Perspectives

The Implications of Artificial Intelligence on Infection Prevention and Control: Current Progress and Future Perspectives

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The rapid advancement of artificial intelligence (AI) has significantly impacted infection prevention and control, particularly amid the coronavirus disease 2019 (COVID-19) pandemic (*1*). AI techniques such as machine learning (ML), deep learning, and natural language processing (NLP) have successfully transformed infection prevention and control strategies (*1*). These technologies have enhanced our understanding of infectious diseases, facilitated disease transmission prediction, and improved public health emergency responses (*2*). Despite these benefits, AI technologies encounter challenges related to ethics, biosafety, and privacy, including concerns about handling medical data by private entities and its potential misuse (*3*–*4*). Effectively utilizing AI in infection prevention and control requires balancing technical potential with ethical, policy, and societal considerations. In-depth research is essential to provide guidance for the responsible and effective use of AI technologies, thereby informing public health decision-makers and practitioners. This article discusses the current progress and future perspectives of AI applications in various aspects of infection prevention and control.

Disease Surveillance, Outbreak Prediction, and Contact Tracing

AI plays a crucial role in the surveillance and prediction of infectious disease outbreaks. Its ability to process diverse types of data allows healthcare authorities to take proactive measures. A notable example is the Canadian AI system, BlueDot, which uses NLP and ML to integrate various datasets and forecast different infectious diseases (*5*–*6*). By analyzing global aviation patterns, climate changes, zoonotic outbreaks, and epidemiological reports, BlueDot can provide earlier warnings compared to traditional surveillance networks. Additionally, it has been highly effective in projecting the spread of infections and identifying high-risk areas, thus informing public health policies and resource allocation. Numerous deep learning models have been developed to predict the antigenic evolution of various viruses, such as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), influenza, human immunodeficiency virus (HIV), Lassa, and Nipah viruses (*7*–*8*). These achievements underscore the essential contribution of AI to global disease management frameworks.

The application of Bluetooth technology in contact tracing during the COVID-19 pandemic is illustrated by Singapore's TraceTogether app and Hong Kong Special Administrative Region (SAR), China's LeaveHomeSafe app (*9*). These applications facilitate the encrypted exchange of identifiers between nearby devices, with the data being securely stored on the users' devices. When a confirmed infection occurs, users can opt to share this data with health authorities, who can then notify potential contacts. A recent study in Hong Kong, China utilized Bluetooth technology for indoor positioning to develop a contact tracing system for high-risk areas such as schools and residential care homes (*10*). This method effectively manages contact tracing while respecting privacy, contributing significantly to the reduction of disease transmission in indoor settings. However, concerns about data security and personal privacy present obstacles to maintaining user compliance with these tracing systems, which require access to personal mobile devices. Additionally, integrating both indoor and outdoor contact tracing into a single platform remains a challenge.

Diagnosis and Treatment

During the initial phase of the COVID-19 pandemic, AI significantly improved the efficiency of diagnosing early-stage COVID-19 infections, particularly through the autonomous analysis of chest X-ray images (*11*). AI algorithms demonstrated the capability to rapidly diagnose COVID-19 even when radiological findings appeared normal by integrating clinical symptoms, exposure history, and laboratory tests (*12*). Deep learning methods have also been widely applied to identify other infectious diseases, including tuberculosis (*13*) and hepatic echinococcosis (*14*). AI-powered image analysis tools exhibit impressive sensitivity and precision, showing significant potential for disease screening in under-resourced areas with limited healthcare facilities.

DeepMind's AlphaFold algorithm has significantly advanced the decoding of protein structures for SARS-CoV-2 and vaccine development (*15*). Traditional techniques like X-ray crystallography and cryo-electron microscopy are both labor-intensive and time-consuming. In contrast, AlphaFold employs a convolutional neural network trained on Protein Data Bank data to accurately predict protein structures. This algorithm has been widely adopted in the identification of drug candidates for cancer, Alzheimer's disease, and vaccine development (*16*).

