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Adesh University Journal of Medical Sciences & Research

Editorial

Revolutionizing medical research: The promise and perils of artificial intelligence

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Received: 10 December 2024
Accepted: 10 December 2024
Published: 16 December 2024

DOI
10.25259/AUJMSR_31_2024

Quick Response Code:

INTRODUCTION

Artificial intelligence (AI) has rapidly emerged like a beacon from the dark. In 1990s, it was defined as "a field of science and engineering concerned with the computational understanding of what is commonly called intelligent behavior and with the creation of artifacts that exhibit such behavior."[1] As the deeper understanding about and technological advances in computation and machine learning (ML) has exploded across the horizon, there was the need to change the definition as:
A technology that enables computers and machines to simulate human learning, comprehension, problem-solving, decision-making, creativity, and autonomy.[2]

Applicability of AI in its variety of formats has revolutionized our daily routine and mundane tasks such as financial transactions mainly in banking and markets based on stock-exchange boards (BSE/NSE), e-commerce (both retail as well as bulk), demand and supply chains, production, and manufacturing. The logical extension of these would be education of all categories, more so Medical and, by corollary, the healthcare and medical research. Other marvels of AI include various revolutionary facilities like web search engines: Google and entertainment over-the-top platforms such as Netflix, home box office (HBO), Disney, and not to forget YouTube. Some of these have become such an integral part of our lives for example, e-commerce platforms like Amazon, Google Pay or communication platforms such as Facebook, WhatsApp, and Instagram, even predictive and intuitive software like ChatGPT. AI has transformed our everyday lives, with an way, we perceive and process information.[3]

And more than anything, AI has emerged as an interdisciplinary science.[4] It was not a coincidence that its integration with medical research is just a natural progression.

Medical research has been evolving by leaps and bounds since its humdrum serendipity back in the early days of medicine. Even today, the traditional modalities are based purely on statistical methods and are fraught with their inherent limitations. Logically, they are being superseded by newer technologies, better applications, and clarity of the understanding. AI is slowly but steadily making inroads in this field, too.

The scope of this has spread encompassing its various fields ranging from cellular biology, biochemistry, applied physics, clinical pharmacology, and toxicology to high flying fields such as nuclear medicine, advanced imaging techniques of radiodiagnosis, and robotic surgeries to mention a few. Its applications range from drug discovery, faster, and appropriate diagnostics, understanding the entire disease process (etiologic factors, incidence, vulnerable population, and natural progression) and improving outcomes.

The potential to revolutionize the drug discovery process to ease of patient care modeling, all the areas have become within the reach of a researcher by offering an efficient, accurate, and broader foundation. However, for the successful applicability of AI, factors, such as large high-quality datasets, the potential ethical concerns, and the understanding of the limitations of AI-based approaches, need to be taken into consideration.[5]

THE PROMISE OF AI IN MEDICAL RESEARCH

AI is transforming the field of medical research by enabling faster, more efficient, and accurate discoveries and deductions across a wide range of disciplines. By implementing AI-powered tools, we can analyze massive and complex datasets, identify patterns, and generate actionable insights that would otherwise take years to uncover.[6]

Accelerated drug discovery and development

Traditional processes of drug discovery are time-consuming, often taking many years, typically over a decade. AI accelerates this process by:

- Predicting suitable drug/vaccine candidates: AI computational models analyze multiples of molecular structures and predict which compound candidates are most likely to succeed as potential treatments.[5,7] One cannot forget the coronavirus disease 2019 (COVID-19) mRNA vaccines, and how rapidly they were developed. For example, companies such as Atomwise and Exscientia use AI to predict how new drugs will interact with disease targets.[8]
- Virtual screening: ML algorithms can quickly and virtually test millions on millions of chemical compounds, specifically identifying those with the highest possibility of interacting with specific biological targets. 3D QSAR and docking studies are used regularly to virtually predict the interaction of the chemical molecules with biologic structures (receptors, enzymes, etc.) before introducing the molecules to cells and/or animals for preclinical studies. For example, AI powered softwares such as Molecular Operated Environment, Glide (Schrödinger), and AutoDock are a few examples of the scores of softwares available for these processes.[8]
- Repurposing existing drugs: AI helps identify new therapeutic uses for already-approved drugs, saving time, and costs. The processes employed are similar to those applied to new molecules, except the chemical nature and biologic activity of existing therapeutics is known and helps AI extrapolate data and predict proposed activity. For example, DeepMind's AlphaFold has revolutionized protein structure prediction, speeding up the process of understanding protein behavior – a vital step in drug discovery.[6]

Personalized medicine

AI enables personalized medicine by analyzing patient data, including genetics, lifestyle, and clinical history, to predict:

- Individualized treatment plans: With the help of the large libraries of literature available to AI, tailoring therapies to the genetic makeup or specific characteristics of each patient has become easier and more timely. For example, oncologists have used AI-powered tools like CURATE. AI to match cancer patients with the most suitable immunotherapy options.[9]
- Predictive biomarkers for personalized medicine: ML enables the discovery of biomarkers that predict patient responses to specific therapies. Furthermore, throughout the course of treatment, based on the trends of the levels the biomarkers, AI can predict the prognosis of the patients' disease condition.[10] AI-based diagnostic systems like IBM Watson Health (WATSONX. AI) assist clinicians in interpreting diagnostic results and offering evidence-based insights.[11]
- Disease risk predictions: As mentioned in the previous point, AI algorithms can help predict prognosis of the disease progression. However, even before the development of the disease process, AI algorithms can help identify patients at higher risk for certain diseases based on their demographics, family history, and exposures (both environmental and personal), enabling early detection and intervention.[12] For example, AI models, like DeepVariant, can analyze genomic sequences to identify mutations that contribute to specific cancers, leading to more targeted treatments.[13]
- Real-time monitoring and decision support: Another major implication of AI that emerged during the COVID-19 era was the use of wearable devices and mobile health apps that collect real-time data on patients' health metrics. In most cases, this data is forwarded directly to the physician's device. AI analyzes this data in real-time to provide continuous monitoring, alerting physicians to potential health issues and recommending interventions.[14]

Early disease detection and diagnostics and minimizing errors

As mentioned above, AI enhances medical imaging, pathology, and diagnostics by identifying patterns in patient data that are imperceptible to humans. AI minimizes human errors by identifying patterns in complex datasets, ensuring more accurate diagnoses.

- Medical imaging: AI-driven systems improve accuracy in detecting anomalies in computed tomography (CT) scans, magnetic resonance images (MRIs), and X-rays (e.g., cancers and fractures). For example, Google's DeepMind has developed AI systems capable of detecting eye diseases and certain cancers from imaging data with accuracy comparable to expert clinicians.[15] Tools such as Aidoc or Viz.ai help in the rapid detection of conditions such as strokes or pulmonary embolisms by analyzing medical images in real time.[16]

- Application to Imaging Biomarkers: ML techniques like convolutional neural networks analyze medical imaging data to identify imaging-based biomarkers. Radiomics, for example, extracts quantitative features from imaging scans, aiding in early disease detection.[17] For example, detection of tumor biomarkers through automated analysis of MRI or CT scans.
- Diagnostic tools: AI detects diseases such as diabetic retinopathy and Alzheimer's. AI enhances the efficiency and scalability of large-scale screening programs, such as mammograms for breast cancer or colonoscopies for colorectal cancer. By prioritizing high-risk cases, AI ensures timely follow-ups and reduces the burden on healthcare providers. AI-powered systems like Zebra Medical Vision support radiologists by flagging potentially cancerous lesions in screening images.[18]
- Pattern recognition in complex data: AI can help in identifying patterns in vast datasets, such as electronic health records, genetic information, and wearable device data. This capability enables the early detection of diseases such as cancer, cardiovascular diseases, and neurodegenerative disorders.[3]

Identifying novel biomarkers using ML

ML is revolutionizing biomarker discovery by uncovering hidden patterns in large and complex biological datasets. Biomarkers – molecular indicators of a biological state or disease – are critical for diagnosis, prognosis, and treatment decisions. Traditional methods of biomarker identification are often limited by their reliance on predefined hypotheses and smaller datasets. ML, however, offers a data-driven approach that accelerates the discovery of novel biomarkers with higher accuracy and efficiency.[10,19]

- Handling high-dimensional data: Modern biological studies generate large, high-dimensional datasets (e.g., genomics, transcriptomics, and proteomics). ML algorithms can process these datasets to identify correlations and patterns that traditional statistical approaches miss.[10]
- Integration of Multi-Omics Data: Combining genomics, proteomics, metabolomics, and imaging data helps uncover complex biomarker interactions. ML techniques integrate diverse datasets for a holistic view of the disease process, especially autoimmune and neurogenerative diseases.[9,19]
- Feature selection: ML techniques such as LASSO regression, random forests, and support vector machines identify relevant features from high-dimensional datasets. These features often serve as candidate biomarkers (specific genes associated with breast cancer subtypes have been identified).[20]
- Learning (unsupervised and supervised):[21] Techniques such as clustering and dimensionality reduction help detect novel patterns in unlabeled data, which may indicate potential biomarkers – for example, principal component analysis and t-SNE have been used to cluster patient subgroups based on molecular profiles, revealing disease-specific markers. Supervised ML models classify data based on labeled training datasets, helping to distinguish between healthy and diseased states. This can pinpoint biomarkers that differentiate between these states – neural networks have been trained on labeled datasets to identify protein markers predictive of cardiovascular disease.

