INTERNATIONAL DEVELOPMENT PLANNING REVIEW
ISSN:1474-6743 | E-ISSN:1478-3401

ARTIFICIAL INTELLIGENCE IN CARDIOVASCULAR RISK ASSESSMENT: CURRENT APPLICATIONS AND FUTURE PROSPECTS

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Abstract

The leading cause of mortality across the globe is cardiovascular disease (CVD), and with the advancement of technology, the focus on Artificial Intelligence (AI) in cardiovascular risk evaluation has been on the increase. This review examines factors such as population health management, patient care, and risk prediction that AI techniques, including machine learning, deep learning, and natural language processing assist in such improvement. In contrast to traditional methods, AI models outperform in the prediction of major cardiovascular events data derived from genetic information, imaging techniques, and e-health records due to their ability to handle huge quantities of data.

Introduction

Cardiovascular disease (CVD) is still the leading cause of death worldwide, accounting for approximately 31% of global deaths [1]. The prevalence of CVD has almost doubled, increasing from 271 million cases in 1990 to 523 million in 2019 [2]. The increase in risk factors such as obesity, diabetes, and tobacco are the main cause of this trend [3]. Notably, significant gender disparities are evident, with females demonstrating consistently higher prevalence rates across various conditions, except for ischemic heart disease and cardiomyopathy [4].

The transformative potential of artificial intelligence (AI) in healthcare, especially within cardiology, cannot be overstated, this holds tremendous potential for enhancing diagnosis, treatment, and overall patient outcomes [5,6]. AI applications in cardiology encompass automated risk prediction, heart failure diagnosis, and clinical decision support systems [6,7]. AI can use machine learning and deep learning to analyze large datasets, including medical imaging, electronic health records, and wearable devices [8,9]. AI is poised to spur the field toward more individualized and targeted care, but there are still many hurdles related to ethics, methodology, and regulation [10,11].

The main aim of introducing the field of AI to cardiovascular risk assessment is overcoming traditional methods' limitations and improve precision medicine [12,13]. More advanced AI techniques — such as machine learning and deep neural networks (DNNs) — could be used to analyze extremely large beyond conventional risk factors [12,14]. These incredible AI-powered models exhibit enhanced accuracy in detecting complex risk variables and patterns, while their integration into medical imaging, genetic information, and electronic health records serves to further bolster their predictive capabilities [15,16]. Although there is promise, several challenges still exist in data quality, model interpretability, generalizability, and ethical considerations [10,12].

AI Technologies in Cardiovascular Risk Assessment

Machine learning models have demonstrated superior predictive performance for predicting CVD risk compared with traditional methods [17,18]. Although these algorithms will potentially empower personalized risk assessment and improve preventive strategies in cardiovascular medicine, challenges such as model interpretability and generalizability still exist [19].

Deep learning methods which include Deep neural networks (DNNs), Convolutional Neural Networks (CNNs), and Recurrent Neural Networks (RNNS) are now employed across the spectrum of cardiology to predict cardiovascular events. The potential of deep-learning algorithms is shown in ECG analysis, imaging technologies risk prediction models [20,21]. Despite achieving unprecedented accuracy in cardiovascular risk stratification, deep learning models face difficulties with interpretability and clinical integration and thus data efficiency [22,23]. For these models to ultimately be clinically feasible, they not only need high accuracy but also have to let us know how and why a certain decision was made [24,25].

One such AI technology is Natural Language Processing (NLP) which has emerged as effectively being employed for cardiovascular risk factor extraction using electronic health records (EHRs). It works well in identifying risk factors such as high blood pressure, cholesterol levels, obesity, and smoking status [26,27]. Advanced NLP methods can achieve high accuracy in extracting key cardiovascular risk information from clinical notes and are likely to contribute significantly to improving healthcare delivery decision-support systems combined with large-scale data mining [28]. NLP has shown to be promising in improving cardiovascular risk assessment although it faces some challenges such as imbalanced data and a lack of standardized reports [29].
AI technologies, such as natural language processing, deep learning, and machine learning, are very useful for risk assessment when it comes to cardiac health monitoring. They collect information from a variety of sources, including imaging, wearable technology, and electronic health records. **Figure 1** illustrates how AI can identify and comprehend this data and apply it to different clinical circumstances.

