Wearable Technology in Cardiovascular Health Monitoring: Current Trends and Future Directions

Ogochukwu Militus Ifenze
Department of Biomedical Engineering Federal University of Allied Health Science, Enugu, Nigeria
Department of Biomedical Engineering Federal University of Technology, Owerri, Imo State, Nigeria

Chinwendu Joy Okanumee
Department of Biomedical Engineering Federal University of Technology, Owerri, Imo State, Nigeria

Kenneth Ikechukwu Nkuma-Udah
Department of Biomedical Engineering Federal University of Technology, Owerri, Imo State, Nigeria

Ekene Samuel Mbonu
Department of Mechatronics, Federal University of Technology, Owerri, Imo State, Nigeria.

Gideon Ihebuzo N. Ndubuka
Department of Biomedical Engineering Federal University of Technology, Owerri, Imo State, Nigeria

doi: https://doi.org/10.37745/ejbmsr.2013/vol13n33760 Published July 21, 2025

Citation: Ifenze O.M., Okanumee C.J., Nkuma-Udah K.I., Mbonu E.S., and Ndubuka G.I.N. (2025), Wearable Technology in Cardiovascular Health Monitoring: Current Trends and Future Directions, *European Journal of Biology and Medical Science Research*, 13 (3), 37-60

Abstract: *Recent Technological Advancements has shown tremendous impact in healthcare especially in personalized remote healthcare monitoring and management. Integration of this advancement in cardiovascular disease monitoring and management through Wearable biosensor technological advancements have emerged as powerful tools for personalized continuous monitoring of cardiovascular activities outside traditional clinical settings. The significant of these wearable technologies can be seen in 5Ps of clinical medicine for cardiovascular disease where it transformed patient care and improve its outcomes. This review provides an overview of wearable technologies' evolution, advancements, challenges, applications clinical impact and future trends in cardiovascular medicine. We discussed the biosensor miniaturization, artificial intelligence (AI) and Machine learning integration, challenges and limitations of proliferating remote patient monitoring solutions for cardiovascular diseases. The impact of smartwatch wearables in the early detection of cardiovascular conditions through personalized health tracking, and remote patient management. Challenges such as data privacy concerns and regulatory hurdles are also addressed. The adoption of wearable technologies holds promise for shifting healthcare from reactive to proactive, enabling precision diagnostics, treatment optimization, and preventive strategies. Collaboration among healthcare stakeholders is essential to harnessing the full potential of wearables in cardiovascular medicine and ushering in a new era of personalized, proactive healthcare.*

Keywords: Wearable Technologies, Biosensor, Cardiovascular Disease, Machine Learning (ML), Artificial Intelligence (AI)

INTRODUCTION

One of the proficient strategies in managing risks associated with cardiovascular diseases is prompt detection and early commencement of therapeutic interventions, which includes adjustments in patients lifestyle as well as the continuous evaluation of their health status (Islam et al. 2022). Wearable technology, which can continuously and remotely monitor physiological and behavioral parameters by incorporated into clothing or worn as an accessory, introduces a new era for ubiquitous health care. This technology, can analyze big data which can long-term cardiovascular care (Miao et al. 2022). Wearable technology in cardiovascular health monitoring has seen significant advancements, driven by the integration of machine learning and deep learning techniques, which enhance the predictive capabilities of these devices. The advancements seen lately are primarily directed towards developing a small, yet robust and long lasting devices with an ability to effectively/efficiently monitoring heart rate and electrocardiogram (ECG) signals, utilizing machine learning models such as Long short-term memory (LSTM) networks alongside convolutional neural networks (CNNs) to predict and detect cardiovascular inconsistencies (Alimbayeva et al. 2024; Nguyen et al. 2024). These devices facilitate continuous, real-time monitoring, providing both patients and healthcare providers with valuable data for early detection and management of cardiovascular diseases (Baikuvekov, Tursynova, and Yespayev 2024; Kang et al. 2024).

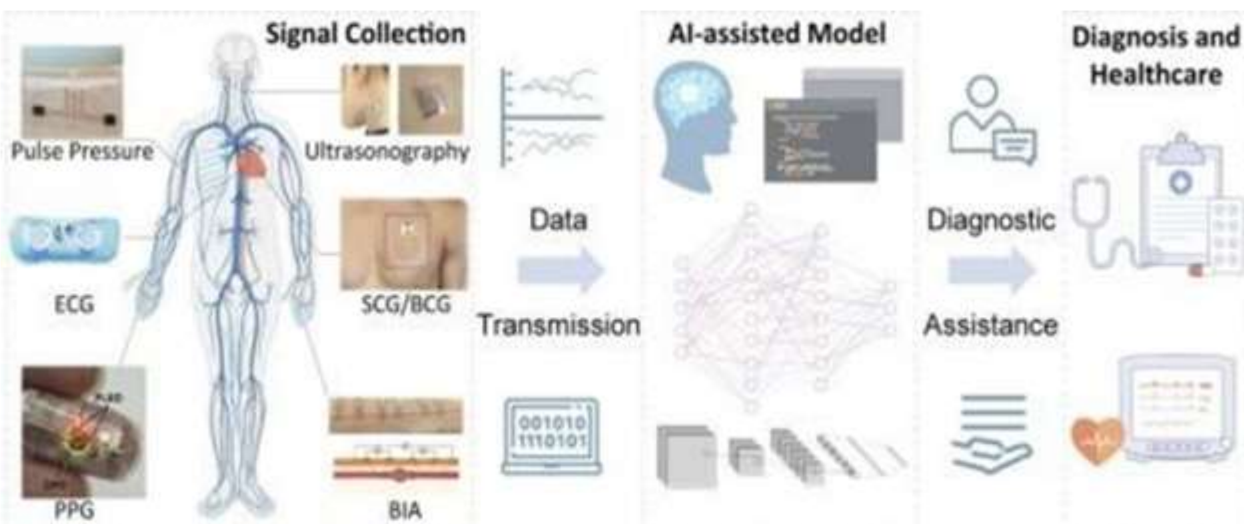

Figure 1.0. Wearable Technology Interface on Human Body (Y. Wang, Zou, and Li 2024).

