ARTIFICIAL INTELLIGENCE AND CARDIOVASCULAR DISEASES: OPPORTUNITIES AND CHALLENGES

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ABSTRACT

Cardiovascular diseases are still the top cause of death in most parts of the world, and the numbers keep increasing. The usual diagnostic methods and risk scores, while helpful, do not always capture the whole picture. In the last several years, artificial intelligence (AI) has been tried in cardiology with the hope of filling some of these gaps. AI, including machine learning and deep learning, can process huge amounts of data and often points to patterns that doctors may not easily see. This review goes over how such systems are being tested for risk prediction, imaging, and treatment planning. A few studies with echocardiography, MRI, and CT show that computer models can shorten reporting times and sometimes improve accuracy. Other projects that combine clinical, genetic, and imaging data suggest that risk can be defined in a more personal way. But problems exist. Many models work like a "black box," and bias in datasets plus privacy issues are still major worries. Newer ideas such as explainable AI, federated learning, and combining different kinds of data are being developed. Overall, AI is not a replacement for the physician, but it looks set to become an extra tool that may slowly change cardiovascular care.

Keywords: artificial intelligence, cardiovascular diseases, machine learning, deep learning, cardiovascular imaging, risk prediction, personalized medicine

1. Introduction:

Cardiovascular diseases (CVDs) pose a substantial global health challenge, significantly contributing to morbidity and mortality rates (1,2). Given their widespread prevalence, there is a pressing need for innovative approaches to enhance diagnostic accuracy, risk prediction, and therapeutic strategies (1,3). The integration of Artificial Intelligence (AI) into cardiovascular therapy has emerged as a transformative path in recent years (2,4). AI, encompassing machine learning and deep learning methodologies, demonstrates the capacity to manage extensive datasets and identify intricate patterns within clinical and imaging data (5,6). This convergence of computational expertise and medical knowledge holds the potential to revolutionize the landscape of cardiovascular healthcare (1,7).

The core assumption of AI, which is based on algorithms that repeatedly learn from data, offers a fresh framework for understanding the intricate linkages inherent in cardiovascular pathophysiology (1,2,8) As the convergence of AI and healthcare advances, understanding its varied influence on cardiovascular medicine becomes increasingly important (1,7). This thorough analysis aims to identify the transformational potential of AI applications in cardiovascular healthcare, focusing on critical topics such as risk prediction, diagnostics, and tailored treatment techniques (1,4,7,9).

The rising incidence of CVDs needs a rethinking of established healthcare paradigms, motivating an investigation into novel technology capable of resolving the complex problems faced by these disorders(1,7,8). In this context, the incorporation of AI not only enhances healthcare practitioners' analytical capacities, but also provides a viable route for early identification, accurate risk classification, and targeted treatment interventions (1–3,8). This study aims to give a thorough evaluation of the present status of AI in cardiovascular medicine, describing its underlying processes, analyzing significant applications, and digging into the larger implications for cardiovascular healthcare in the future (4,7).

2. Basics of Artificial Intelligence:

Artificial Intelligence (AI), a multidisciplinary area bridging computer science and statistical modeling, is reshaping the landscape of medical diagnostics and prognostics (10–13).

Definition and Components:

AI, in its broadest sense, refers to computational systems that can do activities that formerly required human intellect (10–13). Machine learning (ML) and deep learning (DL) are the fundamental components of AI in the context of medical applications. ML methods allow computers to learn from data repeatedly, identify patterns, and make educated predictions, whereas DL, inspired by neural networks, excels at processing complicated and unstructured datasets (10,11,13).

Mechanisms of AI in Healthcare:

In the medical area, AI is used to examine large datasets such as patient records, genetic information, and medical imaging. The iterative learning process allows these algorithms to improve their prediction and diagnostic capacities over time (11–13). Notably, the unsupervised and supervised learning methodologies enable AI systems to discover detailed patterns in data,

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making tasks like illness categorization, risk stratification, and treatment planning possible (10–12).

Ethical Considerations:

The incorporation of AI in healthcare needs a careful examination of the ethical implications. It is critical to protect patient privacy, correct algorithmic biases, and promote openness in decision-making processes (14–17). Because AI algorithms rely on historical records, the possibility for existing biases to be perpetuated emphasizes the significance of ethical monitoring in AI applications in the healthcare sector (14–16).

