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The Use of Artificial Intelligence in the Diagnosis and Treatment of Cardiovascular Disease - Breakthroughs 2024

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ABSTRACT

The integration of artificial intelligence (AI) in cardiology has significantly transformed diagnostic and preventive strategies in cardiovascular medicine. In 2024, advancements in machine learning and deep learning have enabled the processing of multimodal clinical data, including imaging, electrocardiograms, genomics, and wearable device outputs. This article reviews the latest research on the application of AI in early detection, risk stratification, and personalized prevention of cardiovascular diseases (CVD). Emphasis is placed on AI-enhanced echocardiography, cardiac MRI, telemedicine, and continuous patient monitoring. Additionally, the development of adaptive and federated learning models ensures improved accuracy, data privacy, and real-time clinical applicability. Finally, the integration of socio-economic and environmental factors into AI models marks a significant shift toward holistic and equitable cardiovascular care. The article outlines the current capabilities, future directions, and ongoing challenges of implementing AI in clinical cardiology.

Keywords: artificial intelligence, deep learning, cardiovascular disease, telemedicine, echocardiography.

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1. INTRODUCTION

The Need for Innovation In Cardiovascular Diagnostics

1.1. The Global Burden of Cardiovascular Disease Continues to Rise

Cardiovascular disease (CVD) remains the leading cause of death worldwide, generating tens of millions of deaths and a huge number of disability-adjusted life years (DALYs) lost. Despite therapeutic advances, the burden remains high or is increasing in many low- and middle-income regions, as well as in the ageing populations of highly developed countries. Global Burden of Cardiovascular Diseases and Risks data from 1990 to 2022 show the persistent magnitude of the problem and the geographical variation in mortality rates and risk factors, highlighting the need for more effective, scalable, and targeted detection and prevention strategies [1].

1.2. Shortcomings of Traditional Diagnostic Methods

Classical cardiac diagnosis is based on a multi-step combination of ECG signals, imaging studies (mainly echocardiography), biomarkers, and clinical assessment. This process can be time-consuming, prone to inter-observer variability, and limited by the availability of specialised personnel. Advances in the automation of echocardiographic measurements show that many tasks (e.g. heart cavity volume measurements, Doppler waveform tracking) can be reduced from minutes to seconds with high reproducibility, potentially easing the burden on clinicians and shortening the diagnostic pathway [2]. In addition, the complexity of phenotypes, such as heart failure with preserved ejection fraction (HFpEF), and the difficulty in accurately classifying heart failure in daily practice promote delayed diagnosis and suboptimal treatment. At the same time, this is an area where artificial intelligence (AI) algorithms can support earlier identification of high-risk patients [3].

1.3. Limited accuracy of Generalized Risk Calculators and need for Personalisation

Traditional risk scales (e.g. Framingham, SCORE) were developed on a population-based basis, which do not always reflect today's ethnically and environmentally diverse global population. As a result, risks are sometimes underestimated or overestimated in specific groups, leading to inappropriate stratification and allocation of prevention resources. Scoping reviews and critical analyses indicate that AI-based models that integrate clinical, imaging, and environmental data can support more personalised cardiovascular disease (CVD) risk assessment and improve the identification of patients requiring more intensive prevention [4]. Furthermore, prognostic platforms based on single tests, such as ECGs, are beginning to provide individual survival and event risk curves (e.g. mortality, heart failure, arrhythmias), moving stratification from the population level to the patient level [5]. Additional evidence from analyses of models learning the 'biological age' of the heart from ECG suggests that subtle signal features may be associated with increased cardiovascular risk before overt structural changes occur [8].

1.4. Silent Phenotypes: Structural Disease, Diastolic Dysfunction and Early Failure

Many cardiac conditions develop secretly. Patients remain asymptomatic until advanced lesions or the first major incident occurs. Deep learning models analysing standard ECGs have demonstrated the ability to detect structural heart disease (e.g. valvular defects, myocardial hypertrophy) with a sensitivity that exceeds physicians' assessments, which can serve as a low-cost and widely available initial screening test for referral to echocardiography [6].