The adoption of wearable devices expediated during COVID-19 pandemic where non-contact approach are deployed to manage illness from remote areas, with a notable increase in their use among individuals with cardiovascular disease or risk factors, highlighting a growing public interest in personal health monitoring (Dhingra et al. 2023).

Evolution of Wearable Technologies for Cardiovascular Health Monitoring

The evolution of wearables technologies aimed at monitoring cardiovascular health has been highlighted by significant advancements in sensor technologies, data analytics, and integration with artificial intelligence, which have collectively enhanced the capability and relevance of these devices. Initially,

wearable cardiac monitoring devices focused on providing continuous and non-invasive monitoring of cardiac activities, leveraging improvements in sensor materials and big data analytics to enhance signal quality and reliability
(Wang, Zhao, and Li 2023).

Figure 2.0: Summary of Wearable Technologies benefit to patients and clinicians (Tandon et al. 2024).

These devices, including smartwatches and activity trackers, have become integral in managing risks of cardiovascular health through continuous data collection which surpasses the sporadic measurements typically obtained during clinical visits (Hughes et al. 2023). Machine learning techniques integration expanded scope of their clinical applications, enabling functionalities such as arrhythmia screening and remote

management of chronic conditions like heart failure (Hughes et al. 2023). Recent research advancement and innovations have introduced flexible pressure sensors and stretchable elastomer optical fibers, which provide accurate and stable measurements of heart rate and respiratory rate, demonstrating the potential for real-time, unobtrusive monitoring (Mishra, Mohanty, and Ramadoss 2022; Zha et al. 2023). Moreover, the incorporation of artificial intelligence in analyzing electrocardiogram signals has improved the early detection and prediction of cardiovascular diseases, utilizing advanced deep learning methods to handle complex biosignal data (Neri et al. 2023). Despite these advancements, challenges remain in terms of data accuracy, user-friendliness, and the need for training in interpreting complex data outputs, such as those from photoplethysmography (PPG) devices (Duncker and Svennberg 2022). The future of wearable cardiovascular monitoring lies in overcoming these challenges through enhanced sensor fusion, improved data analytics, and greater collaboration among stakeholders to integrate these technologies into routine clinical practice effectively (Hughes et al. 2023; Scataglini et al. 2023). The growth of wearable technology holds a promising transformation in cardiovascular health disease monitoring by providing real-time and extensive evaluations of patient health, which enables a better prevention, early detection, and managing of cardiovascular diseases. (Alugubelli, Abuissa, and Roka 2022; Shiwani et al. 2023).

European Journal of Biology and Medical Science Research, 13 (3), 37-60, 2025
Print ISSN: ISSN 2053-406X,
Online ISSN: ISSN 2053-4078
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

Current State of the Art of Wearable Technologies for Cardiovascular Health Monitoring

The current state of wearable technologies aimed at cardiovascular health monitoring is characterized by notable progressions in advancing sensor architecture, data analytics, and amalgamation with artificial intelligence, which collectively enhances the capacity of continuous and non-invasive monitoring of cardiovascular health. Wearable devices, including smartwatches and activity trackers, play pivotal role in managing cardiovascular health by providing continuous physiological data like pulse rate, cardiac rhythm, blood pressure, and respiratory rate, which are essential for early diagnosis and management of cardiovascular diseases (CVDs) (Hughes et al. 2023; Zhao et al. 2023). These devices integrate an array of sensors, such as electrical, optical, and mechanical sensors, to accurately capture vital physiological signs, with flexible pressure sensors leading as a promising technology owing to its comfort and dependability in the monitoring

of blood pressure and heart rate (Mishra et al. 2022; Zhao et al. 2023). Incorporation of machine learning and deep learning methodologies in these wearable devices further enhanced their diagnostic functionalities, facilitating real-time identification and forecasting of cardiovascular events through the analysis of intricate complex biosignal data (Neri et al. 2023). Furthermore, bioelectric and biosensors advancement have enabled swift detection and continuous monitoring of cardiac biomarkers, thereby providing a more precise viewpoint on a patient's health status in comparison to traditional clinical visits (Tang et al. 2023).

Historical Timelines of Wearable Technologies for Cardiovascular Health Monitoring