To summarize, a basic grasp of AI's components, methods, and ethical implications sets the framework for understanding its complex function in cardiovascular care. As we progress through the parts, the practical uses and transformational potential of AI in tackling cardiovascular issues will become clear (14–16,18).

3.Cardiovascular Diseases: A Global Burden

Cardiovascular diseases (CVDs) are a significant global health concern, posing a widespread and frequently life-threatening burden on communities worldwide (19). This section examines the incidence and significance of cardiovascular disorders, sheds light on contemporary issues in cardiovascular medicine, and articulates the critical role of modern technologies, notably Artificial Intelligence (AI), in tackling these challenges (19–21).

Prevalence and Impact:

The Global Epidemiology:

Cardiovascular illnesses have surpassed cancer as the major cause of morbidity and death worldwide. According to the World Health Organization (WHO), an estimated 17.9 million deaths from cardiovascular illnesses occurred in 2019, accounting for nearly 32% of all worldwide fatalities (19–22). These disorders, which range from coronary artery disease and heart failure to stroke and peripheral arterial disease, have a profound impact on public health (22–24).

Socioeconomic Disparities:

The burden of cardiovascular illnesses is not consistent, and there are significant socioeconomic differences (24). While high-income nations confront issues from an aging population and lifestyle-related risk factors, low- and middle-income countries suffer a combined burden of communicable and noncommunicable illnesses, including an increase in cardiovascular disease. This paradox highlights the intricate interaction of genetic, environmental, and social variables in defining the worldwide cardiovascular health landscape (24–26).

Current Challenges in Cardiovascular Medicine:

1 Rising Healthcare Costs:

Cardiovascular disorders incur significant healthcare costs, which include diagnostic tests, therapeutic treatments, and long-term maintenance. The necessity for recurring hospitalizations, costly drugs, and the care of comorbidities associated with cardiovascular problems all add to the financial burden. This economic strain is a major concern, especially in resource-constrained healthcare systems (27–29).

2 Diagnostic and Therapeutic Gaps:

There are considerable diagnostic and therapeutic gaps in cardiovascular care in many regions of the world. Undiagnosed illnesses, delayed therapies, and a lack of access to specialist treatments all contribute to poor outcomes for many people with cardiovascular disorders. This is especially noticeable in areas with inadequate healthcare infrastructure, highlighting the critical need for scalable and cost-effective solutions (27,28,30,31).

3 Personalized Medicine Obstacles:

The introduction of personalized medicine, which tailors therapies to unique patient profiles, has created both possibilities and obstacles in cardiovascular care. While genetic and molecular insights hold the promise of tailored medicines, implementing personalized medicine confronts challenges such as discovering actionable biomarkers, guaranteeing equal access, and negotiating the ethical issues of genomic data utilization (27–30,32).

The Need for Advanced Technologies like AI:

1 Diagnostic Precision and Efficiency:

Artificial Intelligence (AI) appears as a critical answer to the issues inherent in cardiovascular diagnostics. AI systems that can assess large datasets rapidly and accurately have the potential to change the diagnostic environment. In situations when time is of the essence, AI's efficiency can hasten the detection of cardiovascular problems, allowing for quick action and closing the diagnostic gap (11,13,33–35).

2 Enhancing Risk Prediction Models:

Because cardiovascular illnesses are so complicated, advanced risk prediction models that go beyond standard methodologies are required. AI, with its ability to detect detailed patterns in varied datasets, has the potential to greatly improve the accuracy of cardiovascular risk prediction (36–39). AI-driven risk prediction models provide a more comprehensive and individualized evaluation of an individual's cardiovascular risk profile by combining clinical, genetic, and imaging data, allowing for focused preventative efforts (11,13,33,37).

3 Facilitating Personalized Treatment Approaches:

The use of AI technology enhances the age of customized medicine. Individual patient data may be analyzed by AI algorithms, which take into account genetic differences, lifestyle variables, and response patterns to treatment interventions (1–4,9). This deep knowledge enables treatment strategies to be tailored, improving efficacy while avoiding unwanted effects. AI-powered tailored medicine has the potential to narrow treatment disparities and move us closer to more fair healthcare outcomes (1,3,4,7,9,34,35).

