The Impact of Technology and Digital Health on Cardiology: A Review of the Present to Reach the Future

O Impacto da Tecnologia e da Saúde Digital na Cardiologia: Uma Revisão do Presente para o Futuro

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Abstract

The integration of digital health technologies is revolutionizing the field of cardiology, particularly in the diagnosis, treatment, and management of cardiovascular diseases (CVDs). The rapid advancements in wearable devices, artificial intelligence (AI), and telemedicine have enabled more precise, predictable, and personalized care strategies, transforming the landscape of cardiovascular health. Wearable technologies, such as smartwatches with some electrocardiogram (ECG) capabilities, have improved early detection of arrhythmias, particularly atrial fibrillation (AF), enhancing patient outcomes by enabling timely interventions. Similarly, AI-driven diagnostic tools and machine learning (ML) models have demonstrated superior accuracy in interpreting ECGs and identifying complex arrhythmias, often outperforming traditional methods.

Telehealth has also gained traction, particularly during the COVID-19 pandemic, by facilitating remote monitoring of chronic CVDs. Remote monitoring devices, including implantable pacemakers and defibrillators, have further reduced mortality rates by providing real-time data to healthcare providers, allowing for early interventions. AI language models, such as ChatGPT, are being utilized to accelerate research, aid in clinical decision-making, and enhance patient engagement through personalized education and real-time assistance.

In addition to these advancements, digital therapeutics, and mobile health (mHealth) platforms are providing real-time feedback to patients and improving adherence to medication regimens, which is crucial for managing chronic conditions like hypertension and heart failure. Genomic and metabolomic medicine, with its focus on precision cardiology, allows for more personalized treatment plans based on an individual's genetic profile, further enhancing outcomes for those at risk for inherited cardiovascular diseases.

Despite the promising developments, challenges remain, including the need for better integration with healthcare systems, data privacy concerns, and ensuring equitable access to these technologies. Nevertheless, the future of cardiology is expected to be shaped by advancements in AI, wearable technologies, and precision medicine, paving the way for real proactive and personalized care.

Keywords: Artificial Intelligence; Biomedical Technology; Cardiac Imaging Techniques; Cardiology; Therapy, Computer-Assisted; Wearable Electronic Devices

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Resumo

A integração das tecnologias de saúde digital está a revolucionar o campo da cardiologia, particularmente no diagnóstico, tratamento e gestão das doenças crónicas cardiovasculares (DCV). Os rápidos avanços em *wearables*, em inteligência artificial (IA) e na telemedicina permitiram estratégias de cuidados mais precisas, previsíveis e personalizadas, transformando o panorama da saúde cardiovascular. Os *wearables*, como os relógios inteligentes com capacidades de eletrocardiograma (ECG), melhoraram a deteção precoce de arritmias, em particular da fibrilhação auricular (FA), melhorando os resultados nomeadamente por intervenções mais atempadas. De igual modo, as ferramentas de diagnóstico impulsionadas por IA e os modelos de aprendizagem automática (*machine learning*, ML) demonstraram uma precisão superior na interpretação de ECGs e na identificação de arritmias complexas, frequentemente com capacidade de superar os métodos tradicionais.

A telessaúde também ganhou relevância, especialmente durante a pandemia de COVID-19, ao facilitar a monitorização remota de DCV crónicas. Os dispositivos de monitorização remota, incluindo *pacemakers* implantáveis e desfibriladores, reduziram ainda mais as taxas de mortalidade ao fornecer dados em tempo real aos profissionais de saúde, permitindo intervenções cada vez mais precoces. Os modelos de linguagem de IA, como o ChatGPT, estão a ser utilizados para acelerar a investigação, auxiliar na tomada de decisões clínicas e melhorar o envolvimento dos pacientes através de educação personalizada e assistência em tempo real.

Para além destes avanços, as terapêuticas digitais e as plataformas de saúde móvel (mHealth) estão a fornecer *feedback* em tempo real aos pacientes e a melhorar a adesão às prescrições médicas, o que é crucial para a gestão de condições crónicas como a hipertensão e a insuficiência cardíaca. A medicina genómica e metabolómica, com o seu enfoque na cardiologia de precisão, permitem planos de tratamento personalizados com base no perfil genético do indivíduo, com uma mais notória melhoria com risco de doenças cardiovasculares hereditárias.