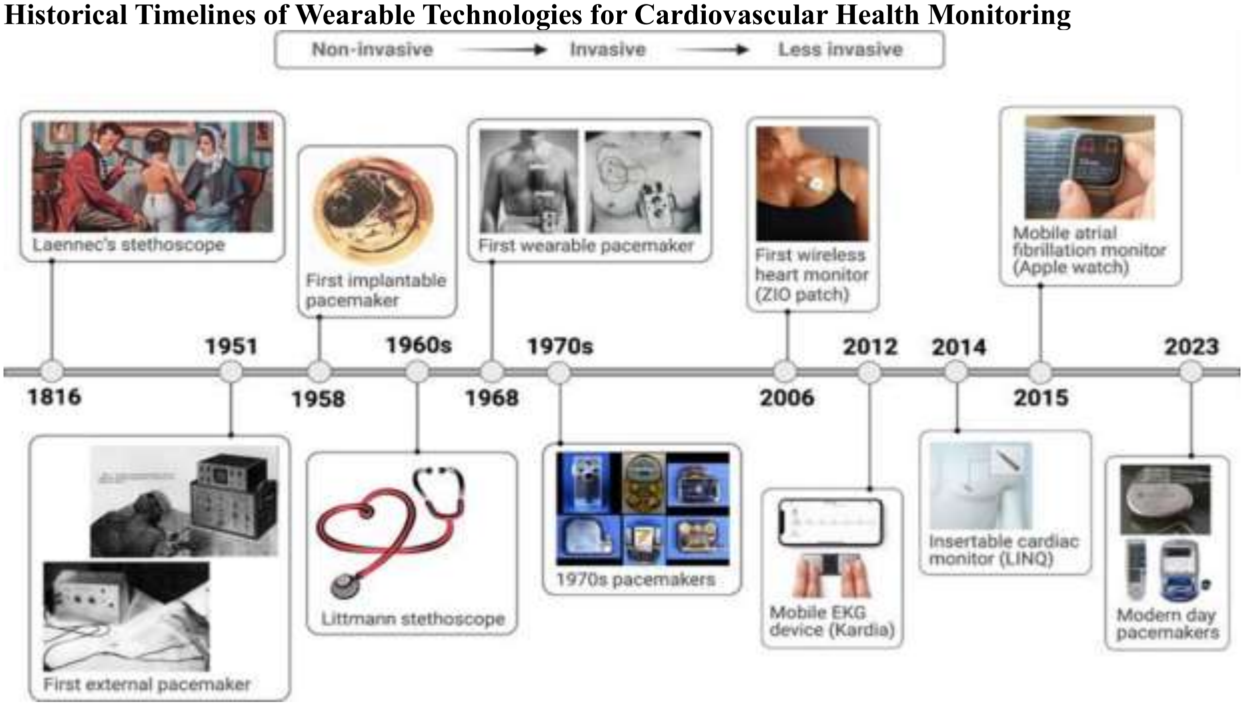

Figure 3.0: Historical timeline of cardiac monitoring devices, starting noninvasively with the Laennec's stethoscope, to progressive more invasive with pacemakers, before ultimately becoming less invasive again with the commercial devices (Pelter, Quer, and Pandit 2023).

Biosensors used in Development of Wearable Technologies for Cardiovascular Health Monitoring Wearable biosensor technologies have been employed in different areas of evaluating, monitoring and managing cardiovascular diseases through various sensing techniques like the photoplethysmography (PPG), electrocardiography (ECG), and electrochemical sensors, that are aimed at gathering real-time and continuous vital parameters and biomarkers such as pulse rate, blood pressure, cardiac rhythm and blood oxygen saturation

levels of a cardiovascular patient (Anbuselvam et al. 2024; Khatoun et al. 2023; Tang et al. 2023). Recent technological advancements have facilitated the incorporation of flexible electronics and non-contact electrodes, which significantly improve the user comfort and precision of these devices, even during physical exertion (X. Wang et al. 2022). For instance, flexible non-contact electrodes have been shown to provide high- quality ECG signals comparable to traditional medical electrodes, even during physical exercise (X. Wang et al. 2022). Moreover, optical sensor arrays employing PPG can effectively map cardiovascular biomarkers and investigate blood pulsation at various dermal depths, thereby providing novel insights into cardiovascular health (Khatoun et al. 2023). The development of multimodal sensors that integrate ECG and PPG with advanced signal processing algorithms, such as machine learning models, further enhances the capability of these devices to provide comprehensive cardiovascular monitoring (Y. Wang et al. 2022). These innovations are supported by enabling big data technology incorporation, which facilitate analysis of large datasets for long-term cardiovascular care and personalized health feedback (Miao et al. 2022). Despite these advancements, challenges such as device accuracy, data security, and user compliance remain, necessitating ongoing research and development to optimize wearable biosensors for widespread clinical use (Miao et al. 2022; Smith, Li, and Tse 2023). The prospective advancements of wearable biosensors in the realm of cardiovascular health monitoring are rooted in their capacity to revolutionize the provision of healthcare by through remote patient assessment and prompt diagnosis, thereby significantly reducing the global prevalence of cardiovascular ailments (Xian 2023; Zhao et al. 2023).

Table 1.0: Different Biosensors Used in Designing Wearable Technologies for Cardiovascular Health Monitoring (Williams et al. 2023)

Table 1.0: Different Biosensors Used in Designing Wearable Technologies for Cardiovascular Health Monitoring (Williams et al. 2023)

Type of Biosensor	Sensor Principle	Applications	Wearable device
Remote Di-Electric Sensing	Di-Electric coefficient quantification of tissues and fluid concentration correlation.	Pulmonary oedema detection	Shirt or vest
Phonocardiogram	Opening and closing of heart valves detection using subaudible vibrations it created.	Heart Rate	Stethoscope or Patch
Photoplethysmography	Detect changes in blood volume within the microvascular tissues through optical sensors.	Heart Rate/rhythm, blood Oxygen saturation and cuffless blood pressure.	Wristwatch, wrist band, or Eyeglasses.
Accelerometer	Force sensor to measure the acceleration in a single or multiple directions.	Classification and recording of gaiting, steps and physical activities.	Smartphone, wristwatch/band, armband, or belt.
Electrocardiogram	Measures electrical activities of heart through electrode potential difference of cardiac impulse.	Heart rate monitoring, and heart rhythm assessment	Wristwatch or shirt or vest.
Ballistocardiography	Mechanical ventricular contraction recoil measurements for quantification of cardiac outputs and dynamics.	Cardiac energetics and cuffless blood pressure measurement.	Wristwatch/band
Bioimpedance (Impedance -Plethysmograph)	Uses changes in blood electrical activities to measure cardiovascular characteristics like radial pulse volume, and ascending aortic blood volume.	Cuffless blood pressure measurement, and measurement of intrathoracic impedance in heart failure.	Wristwatch/band, shirt, or vest
Magnetoplethysmography	Uses the diamagnetic properties of water (Hall Effect) to detect magnetic flux created by pulsating blood flow.	Cuffless blood pressure measurement	Wristwatch/band