4 Data-Driven Insights for Healthcare Planning:

AI adds to data-driven insights that improve healthcare planning and resource allocation in addition to diagnosis and therapy. Predictive analytics, aided by AI algorithms, can forecast the frequency and spread of cardiovascular illnesses in certain populations (2,8,13,27,33,40). This proactive strategy allows healthcare organizations to design preventative actions, efficiently manage resources, and solve the fiscal issues associated with the growing burden of cardiovascular illnesses (3,4,11,34,35,40).

4 The Intersection of Global Health and Technological Innovation:

1. **Alleviating Healthcare Disparities**: The utilization of AI in cardiovascular medicine shows potential in addressing current gaps in healthcare access. AI-driven telehealth systems can extend cardiovascular care to remote and underserved areas, ensuring that individuals in regions with limited access to specialized healthcare receive accurate and timely diagnoses (1,3,4,7,34,35).

2. **Enhancing Healthcare Professionals**: AI holds the promise of boosting the capabilities of healthcare workers by enhancing their diagnostic and decision-making abilities (3,4,9,12,13). Through the automation of routine processes, provision of real-time insights, and facilitation of personalized treatment plans, AI empowers healthcare practitioners to provide cardiovascular care more efficiently and effectively, regardless of geographical limitations (8,9,34,35).

3. **Global Collaborative Endeavors**: Confronting the global burden of cardiovascular diseases necessitates collaborative initiatives on an international scale (1,7–9,11,13,33). Programs that facilitate the exchange of information, technology, and best practices can nurture the development of AI solutions applicable across diverse healthcare settings (2,11,13,33,34). Collaborations involving governments, healthcare institutions, technology developers, and ethical frameworks

can establish a foundation for a more comprehensive and successful strategy in addressing cardiovascular disease globally (34,35,40).

Cardiovascular illnesses, as a worldwide burden, necessitate new and scalable solutions to address current difficulties. With its transformational potential in diagnostics, risk prediction, and tailored medication, artificial intelligence (AI) emerges as a beacon of hope in resolving the complexity of cardiovascular healthcare (1,3,4,33,34,40). The convergence of global health and technology innovation has the potential to not only reduce the burden of cardiovascular illnesses, but also to drive healthcare toward a more egalitarian and efficient future. As we negotiate this changing landscape, ethical issues and collaborative endeavors will be critical in ensuring that AI becomes a worldwide catalyst for good change in cardiovascular care (1–4,7–9,41).

4. AI in Cardiovascular Risk Prediction:

The use of Artificial Intelligence (AI) into cardiovascular risk prediction marks a watershed point in the preventive medicine landscape (36,38,42). This section delves into the complexities and real-world applications of AI-based risk prediction models, offering light on their methodological foundations, nuanced capabilities, and concrete influence on improving cardiovascular risk assessments (38,43,44).

AI-Based Risk Prediction Models:

The creation and use of advanced predictive models is at the basis of AI's entrance into cardiovascular risk prediction. Deep Learning (DL) algorithms, in particular, have emerged as stalwarts in recognizing complicated patterns throughout large and diverse datasets (37,43). These algorithms, which have been trained on a multitude of clinical, genomic, and imaging data, have an unrivaled capacity to find subtle correlations and uncover hidden risk variables that conventional risk assessment methods frequently miss (36,38,42).

A research in which a deep neural network examined electronic health information from a large patient cohort is one example of a real-world use of AI in cardiovascular risk prediction (4,8,36,37). The algorithm not only correctly predicted cardiovascular events but also discovered previously unknown risk variables, demonstrating AI's ability to outperform traditional risk assessment approaches (3,7,36,37,42–44).

Integration of Clinical and Imaging Data:

The effectiveness of AI in cardiovascular risk prediction is enhanced by its seamless integration of heterogeneous datasets spanning clinical and imaging aspects. This comprehensive method overcomes the constraints of existing risk models, which mostly depend on clinical characteristics (36,37,42–44). In one notable real-world example, a convolutional neural network (CNN) was used to assess multimodal imaging data, such as echocardiograms and cardiac MRI scans, in addition to clinical information (38,42,44). The resultant model has improved discriminatory power, exposing detailed correlations between imaging biomarkers and cardiovascular risk, and so providing a more complete risk stratification paradigm (2,3,36,42,44).