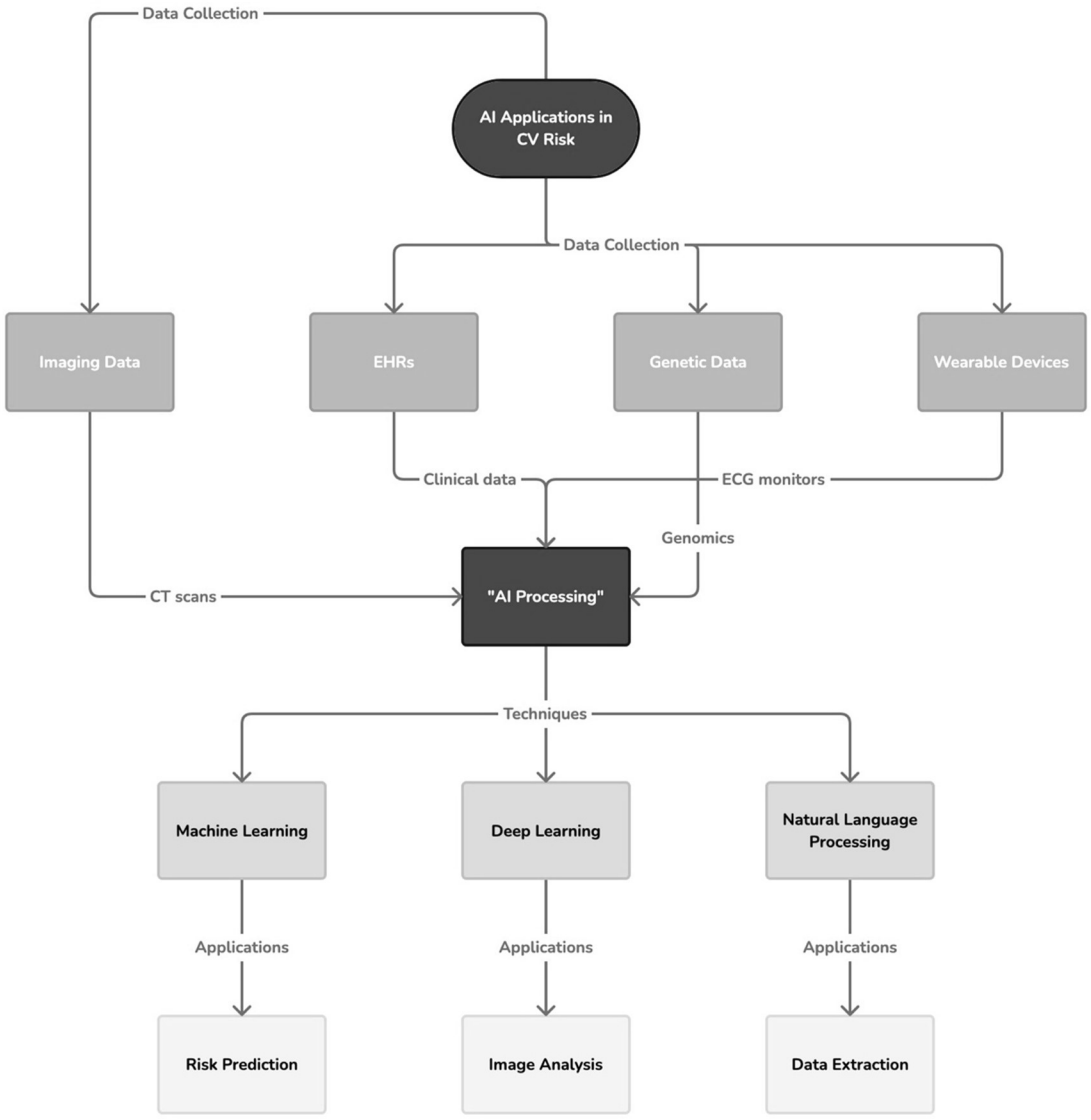

Figure 1: Overview of AI applications in cardiovascular risk assessment, illustrating the flow from data collection (e.g., imaging data, EHRs, genetic data, wearable devices), through AI processing to specific applications like risk prediction and image analysis.