Types of Wearable Devices for Monitoring Cardiovascular Health

Smartwatches and Fitness Tracker devices

In monitoring and management of cardiovascular diseases (CVDs), Smartwatches and fitness trackers have emerged as pivotal tools which enables continuous health data collection that can significantly enhance patient care through the 5P medical approach (Predictive, Preventive, Participatory, Personalized, and Precision) (Alugubelli et al. 2022; Pires et al. 2021; Shiwani et al. 2023). These systems assist in the evaluation of different health statistics, including heart rate and its variations, and electrocardiogram (ECG) signals, which are

important for evaluating cardiovascular risks and forecasting adverse events (Alugubelli et al. 2022; Neri et al. 2023; Shiwani et al. 2023). The incorporation of artificial intelligence (AI) within these wearable technologies further enhanced their diagnostic functionalities, enabled the real-time detection and prediction of cardiovascular conditions. Artificial Intelligence (AI) methodologies, such as machine learning and deep learning, are increasingly utilized to analyze big and complex biosignal data, thereby improving the precision and predictive efficacy of these devices (Neri et al. 2023). Patients can personalized their treatment plans and self-monitor their cardiovascular activities, thereby promoting active patient engagement and quality of life improvement with the 5P of medical approach (Pires et al. 2021). Despite the potential and effectiveness of smart wearables in managing Cardiovascular disease, there are ongoing studies and research aim towards refining their accuracy and usability (Moshawrab et al. 2023).

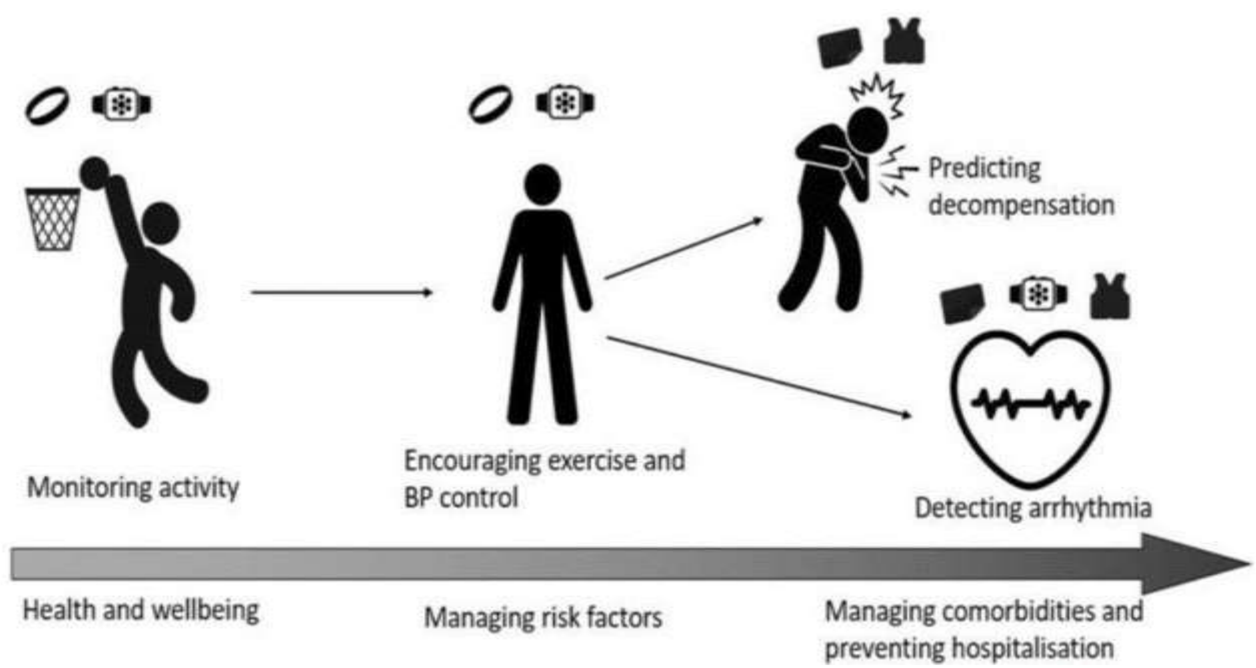

Figure 4.0 Monitoring Cardiovascular Activities during sports/exercises using Smartwatches and Fitness Trackers Device (Singhal and Cowie 2020).

By facilitating continuous health monitoring through timely data processing and secure data management via cloud-based systems, the integration of smartwatches and fitness trackers in cardiovascular care represents a significant advancement in the field of cardiovascular disease studies (Alugubelli et al. 2022). It has brought a promising addition to modern healthcare practices that offers a more comprehensive and proactive approach to cardiovascular disease management.

Holter Wearable Patient Monitor devices

Wearable Holter patient monitoring devices have emerged as a significant advancement in monitoring cardiovascular diseases (CVD), offering a blend of convenience, accuracy, and real-time data processing. The device offers user-friendly and non-invasive technique, sporadic detection atrial fibrillation without requiring medical expertise for operation (Randazzo, Ferretti, and Pasero 2021). The device is designed to provide continuous monitoring of heart rate, electrocardiogram (ECG), and other vital signs, with significant improvements over traditional stationary electrocardiographs machines. For instance, the system utilizing capacitive sensors connected by stretchable interconnections allows for the recording of a standard 12-lead ECG, with data transmission capabilities via USB, MicroSD, or Bluetooth, enhancing the diagnostic capabilities of Holter systems (Gorlov et al. 2023). The incorporation of advanced machine learning algorithms, like Long Short-Term Memory (LSTM) networks and Convolutional Neural Networks (CNN), significantly enhances the predictive and diagnostic capabilities with regards to anomalies in electrocardiogram (ECG) signals recorded by the device, thus enabling the early identification of possible cardiovascular diseases (Alimbayeva et al. 2024; Nguyen et al. 2024). In Telemedicine, wireless wearable Holter can upload recorded cardiovascular data to a cloud server for remote monitoring and equally utilize oscillometry principles in offering both on-demand and programmable measurement modes, although it shows reduced accuracy under arrhythmic conditions (Thi Thuy Le et al. 2024). In countries classified as low- and middle-income, cost- effective Internet of Things (IoT)-enabled wearable technologies have been suggested to mitigate the obstacles related to accessibility and financial feasibility in the realm of cardiovascular disease monitoring. These technologies deliver real-time instantaneous and continuous data pertaining to heart rate, arterial pressure, and blood oxygen levels, triggering alarm upon manifestation of irregularities, thus connecting patients with medical support efficiently (Sumwiza et al. 2023).

