THE ROLE OF ARTIFICIAL INTELLIGENCE IN PREVENTING COVID-19: CAPABILITIES, EVIDENCE, AND LESSONS FOR FUTURE OUTBREAKS

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Abstract
Artificial intelligence (AI) played a significant role in the COVID-19 response by anticipating disease spread, detecting cases, allocating resources, accelerating biomedical discovery, and informing policy decisions. This paper synthesizes peer-reviewed research and official guidance to evaluate the areas where AI delivered clear benefits and where it faced limitations. Evidence demonstrates measurable public health impacts, particularly in digital contact tracing and wastewater analytics for early warning, as well as the successful repurposing of drugs—such as the AI-identified immunomodulator baricitinib. However, several high-profile applications, including imaging-based diagnostics and cough-audio screening, were hindered by bias, data leakage, or limited clinical utility. We present governance principles aimed at maximizing AI's benefits while minimizing risks and propose a pragmatic roadmap that integrates AI with robust data infrastructure, transparent evaluation, and human-in-the-loop decision-making to enhance future epidemic responses.
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1. Introduction

The unprecedented scale and rapid progression of COVID-19 prompted accelerated experimentation with AI across surveillance, clinical care, and research domains. Public health agencies and researchers leveraged machine learning on diverse data sources—such as mobility traces, Bluetooth proximity, biomedical literature, medical imaging, and wastewater metagenomics—to predict transmission, prioritize testing, and guide interventions. Concurrently, AI-powered knowledge extraction and protein structure prediction aimed to speed up therapeutic development and vaccine-relevant biological discoveries. However, outcomes were inconsistent: while some AI systems yielded actionable insights, others struggled to perform outside controlled development environments. Thoroughly understanding this landscape is essential for designing effective, evidence-based AI solutions for future pandemics.

2. The role of AI in early Warning and Health Situational Awareness

2.1 Event-Based Surveillance and Outbreak Intelligence

Artificial Intelligence (AI) has emerged as a critical tool in enhancing global disease surveillance and outbreak intelligence. Event-based surveillance systems powered by AI algorithms continuously aggregate and analyse heterogeneous data streams, including digital news outlets, online forums, and official public health reports, to identify signals of anomalous epidemiological activity. For instance, HealthMap and Blue Dot independently detected early indications of a novel respiratory outbreak in Wuhan, China, on 30–31 December 2019, nearly concurrent with the first official public health notifications. Such cases highlight the capacity of AI-driven systems to augment traditional surveillance mechanisms by providing timely horizon scanning and situational awareness. However, their effectiveness is maximized when automated outputs are subjected to expert epidemiological validation, ensuring accuracy and contextual interpretation.

2.2 App-based contact tracing and exposure alerts.

Bluetooth-based exposure notification apps (Arogyasetu), developed on the Google-Apple framework, allowed quick identification of people who had been in close contact with an infected individual. In England and Wales, the NHS COVID-19 app was shown in a Nature study to reduce transmission during its rollout from September to December 2020. Later research also showed that such apps provide detailed information about how diseases spread and how people interact, which can guide public health policy. The overall effectiveness of these systems depended on factors such as how many people used the app, how quickly notifications were sent, and whether users followed the advice given. Modelling studies have been useful in identifying how these factors can be improved.

2.3 Wastewater-Based Epidemiology (WBE) with Machine Learning

AI is now used in wastewater monitoring to predict case trends and detect new variants earlier than clinical testing. In several U.S. states, wastewater data successfully predicted COVID-19 hospitalizations. Using machine learning on thousands of samples, researchers also identified variant patterns in sewer systems. Campus programs showed that wastewater monitoring can be very sensitive and even change people's behaviour when alerts are given. Together, these findings suggest that AI-enhanced WBE can serve as a reliable and fair early-warning tool for respiratory diseases.

3. The role of AI in Clinical and public health operations

3.1 patient prioritization, Risk assessment, and Resource Distribution

Machine learning techniques have been applied to assess patient risk and support hospital admission decisions through the analysis of routine clinical and imaging data. Recent research has proposed prognostic models with improved interpretability for clinicians; however, these approaches still require rigorous prospective validation before they can be reliably implemented in clinical practice.