AI's integration with traditional risk models, such as the Framingham Risk Score (FRS), leads to significant improvements in predicting cardiovascular risk. AI models can process much larger datasets with many more variables that occur over longer periods, addressing lifestyle measurements as well as from medical imaging files to genetic information making them individual and specific health risk predictions accurate [12,15]. AI models have been shown to outperform conventional risk assessment by behaving as non-linear processing elements in addition to capturing the complex relationships that create risks [30]. Challenges regarding data quality, model interpretability, and ethical considerations need addressing for full AI potential in cardiovascular risk assessment [31,32].

Current Applications of AI in Cardiovascular Risk Assessment

AI has been particularly effective at predicting major adverse cardiovascular events (MACE), often showing superiority over traditional risk models. For example, random forest models based on routine clinical variables have demonstrated high predictive accuracy for MACE in special patient populations such as patients with tetralogy of Fallot [33]. In coronary artery disease patients, AI-aided analysis of coronary CT angiography was also efficient at predicting MACE [34]. On the one hand, some studies suggest if only ECG information is used, predictive performance might be low while on the other accuracy models can be built by the addition of clinical factors [34,35]. Summing up, AI models seem promising for better risk prediction of MACE.

AI is also leading to more personalized patient risk stratification and custom approaches in cardiovascular care. For instance, AI algorithms used in cardiovascular imaging can scale the estimation of prognostic biomarkers and integrate them with clinical factors for personalized risk prediction [36]. By means of its capacity to process vast databases, AI has been able to more precisely reflect on risk prediction and treatment planning for different diseases, including thyroid cancer and congenital heart diseases [37,38]. Additionally, multimodality integration using AI has demonstrated potential in risk stratification for prostate cancer as well as other personalized medicine applications [39].

AI has a profound impact on the early identification of high-risk patients by using it in screening and detection to revolutionize the field of cardiovascular medicine. By combing through large volumes of medical data, AI algorithms can enhance the diagnosis and risk prediction for numerous cardiovascular diseases like heart failure, atrial fibrillation, or hypertrophic cardiomyopathy [40]. AI-guided analysis of cardiovascular images is a validated and rapidly growing field for the identification and quantification of cardiovascular risk [41]. This has the potential to significantly improve patient outcomes [14].

It is also important in population health management and can be a big part of assessing and controlling cardiovascular risk on a much wider scale. By combining data from various sources, such as medical imaging, electronic health records, and genetic information in AI-assisted models the estimation of risk becomes more accurate making intervention at a very early stage possible [12,42]. AI in cardiovascular medicine will range from disease detection and diagnosis through treatment planning to decision-making [43]. AI can do so at a population level for cardiovascular care but is challenged by data quality, model interpretability, and ethical considerations as mentioned before [12,42].

Challenges and Limitations

AI has demonstrated potential in assessing cardiovascular risk, but data quality and availability present significant challenges that degrade AI performance. The need, specifically given the COVID-19 pandemic and beyond, includes but is not limited to access to diverse high-quality datasets (associated with ethical considerations) as well as challenges related to data findability/accessibility/interoperability/reusability [44,45]. In addition, the incorporation of different health datasets is complicated and makes maintaining data quality and diagnostic accuracy challenging; this creates a need for developing personalized models in populations as well as better methods to share important data [46,47].

