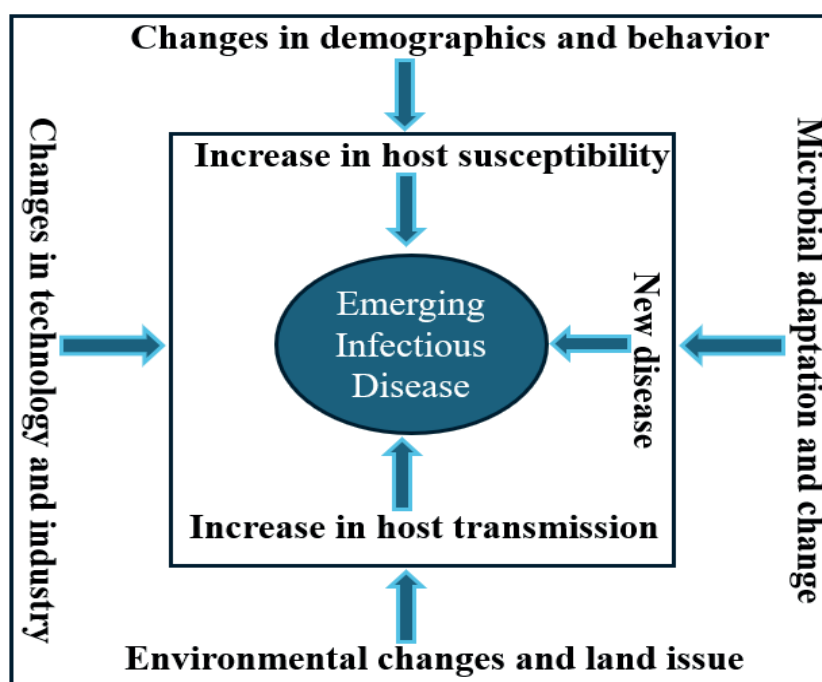


Figure 2: The major factors for the emergence of diseases

7.1. Rapid Gene Mutation and Adaptation

Influenza viruses and SARS-CoV-2, among other pathogens, can mutate rapidly by changing the genetic makeup of the virion. Such mutations may cause the appearance of new strains, much more virulent, transmissible, or immune to current medications and vaccines. This rapid mutation rate poses challenges in managing and eradicating the diseases since the new strains may not be inhibited by immunity offered by previous infections or vaccines (Manzanares-Meza & Medina-Contreras, 2020; Upadhyay, 2021).

7.2. Adaptation:

Viruses, for instance, can transform into other strains due to the availability of new hosts/targets and vice versa (zoonotic diseases). For example, the Ebola virus and the coronaviruses or SARS, MERS, and the recent SARS-CoV-2 virus have crossed the species jump from animals to humans. This adaptability increases their likelihood of spreading infections in new and varied populations. The ability amplifies the extent of their capability to generate epidemics in other new communities (Olival et al., 2017).

7.3. Antimicrobial Resistance:

The mentioned processes, such as horizontal gene transfer, explain the adaptation of bacteria to antimicrobial agents leading to AMR. AMR contributes to the emergence of more potent bacteria and new diseases and prolongs patients' suffering and mortality. The emergence and growth of resistance are made worse by the improper and irrational use of antibiotics in human and veterinary practice and animal production (Thakur & Panda, 2017; Von Wintersdorff et al., 2016).

7.4. Globalization and Spread

7.4.1. Global Travel and Trade:

The circumstances and conditions the modern world provides contribute to the rapid spread of pathogenic agents. Epidemics can be transmitted through flight, and diseases move from one continent to another in hours, as evidenced by COVID-19. Also, through trade, items and animals are transported from one place to another, bringing pathogens to other parts of the world (Hulme, 2009; Kimball, 2016).

7.4.2. Urbanization:

High population and high rate of urbanization increase the population density, leading to the effective spread of infectious diseases. Populace centers are significant breeding grounds, where amenities such as sanitation and health care are hard to come by. The primary transmission mode is elevated human contact and low levels of hygiene, which are hallmarks of such facilities (Alirol et al., 2011; Neiderud, 2015).