Apesar dos desenvolvimentos promissores, permanecem desafios, incluindo a necessidade de uma melhor integração com os sistemas de saúde, preocupações com a privacidade dos dados e a garantia de acesso equitativo a estas tecnologias. No entanto, o futuro da cardiologia deverá ser pautado por avanços contínuos na conjugação das diversas tecnologias, abrindo caminho para cuidados verdadeiramente proativos e personalizados.

Palavras-Chave: Cardiologia; Dispositivos de Monitorização; Inteligência Artificial; Técnicas de Imagem Cardíaca; Tecnologia Biomédica; Terapia Guiada por Computador

Introduction

The landscape of cardiology has been dramatically transformed by the rapid integration of digital health technologies, mainly with exponential technology. These innovations—ranging from wearable devices to artificial intelligence (AI) and genomic medicine—are changing the way cardiovascular diseases (CVDs) are diagnosed, treated, and managed. As real-time monitoring becomes more accessible, and AI and machine learning (ML) improve diagnostic accuracy, the field is moving towards more personalized, preventive, predictive care strategies.[1,2] These advancements pose challenges, including ensuring patient data privacy, integrating with existing healthcare systems, and providing equitable access. We asked the technology to show, in an image, Fig. 1, how technology impacts cardiology.

This review synthesizes key studies from various domains, identifying common themes and challenges while drawing insights from cutting-edge research to suggest future directions for the field of cardiology.

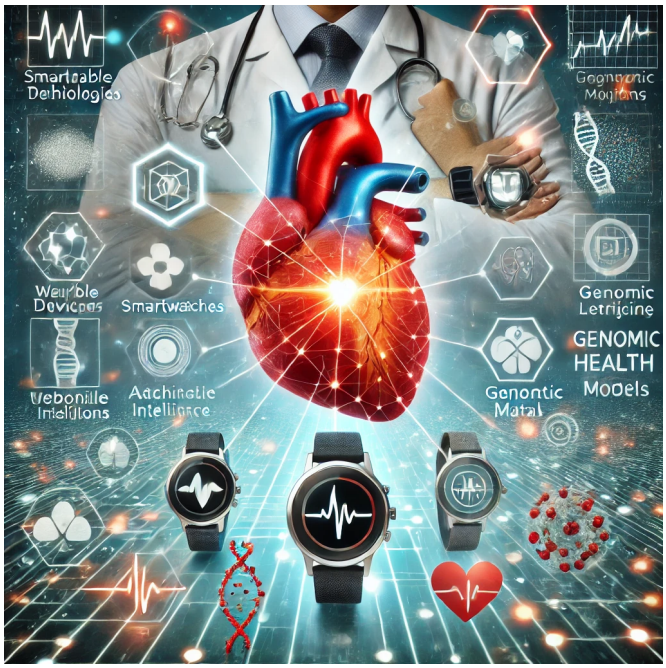

Figure 1: representation created by chatGPT on the subject "how technology is impacting cardiology".

Diagnostic Tools and Wearable Technologies

Wearable devices have become integral to modern cardiology, playing a vital role in both preventive care and the management of chronic conditions. These devices can monitor key metrics like heart rate, blood pressure, and oxygen saturation continuously, making them invaluable for detecting early signs of CVDs, particularly arrhythmias such as atrial fibrillation (AF). One commonality found across studies is the growing use of these devices in detecting AF, a condition strongly associated with an increased risk of stroke and heart failure.