PERILS OF AI: CHALLENGES AND LIMITATIONS

While AI offers transformative potential in medical research, it also comes with significant challenges and limitations that must be addressed to ensure safe, effective, and ethical deployment. Some of the major concerns are as follows:

Data quality and bias

- AI models are only as good as the data they are trained on. Poor-quality, incomplete, or unrepresentative datasets can result in unreliable and biased outcomes. If datasets lack diversity (e.g., underrepresentation of certain ethnic groups) further bias can be perpetuated, and AI models may fail to generalize across populations, leading to disparities in diagnosis or treatment.
- This can lead to misleading results, inaccurate biomarker identification, and potential harm to marginalized populations.
- To overcome this, promotion of data diversity, ensuring rigorous curation, and implementation of fairness auditing tools.[22]

Black-box nature and lack of interpretability

- Many AI models, especially deep learning algorithms, act as "black boxes," providing outputs without clear explanations of how decisions are made, for example, AI might predict disease risk but fail to clarify the biological reasoning behind its predictions.[23,24]
- This reduces trust among clinicians and researchers, slowing adoption in critical healthcare settings. One can develop explainable AI models, such as model-agnostic methods (LIME and SHAP) or visualization tools (saliency maps and attention mechanisms), to ensure transparency and improve trust.[19]

Validation and generalizability

- AI models often perform well in controlled research environments but struggle when applied to real-world clinical settings. An AI system trained on a specific dataset might fail when tested in a different hospital with varied protocols and equipment.
- Overreliance on poorly validated models can lead to inaccurate results, affecting patient outcomes.
- It becomes imperative to conduct rigorous external validation using diverse, real-world datasets before clinical implementation.[13]

Ethical and privacy concerns

- AI models in healthcare rely heavily on sensitive patient data. Improper data handling, storage, or breaches raise privacy risks. Sharing genomic data or patient health records could lead to unintended exposure or misuse.
- This is a serious violation of privacy regulations such as general data protection regulation, health insurance portability and accountability act, and loss of public trust in AI technologies. Implementation of robust encryption and anonymization protocols and compliance with ethical data-sharing practices is necessary.[3]

Algorithmic bias and inequities

- AI systems can perpetuate existing biases in healthcare by learning from historical data that reflects systemic inequities, for example, an AI diagnostic tool trained on data primarily from male patients may perform poorly for female patients.
- AI can worsen health disparities instead of addressing them. The use of diverse datasets, regularly test for bias, and incorporate fairness measures in model development can minimize these problems.[19,24]

Over-reliance on AI

- The sustained use can lead to over-reliance on AI may lead researchers and clinicians to undervalue human expertise and intuition. Blind trust in an AI model's predictions without critical evaluation can result in missed diagnoses or false-positive results.
- One must never forget that AI is a tool, not a replacement for human judgment; over-reliance can compromise patient care. Fostering of human-AI collaboration where AI assists, rather than replaces, clinicians should be the dictum.

Regulatory and legal uncertainty

- The rapid development of AI in medical research has outpaced regulatory frameworks, creating ambiguity about liability and safety standards. For example, who is responsible if an AI-driven diagnostic tool makes an incorrect prediction – developers, hospitals, or clinicians? This can be the grounds for medico-legal wrangles. Developing clear regulatory guidelines for AI validation, approval, and liability is imperative.[3]

Data security and cybersecurity threats

- AI systems are susceptible to hacking, adversarial attacks, and data breaches.
- Manipulated input data could deceive an AI model into providing incorrect medical insights. This can compromise patient safety and erodes confidence in AI tools. To overcome this, enhancing cybersecurity frameworks and implementing robust adversarial defenses is necessary.[2]

Ethical use of AI in research

- Unethical AI use, such as predictive algorithms for insurance risk assessments, raises concerns about discrimination and misuse. AI could be used to deny insurance coverage based on predicted health outcomes.[24]
- This raises serious ethical concerns and undermines trust in AI-powered medical research. Establishing clear ethical guidelines and making sure AI aligns with patient-centered care principles is the goal.

While AI holds incredible promise and offers immense potential in advancing medical research, its challenges cannot be ignored. Addressing these challenges through Ensuring data quality, reducing bias, improving transparency, and addressing ethical, legal, and computational concerns, building robust regulatory and ethical frameworks and collaborative development, are essential to maximize the benefits of AI. By fostering responsible AI development and implementation, we can harness its potential while minimizing its perils, leading to safer and more equitable advancements and achievements in the very rapidly evolving field of medical research.

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How to cite this article: Panditrao MM. Revolutionizing medical research: The promise and perils of artificial intelligence. Adesh Univ J Med Sci Res 2023;5:47-51. doi: 10.25259/AUJMSR_31_2024