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Artificial Intelligence in Cardiovascular Care: From Diagnosis to Precision Medicine

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ABSTRACT: As the population ages and risk factors become more common, cardiovascular diseases (CVDs) continue to be a major cause of morbidity and mortality worldwide. In cardiovascular medicine, artificial intelligence (AI) has become a game-changing tool that offers advancements in risk assessment, early diagnosis, prevention, and individualized care. AI improves the interpretation of clinical data, medical imaging, electrocardiography, wearable device monitoring, and interventional treatments through machine learning, deep learning, and big data analytics. These apps lessen the strain for clinicians while enhancing therapeutic effectiveness, diagnostic accuracy, and precision medicine. Nonetheless, there are still a lot of restrictions pertaining to data quality, generalizability, cost, and ethical issues, especially those involving privacy, consent, and justice. In order to safely and successfully incorporate AI into cardiovascular treatment and lessen the overall burden of CVDs, these issues must be resolved.

KEY WORDS: Artificial Intelligence, Machine Learning, Electrocardiography, Cardiac magnetic resonance imaging, Single-photon emission computed tomography, Precision Medicine.

I. INTRODUCTION

One of the main causes of high morbidity and death in the world is cardiovascular disease. Over the past ten years, the illness burden has continued to rise, necessitating immediate actions to prevent cardiovascular diseases and enhance treatment outcomes. A complete approach is needed to manage cardiovascular diseases, including prevention, early diagnosis, appropriate therapy, and ongoing monitoring and follow-up. Notable developments in medical research and technology in recent years have greatly enhanced healthcare delivery in each of these areas. However, the aging population and rising incidence of cardiovascular diseases emphasize how urgent it is to adopt emerging technology in order to enhance patient outcomes and lessen the overall burden of cardiovascular diseases. Cardiology is one of the medical specialties that has seen a paradigm shift as a result of the use of artificial intelligence (AI) in healthcare (1).

In cardiology, the survival of the patient depends on accuracy, speed, and precision. In addition to saving lives, a doctor's job is to properly comprehend his patient and provide guidance for his general well-being. A comprehensive artificial intelligence solution that helps the cardiologist be skilled, agile, and sympathetic to the greater social community can accomplish all of these. Based on the patient's unstructured EHR dataset, including age, gender, ethnicity, family history, demographic location, lifestyle, prior treatment history, and health vitals, AI can be used to give the doctor prescriptive analytics.AI might be used by the cardiologist to identify the condition and create a precise, individualized treatment plan for every patient. AI can thereby lighten the doctor's workload and enable him to treat patients more precisely (2).

BASICS OF AI:

The ability of a computer to do tasks in a way that is usually associated with a rational human being is known as artificial intelligence (AI). The ability of AI systems to learn on their own by identifying patterns in labelled data (supervised learning) or unlabeled raw data (unsupervised learning) is known as machine learning (ML). Neural networks are developed to simulate the operation of a human neural system in deep learning, a machine learning technique. Last but not least, natural language processing is a branch of artificial intelligence that analyzes, interprets, and transforms text using a variety of ML and deep learning approaches. Big data is information that is defined by "the 6 V's," which include a large volume, velocity, and variety of data that call for certain analysis techniques to turn it into value (3).

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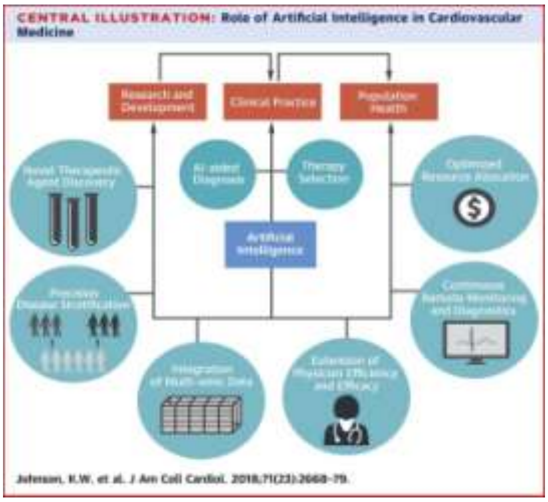
AI has the ability to leverage big data to improve medical care. Because they are brought on by a variety of genetic, environmental, and behavioral variables (such as nutrition and gut microbiota), cardiovascular diseases (CVDs) are actually complicated and diverse in nature. Instead of evaluating a straightforward score system or conventional CV risk variables, many more developments are currently required to reliably and successfully forecast outcomes. Image recognition in CV imaging and pattern recognition in diverse syndromes are two applications of deep learning AI with massive data. AI can identify new genotypes or phenotypes of heart failure (HF) with preserved ejection fraction (HFpEF), for instance, and new diagnostic echocardiographic characteristics may result in new targeted treatments (4).