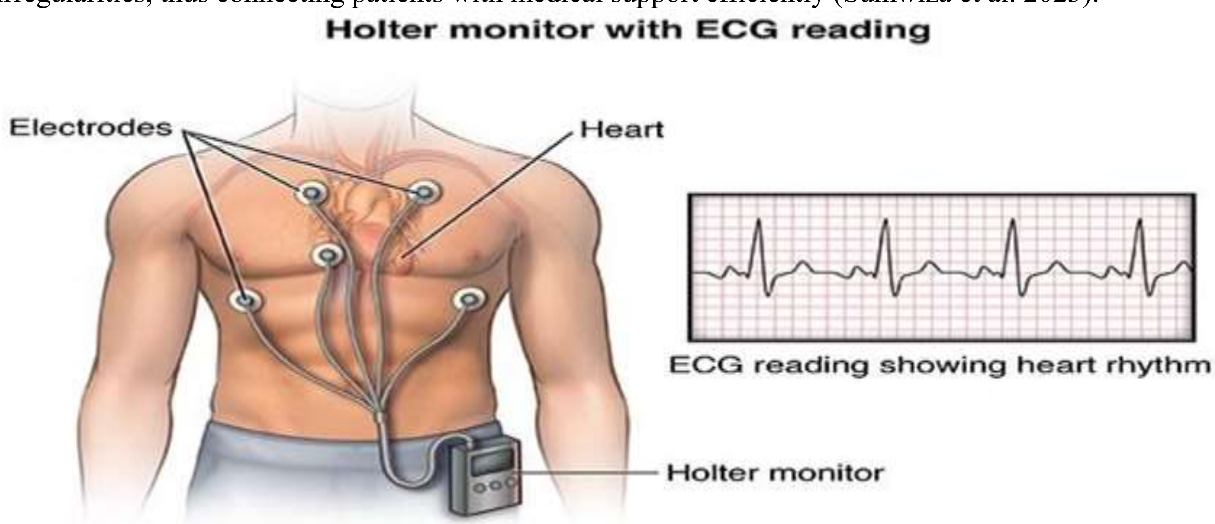

Figure 5.0: Holter Wearable Patient Monitor (John Hopkins Medicine 2024).

Wearable Blood Pressure Monitors devices

In the cardiovascular system, blood pressure (BP) measurement remains a key factor for the safety of an individual with heart problems (Nazir and Iqbal 2023). Despite significant advancements in healthcare and the availability of low-cost, effective therapies, overall progress in BP control has been slow due to the large number of undiagnosed cases of high BP and lack of regular BP assessment over time. Conventional management strategies rely on physician-centric diagnosis and BP assessment in clinics, which has several limitations, including measurement errors, 'white-coat hypertension' and failing to measure the circadian and seasonal variations in BP (Islam et al. 2022). An Out-of-office blood pressure (BP) monitoring device conducted through ambulatory BP monitoring (ABPM) and/or home BP monitoring (HBPM) are advocated for the diagnostic evaluation of hypertension according to prominent international guidelines. Evidence suggests that home and/or ambulatory BP measurements yield superior prognostic insights regarding target organ impairment and cardiovascular risk compared to traditional office BP evaluations. Nevertheless, existing methodologies pertaining to ABPM and HBPM are not without their recognized limitations, which encompass factors such as patient comfort, disturbances in sleep patterns, accessibility, and financial implications (Kario 2020). This continuous non-invasive device for monitoring and managing cardiovascular diseases has the capability of enhancing patient care when integrate in telemedical interventions. It demonstrated effectiveness in controlling cardiovascular risk factors among elderly patients with comorbidities like coronary heart disease, hypertension, and diabetes (Kong et al. 2022). Wearable devices designed with photoplethysmography (PPG) technology have been used to monitor blood pressure and detect atrial fibrillation (AF) risk. These devices can identify high average 24-hour blood pressure and other patterns like reverse-dippers blood pressure, which are associated with increased AF susceptibility (Guo, Zhang, and mAFA investigators 2022). Furthermore, wearable blood pressure monitors provide insights into diurnal variations of hemodynamic parameters, revealing significant changes in blood pressure and other cardiovascular metrics throughout the day, which vary by sex, age, and body mass index (Nachman et al. 2022). The advancements of flexible sensors and cuffless systems lead to the capability of these devices in continuous beat-to-beat monitoring with critical insights in blood pressure variability, a known risk factor for cardiovascular diseases (Savage 2020; Sheikh et al. 2023). In clinical settings it been shown that feasibility of wearable BP monitoring devices (HeartGuide) are reliable blood pressure measurements during hypotensive episodes, comparable to traditional monitoring methods (Groppelli et al. 2022). Collectively, these advancements highlight the potential of wearable blood pressure monitors to provide personalized, real-time health data, facilitating early intervention and improved management of cardiovascular conditions.