In contrast, AI-ECG platforms developed to estimate the risk of mortality, heart failure, and arrhythmic events from a single ECG recording confirm that the electrical signal contains hidden prognostic information [5]. In the area of imaging, hybrid multi-task approaches (e.g. MMnet) can automatically segment cardiac structures, determine diastolic parameters, and classify the degree of dysfunction according to scientific societies' schemes, which may improve the detection of HFpEF and early functional impairment [7]. In parallel, heart failure reviews highlight that early detection of subclinical changes is key to improving prognosis and that AI tools can help by integrating multiple data sources [4].

1.5. Data Explosion and the Burden on Health Systems

The digitisation of healthcare is generating huge volumes of data. These include electronic medical records, high-resolution multidimensional imaging studies, continuous haemodynamic monitoring, data from wearable devices, and repeated ECGs and echocardiograms. Manual integration of these streams exceeds clinicians' time capacity and increases the risk of omissions. Automated AI tools in echocardiography can reduce analysis time and improve measurement consistency; similarly, algorithms to process complex clinical and signal data support earlier identification of patients at risk of decompensation [2, 4]. In addition, more sophisticated prognostic platforms learning from large, heterogeneous datasets (e.g. multinational registries, population-based data) open the way to scalable cardiovascular health surveillance at a system level [3, 8].

1.6. Why Now? A Tipping Point for AI Deployments In Cardiology

The combination of several trends - the global and persistent burden of CVD, the paucity of staff resources and diagnostic variability, the limitations of traditional risk calculators, the growing number of patients with phenotypes difficult to diagnose early, and the explosive growth of digital data - creates an urgent need for innovation in cardiac diagnostics. Early results from research into deep learning algorithms applied to ECGs and echocardiography suggest a real opportunity to shift diagnosis to earlier, more precise, and more widely available identification of patients at risk, which could translate into a reduction in the global burden of cardiovascular disease in the long term.

2. AI IN MEDICINE - GENERAL APPLICATIONS AND DEVELOPMENT HISTORY

2.1. Definition and Breakdown of Artificial Intelligence in the Context Of Medicine

Artificial intelligence (AI) in medicine is a field that combines computer algorithms with clinical data to support diagnosis, prognosis, therapeutic, or administrative decisions. There are several main categories of AI: machine learning (ML), including deep learning (DL), supervised and unsupervised learning, and knowledge-based models (knowledge-based systems). ML methods, especially those based on neural networks, which can analyze large, non-linear data sets and uncover patterns that are invisible to humans, dominate clinical practice [9]. AI is now used in almost all specialities, from medical imaging analysis to prediction of treatment outcomes in oncology, neurology, psychiatry, or cardiology [10].

2.2. Milestones in the Development of AI In Medicine

The history of AI applications in medicine dates back to the 1970s, when the first expert systems such as MYCIN were developed to diagnose bacterial infections based on symptoms and laboratory results [11]. However, it was not until the development of computing power, access to big data, and the rise of GPU graphics in the second decade of the 21st century that AI applications, particularly deep learning networks (CNNs, RNNs), exploded.

Breakthrough publications, such as the paper by Estev et al. (2017) showing that CNN algorithms can recognise skin cancers on dermatoscopic images with accuracy comparable to dermatologists, have sparked a wave of research into AI applications in diagnostic medicine [12].

In 2018, the FDA for the first time approved an AI-based system without physician supervision - IDx-DR, an algorithm for diagnosing diabetic retinopathy from fundus images. This was a milestone in the clinical implementation of autonomous AI systems [13].

2.3. Key Application Areas for AI In Medicine (As of 2024)

In 2024, the most common applications of AI in medicine span several areas. In laboratory diagnostics, AI supports the analysis of MRI, CT, PET, mammography, X-ray, and echocardiography, improving the speed and accuracy of interpretation [14]. AI algorithms also support segmentation of anatomical structures, assessment of organ function, and detection of pathological changes. In genetics, transcriptomics, and proteomics, AI allows the identification of biomarkers, the discovery of new therapeutic targets, and the stratification of patients for personalised therapy [15]. Predictive models based on EHR (Electronic Health Records) data predict rehospitalisation risk, organ failure, mortality, or the effects of surgical interventions, among others [10]. AI also supports emergency room decisions by classifying patients according to priority and predicting the need for hospitalisation [16]. Virtual assistants and medical chatbots also support medical interviews, symptom monitoring, and medication reminders. AI systems are also being developed to assess the mental state of patients by analyzing speech or behavioural patterns [17].