Artificial intelligence (AI) in cardiovascular medicine will have an impact on every facet of cardiology, including public health, clinical practice, and research and development. Selected applications from each of the three cardiovascular care domains are shown in this image (5).

Artificial intelligence (AI) and machine learning will probably help doctors in the near future with differential diagnosis, recommendations for treatment alternatives, and, in the case of medical imaging, cues for picture interpretation. Millions of people worldwide were captivated by the IBM Jeopardy! Challenge, which pitted the greatest human players in history against the Watson machine and showed how AI techniques could be applied to a wide range of topics, including medicine. AI, big data, and massively parallel computing have the potential to revolutionize the practice of individualized, evidence-based medicine (6).

AI can first be used for remote follow-ups, prescription reminders, real-time illness counseling, and early symptom alerts from the perspective of the patient. In addition, from a clinician's point of view, AI can assist in gathering speech data (such medical history), connecting electronic medical record systems, and lightening their burden. In the future, clinicians will be able to make precise decisions and forecast patient outcomes with the use of cognitive computersdevices that are educated using machine learning or deep learning algorithms and can solve issues without human assistance.AI is most likely to be used to develop a precise medical plan that tailors treatment to each patient. Many believe that AI won't take the position of medical professionals. On the other hand, in order to improve the diagnosis and treatment of cardiovascular illness using big data analysis, professionals need learn how to use AI technology and develop expertise in the clinical practice. will aid in the transition to precision medicine. AI is most likely to be used in precision medicine, which will tailor treatment to each patient. AI is not expected to take the position of physicians (7).

APPLICATIONS OF AI IN CARDIOLOGY:

Electrocardiography:

Electrocardiography has already been significantly impacted by the use of AI and ML in the ECG. First, human capacities can be greatly expanded by automating interpretation, making it possible to interpret an exponentially increasing quantity of ECGs. Second, AI/ML algorithms can improve disease phenotyping by identifying subtle and connected nonlinear patterns in the ECG that are frequently unrecognizable to specialists. Third, such algorithms may make it possible to identify concealed disease and anticipate coming disease because cardiac electrical activity may be impacted before mechanical or structural problems are seen on imaging. AI/ML of the ECG may identify new phenotypes by separating subgroups of comparable illnesses (8).

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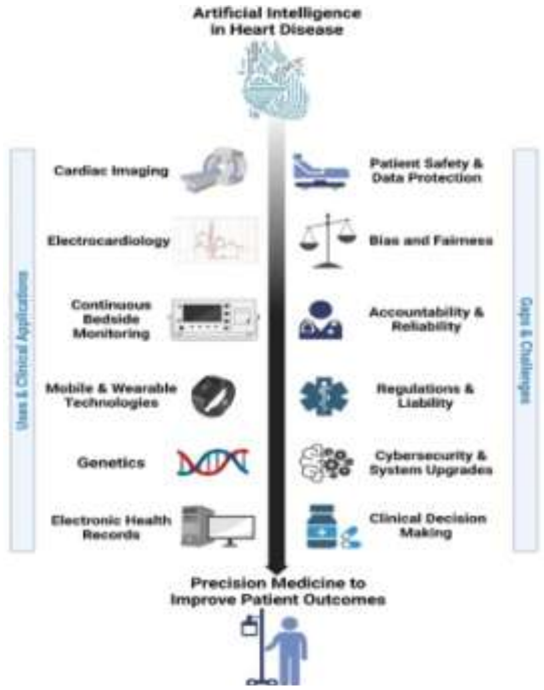