Wearable Biosensors Smart Clothing

Wearable biosensors (wearables) facilitate continuous, non-invasive physiological and behavioral monitoring of patients in their naturalistic environments. In a clinical setting, wearables biosensors provide a unique opportunity for the continuous collection and monitoring of physiological data, offering early clinical indications of changes in patient condition. It empowers individuals to access their personal health data and engage in self-monitoring, thereby fostering positive behavioral modifications (Tandon et al. 2024). In the realm of cardiovascular medicine, it assumes a critical function in facilitating continuous and non-invasive monitoring of cardiovascular physiological parameters. These biosensors are flawlessly incorporated into wearable devices such as garments, provide real-time data pertaining to heart rate, blood pressure, electrocardiogram (ECG), and an assortment of additional biophysical and biochemical markers (Bhaltadak et al. 2024). The interfuse of artificial intelligence and machine learning within wearable biosensors and smart clothing to monitor cardiovascular pathologies, added a novel dimension in improving predictive accuracy with tailored user feedback. These wearable biosensors are capable of evaluating vast datasets, uncovering patterns, and producing well-informed predictions pertaining to an individual's cardiovascular health status in real-time (Vo and Trinh 2024). Machine learning-empowered systems are proposed to improve motion tolerance in wearable devices through the use of ear-ECG/PPG sensors for blood pressure and heart rate monitoring, thereby demonstrating lower error rates compared to state-of-the-art methods (Zhang et al. 2017). For instance, smart clothing systems have been developed to monitor electrocardiogram (ECG) and respiratory signals using fabric-based electrodes and capacitive respiration transducers, achieving high accuracy and signal quality suitable for clinical applications (Lee et al. 2022). Advanced systems incorporating dual tripolar concentric ring geometries in electrocardiogram (ECG) electrodes facilitate high-fidelity cardiac monitoring; this technological advancement proves to be exceptionally beneficial for the assessment of cardiac rhythm throughout the sleep cycle (Wang et al. 2019). For detection of cardiovascular biomarkers, wearable biosensors that are integrated with microfluidic systems and seismocardiography-based wearables biosensors underscores the potential in cardiovascular disease risk assessment (assessing stroke volume in congenital heart disease patients) and personalized medicine through non-invasive alternative to traditional methods (Ganti et al. 2022; P.-R. Li et al. 2024).

Different Advancements in Wearable Technologies for Cardiovascular Health Monitoring

Miniaturization and Portability of wearable technologies for cardiovascular disease monitoring The miniaturization and portability of wearable technologies have profoundly transformed the fields of healthcare and medical electronics, leading to the development of more compact and efficient devices that enhance portability for user convenience (Bhaltadak et al. 2024). This advancement in miniaturization and portability of wearable technologies for cardiovascular disease (CVD) monitoring are propelled by inventions in flexible electronic systems, Internet of Medical Things (IoMT), and artificial intelligence (AI) (Ifenze et al. 2024). Wearable devices such as smartwatches, fitness trackers, and portable ECG devices are increasingly used for real-time monitoring of vital signs like heart rate, blood pressure, and oxygen levels, facilitating early detection and intervention for CVDs (Faderin, Oginni, and Alade 2024; Lee et al. 2024). The development of flexible electronics has enabled continuous, non-invasive, and portable monitoring, which is a stark contrast to traditional bulky medical instruments (T. Zhang et al. 2023). For instance, the HiCardi device, a portable ECG system, demonstrated effectiveness in detecting abnormal cardiovascular signals during daily activities, leading to timely medical interventions (Lee et al. 2024). Similarly, a wearable vest with integrated multi- channel phonocardiogram (PCG) sensors has been developed for coronary artery disease pre-screening, showcasing the potential for mass screening with high accuracy and efficiency (Fynn et al. 2024). The use of nanocomposite materials and reconfigurable mixed signal systems on chip (SoC) in wearable ECG sensors further contributes to their miniaturization and energy efficiency, making them suitable for mobile health platforms for continuous monitoring of cardiovascular parameters like heart rate and blood pressure (Gawali et al. 2022; Khumngern and Jeerapan 2024; Xue et al. 2024). In all miniaturization and portability of wearable biomedical technologies transformed cardiovascular healthcare by enabling more personalized, accessible, and efficient monitoring and management of Cardiovascular diseases (Faderin et al. 2024; Rong et al. 2023).

Accuracy, Reliability and Enhancement of Biosensors

The Integration of outputs from multiple sensors through hardware or software mechanisms significantly addresses individual biosensor limitations such as noise, drift, and placement errors thereby enhancing accuracy of these wearable devices. This is exemplified in various applications, such as finite impulse response (FIR) complementary filters in fuse displacement and inertial sensors, this effectively suppressed noise and extend low-frequency measurement bandwidth, thereby improving biosensor performance and reliability (J. Wang et al. 2024). In the realm of healthcare, Wireless Body Area Networks (WBANs) integrate diverse sensors to provide real-time monitoring and data fusion, ensuring accurate health assessments and enabling predictive analytics for early detection of health issues (Raffi et al. 2024). Enhancement of wearable biosensors has led to significant improvement in accuracy and reliability of wearable Technologies in cardiovascular health monitoring and management. Recent developments in wearable electrochemical biosensors have focused on using soft, stretchable materials like hydrogels, which mimic human tissue properties, to improve sensitivity and responsiveness. These materials, combined with conductive nanofillers, enhance the sensitivity of biosensors, allowing for continuous monitoring of biochemical markers in body fluids, which is crucial for cardiovascular health management (Fakhr et al. 2024). For instance, the INTERPRET-AF study demonstrated that the diagnostic accuracy of photoplethysmography (PPG)-based devices is comparable to traditional ECGs when combined with automated algorithms, although training in PPG interpretation is necessary for optimal use (Duncker and Svennberg 2022). Similarly, a wearable neck patch which uses a single-channel impedance plethysmography (IPG) has shown promising results in continuous blood pressure and heart rate monitoring, meeting standard criteria for accuracy in clinical use (Wang et al. 2020). In quantification of critical markers for personalized medicine, microfluidic systems for detecting cardiovascular disease biomarkers like NT- proBNP and cardiac troponin I, showed an accurate rapid quantification of these critical markers with a process time of just 15 minutes (P.-R. Li et al. 2024). Additionally, the use of frequency-multiplexed electrical impedance tomography (EIT) and multilead ECG data acquisition in wearable sensors has reduced cabling complexity and improved the feasibility of non-invasive cardiovascular monitoring (Rapin et al. 2019).