3.2 Imaging-Based Diagnosis: Promise Tempered by Pitfalls

During the early phase of the COVID-19 pandemic, numerous studies introduced deep learning systems aimed at diagnosing or grading disease severity from chest radiographs and computed tomography (CT) scans. However, systematic reviews have demonstrated that the majority of these models lacked clinical utility, largely due to limitations such as biased datasets, shortcut learning, and methodological flaws, including confounded labels and data leakage. Current perspectives, therefore, adopt a more cautious stance, positioning imaging-based AI as a potential tool for clinical decision support rather than as a standalone diagnostic modality. To advance clinical translation, future research must prioritize the development of high-quality, representative datasets and ensure rigorous external validation.

3.3 Audio and Symptom Screening

Artificial intelligence models developed to analyse cough or voice recordings have been investigated as potential tools for COVID-19 detection. However, when assessed under rigorous evaluation protocols, these approaches have not demonstrated clear advantages over conventional symptom checkers. This underscores the importance of developing standardized datasets and implementing preregistered evaluation frameworks to ensure reliability and reproducibility in future research.

4. AI for Biomedical Discovery

4.1 Drug Repurposing: From Knowledge Graphs to Clinical Trials

Artificial intelligence has been increasingly employed to accelerate drug repurposing by systematically mining biomedical literature and integrating mechanistic knowledge graphs. Through these approaches, researchers were able to prioritize existing molecules with potential therapeutic relevance for COVID-19. A notable example is baricitinib, which was identified in early 2020 on the basis of its dual antiviral and anti-inflammatory properties. Subsequent clinical studies provided evidence of benefit, leading to its emergency use authorization. This case illustrates how AI can rapidly narrow the therapeutic search space and facilitate the translation of computational predictions into clinical applications.

4.2 Structural Biology and Protein Design

Advances in AI-based protein structure prediction, exemplified by AlphaFold and its successors, have markedly accelerated the modeling of viral and host proteins as well as their molecular complexes. These innovations have enabled rapid hypothesis generation regarding variant effects, antibody binding, and potential small-molecule targets, thereby facilitating pandemic-relevant research. Although computational predictions continue to require rigorous experimental validation, AI-driven structural biology has become an indispensable tool in the biomedical research pipeline.

4.3 Knowledge Access at Scale

The rapid growth of scientific publications during the COVID-19 pandemic created an urgent need for efficient knowledge access. Open resources such as the CORD-19 corpus and community-driven initiatives like the TREC-COVID challenge catalysed advances in text mining, question answering, and evidence synthesis under conditions of intense time pressure. These efforts enhanced information retrieval across a rapidly evolving literature base and provided valuable support to researchers and guideline developers.

5. Policy Analytics and Behavioural Insights

Artificial intelligence has been increasingly integrated into policy analytics by leveraging mobility data, population surveys, and administrative records to forecast epidemic waves, evaluate the effectiveness of non-pharmaceutical interventions (NPIs), and inform resource allocation. Case studies, such as the experience in Valencia, Spain, demonstrate the value of interdisciplinary "AI + policy" teams embedded within governmental structures. These groups provided evidence-based support for calibrating restrictions, optimizing testing strategies, and tailoring public health communications, thereby enhancing the responsiveness and effectiveness of pandemic management.

6. 7. Ethics and Governance

The World Health Organization's 2021 guidance on artificial intelligence in health underscores six foundational principles: protecting autonomy; promoting human well-being and safety; ensuring transparency; fostering responsibility and accountability; advancing inclusiveness and equity; and promoting responsiveness and sustainability. Translating these principles into practice during pandemics requires concrete measures such as data minimization, privacy-preserving computation techniques (e.g., differential privacy, on-device processing), algorithmic impact assessments, and independent audits. The case of digital contact tracing illustrates how privacy-aware design—through mechanisms such as ephemeral Bluetooth beacons and decentralized risk scoring—can preserve individual rights while still delivering meaningful public health benefits. This model provides an important template for the ethical and responsible deployment of future digital health tools.

Conclusion

While artificial intelligence did not "solve" the COVID-19 pandemic, it contributed in targeted and measurable ways when supported by high-quality data, rigorous evaluation, and robust governance. Digital exposure notification systems helped reduce transmission where adoption was sufficient; wastewater analytics provided earlier epidemiological signals than conventional case counts; AI-assisted drug repurposing accelerated the identification of effective therapies; and advances in protein structure prediction transformed pathogen biology workflows. The central lesson is not the indiscriminate deployment of AI, but rather the institutionalization of effective combinations—such as privacy-preserving population technologies, validated forecasting from environmental signals, and discovery pipelines that integrate AI with rigorous experimental validation—so that these capacities are operationally ready before the emergence of future outbreaks.

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