Introduction

Applied artificial intelligence in healthcare: Listening to the winds of change in a post-COVID-19 world

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Abstract
This editorial article aims to highlight advances in artificial intelligence (AI) technologies in five areas: Collaborative AI, Multimodal AI, Human-Centered AI, Equitable AI, and Ethical and Value-based AI in order to cope with future complex socioeconomic and public health issues.

Keywords: Health AI, artificial intelligence, machine learning, AI governance, multimodal AI, human-centered AI, ethical AI, COVID-19

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Introduction

The COVID-19 pandemic impacted almost every sector of our modern world and created unprecedented change and disruption in the way we live, work, communicate, commute, socialize, learn, entertain ourselves, and do business. From the onset of the COVID-19 pandemic, artificial intelligence (AI) tools and technologies have been used to improve disease surveillance, screening, diagnostics, case detection, prediction, risk stratification, drug and vaccine development, resource allocation, and socioeconomic interventions. Despite their great potential, these AI tools have had little, if any, impact on the response to this devastating pandemic. Many of published prediction models were inadequately reported and most of them had low accuracy, weak predicative power, high risk of bias,[1] and methodological flaws with limited potential for medical and clinical use.[2] Part of the problem might have originated from the lack of access to high-quality COVID-19 data sets,[3] insufficient historical data, and inaccurate training data, which may cause researchers to rely on heterogeneous and noisy data collected at low temporal and geographic resolutions. Furthermore, critical issues stem from the frequent suboptimal implementation and use of AI technologies including the ways they are shared, evaluated, governed, and regulated.[4,5]

The road ahead

Regardless of the above-mentioned challenges, the experiences gained from the COVID-19 pandemic can accelerate innovations in AI technology to better prepare societies to respond to future crises. According to the World Bank,[6] to accelerate AI development at the country level, policymakers are advised to focus on AI research, talent development, supporting entrepreneurship, ethical or trustworthy AI, increasing access to quality data, adoption of AI for public service, strategic sectoral targeting of AI, and strengthening AI governance. Furthermore, to cope with complex socioeconomic and public health issues, we anticipate AI technologies to advance in the following five areas:

1. **Collaborative AI:** During the emergencies imposed by the pandemic, researchers tried to create their own solutions, which often led to many isolated, standalone, and redundant models with similar limitations and biases. Future AI must foster opportunities to promote collaboration (cooperation, competition, or coordination)[7] from multiple stakeholders (human and machines) to maximize a common goal while balancing each entity's individual interests.
2. **Multimodal AI:** Multimodal technologies[8] enable users to access, integrate, and process ever-increasing

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multimodal and complex medical data sets and interact with a system in different modalities at the same time. Multimodal AI particularly attempts to process, manage, and understand these multimodal data through making multimodal inferences to analyze complex associations and relationships between various biological processes, health indicators, risk factors, and health outcomes, and developing exploratory and explanatory models.

3. **Human-centered AI:** With the intention to create AI models that "amplify and augment rather than displace human abilities. It seeks to preserve human control in a way that ensures AI meets human needs while also operating transparently, delivering equitable outcomes, and respecting privacy,"[9] human-centered AI focuses on including the human in the loop. In this way, it provides substantial gains in transparency, fairness, accountability, reliability, and explainability of AI systems.[10,11] The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems recently announced a few principles to advance discussion on the alignment between AI models and human rights and interests.[12]
4. **Equitable AI:** The Covid-19 pandemic once again exposed social, economic, and racial inequalities among under-represented and marginalized communities across the globe.[13,14] Precision equity[15] should be an integral part of precision health[16] and health AI. According to the World Economic Forum's call for more inclusive AI infrastructure,[17] AI scientists and designers "should identify and partner with representatives of these impacted stakeholders on data collection methods, especially when identifying new or non-traditional resources for gathering data." Algorithmic equity[18] is also an important area that needs special attention to ensure that decisions and policies made based on AI algorithms are nondiscriminatory.
5. **Ethical and value-based AI:** Future AI solutions should consider ethical issues and incorporate human values, in their design and use.[19] An important step here is listening to and understanding individuals' concerns and respecting their personal autonomy and right to informed consent, and dissent.

Thematic issue on the future of AI

This thematic issue on the future of AI includes various contributions presenting results on theory, methods, systems, and applications of AI in medicine and healthcare. Boursalie *et al*.[20] studied the challenges of evaluating deep learning–based imputation models by conducting a comparative analysis between root mean square error (RMSE), a predictive accuracy metric, and evaluation metrics used in statistical literature, including qualitative, predictive accuracy, statistical distance, and descriptive statistics metrics. Using two tabular data sets from the healthcare and financial sectors, they design an aggregated metric to evaluate deep learning–based imputation models called reconstruction loss (RL). Tanwar A *et al*.[21] proposed an unsupervised method that leverages external clinical knowledge and contextualized word embeddings by ClinicalBERT for numerical reasoning in different phenotypic contexts. Jana *et al*.[22] presented methods for predicting intensive care unit (ICU) length of stay as well as need for critical interventions for patients based on vital signs, laboratory measurements, and nursing notes prepared within the first 24 h of ICU stay. Their approach has been built and cross-validated over publicly available Medical Information Mart for Intensive Care (MIMIC-III v1.4) data set.

Xia *et al*.[23] summarized publicly available data sets annotated by respiratory experts and reviewed the latest machine learning methods used for respiratory screening during the Covid-19 pandemic. Scaboro *et al*.[24] compared some of the current systems for detecting adverse drug events using social media data and proposed strategies to increase the robustness of these systems. Using unstructured clinical notes, Karisani *et al*.[25] created pipeline to infer the existence of alternative biological pathways from clinical phenotypes. Mohammadi *et al*.[26] applied an existing weakly supervised learning algorithm to a real-world data set in histopathology, with over 90% validation accuracy. Then they extended this method to handle multiclass slide-level labels and presented an end-to-end saliency-mapping algorithm to segment regions of interest at the pixel level based only on slide-level labels.

AUTHORS' CONTRIBUTIONS

A.S.N., M.M., S.B. conceptualized, drafted, reviewed, and edited the manuscript. J.S.B., D.L.B., R.L.D. reviewed and edited the manuscript.

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