Artificial Intelligence and Machine Learning Integration

The integration of artificial intelligence (AI) and machine learning (ML) in wearable technologies has significantly advanced the potential in transformation of cardiovascular health monitoring and management. Smartwatches and connected T-shirts are increasingly being equipped with biosensors that collect vital physiological biosignals like heart rate, electrocardiogram (ECG) data, cardiac rhythm and physical activity metrics. When these devices are combined with AI and ML, can facilitate the early detection, diagnosis and prediction of cardiovascular diseases (CVDs), which are the leading cause of mortality worldwide (Huang et al. 2022; Moshawrab et al. 2023; Neri et al. 2023). AI algorithms, particularly deep learning models like convolutional neural networks (CNNs), are employed to analyze complex biosignal data, enabling real-time disease detection and prediction. For instance, AI-based devices have been developed to classify major cardiac diseases using heart sound signals processed through CNNs, providing a low-cost diagnostic tool for both clinical and personal use (Joshi et al. 2022). Moreover, machine learning models have demonstrated superior accuracy in predicting CVD risk compared to traditional methods, as evidenced by studies showing improved precision in statin therapy recommendations and risk assessments (Martyn-Nemeth and Hayman 2023). This led to wearable technologies supporting continuous monitoring of cardiovascular fitness through unobtrusive data collection and allowing for the prediction of maximum oxygen uptake using ML algorithms like support vector regression (Frade et al. 2023).

Advancement in Network Connectivity Improvement and Data Management

This enabled IoT-based wearable systems designed for low-cost and energy-efficient to be accessible for use in low- and middle-income countries, thereby addressing healthcare disparities. Wearable devices can intercommunicate, utilizing various transmission mediums like BLE, Zigbee, or Wi-Fi, enabling efficient data transfer and analysis for personalized health insights. By collecting and analyzing long-term continuous data on physiological functions, wearable devices offer clinicians a more comprehensive understanding of patient's health status than conventional sporadic assessments (Hughes et al. 2023; Vijayan et al. 2021). The integration of Bluetooth Low Energy (BLE) communication technology further elevates the capabilities of wearables in healthcare applications, enabling the assessment of nerve conduction, muscle contractions, and muscle response in injured tissue (Vijayan et al. 2021). advancements in communication networks, exemplified by fifth-generation (5G) technology, has bolster broadband networks to accommodate demanding requirements such as low latency and high data rates, in order to facilitate seamless data transmission between wearables and remote systems (Vijayan et al. 2021). These systems provide real-time data transmission and alerts, connecting patients with medical support when necessary (Sumwiza et al. 2023). Network connectivity and data management of wearable technologies for cardiovascular health monitoring have significantly enhanced the capabilities of the device to remotely monitor and continuously assess cardiovascular parameters non-

invasively. These parameters such as ECG, heart rate variability, and blood pressure, which are crucial for managing conditions like atrial fibrillation and heart failure (Bashkirtsev et al. 2023; Hughes et al. 2023). The use of Internet of Things (IoT) in healthcare has facilitated the collection and analysis of vast amounts of data, enabling early disease detection and improved patient management, although challenges such as data privacy and accuracy remain (Shiny, Ramrao, and Murugan 2023). Big data technologies have further enhanced the utility of wearables by enabling the analysis of large datasets to improve long-term cardiovascular care, despite issues like data redundancy and security concerns (Miao et al. 2022).

Challenges and Limitations of Wearable Technologies for Cardiovascular Health Monitoring

The integration of wearables technologies into healthcare systems is complicated by the lack of clinical validation and the need for collaborative efforts among stakeholders to ensure its effective use in cardiovascular care (Joy and Kanagamalliga 2024; Varma et al. 2024). Wearable technologies for cardiovascular health monitoring present several challenges and limitations, as highlighted across multiple studies. One significant issue is the reliability and accuracy of data collected by consumer-based ECG wearables, which can be compromised by motion artifacts, especially during physical activities, leading to potential misinterpretation of cardiac health data (Kang et al. 2024; R. Wang et al. 2024). The unregulated nature of direct-to-consumer wearables further exacerbates these concerns, as they may produce clinical non-actionable data that could overwhelm healthcare systems and lead to unintended psychological impacts on users (Varma et al. 2024). There are concerns about data privacy and ethical implications, as the continuous tracking of physiological cardiovascular parameters raises questions about the security and use of personal health information (Rukundo 2024). Wearable technologies also risk widening health disparities, as access to these devices and the necessary digital literacy to interpret their data may not be evenly distributed across different populations (Varma et al. 2024). Despite these challenges, wearables hold promise for enhancing cardiovascular care by enabling real- time monitoring and facilitating patient engagement in health management, particularly when integrated with telehealth platforms (Faderin et al. 2024). However, the development of flexible wearable electrodes that minimize motion artifacts and improve signal quality remains a critical area for future research to ensure these technologies can reliably support cardiovascular health monitoring (Kang et al. 2024).