7.4.3. Climate Change:

The climate also alters the breeding grounds and behaviors of vectors like mosquitoes and ticks, increasing incidences of vector-borne diseases like malaria, dengue, and Lyme disease. Alteration of climatic factors such as temperature, humidity, and rain affects the breeding of these vectors and their respective diseases (Biswas, 2022).

7.5. National and International Health Policies

One of the most crucial intervention targets is health policies at the national and international levels since they control and promote strategies for preventing infectious diseases. At the national level, health plans define the legal and organizational Epidemiological Surveillance and Disease Notification, Vaccination, Rational Use of Antimicrobials, and Health Promotion and Education (Anderson et al., 2019). They also help to promote the wise utilization of resources and readiness of health facilities in case of an outbreak. At the country level, health policies are guided by instruments such as the IHR, which enumerate countries' expectations in identifying, evaluating, reporting, and managing PHEs. They supplement international collaboration, which is essential for organized responses to health risks that have a global character (Ellwanger et al., 2021).

These health policies involve national and international guidelines and policies regarding the health of citizens. Healthcare policies at the country and global levels are central to planning and executing measures to prevent infection. The ministries of health at the national level draw out legal and institutional frameworks regarding disease surveillance and control, vaccination, antibiotics use, and health promotion. They help determine how funds are used and how healthcare institutions are ready for possible epidemics or other disease-endangering events. At the international level, health policies are embodied in the IHR, which outlines the commitment of countries to monitor, evaluate, notify, and address events of health importance. They enable people worldwide to collaborate and respond to threats whose impacts cross borders (Organization, 2021).

7.6. Organizations (e.g., WHO, CDC)

Infectious diseases are controlled by global and national organizations like WHO and CDC, which are some of the most critical organizations. WHO is a United Nations-related institution that offers international direction in health issues through leading global health initiatives, mobilizing and organizing international surveillance and response to diseases, and standard setting and providing technical cooperation for countries. CDC, being one of the most critical public health organizations in the United States, engages in scientific studies, offers recommendations for optimal delivery of disease prevention and control measures, and helps with the execution of those measures locally

and globally. Both organizations engage governments, non-governmental, and other actors to increase the resilience of health systems, disease monitoring, and health security globally (Cash & Narasimhan, 2000).

7.7. Legal and Ethical Issues of Disease Control

Legal and ethical issues are critical components of the management of infectious diseases. In legal terms, countries must regulate the protection of individual liberties and public health requirements to facilitate quarantine, isolation, and mandatory immunization for diseases while at the same time protecting the rights of the people (Organization, 2017). Ethical issues, therefore, relate to a) Fair and accountable implementation of public health interventions and b) the Dilemma of avoiding prejudice against vulnerable groups in the communities (Carter et al., 2011). Disease control is therefore anchored on several ethical principles such as informed consent, confidentiality, and the right to access one's records. Since Ebola is unusually lethal, matters of morality quickly show themselves during outbreaks regarding resource allocation and restrictions (Kass et al., 2019). Solving these issues implies compliance with the principles of ethics and legislation protecting human rights and justice. Hence, infectious disease policy and governance are essential for today's society. It starts with national and international health policies forming the backdrop for cooperative action since the phenomena affect many nations; while organizations such as the WHO and CDC function as leads as they facilitate the efforts in the society, legislation, and ethics serve as a balancing factor in ensuring that the action taken is fair and just to all as well as covers the entire population's need for health.