A study in *The Lancet* showed that smartwatches equipped with electrocardiogram (ECG) capabilities significantly improved early AF detection, which in turn led to better outcomes by enabling timely interventions.[1,2] Not only do these wearables detect AF more efficiently, but they also empower patients by providing real-time health feedback. This finding aligns with other research suggesting that wearable technology enhances patient engagement and adherence to daily, real-world preventive measures.[1-6] Moreover, the role of AI in wearable devices is becoming more prominent. AI algorithms now assist in diagnosing complex arrhythmias, such as ventricular tachycardia, improving diagnostic precision.[3,6]

Wearables are not limited to arrhythmia detection. Devices equipped with biosensors can track heart failure progression by monitoring fluid retention, weight changes, and heart rate variability. In several studies, including a review in *Frontiers in Cardiovascular Medicine*, these wearables were found to significantly reduce hospital readmissions by alerting patients and healthcare providers to early signs of worsening heart failure.[5,7] This integration of wearables into chronic disease management is part of a broader movement towards proactive healthcare, which allows clinicians to act where it brings more benefits: before severe complications arise.[7-11]

Telemedicine and Remote Monitoring

Telemedicine has grown in importance and dissemination, particularly during the COVID-19 pandemic, as a vital tool for managing chronic CVDs remotely. Telehealth platforms enable cardiologists to monitor patients with conditions such as heart failure and coronary artery disease (CAD) in real-time, reducing the need for frequent in-person visits. A notable study in *JAMA Cardiology* found that telemedicine services significantly reduced hospital readmissions for heart failure patients by allowing clinicians to monitor vital signs remotely and intervene early when necessary.[2,4] In real-world evidence is becoming more and more evident the benefit for health and the sustainability of the planet, with numerous studies regarding the calculation of the carbon savings- due to telecare.

Moreover, the use of remote monitoring devices, such as implantable pacemakers and defibrillators, has expanded the scope of telehealth. These devices transmit real-time data to healthcare providers, allowing them to detect arrhythmias, device malfunctions, or worsening patient conditions earlier than would be possible with traditional follow-ups. The ability to act on this real-time data was shown to reduce mortality rates by up to 50% in patients with ICDs.[3,5]

Telehealth as a whole, opens new avenues for cardiac rehabilitation too. Research has shown that remote rehabilitation programs, including virtual exercise routines, dietary monitoring, and support groups, lead to better patient outcomes, particularly for those recovering from myocardial infarction,[3] due to a variety of reasons being one of the most promising ones the capacity of technology to adapt to people at their own pace of recovery. Moreover, innovation reduces the need for hospital-based rehab and offers patients more flexibility in their recovery plans.

Artificial Intelligence: Machine Learning, Large Language Models and Open AI in Cardiology

Artificial intelligence (AI) and machine learning (ML) are having a transformative effect on the field of cardiology, particularly in diagnostics, risk prediction, and treatment planning. AI algorithms can process vast datasets, identifying patterns that may be invisible to the human eye. Studies from *JACC* have shown that AI-driven risk stratification models, which integrate clinical data, genetics, and lifestyle factors, outperform traditional calculators such as the Framingham Risk Score.[5,11-14]

One of the most significant breakthroughs in AI has been in the interpretation of electrocardiograms (ECGs). A Stanford study demonstrated that deep learning models could accurately diagnose 14 different arrhythmias, including atrial fibrillation and ventricular tachycardia, with accuracy levels comparable to experienced cardiologists.[5,10-15] The implementation of AI in ECG interpretation not only improves diagnostic accuracy but also reduces the time required for analysis, allowing clinicians to act faster. Even clinicians who might not be so specialized in the subject.[15-25]

Beyond diagnosis, AI tools are also playing a pivotal role in clinical decision support.[19,21,22] AI-based platforms, such as ChatGPT and other large language models (LLM), can rapidly analyze and summarize the latest research, helping healthcare professionals stay updated on evolving guidelines and evidence-based practices.[7,8,12] These tools reduce the cognitive burden

on clinicians, enabling them to make quicker, more informed decisions.[18,20,21]

1. Research Acceleration and Knowledge Dissemination

AI language models, like ChatGPT, are significantly accelerating research in cardiology by streamlining the process of literature review and knowledge synthesis. In the field of cardiology, staying up to date with the latest research and clinical guidelines is essential due to the rapid advancement of new technologies, therapies, and diagnostic methods. However, the vast amount of literature published each year can overwhelm researchers and clinicians.