Echocardiography:

The ability of AI to automatically assess features from images and data that are beyond human perception is the basis for its application in echocardiography to diagnose disease states. Because it can be difficult for human experts to quickly analyze all of the data provided during normal echocardiogram, a significant amount of potentially diagnostic information may be underutilized. AI is able to examine this data more quickly than human experts and can assist in determining the actual value of these undiscovered discoveries. Consequently, the identification of particular disease states and processes, such as valvular heart diseases, coronary artery disease, hypertrophic cardiomyopathy, cardiac amyloidosis, cardiomyopathies, and cardiac masses, is one of the rapidly expanding potential clinical applications of AI in echocardiography (9).

Cardiac magnetic resonance imaging

Because it offers unmatched insights into tissue characterisation, functional assessment, and anatomical detail without the use of ionizing radiation, CMR imaging is essential in the evaluation of cardiovascular disorders. AI has been incorporated into CMR in recent years, leading to important developments that have improved several facets of image capture, processing, analysis, and interpretation. AI has greatly improved the quality and efficiency of CMR image reconstruction and capture. There are difficulties with traditional CMR imaging, especially for some patient demographics, because of its long scan periods and breath-holding need. AI methods, particularly deep learning models, have been created to speed up image acquisition and enhance reconstruction procedures in order to overcome these problems.For instance, CNN has been effectively used to rebuild high-quality images from under-sampled data, allowing for quicker scans without sacrificing diagnostic precision. Furthermore, real-time CMR imaging has been made possible by the combination of compressed sensing methods with AI-driven reconstruction, which is particularly helpful in dynamic studies like cine imaging. These developments not only increase patient comfort but also make CMR more accessible, which may lead to a wider range of clinical applications (10).

Computed tomography and Nuclear Imaging:

The use of cardiac imaging for the diagnosis and prognostic assessment of CAD has significantly increased. The need for advanced imaging examinations has significantly increased as a result. AI has significantly advanced cardiac CT in recent years, especially with the creation of complex algorithms designed for the post-processing stage. By automating several parts of image interpretation, these AI-driven methods aim to improve diagnostic accuracy, lower radiation exposure, and improve image quality. Because it maximizes both efficiency and accuracy in evaluating complex cardiovascular diseases, the integration of AI into cardiac CT workflows constitutes a paradigm leap in the field.AI has primarily been used in CAC and CTA. The integration of CACS into non-gated CT scans, which could serve as a screening tool for a standard CT scan, is the most promising feature of CAC evaluation. One of the most challenging areas is developing a model for plaque assessment (11).

AI-based algorithms have demonstrated a level of accuracy comparable to expert human interpretation of myocardial perfusion single-photon emission computed tomography (SPECT) images in the classification of normal and dysfunctional myocardium in CAD. AI-based methods have been utilized in other research to identify regions with aberrant myocardium.It has been demonstrated that combining quantitative imaging features with clinical data in an ML system improves SPECT accuracy. Using an integrative algorithm, Arsanjani et al. were able to detect obstructive CAD with a somewhat better performance than using only clinical variables (79% vs. 76%). The algorithm's performance was

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superior to another (73%) and comparable to that of one seasoned reader (78%). In order to predict obstructive CAD more effectively than the existing clinical approach, Betancur et al. employed DL algorithms trained on raw and quantitative perfusion polar maps (AUC 0.80 vs. 0.78). Another study combined SPECT data with clinical and functional characteristics and shown that ML could predict the need for revascularization just as well as or better than two skilled readers. An ML algorithm that combined clinical data with myocardial perfusion SPECT data exhibited an AUC greater than the system using only imaging features (0.81 vs. 0.78), according to another investigation of significant adverse cardiovascular events (12).

Wearables and Remote monitoring:

With their continuous, patient-centered monitoring that can close gaps in detection, risk assessment, and prompt action, AI-integrated WDs have become revolutionary tools in cardiovascular medicine. High diagnostic accuracy for arrhythmia detection, clinically significant decreases in HF hospitalizations, and the potential for cost savings when integrated into structured treatment pathways are all demonstrated by data from both controlled trials and early real-world deployments. However, intentional alignment of research, policy, and practice is necessary to fully realize the potential of these technologies (13).