Pandemic Preparedness and Response

During the pandemic, AI techniques can be utilized for epidemic forecasting, resource management, and information dissemination to alleviate pressure on hospitals (*17*). A study conducted in Hong Kong SAR, China, utilized deep reinforcement learning (DRL) to analyze diverse data, including travel behaviors, climatic variations, and social media trends. The study aimed to develop adaptive non-pharmacological interventions (NPIs) for managing COVID-19 and other respiratory infectious diseases (*18*). These interventions effectively contained disease outbreaks within the capacity constraints of healthcare systems. The DRL approach strategically controlled the trajectory of the outbreaks, ensuring they remained close to full capacity limits. This strategy expedited the achievement of herd immunity while minimizing resource utilization.

Furthermore, AI has significantly contributed to the effective dissemination of disease prevention and control information. A notable example is the AI-powered chatbot developed by the World Health Organization, which provided reliable information and helped alleviate public anxiety during the pandemic (*19*). Additionally, AI has been crucial in monitoring social media platforms to identify and address COVID-19 misinformation, thereby reducing the spread of rumors (*20*). For instance, NLP methods have been employed to conduct sentiment analysis on posts from Twitter and Reddit, aiming to identify negative communications and misinformation related to COVID-19 (*21*).

Ethical and Safety Concerns

The growing application of AI in medicine and public health underscores its crucial role in enhancing disease surveillance, early detection of infectious diseases, resource allocation, and crisis management. Nevertheless, this expansion also raises significant ethical and safety concerns.

The application of AI in vaccine development raises ethical issues related to data privacy, bias, and equity. AI is widely used to analyze data, including personal health records and genetic information, which underscores the necessity of protecting data privacy. Furthermore, the uneven distribution of healthcare resources leads to biased data in vaccine development, often favoring populations with greater healthcare access (*22*). This imbalance, combined with potential biases, can result in vaccines being less effective and safe for various populations. On a national level, this disparity can exacerbate differences in healthcare standards between developed and developing countries. Therefore, it is essential to use AI ethically in vaccine development to ensure that populations with limited healthcare access also benefit from emerging technologies and to reduce global health disparities.

Without adequate regulation and oversight, the use of AI in vaccine development and distribution may present significant ethical and safety concerns. To address these issues, international legislative efforts, such as those led by the WHO, as well as initiatives in countries like the United States and the United Kingdom, have been implemented (*23*).

The rapid dissemination of information facilitated by AI has inadvertently contributed to the spread of misinformation, particularly during the COVID-19 pandemic. This misinformation poses substantial challenges to epidemic prevention and control. One study conducted a large-scale observational analysis of 76,985 Twitter (now known as X) users, examining over 80 million posts published over 18.5 months (*24*). The findings indicated that individuals who shared COVID-19 misinformation experienced approximately twice the level of anxiety compared to those who did not spread misinformation, resulting in significant adverse psychological effects. These results underscore the psychological impact of misinformation on public mental health and emphasize the need to enhance public discernment of information sources and enforce robust regulation of social media and online platforms. In response, China has reinforced its regulations to protect data security and personal privacy. This includes the 2021 implementation of the "Cybersecurity Law," "Data Security Law" (DSL), and "Personal Information Protection Law" (PIPL) (*25–27*).

In summary, recent advancements in AI, particularly in generative AI models, have significantly impacted various industries. AI has been crucial in predicting epidemics and optimizing resource allocation during the pandemic. It has revolutionized drug design and disease management by providing fast and accurate predictions for diagnosis, disease progression, and treatment development. AI is expected to play an increasingly important role in managing future public health emergencies, particularly in addressing infectious disease outbreaks (*28–29*). However, it is essential to address the ethical and safety concerns that accompany this growth. The recent breakthroughs in generative AI, such as OpenAI's ChatGPT and video generation tools like SORA, offer significant opportunities for interactive and personalized health education. Nevertheless, the potential for misinformation through hallucinations and fake videos poses a risk of disseminating false information, thereby undermining efforts to combat infectious diseases.

To effectively address these challenges, it is crucial to establish international collaboration, enforce strict regulations, maintain ethical oversight, and improve public information literacy. These measures are essential for maximizing the benefits of AI while mitigating associated risks. The successful realization of AI's transformative impact on human civilization depends on a unified effort from global public health organizations, research institutions, and scientists, all focused on promoting universal human welfare (*2*). Regulators should continuously assess and manage the ethical and safety concerns associated with the use of AI in infection prevention and control. Policymakers must proactively address future challenges by enacting laws and regulations that guarantee information security and uphold medical ethics. This approach will foster a conducive environment for the stable development of AI.

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