Furthermore, incorporating genetic data into AI-driven risk prediction models has real-world implications for identifying inherited components of cardiovascular risk. In fact, AI algorithms have been used to scan large genomic datasets in order to uncover genetic markers linked with increased cardiovascular risk (37,38,43,44). These integrated techniques demonstrate AI's resilience in accepting many data modalities for a more sophisticated knowledge of cardiovascular risk in real-world circumstances (36,39,43,45–48).

Accuracy and Reliability:

The accuracy and reliability of AI-based risk prediction models must be rigorously evaluated before they can be translated into therapeutic usefulness. Robust validation studies are critical in demonstrating the usefulness of AI models in predicting cardiovascular events and confirming their value as important tools in preventive and tailored patient treatment (37,42–48).

A real-world study used separate cohorts to expose AI models to thorough validation processes. The resultant models not only had improved accuracy in predicting cardiovascular events, but they also had strong generalizability across a wide range of patient demographics (37,39,43,45–48). These findings highlight AI's practical value as a dependable auxiliary in clinical decision-making, providing enhanced risk classification that is consistent with the dynamic nature of cardiovascular pathophysiology (36,37,42,44).

However, issues remain in ensuring that these powerful AI models are interpretable and transparent. Practical solutions and current research activities addressing these issues are critical for building clinician trust and supporting the smooth incorporation of AI-derived risk forecasts into normal cardiovascular treatment (37–39,44).

Real-Life Impact:

The use of artificial intelligence in cardiovascular risk prediction has real-world consequences for patient treatment. Consider the following scenario: a middle-aged man with various cardiovascular risk factors seeks preventative therapy (9,45,49). Traditional risk assessment systems may place this person in a wide risk group, ignoring small subtleties that may impact individualized risk (5,36,37,43,45,46,49).

An AI-based risk prediction model, on the other hand, might provide a more precise and individualized risk profile by relying on a large dataset that includes clinical factors, genetic information, and imaging data (36,38,42,44,45). AI has the capacity to detect hidden risk indicators that conventional approaches may miss by identifying subtle patterns and correlations within data (5,37,39,47,49).

This improved risk prediction accuracy results into more focused and effective preventative measures. Individuals who have been identified as having a certain genetic predisposition or modest imaging biomarker indicative of increased risk may benefit from specialized preventative strategies such as tailored lifestyle modifications, attentive monitoring, or early pharmaceutical intervention (38,42–44,47).

Furthermore, AI models' real-time flexibility to evolving patient data guarantees a dynamic and responsive risk assessment. As patients change their lifestyles or get therapeutic therapies, the AI model may learn and update predictions in real time, offering a personalized risk trajectory that changes with the individual's health journey (5,38,39,42,44,45,50).

5. AI in Imaging and Diagnostics:

The convergence of AI and cardiovascular diagnostics represents a substantial leap in medical imaging interpretation. In this part, we explore the complex environment of AI-driven diagnostics, highlighting how it has transformed Magnetic Resonance Imaging (MRI), Computed Tomography (CT), and echocardiography (51–53). We will look at how AI may speed up the diagnosis process, improve accuracy, and refine the delineation of cardiovascular diseases using real-world examples (17,41,52,54).

Automated Diagnosis and Image Segmentation:

The capacity of AI to automate the interpretation of medical imaging has marked its introduction into cardiovascular diagnostics, altering the diagnostic process. A deep learning system, for example, was used to analyze cardiac MRI data for the automated identification of myocardial infarction (41,51–54). This approach shows not only outstanding accuracy in recognizing infarcted areas, but also efficiency by drastically lowering diagnostic time. This example demonstrates AI's potential for speeding up essential diagnostic operations (3,4,8,51,54,55).

Beyond diagnosis, AI's expertise in picture segmentation is critical in improving the precision of cardiovascular examinations. Another research used a convolutional neural network (CNN) to distinguish heart regions in echocardiographic pictures (1,7,41,51,53,55). The method performed well in identifying heart chambers, valves, and myocardium, providing doctors with a thorough and quick study of cardiac morphology (3,41,51,53,54). This automated segmentation capability has the potential to improve diagnostic accuracy and contribute to a more sophisticated knowledge of cardiovascular diseases (53,55).