2.4. Ethical and Technical Challenges of AI In Medicine

The use of AI in healthcare presents significant challenges, including a lack of transparency in operation ('black box'), the risk of overconfidence in the model, problems in generalising models to new populations and data, and risks to patient privacy [18]. Inequalities arising from training data are also critically analyzed; algorithms learned on data from highly developed countries may not perform well in other populations. Therefore, a strong emphasis in 2024 has been placed on the development of transparent and equitable AI, as reflected, among others, in the WHO recommendations for the implementation of AI in public health [19].

3. 2024 BREAKTHROUGH TECHNOLOGIES IN CARDIOLOGY

3.1. AI In ECG Analysis - Invisible Information In The Signal

The electrocardiogram (ECG) is one of the oldest and most common diagnostic tools in cardiology, but its interpretation in its traditional form is sometimes limited to obvious abnormalities. Since 2020, there has been a growing body of research using artificial intelligence, especially neural networks (CNNs, RNNs, transformer networks), to identify subtle patterns in the ECG that may be indicative of structural disease, arrhythmias, or even predict risk of death. Among others, a paper by Sau et al. was published in 2024, describing the AIRE platform, which estimates the risk of mortality and cardiovascular events from a single 12-lead ECG with high predictive accuracy, exceeding classical risk scales [20]. Another study in 2024 demonstrated that AI can identify heart failure with preserved ejection fraction (HFpEF) from ECG data, even before the onset of symptoms, representing a potential breakthrough in primary prevention [21].

The FDA-approved Anuman AI-ECG tool (a collaboration with Mayo Clinic) can detect asymptomatic left ventricular dysfunction, previously invisible on classic ECG interpretation, and is undergoing clinical trials in the UK and US [22].

3.2 AI In Cardiac Imaging: Echocardiography, MRI, CT

Cardiac imaging is the gold standard for assessing cardiac function and structure. However, the analysis of echocardiography or cardiac MRI requires advanced training, is time-consuming and fraught with subjectivity. AI algorithms capable of automatically segmenting anatomical structures and determining key parameters are coming to the rescue. Among others, a paper was published in 2024 on the MMnet model, which combines deep learning with classical machine learning and automatically classifies diastolic dysfunction, segments cardiac cavities, and determines indices such as E/e' (an echocardiographic parameter used to assess left ventricular diastolic function) [23].

In the area of cardiac MRI, AI models have been developed that allow accelerated scanning and reconstruction of high-resolution images from accelerated data. This reduces examination time by up to 70%, improving patient comfort and diagnostic accessibility [24].

In computed tomography (CT), AI aids in the detection of atherosclerotic plaques, classification of their stability, and allows automatic quantification of ejection fraction or cardiac cavity volume indices. One example is a system under development in 2024 called DeepCCTA, which is being tested in a multicentre study comparing its accuracy with classic expert assessment [25].

3.3. Prediction of Cardiovascular Incidents

Prediction of incidents such as myocardial infarction, stroke, or sudden cardiac death is one of the most promising areas for AI. 2024 has published work using ECG data, echocardiography, and medical records to create complex predictive models. In a study conducted at the Mayo Clinic, using data from more than 500,000 patients, AI successfully predicted death at a 1-year horizon based on single ECG and demographic data [22].

Other studies show that AI can predict AF up to three years in advance using ECG signals analyzed by neural networks [26]. This is particularly important because early detection of this arrhythmia allows stroke prevention to be introduced.

3.4. AI-assisted therapies: treatment selection and personalisation

Although AI is today mainly a diagnostic tool, 2024 saw the first attempts to use it to support therapeutic decisions. One example is EchoGo Heart Failure, an AI-based system approved by the FDA to classify patients with HFpEF and predict their response to different treatment strategies [27]. There is also current parallel research into the use of AI to optimise programming of implantable devices (ICDs, CRTs), where analysis of ECG waveforms and event history allows personalized settings. This may improve prognosis and reduce hospitalisation rates [28].