8. Future Directions and Innovations

8.1. New Trends in the Identification of Pathogens

Despite their traditionally inconspicuous role, emerging technologies are changing how societies identify pathogens and their presence. Current technologies that speed up genomics involve NGS, which again aids in identifying pathogens and allows for quick tracking of outbreaks. Diagnostics based on CRISPR are highly specific and transferrable to the field, allowing for early intervention even in a virus or bacteria (Bhattacharjee et al., 2021). The techniques in Biosensors and lab on the chip are advanced, which gives the result of the testing done at point care testing where the testing is done in minutes. Health technology enhances our capacity to identify and manage diseases that break out quickly, thus limiting their ability to spread (Umesha & Manukumar, 2018).

8.2. Data Analysis – Predictive Modeling and Forecasting

Forecasting and predictive modelling are indispensable paradigms in containing the spreading of infectious diseases, where historical and real-time data and AI are used to avoid infections. The machine learning algorithms use extensive data analysis, ranging from diseases, population, climate data, and other factors, to determine the likelihood of an epidemic and find possible outbreak areas. These models can also mimic a set of circumstances, assisting policymakers by planning and distributing all the resources. For example, possible scenario aids were used during the COVID-19 pandemic, predicting cases and actions related to the lockdown (Albalawi & Mustafa, 2022). Further development of AI and data assimilation will improve the steps that can be anticipated and taken to minimize the impacts of infection, thus making the measures taken by the public health organization much more anticipatory and effective (Zhao et al., 2024).

8.3. Ethics in the Control of Infectious Diseases

We are using new methods and technologies in the transmission of infectious diseases. Therefore, there are ethical issues that need to be discussed and realized. The application of one's biography into surveillance and utilization into predictive analysis significantly includes privacy and consent issues. Accomplishing purposeful and responsible collecting and analyzing of data

is essential while respecting people's rights. New technologies and treatments for diseases must be available to all since many patients can be discriminated against. Interventions that need to be introduced in organizational settings should be ethics-approved to not worsen existing disparities. Further, people's cooperation in implementing preventive and control measures, disease surveillance, and treatment are vital as the public requires confidence in the health systems. Therefore, there is a need to optimize multidisciplinary approaches to use new technologies for the prompt identification of infectious agents, the application of advanced modelling methods for anticipating disease emergence and investigating the ethical aspects toward proper respect of people's rights within the context of infectious disease prevention and control. Each of these innovations holds the potential to improve our capacity to prevent, diagnose, and manage the outbreak of contagious diseases and thereby create more robust health systems around the globe.

8.4. "One Health" Approach

The origin of around 70% of newly developing infectious illnesses in humans is zoonotic, and it is possible that there are almost 1.7 million viruses that have not yet been found in mammals and birds. Viral transmission of the Hendra and Nipah viruses, two henipaviruses that are associated with significant fatality rates, may occur when an individual comes into close contact with ill horses, pigs, or bats. Even before the coronavirus epidemic, scientists researching zoonotic illnesses have cautioned that actions such as uncontrolled wildlife trading, deforestation, and urbanization had moved humans closer to animals, raising the likelihood of viral spillovers (Cheng, 2022). These practices have brought people closer to animals. The Earth's human population is rapidly approaching 8 billion, yet nobody believes that the amount of contact between humans and animals will diminish. Instead of putting bats to death, experts believe that the most important thing is to lessen the likelihood of a catastrophic spillover. However, they admit that the forces of culture and the economy make reform challenging to achieve. According to several academics, the pandemic caused by the coronavirus highlights the need to adopt a more holistic approach known as "one health," which considers the health of humans, animals, and the environment to be interrelated. There is a need for a cultural transformation that begins at the community level and extends upwards about the manner in which we handle animals, as well as our comprehension of the hazards and biosecurity risks that we are putting ourselves in. maintaining the integrity of ecosystems rather than destroying them (Brulliard, 2020).

8.5. Emergency Preparedness

There has been a failure on a worldwide scale in terms of the coordination of operations, the integrity of public health systems and practices, and transparency. The strategy that governments have taken to address the difficulties posed by previous pandemics has been characterized by a lack of zeal. The majority of vulnerable groups were dismissed, which led to the loss of millions of lives that might have been avoided and had a negative impact on sustainable development. To protect populations, it is essential to have a sustainable vaccination strategy, to strengthen health systems and to broaden the coverage of health services, to address the global climate crisis, to have a better-prepared architecture that is driven by shared responsibility, and to integrate the international response to the risk of future pandemics with actions that are appropriate and definitive (Polgreen & Polgreen, 2017).