Improving Speed and Accuracy: The significance of AI applications is defined by the synergistic alliance of speed and accuracy in cardiovascular diagnosis (41,51,54). In one important study, a machine learning method evaluated coronary CT angiography pictures to detect coronary artery stenosis quickly. The model not only sped up the diagnostic procedure, but it also improved accuracy in determining the degree of stenotic lesions (51,54,55). Such rapid and precise diagnostic skills highlight AI's transformational promise in the field of cardiovascular imaging (3,4,17,41,53).

Furthermore, the integration of AI with functional imaging modalities such as Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) represent a new path for complete cardiovascular diagnosis. A deep learning model, for example, was used for automated interpretation of cardiac perfusion pictures, detecting modest perfusion irregularities indicative of ischemia (51,54,55). The program greatly decreased interpretation time, demonstrating the synergistic benefits of AI in improving both speed and accuracy in functional imaging diagnosis (51,54).

Challenges and Ethical Considerations:

While the potential benefits of AI in cardiovascular diagnostics are clear, obstacles remain, prompting a careful examination of ethical issues ((14–16). Issues concerning the interpretability of sophisticated AI models, possible biases in training datasets, and the ethical implications of automated decision-making necessitate investigation (14–16). Ongoing research attempts to develop ethical norms and frameworks to address these issues, guaranteeing the appropriate use of AI in diagnostic procedures (3,7,14,16,50).

In conclusion, the disruptive influence of AI in cardiovascular diagnostics is highlighted by its ability to automate diagnosis, improve precision through picture segmentation, and accelerate crucial diagnostic procedures (4,14,16,50). The practical examples demonstrate how AI may improve the speed and accuracy of cardiovascular imaging interpretation. As the area advances, ongoing attempts to overcome difficulties and maintain ethical standards will be critical in fulfilling AI's full potential as a cornerstone in cardiovascular diagnosis (3,14–16,50).

6. AI in Treatment Planning and Personalized Medicine:

The integration of Artificial Intelligence (AI) into treatment planning and personalized medicine has attracted significant attention within the cardiovascular healthcare sector. This section delves into the scientific intricacies and practical implications of AI applications, exploring how these technologies are revolutionizing therapeutic approaches based on individual patient profiles.

Tailoring Treatment Plans:

The use of AI powered algorithms provides the possibility of the implementation of personalized treatment strategies via data-driven methods like machine learning, clustering and other AI based technologies which can improve patient outcomes. The data collected could be instrumental in conducting new clinical trials (56).

Analytic of big data (refers to massive datasets that are too large to be processed, analyzed, searched, or stored using conventional data-processing techniques) by the application of AI may prospectively enable identification of unique phenotypes or genotypes of heterogeneous syndromes, such as HFpEF, Takotsubo cardiomyopathy, hyper-trophic cardiomyopathy, primary pulmonary hyper-tension (PH), hypertension (HTN), and coronary artery disease, which would potentiate personalized and targeted therapy (57).

Let us take arterial hypertension (AH), for example. Since the management of AH is reliant on evidence based medicine, it creates a tough challenge for physicians. In such scenarios, AI can help in the identification of modifiable risk factors which contribute to the development of AH, and thus, it could simplify the path to choosing the appropriate treatment plan for each patient of AH by identifying the best combination therapy of medication and lifestyle changes as compared to standard analysis (58).

Potential for Personalized Medicine:

Due to the intrinsic variability of many disease pathophysiological processes, the current belief is such that the treatment, monitoring and prevention of said disease should be tailored or ‘personalized’ to each individual’s unique situation in relation to biochemical, physiological and environmental exposure as well as behavioral profile (59). The integration of such data from diverse and comprehensive sources which include genetic, environmental and lifestyle factors is a challenge for even a team of humans but considerably easy for AI systems which can thus be leveraged to enhance the personalized medicine approach (60).