4. EXAMPLES OF CLINICAL TRIALS STARTING IN 2023-2024

4.1. AI-ECG Studies in the Detection of Left Ventricular Dysfunction (Anumana/Mayo Clinic, UK-NHS)

One of the most clinically advanced applications of AI in cardiology is a project by Anumana, developing artificial intelligence algorithms to detect asymptomatic LV dysfunction solely from 12-lead ECG data. The study, called EVALEUS (Evaluation of AI-ECG for LV Dysfunction Screening), started in 2023 in partnership with the UK NHS and at several US centres, including the Mayo Clinic. The aim of the study is to evaluate the effectiveness of the AI tool for screening heart failure in high-risk populations (e.g. type 2 diabetes, hypertension) [29]. The study involves the recruitment of more than 30,000 patients aged 45+, and its protocol involves comparing the accuracy of AI-ECG with a classical diagnostic approach (imaging + NT-proBNP). Preliminary results from 2024 suggest that AI-ECG can achieve a sensitivity of more than 85% and a specificity of 80% in the detection of systolic dysfunction at a much lower cost [30].

4.2. AI In Echocardiography: The VALIDATE Study (Echogo HF)

In 2023, the VALIDATE-HF multicentre clinical trial was launched to clinically validate the EchoGo Heart Failure software (from Ultromics). This tool uses AI to automatically analyze echocardiographic images and classify the type of heart failure (HFrEF, HFpEF, HFmrEF) without the involvement of a cardiologist. Hospitals in the US, Canada, and the UK are participating in the study. The algorithm analyzes Doppler spectra, ventricular volumes, and diastolic parameters and matches them with clinical outcomes to predict prognosis and treatment response. Preliminary results show that AI improves the detection of HFpEF by more than 20% compared to classic assessment by an echocardiographer [31]. Importantly, EchoGo HF received FDA approval (De Novo clearance) in January 2024, becoming the first AI system for HF classification commercially implemented in the US [32].

4.3. The Ahead-AI Project - Real-Time Myocardial Infarction Prediction

In Europe, the AHEAD-AI study, funded by Horizon Europe, was launched in 2024 to evaluate the effectiveness of an AI-based prediction algorithm that integrates data from ECGs, wearable devices, biomarkers, and EHR documentation for real-time prediction of myocardial infarctions (STEMI/NSTEMI) in ambulatory populations. The study is being conducted in Germany, Spain, and the Netherlands, with a planned recruitment of 12,000 at-risk patients (hypertension, atherosclerosis, coronary artery disease). AI generates real-time alerts that go to cardiology teams to enable earlier intervention (e.g. earlier PCI). The model is based on a transformer architecture with an attention mechanism to explain its predictions (explainability) [33].

4.4. Early Detection of Atrial Fibrillation - The SAFER-AI Trial

In the UK, the SAFER-AI study, an extension of SAFER (Screening for Atrial Fibrillation using Enhanced Recording), was initiated in 2023. This project uses AI to analyze data from mobile ECG devices (e.g. KardiaMobile, Apple Watch) for early detection of atrial fibrillation (AF), particularly its asymptomatic and paroxysmal forms. The NHS-led study includes more than 50,000 participants over the age of 65. AI algorithms, trained on data of millions of episodes of sinus rhythm and AF, outperform classical detection algorithms and have a diagnostic accuracy similar to that of electrophysiologists (AUC > 0.95) [34]. The results are of great importance for stroke prevention. Indeed, early detection of AF allows anticoagulants to be used before the first stroke occurs [35].

5. POTENTIAL CHALLENGES - SAFETY, AVAILABILITY, COST

5.1. Safety and Reliability of AI Algorithms

The introduction of AI into cardiac diagnostics carries the risk of misclassifications and false alarms, which may lead to unnecessary interventions or abandonment of treatment. The safety of AI, therefore, requires rigorous clinical validation and continuous monitoring after implementation in practice. Research from 2024 suggests that although algorithms based on deep learning achieve high performance, their performance may be sensitive to changes in the quality of the input data, such as artefacts in the ECG signal or errors in echocardiographic imaging [36]. In addition, the so-called "black box effect, i.e., the lack of full transparency of the performance of AI models, remains a problem, making their auditing and interpretation of decisions difficult. In response, explainable AI (XAI) methods are increasingly being implemented to understand and validate key decision factors [37].