ChatGPT and similar models help by quickly summarizing large volumes of research, extracting key findings, and generating overviews of clinical trials. This capability reduces the time required for clinicians to stay informed about evolving best practices, emerging treatments, and new diagnostic tools. For example, ChatGPT can be used to search and synthesize information from peer-reviewed studies, making it easier for cardiologists to keep up with the latest developments in areas such as AI-driven diagnostics, genomic medicine, or novel interventional techniques.[22,26-28]

2. Clinical Decision Support

In cardiology, clinical decision-making is often complex and multifactorial. AI tools like ChatGPT can provide real-time decision support by processing vast information and offering evidence-based recommendations. For instance, it can be integrated into electronic health record (EHR) systems to analyze patient data and suggest possible diagnoses or treatment plans, based on established guidelines and the latest research findings. For this to be a reality medical device classification should be a common knowledge for all clinicians.

ChatGPT's ability to analyze vast amounts of data and offer insights can reduce the cognitive load on healthcare professionals, allowing them to make faster, more informed decisions. This has particular relevance in acute care settings, such as emergency departments, where time-sensitive decisions can dramatically impact patient outcomes.

3. Enhancing Patient Education and Engagement

Patient education and literacy are critical aspects of managing chronic cardiovascular diseases. ChatGPT is increasingly being used to support patient engagement by providing clear, accessible information on complex medical topics. Patients with conditions like heart failure or hypertension often need to understand their diagnosis, treatment options, and lifestyle changes. AI models can assist healthcare providers in delivering personalized education, ensuring that patients comprehend their health status and the importance of adherence to prescribed therapies.

Additionally, it can act as a virtual assistant, answering patient queries in real-time. By integrating those solutions into patient portals, healthcare providers can offer 24/7 support, empowering patients to take a more active role in managing their cardiovascular health. For instance, patients can ask the virtual assistant questions about their medications, side effects, or recommended lifestyle changes, receiving instant, evidence-based responses. This reduces the need for frequent in-person consultations and allows patients to engage with their healthcare team remotely.

4. AI-Powered Administrative Support

In addition to its clinical applications, ChatGPT is also being used to streamline administrative non-clinical tasks in cardiology. The healthcare sector often struggles with administrative burdens, such as documentation, billing, and patient record management. These type of solutions can automate many of these tasks, such as generating clinical notes, summarizing patient encounters, or assisting in insurance claims processing.

This automation allows healthcare professionals to spend more time on patient care, rather than focus on administrative work. In busy cardiology departments, where physicians and nurses are managing high patient volumes, this kind of support can significantly improve workflow efficiency and reduce burnout among healthcare providers. Workflows and work distribution can also be supported by digital tools that not only engage everyone in a common empowered task, but also boost efficient responses by managing time and location of tasks for instance.[20-22]

5. Limitations and Ethical Considerations

While ChatGPT or similar solutions have clear benefits in cardiology, there are also limitations and ethical considerations to be addressed. Open AI models rely on vast datasets to generate their responses, which means the accuracy and relevance of their recommendations are only as good as the data they are trained on. In some cases, AI may struggle with highly specialized or nuanced clinical situations, and there is always the risk of generating biased or incorrect information. Besides the bias that era represented in the data sets suffer incredible amplification, so they should be anticipated and addressed.

Moreover, patient privacy remains a concern. The integration of AI tools into clinical practice requires strict adherence to data

protection regulations such as the General Data Protection Regulation (GDPR) and the Health Insurance Portability and Accountability Act (HIPAA) to ensure that sensitive patient data is not compromised or used for non-authorized purposes. Anonymization is also a great topic for discussion, as the more we engage with specific patient data, the harder it is to really anonymize, as tracing back processes tends to be easier as well.

6. The Future of AI Language Models in Cardiology

Looking ahead, the role of AI models in cardiology will likely expand as the technology continues to evolve. Future applications may include more advanced clinical decision support systems, deeper integration into telemedicine platforms, and the development, or optimization, of societal predictive models for cardiovascular risk based on patient data. As AI becomes more adept at interpreting complex clinical scenarios and providing actionable insights, its potential to enhance both patient care and clinical outcomes in cardiology will grow exponentially.