Taking the example of coronary artery disease (CAD), it is believed that different patient subgroups may benefit from different medication regimens and revascularization strategies. Optimal treatment strategies can be derived using ML, leading to an increase in population life expectancy as well as symptom reduction. For example, in a study conducted by Bertsimas et al., their methodology using ML created personalized CAD management which led to the improvement of TAE (time from diagnosis to potential adverse event) by 24% or 1.1 years from baseline which is 4.56 years (61).

Challenges and limitations:

In spite of the prospective promises of integration of AI in healthcare, the successful implementation of this endeavor requires collaboration between stakeholders including knowledge experts, decision-makers and end-users (62).

An important factor to be considered here is the ethics of using AI even though it shows great promise to improve and enhance the level of healthcare. Thus, some major ethical issues must be addressed including informed consent to use patient data, complete transparency and assurance of safety, as well as data privacy (14).

The most common ethical conundrum is that of unfairness caused by bias in data sources as most data sets tend to be biased to an extent. Since AI programs are developed based on existing data, which capture patterns of inequality in healthcare, these inequalities may be perpetuated (63).

Real Life Impact:

Taking the example of the impact of AI in the diagnosis and treatment of hypertrophic cardiomyopathy (HCM), the real life impact of AI in cardiovascular medicine can be understood. HCM is a complex disease with a heterogeneous phenotype and which makes accurate and timely diagnosis a difficult task. AI trained to analyze ECG signals using Deep Learning models such as CNNs (Convolutional Neural Networks) have great prospects in accurately recognising HCM-related abnormalities on ECGs which may outperform traditional diagnostic methods. Machine Learning models have, with great accuracy, been able to differentiate between HCM and other cardiac conditions despite not having abnormal ECG findings (64).

Currently, the risk prediction of mortality is done using traditional statistical methods. ML and AI show potential in this field by considering multiple factors such as current clinical data, genetic data, imaging data and medical history enabling the identification of patients at risk for any major adverse cardiac event with higher accuracy (65).

With these findings, AI centric approaches present the opportunity to transform HCM management by offering early and accurate diagnoses, prognoses and personalized treatment plans that are extrapolated from individual patient factors (64).

Thus, the involvement of AI in cardiovascular medicine goes beyond the theoretical and has real world ramifications which potentiate the possibility of early accurate diagnosis with explainability and tailored treatment plans for each individual patient based on unique patient factors (60,61,66).

With the progress being made in the integration of AI systems with cardiovascular care, there will be a paradigm shift from traditional methods to precision cardiovascular medicine (57). With the application of AI and ML models in this field, there will be a cumulative benefit to physicians - assistance in diagnosis, patients - personalised treatment, and the healthcare system - reduction of overall morbidity and mortality (60,64).

7. Future Directions and Challenges

As Artificial Intelligence (AI) permeates the fabric of cardiovascular health, the trajectory of its progress invites research into the unexplored territory of new trends and problems. This section outlines the trajectory of AI in cardiovascular healthcare, diving into the complexities of emerging technology, possible hurdles, and the need for continued study.

Emerging Trends:

1. **Explainable AI:**

The complex criteria used by AI systems in personalized medicine strategies makes it difficult to understand and interpret the decisions made by the model creating a need for explainable AI which centres around the ability to understand and interpret the AI system since healthcare practitioners are more likely to trust the outcome of an algorithm if they can understand the reasoning behind it. Thus, explainability of an AI system not only makes it more understandable and interpretable but also transparent, responsible and thus reduces risks (60,66).

2. **Federated Learning**

Federated Learning (FL) eliminates the requirement of data sharing and allows local data to be used for local models, thus providing a distributed machine learning system ensuring that raw data remains private, preventing its exposure. This technology helps to maintain data privacy while still promoting collaborative training making it particularly suitable for the healthcare domain (67,68).

3. Multimodal Data Integration

Cardiovascular diseases are highly complex with multifactorial causes which necessitates personalised and individualistic assessment and treatment. This requires the integration of a large volume of data including genomic, transcriptomic, phenotypic and clinical data as well as environmental and lifestyle factors. However, due to the heterogeneous nature of such data, there is a lack of standardisation which limits data integration. This can be addressed by the assimilation of precision medicine and AI/Machine Learning approaches, which would aid in the interpretation and analysis of variant data thus, help identify high risk patients as well as provide highly accurate diagnosis in patients of complex diseases including cardiovascular diseases (60,69).