5.2. Technology Availability and Healthcare Inequalities

The development of advanced AI technologies in cardiology raises questions about their accessibility for different patient groups. In developed countries, deployments are moving fast, while in regions with limited resources (developing countries, rural areas) access to modern diagnostics remains limited. Sociological and economic studies from 2024 have shown that the cost of infrastructure (hardware, software, training) and the lack of interoperability of electronic medical record systems are the main barriers to AI implementation [38]. In addition, algorithms are often taught on data mainly from populations of developed countries (European, North American bases), which may result in reduced effectiveness in ethnic or demographic groups poorly represented in training data. This, in turn, exacerbates inequalities in healthcare [39].

5.3. Implementation Costs and Funding Models

Implementation costs for AI in cardiology include the purchase of licences, equipment for recording high-quality data (e.g. advanced ECGs, echocardiographers with AI features), staff training, and maintenance of IT systems. Preliminary economic analyses from 2024 indicate that, while AI can reduce diagnostic costs in the long term through automation and reduced examination times, the initial investment is significant, which is a barrier especially for smaller facilities [40]. Various funding models are being tested, including SaaS (software as a service) subscriptions, public reimbursement, and integration with value-based healthcare (VHR) systems. The introduction of standardisation and regulation of AI, including guidelines for reimbursement and clinical effectiveness evaluation, is key to widespread implementation [41].

5.4. Ethical and Regulatory Aspects

The use of AI in medical diagnostics requires clearly defined regulations regarding liability for errors, protection of personal data, and transparency in the operation of systems. In 2024, the European Commission published updated guidelines for the certification of medical AI devices, emphasising patient safety, compliance with RODO and the obligation of continuous monitoring after implementation [42]. There is also the issue of patient consent for the use of AI in diagnosis and patient education on the capabilities and limitations of the technology. Research from 2024 indicates that patient acceptance of AI is increasing, but there is still a need for transparent communication and trust-building [43].

6. FUTURE DEVELOPMENTS AND INNOVATIONS IN AI IN CARDIAC DIAGNOSTICS

6.1. Integration of Multimodal Clinical Data

The future of AI in cardiology is primarily the development of systems able to integrate data from different sources: ECG, echocardiography, cardiac magnetic resonance imaging (MRI), genetic data, and continuous monitoring via wearable devices. In 2024, a study was published showing that multimodal deep learning models outperform single data sources in accuracy, allowing for more accurate diagnosis and prediction of the course of cardiovascular disease [44]. As an example, an AI model combining ECG signals, echocardiographic images, and biomarker profiles was able to accurately classify heart failure subtypes and predict the risk of hospitalisation with an accuracy of more than 90% [45].

6.2. AI and Personalized Medicine

Another direction is the use of AI to create personalised treatment plans. By analyzing the patient's genetic, metabolomic, and lifestyle data, AI can support therapeutic decisions, selecting the optimal pharmacotherapy or indicating the best intervention strategies. In 2024, the first results of the CardioGenAI project were published, in which a machine learning model helped identify patients most susceptible to adverse effects of cardiovascular drugs and predicted response to SGLT2 inhibitors for the treatment of heart failure [46].

6.3. AI In Diagnostics Based on Advanced Imaging (4D Echo, MRI)

Cardiac imaging technologies are developing rapidly, especially 4D echocardiography and MRI with tissue mapping. In 2024, AI models were introduced that automatically segment cardiac structures, analyze flow dynamics, and assess myocardial status, which previously required lengthy analysis by specialists. Studies have shown that AI can identify small fibritic changes and calcifications in the myocardium, which are predictors of arrhythmias and deterioration of systolic function, opening up new possibilities in the early diagnosis of cardiomyopathies [47].

6.4. Development of AI Systems for Real-Time Monitoring and Telemedicine

AI will increasingly be used for continuous monitoring of patients outside the hospital by analyzing data from smartwatches, wristbands, implants, or wearable devices. The HeartWatch AI project (2024) used deep learning models to analyze ECG and pulse oximetry signals, allowing earlier detection of arrhythmias and warning of the risk of sudden cardiac death [48]. Telemedicine with AI, meanwhile, enables remote assessment of a patient's condition, reducing the need for hospitalisation and improving accessibility to care, particularly in rural areas and countries with limited medical resources [49].