One of the most essential lines of protection against each newly discovered infection is the ability to recognize and identify it quickly. Considering the increasing rates of worldwide travel and commerce, which may make it possible for novel infectious illnesses to spread throughout the globe in time frames of days or weeks, surveillance must be conducted globally. The emergence of pathogens is an issue that affects the whole world. Initial outbreaks are the only way to accurately estimate the potential for a novel infection to spread across the human population. This can only be accomplished by carefully monitoring the outbreaks. In the not-too-distant future, it is quite probable that we will come across new species of agents that cause disease in humans. The ongoing

transmission of viruses from natural hosts to people and other animals is primarily attributable to human actions, such as implementing contemporary farming methods and expanding metropolitan areas. As a result, the most efficient method for preventing viral zoonosis is to keep the borders between natural reservoirs and human civilization intact, keeping in mind the notion of "one health." The following are three practical activities that may be taken to reduce the effect of future pandemics: improved monitoring of pathogen spillover and the construction of worldwide databases of viral genomes and serology; improved regulation of wildlife commerce; and a significant decrease in deforestation. These basic pandemic preventive efforts offer large co-benefits and cost less than one-twentieth of the lives typically lost each year due to newly developing viral zoonoses (Bernstein et al., 2022). It is known that there are 219 different types of viruses that are capable of infecting people. Although a significant number of human virus species have not yet been identified, there has been a noticeable slowdown in the pace at which species belonging to various families have been discovered. This may imply that there are limits to the possible range of variety. Phylogenetically conserved cell receptors are one of the few viable predictors of species leaps that may be found. Other putative predictors include species gaps. It seems that new human viruses will continue to originate, mostly from other mammals and birds, for the foreseeable future. This is something that appears to be practically unavoidable. It is necessary to have a worldwide monitoring system that is efficient at detecting new viruses (Woolhouse et al., 2012).

8.6. Primary Prevention of Pandemics

Every year, zoonoses are responsible for around one billion instances of disease and millions of deaths among people all over the world. Approximately sixty percent of newly discovered infectious illnesses that are reported on a worldwide scale are zoonoses. In the last three decades, more than thirty novel human infections have been identified, with seventy-five percent of these pathogens having their origins in animals. Viral infections are the root cause of illnesses that significantly risk the general population's health. Coronaviruses, Marburg syndrome: MERS and SARS-CoV-1, Human Immunodeficiency Virus (HIV), Hendra, Nipah virus (NiV), and the viruses responsible for Crimean-Congo hemorrhagic fever, Lassa fever, Ebola, Influenza A virus subtype H1N1, Asian highly pathogenic avian influenza (HPAI) A(H5N1) virus, or Rift Valley Fever (RVF) viruses have all been responsible for several epidemics in recent years. These epidemics were marked by high morbidity and death rates, and they mainly occurred in underdeveloped nations in South America, Africa, and Asia (Jones et al., 2008; Kulkarni et al., 2015). There is an increase in the frequency of epidemics, which are also growing and spreading further. They believe that we may anticipate around 3.3 million fatalities annually because of zoonotic outbreaks. This estimate is based on the Earth's present population, which is close to 8 billion people.

Among these preventative treatments, identifying viral infections is the most essential component. Inevitably, other epidemics will occur in the future. By enhancing healthcare for underprivileged populations that are located in close proximity to tropical forests, it would be possible to identify outbreaks of infectious diseases and limit their transmission before they can spread further. The investments in conservation and health systems that concentrate on spillover risk are investments in pandemic prevention. Pandemic prevention has the potential to save billions of dollars and millions of lives (Elias et al., 2021). When the first person falls unwell, new and improved mechanisms for identifying and monitoring possible health hazards will be implemented.