Challenges and Ethical Considerations:

1. Interpretability and trust

The advancement of AI and its application in healthcare has a multitude of benefits including higher accuracy of risk assessment and personalised treatment plans and overall optimisation of healthcare workflow. However, this also leads to complex ethical, legal and clinical questions due to the lack of understanding about how ML and AI models come to a conclusion and generate outputs. This is commonly known as the 'black box problem'. And unless this issue is not solved, the healthcare workers would not be able to fully explain the patients which would infringe upon their rights. But with the upcoming development of explainable AI, this problem is being addressed (60,70).

2. Data privacy and security

With the integration of AI into the healthcare sector, there are increasing concerns about data privacy and security regarding the sensitive patient data since any breach could result in severe consequences both on the account of patient trust as well as data integrity. Thus, there must be guidelines made specifically for AI in healthcare regarding data collection, storage and sharing which adhere to internationally recognized data security standards. A process of continuous reflection, adaptation and collaboration is necessary to gain the benefits of this technology while not sacrificing on security and trust (71).

3. Bias mitigation:

AI algorithms are prone to inadvertently perpetuate and even amplify the biases prevalent in the data that they are trained on which would lead to gaps in the diagnosis and treatment of patients (71). Thus, strategies for bias detection and mitigation will be instrumental for the success of AI incorporation in healthcare and creating AI technology that is generalisable and fair (72).

Areas for Further Research:

1. **Real Time monitoring**

The early detection of cardiovascular disease may lower the occurrence of severe life threatening events such as myocardial infarctions and thus would reduce the mortality in such patients (73). Using wearable devices such as smartwatches, this might be possible by ensuring continuous real time monitoring of physiological data. Taking an example of ECG devices enabled by smartwatches, gives widespread access to the population without the ability of accurate interpretation. By incorporating AI into such devices which can suggest the consumer to consult a physician/cardiologist, there is a potential of cost-effective screening of the general population as well as early detection which could reduce the deaths due to cardiovascular disease (74).

2. **Predictive Modelling of Treatment Responses:**

Despite the success in the fields of early detection and diagnosis, the use of AI via deep learning techniques for the predictive modelling of treatment responses has not had much growth or progress. This is a field which would benefit greatly from the integration of AI as it would be an important factor in mapping out personalised treatment strategies and cost-effective disease management, by providing reliable predictions of treatment outcomes (75,76).

3. **Patient-Reported Outcomes:**

Patient-reported outcomes or PROs are reports of a person's health status that come directly from the patient without interpretation by a healthcare professional which provide a more patient oriented outlook on the outcomes of an intervention or treatment on the symptoms and quality of life and, thus, include global, mental, physical and social domains of health. They can aide in various aspects of healthcare policy making. But due to a lack of tools to properly collect and organise this data, PROs are not yet routinely collected and used effectively (77). The use of AI in such situations could help better assess PROs and presents a great opportunity in a previously neglected field. It not only humanizes AI in healthcare but encourages collaborative decision-making and offers a comprehensive view of health (78).

However, the journey forward is filled with both promises and problems which must be navigated delicately and deliberately for the success of this technology (74).

Applications of AI like ML and DL are changing the landscape of cardiovascular diseases with respect to diagnosis, risk prediction, prognosis, prevention and treatment strategies (74). The future is lined with advances in the emerging fields of explainable AI, federated learning systems and the application of multimodal data integration in cardiovascular healthcare (60,66–69). However, the journey forward is filled with both promises and problems which must be navigated delicately and deliberately for the success of this technology (74). Thus, certain ethical questions and considerations must not be overlooked while moving forward such as the development of interpretability and trust, maintenance of data privacy and security and the need for bias mitigation (60,70–72).

Mindful navigation of this field will allow for the progress of AI technology in cardiovascular medicine with the eye on prospects like advances in the fields of real-time monitoring, predictive modeling for treatment responses and patient-reported outcomes (74–78). This is achievable through a multidisciplinary and collaborative effort including multiple stakeholders: computer and social scientists, operational and research leaders, subject experts, and clinical stakeholders including healthcare workers and patients (8,74).

Conflict of Interest

The authors declare that they have no conflicts of interest relevant to this article.

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