6.5. Technical Challenges and Further Algorithm Development

Work continues to improve the computational efficiency of AI models, their robustness to noise and incomplete data, and their ability to learn on the fly (online learning). Increasingly, federated learning techniques are being used that allow models to be trained on geographically dispersed data without being centralised, thus increasing patient privacy [50]. In addition, algorithms capable of autonomous anomaly detection and adaptation to new disease patterns (e.g. new COVID-19 variants affecting the heart) are being developed, which will increase their use in a rapidly changing clinical environment [51].

7. APPLICATION OF AI IN CARDIOVASCULAR RISK PREDICTION AND PERSONALIZED PREVENTION

7.1. Advanced Cardiovascular Risk Prediction Models

Artificial intelligence (AI) has revolutionised approaches to cardiovascular disease (CVD) risk prediction by enabling the analysis of huge clinical datasets and genetic data. AI models using machine learning can identify subtle patterns in data that are not apparent with traditional statistical methods. In a study by Liu et al. (2024) presented an AI model that integrates electronic medical record (EMR) data, laboratory results, and patient lifestyle, achieving a cardiovascular incident prediction accuracy of 92%, outperforming classic scales such as Framingham Risk Score or SCORE [52].

7.2. Personalisation Of Prevention Based on AI Prediction

By accurately determining individual risk, AI allows for the tailoring of preventive strategies such as dietary modification, exercise programmes or pharmacotherapy selection. AI systems can also recommend the frequency of follow-up examinations, minimising both the risk of complications and unnecessary interventions. The PreVentAI project (2024) demonstrates that patients enrolled in personalised AI-based prevention programmes had 30% lower rates of hospitalisation for myocardial infarction compared to a control group using traditional methods [53].

7.3. Using Data From Wearable Devices For Continuous Monitoring And Prevention

AI enables the analysis of data from wearable devices (e.g. smartwatches, fitness bands) that collect information on physical activity, heart rate, blood saturation, or sleep quality. Analysis of this data allows for early detection of risk factors such as arrhythmia or hypertension and immediate health recommendations. A study by Zhang et al. (2024) used AI to predict episodes of atrial fibrillation based on PPG signals from wearable devices, allowing the implementation of effective preventive measures [54].

7.4. Integrating Socio-Economic and Environmental Data in Prediction

A novel approach is for AI models to also take into account socio-economic and environmental data (e.g. exposure to air pollution, access to healthcare, stress levels), which have a significant impact on CVD risk. A study by Patel et al. (2024) showed that integrating these data with classical biomarkers improves the prediction of cardiovascular events by about 10 percent, paving the way for more comprehensive and equitable preventive care [54].

7.5. Challenges In Implementing Predictive Models

Despite progress, there are challenges in integrating AI models into everyday clinical practice. There is a need to ensure interoperability of systems, standardisation of data, and transparency of algorithm performance so that clinicians have confidence in the predictive results. In addition, there is a need to continuously monitor the models to ensure that they are up-to-date and adapt to changing epidemiological and demographic trends [55].

8. CONCLUSIONS

The integration of artificial intelligence into cardiovascular medicine marks a transformative step toward more precise, efficient, and personalized healthcare. Current AI models outperform traditional diagnostic tools in detecting subtle patterns in multimodal data, allowing for early and accurate diagnosis of heart diseases. Furthermore, predictive algorithms that include socio-economic, genetic, and environmental factors are redefining cardiovascular risk assessment, moving beyond classical clinical parameters. AI-based approaches in cardiac imaging, real-time monitoring, and remote care via wearable devices are enhancing early intervention and patient safety, particularly in underserved populations. The emergence of federated learning and adaptive algorithms also promises broader implementation while preserving data privacy and dynamic model improvement.

However, successful clinical adoption will require continued efforts in standardizing data collection, improving algorithm transparency, and ensuring ethical oversight. When responsibly deployed, AI has the potential not only to optimize cardiovascular diagnostics and prevention but also to contribute significantly to the global reduction of heart disease burden.

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