In cardiology, there are also ethical and regulatory implications for the use of AI in healthcare. Key concerns related to data privacy and security, possible biases and healthcare disparities (especially when AI models are trained on biased datasets), lack of transparency in the functioning of AI algorithms, along difficulty in attributing responsibility for errors [42,48]. Both of these are adaptive technologies and process data in very complex ways, which makes it hard for regulatory bodies to get their heads around and ends up leading down a path where the risk becomes insidious [49]. Convergence among computer scientists, clinicians,

and regulatory bodies will be needed for responsible AI adoption in cardiology, where innovation must not only spur new ideas but maintain integrity with ethical standards and build patient confidence [50,51].

Despite the potential advantages of integrating AI into clinical care, challenges remain particularly related to privacy and safety but also in ensuring that an alignment between AI algorithms and clinician decision-making patterns is maintained [52,53]. Clinicians also worry about relinquishing professional autonomy and the prospect of integrating AI into their workflows [54]. To increase the use of AI in clinical practice, clinicians should be engaged early on during development and provided with appropriate training so that they perceive it as a useful tool rather than something detrimental [55,56].

The adoption and development of AI-based risk assessment tools in clinical practice are greatly affected by patient privacy and data protection. Some of the biggest challenges include complex, liberal compliance in not only protecting health information but also sustaining patient agency and consent as well as keeping it protected from any external privacy breaches [57]. Patients must be able to trust the system and therefore issues around things like algorithmic bias, and informed consent need to be taken into account at a very early stage however as with any development additional support from focusing risk management strategies and enhanced privacy policy is essential to try and protect against security risks [58,59].

Future Prospects and Directions

The future of AI in cardiovascular risk assessment is bright and great strides will be made that can conceivably reshape the practice. AI methods in general, such as machine learning and deep neural networks have the potential to enable personalized risk prediction that outperforms conventional techniques thanks to their ability to handle complex data streams such as imaging, genetic information, and lifestyle factors [12,60]. AI in cardiovascular medicine will expand to automated image interpretation, disease subtyping, and remote monitoring systems which can be used for improving clinical decision-making toward patient-centred care [10,47].

Another promising development is the delivery of automatic AI-based real-time and continuous cardiovascular risk monitoring with wearable technology. AI-based models can also be used for the prediction of cardiovascular events, and combining 5G-enabled wearable devices will enable intelligent transmission in real-time to monitor high-risk patients more efficiently [61,62]. There will be challenges with AI-driven cardiovascular monitoring via wearables like data accuracy or privacy but it is bound to improve early interventions and personalized care [43].

The ability of AI to combine the data generated by genomics and proteomics is seen as key to getting precision medicine off the ground. Using huge amounts of multi-omics data, such as genomic sequences and clinical records, AI can learn from this vast knowledge to spot patterns or predictions on the diseases we will get in life; and how they may be treated [31,63]. The fusion of multi-omics and clinical data by AI will lead to a holistic understanding of disease pathogenesis and early therapeutic intervention, which undoubtedly represent breakthroughs in precision medicine [64].

Working together with an AI for healthcare experts needs to meet the wishes of future healthcare. AI has many advantages with faster decision-making and intervention precision, but it must be navigated within the confines of data privacy, ethical considerations, and biases [65,66]. To ensure that AI is complementary to healthcare professionals, determinative interdisciplinary collaboration, strong and novel ethical guidelines for practice as well as research will be essential so that it is understood how the human element of care can best be preserved [67].

Conclusion

Advances in AI are transforming cardiovascular risk prediction, and have the potential to provide individualized measures of disease susceptibility. AI models can process large amounts of data and factor in very complex aspects. Challenges with data quality, model interpretability, and ethical considerations still need to be overcome before AI is universally adopted in cardiovascular medicine. The potential of AI to transform cardiovascular risk assessment and drive precision/cardiovascular medicine is profound. AI tools such as automated image interpretation, clinical decision support systems, and early-stage disease detection in cardiology all improve workflow efficiency and patient outcomes. Areas of further research include the evolution of AI-enabled diagnostics, telehealth services supported by remote monitoring and 'big data' analytics, as well as moving towards a 'digital twin', with targeted treatments tailored based on an individual's digital health profile. Interdisciplinary collaboration is crucial for successful implementation in cardiovascular medicine.

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