Digital Therapeutics and Mobile Health (mHealth)

Digital therapeutics and mobile health (mHealth) platforms are becoming essential tools in managing cardiovascular health as well. These platforms provide real-time feedback to patients and allow healthcare providers to monitor patient progress remotely. A major study found that patients using digital therapeutics for hypertension management achieved significantly better control of their blood pressure compared to those receiving standard care.[6,11,14] The ability to track blood pressure, combined with personalized health advice, has been a game-changer for chronic disease management. Besides the high-rated Patient Reported Outcomes Measures (PROMS) and Patient Reported Experience Measures (PREMS).

Similarly, mobile health apps designed for heart failure patients are proving effective in reducing hospital readmissions. These apps monitor symptoms and provide alerts when a patient's condition worsens. Research shows that patients who use these platforms are more likely to adhere to their medication schedules and report improved self-care behaviors.[7,15]

One area where digital therapeutics have shown great promise is in the management of arrhythmias. For example, AI-driven algorithms within mHealth apps can analyze heart rate data in real-time, alerting patients and their doctors to potential issues before they become severe.[7,11,16,17] (This proactive approach significantly reduces the risk of complications associated with arrhythmias and other cardiovascular conditions.

Genomic Medicine and Precision Cardiology

Genomic medicine is revolutionizing health and consequently, the field of cardiology, enabling more personalized treatment strategies. By analyzing a patient's genetic makeup, clinicians can identify individuals at higher risk for inherited cardiovascular diseases, such as diseases like hypertrophic cardiomyopathy or familial hypercholesterolemia, or even life risk factors. These insights, again, allow for targeted prevention and early intervention, improving long-term outcomes.

A review in *Nature Reviews Cardiology* highlighted the integration of genomic data with clinical and environmental factors as a key element of precision cardiology. This approach enables the development of highly personalized treatment plans that are tailored to a patient's unique risk profile against the classic clustered-guided treatment.[6,13] For example, pharmacogenomics allows clinicians to prescribe medications based on how a patient's genetics will affect their response to certain drugs. In cardiology, this approach is particularly useful for determining the efficacy of antiplatelet medications, such as clopidogrel, in patients with specific genetic variations.[6]

The future of precision cardiology lies in the combination of genomic data with AI-driven predictive models. These models can analyze a patient's genetic predispositions alongside clinical history and lifestyle factors to create a personalized care plan, significantly improving outcomes for patients with complex cardiovascular conditions.[16,19, 27]

AI in Cardiac Ultrasound Imaging

The use of AI in cardiac imaging is one of the fastest advancing field, particularly in the area of ultrasound diagnostics. One notable example is the FDA's approval of Caption Guidance, an AI-driven software designed to assist clinicians in obtaining high-quality echocardiographic images. The software uses machine learning to differentiate between acceptable and unacceptable images and suggests the best video clips for diagnostic purposes.[3,7,17,25] This technology has the potential to expand access to echocardiography by enabling healthcare providers without specialized training to capture high-quality images.

In emergency and critical care settings, where quick diagnostic decision-making is essential, AI-guided ultrasound systems like Caption Guidance, or others that are now trying to be certified as medical devices by FDA and EMA, are improving the accuracy and speed of diagnoses, leading to better outcomes for patients with acute cardiovascular conditions.[7,18,25]

Conclusion

It is interesting to note that with the growing availability of technology, diagnostic systems, and digital therapeutic options more and more positive changes in the management of patients suffering from cardiovascular diseases can be fostered or brought forth in contemporary and future practices. The management of heart-related conditions is changing dramatically with the embracing of fancier modalities such as wearables, AI, telehealth and genomics with enhanced treatment options tailored to the patients as well as easy and timely interventions. However, these trends will need to work towards resolving issues relating to data security, ethics, liability, access equity, and incorporation of the said technology into the traditional healthcare system to make these trends realize their fullest potential.

Future directions in cardiology will be shaped by a stronger and synergetic relation between humans and machines. The further expansion of cardiac diagnostic and treatment options will be based on artificial intelligence assisted research methods, digital therapeutics, precision medicine, and telehealth technologies, including various materials and devices worn by patients. Therefore it is remarkable as these advancements propose prospects of enhancing patient conditions, lowering the burden of health expenses and extending the scope of care, through being preventative rather than reactive and personalized rather than generalized. We will be actively promoting evolution by increasing literacy on the subject.

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