Robotic-assisted percutaneous coronary intervention (R-PCI)

One new development in transcatheter therapy is robotic-assisted percutaneous coronary intervention (R-PCI). R-PCI could lower radiation exposure and lower the risk of physician injury by enabling interventional cardiologists to operate guidewires, catheters, and devices from a nearby or even remote cockpit. Despite the high procedural success rates reported by industry-backed studies, real-world implementation has shown many important limits. Complex lesion navigation may be hampered by a lack of haptic feedback, increasing the need for imaging modalities and operator intuition. Additionally, system setup requirements might prolong processes, potentially offsetting the advantages of efficiency.Another significant obstacle is cost; R-PCI necessitates a large investment in robotic platforms, upkeep, and specialized training, which is prohibitive for many hospitals. Patients with unstable coronary syndromes (e.g., ST-elevation myocardial infarction complicated by shock) and complex coronary artery disease (e.g., highly calcific lesions) may present additional and significant challenges, such as delays in system setup or switching from R-PCI to manual PCI, or an inability to maneuver guidewires efficiently via the robot.

Although it has been suggested that integrating AI with R-PCI will improve real-time decision assistance and automate procedure changes, its efficacy is still mainly theoretical. There are no solid, independent studies that demonstrate AI-driven R-PCI outperforms skilled manual operators (14).

Limitations:

Despite tremendous advancements over the last ten years, the current approaches to AI development still have serious flaws, including a limited scope that makes it difficult to identify outlier cases and increases the risk of misdiagnosis, vulnerability to hostile attacks, and the incapacity of AI to integrate intuition, cognition, and abstract reasoning. The recent special report by Ng et al. provides a great explanation of these limitations. For AI to be confidently used in therapeutic settings, these constraints must be resolved immediately (15).

Ethical Considerations for Use of AI in Cardiovascular Medicine:

The World Health Organization has established a number of ethical considerations that must be taken into account when integrating AI into healthcare, particularly cardiovascular medicine. These concepts are outlined below. When developing, implementing, and continuously evaluating the use of AI in healthcare, developers, users, and regulators have an obligation to uphold ethical standards. When examining AI-specific ethical issues, the foundational bioethical principles of beneficence, nonmaleficence, autonomy, and fairness are crucial. We summarize the conflicting ethical potential and challenges in this field in the figure. It is inevitable that the ethical questions raised by AI may not be satisfactorily addressed by the ordinary application of standardized ethical norms.In order to effectively address this issue, it will be necessary to critically examine what society and doctors value about health care as well as what we believe to be its primary vulnerabilities (16).

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Privacy and Consent

Patient data should not be accessed by AI systems without explicit and informed consent. Whether their data is deidentified or identified, patients should be made aware of how it is being utilized. In order to identify the appropriate category (no notification or no informed consent [IC], notification only, and formal IC), Rose and Shapiro suggested assessing AI use cases based on the following criteria: (1) the degree of autonomy of the AI model; (2) the degree to which the AI deviates from standard practices; (3) whether the AI model interacts directly with patients; (4) the clinical risks associated with the model; and (5) the administrative burdens involved(17).

II. CONCLUSION

Cardiology is undergoing a revolution thanks to artificial intelligence (AI), which presents new possibilities for bettering cardiovascular disease prevention, diagnosis, and therapy. AI can ease the complexity of modern medicine because of its capacity to evaluate vast volumes of data and assist with therapeutic decisions. However, organizational, ethical, and methodological barriers restrict its advancement. By examining important algorithms, opportunities, and constraints, this review seeks to provide the prospective applications of AI in cardiology in a useful and understandable manner. In order to fully realize the promise of AI in everyday cardiology practice, it is imperative to aggressively promote collaboration between clinicians and informatics professionals and address the essential concerns related to AI in order to ensure its ethical and responsible usage in support of clinical knowledge (18).

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