Additionally, the preservation of habitats for wild animals will be enforced, which will assist in the transition to a more preventive approach regarding maintaining people's health. Preventative measures are preferable to curative ones. Identifying newly emerging pathogens, which leads to the prompt implementation of preventative measures, has the potential to be very helpful in the fight against outbreaks of non-traditional illnesses. Nevertheless, there are a few specific difficulties that arise while doing surveillance for new diseases. It is necessary to address the deficiencies that currently exist in healthcare delivery systems as well as access to new developments in biological therapies. The importance of international collaboration in the fight against pandemics cannot be

overstated. As people continue to expand into wildlife areas, the danger of pandemics grows. This is because they are increasing the amount of interaction that animals and humans have with one another, which raises the risk of illnesses passed from one species to another. The following are three practical initiatives that have been recommended to lessen the effect of future pandemics: improved monitoring of pathogen spillover and the construction of worldwide databases of viral genomes and serology, improved regulation of wildlife commerce, and a significant decrease in deforestation. The cost of these core pandemic preventive efforts is less than one-twentieth of the value of the lives that are lost annually due to newly developing viral zoonoses, and they confer significant co-benefits. Scientific investigation, policy actions, and financial and organizational resources are required to prevent the next pandemic. It is estimated that primary pandemic prevention actions are remarkably inexpensive compared to the number of lives lost due to emerging viral zoonoses or the direct economic damage they cause (Elias et al., 2021; Tabish & Nabil, 2022).

9. Conclusion

Both natural processes and human behavior, including population expansion, migration, international air travel, poverty, conflicts, and ecological changes, cause infectious diseases. As the human population grows, the likelihood of humans coming into close contact with animal species that host infectious agents increases. Climate change and the evolution of microorganisms over time make traditional treatments no longer suitable for treating infections. The COVID-19 pandemic highlights the need for constant alertness and creativity in addressing the spread of infectious diseases. Conventional approaches are insufficient due to the availability of new pathogens, environmental changes, growing international travel, and mutations of pathogens. Solutions require healthcare, prevention, early diagnosis programs, vaccination, health promotion, and the use of diagnostic tools, data analytics, and vaccine efficacy. International cooperation and policy frameworks support people's cooperation and the exchange of resources and information. Emerging pathogens, such as SARS, H1N1, influenza, Ebola, Zika, and COVID-19, are crucial for studying infectious disease control due to their rapid spread, limited preparedness, public health and economic consequences, antimicrobial resistance, and need for innovation and collaboration. Genomic sequencing, big data analytics, and artificial intelligence are new methods for managing and preventing infectious diseases. Surveillance systems are essential for controlling contagious diseases and enabling early detection of events, trends, and interventions. Modern technologies like genomic sequencing have improved disease detection methods, allowing for identifying and characterizing pathogens, tracking and monitoring pathogen spread, and developing the best vaccines and treatments. Preventive measures include vaccination, which involves various phases, such as exploratory/research, pre-clinical/animal studies, clinical trials, and regulatory approval. Public health campaigns focus on hygiene, sanitation, education, and awareness programs to reduce disease spread. Quarantine and isolation measures are essential to control contagious diseases. Treatment strategies include vaccination, raising public awareness, and quarantine and isolation measures. Antimicrobial therapies, such as antibiotics, antifungals, and antiparasitics, treat bacterial, fungal, and parasitic infections. Biotechnology advancements, such as genomic sequencing, monoclonal antibodies, and mRNA technology, have significantly improved the diagnosis, treatment, and control of infectious diseases. Telemedicine, biotechnology, and applying big data and AI in disease control positively impact health and the healthcare system's capacity. Legal and ethical issues are critical components of disease control, involving regulation of individual liberties and public health requirements while protecting the rights of vulnerable groups. Future directions and innovations in pathogen identification include new technologies such as NGS, diagnostics based on CRISPR, biosensors, and chips.

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