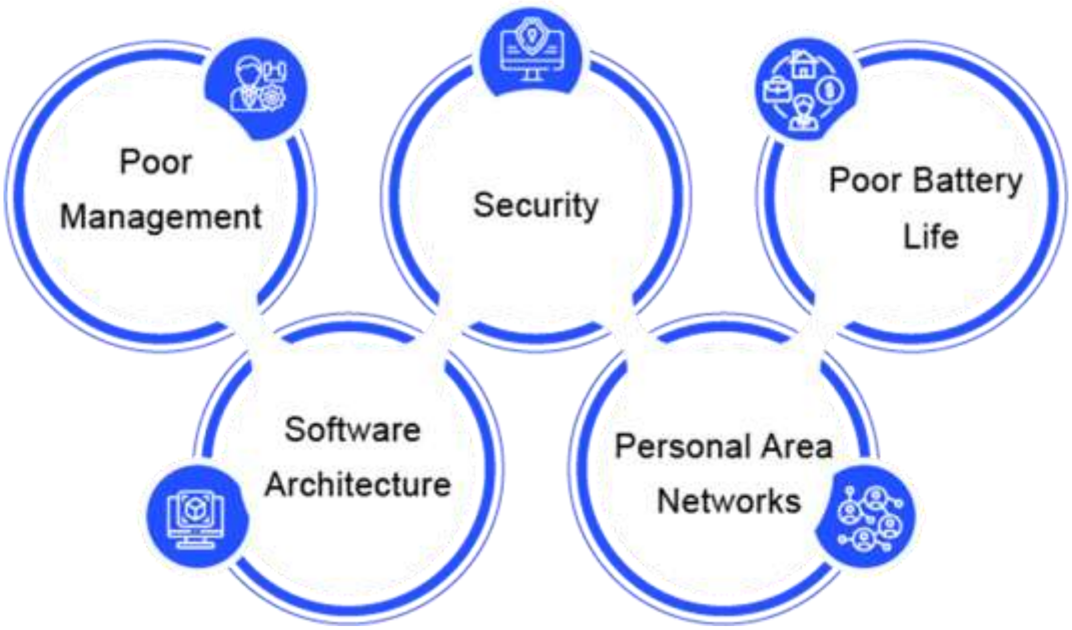

Figure 6.0: Key Challenges and Limitations of Wearable Technologies for Cardiovascular Health Monitoring

Furthermore, while wearables have shown promise in monitoring cardiometabolic health indicators such as heart rate and glucose levels, their impact on other indicators like blood pressure and cholesterol remains underexplored, indicating a need for further research (Lee et al. 2023). The design of non-invasive, user-friendly sensors that can handle noisy data from uncontrolled environments is another challenge, as is the need for advanced AI-based analytics to make reliable inferences from longitudinal data (Scataglini et al. 2023). Moreover, the current wearable devices often support only a limited range of vital sign measurements, lacking comprehensive physiological models to link these signals to broader cardiovascular conditions (Qiu, Yan, and Zhao 2024). Despite these challenges, the continuous development of sensor technology, big data, and artificial intelligence holds promise for overcoming these limitations and enhancing the role of wearables in cardiovascular health monitoring (Wang et al. 2023).

Future Trends of Wearable Technologies for Cardiovascular Health Monitoring

Wearable Biosensors Technologies

Future advancements in wearable biosensor technologies are poised to significantly enhance the effectiveness of wearable devices for cardiovascular health monitoring in addressing current limitations and integrating novel functionalities. Major area of this development is the improvement of flexible and stretchable materials, which are crucial for creating sensors that can conform to the human body and provide accurate, long-term monitoring. For instance, advancements in materials such as polymer-engineered semiconductor nanowires have led to the creation of stretchable photodiodes that offer high fidelity measurements of cardiovascular variables like heart rate variability and oxygen saturation, potentially enabling more reliable and accessible wearable photoplethysmography devices (Mao et al. 2023). Additionally, the integration of miniaturized high- performance hybrid nanogenerators (MHP-HNG) in wearable sensors allows for self-powered operation, reducing reliance on batteries and enhancing portability and application in the Internet of Things (IoT) (Wu et al. 2024). The development of multifunctional devices, such as electrolyte-gated transistors (EGT), which integrate synaptic learning, memory, and autonomous discoloration functionalities, represents another significant advancement. These devices can provide real-time health warnings through intelligent displays, offering a more interactive and immediate form of health monitoring (Sun et al. 2024). Furthermore, the use of capacitive pressure sensors with dual dielectric layers and integrated composite electrodes has improved sensitivity, detection range, and stability, which are essential for accurate gait and cardiovascular monitoring (X. Li et al. 2024). Textile-based sensors, incorporating materials like gold nanowires, have also been developed to maintain performance even after mechanical washing, ensuring durability and practicality in everyday use (Zhao et al. 2022). The integration of advanced data analysis algorithms, such as those based on artificial intelligence and deep learning, into wearable devices is another promising direction. These algorithms can enhance the accuracy of cardiovascular monitoring by enabling real-time analysis and classification of ECG waveforms, thus improving the diagnostic capabilities of wearable devices (Scrugli et al. 2022). Collectively, these advancements in materials, device design, and data processing are expected to significantly enhance the effectiveness and utility of wearable devices for cardiovascular health monitoring, paving the way for more personalized and continuous healthcare solutions (J. Li et al. 2024; Liu et al. 2023).

Machine Learning and Artificial Intelligence

Wearable cardiovascular disease monitoring devices equipped with ML algorithms can analyze complex patterns in high-dimensional data, enabling the detection of conditions such as arterial hypertension and atrial fibrillation (AF) with high precision. For instance, a study demonstrated the use of a Random Forest model to classify individuals as hypertensive or normotensive based on single-lead ECG data, achieving an accuracy of 81% and an AUC of 0.85, highlighting the potential of AI in transforming ECG signals from smartwatches into diagnostic tools (Angelaki-Kaxiras et al. 2023). Similarly, AI algorithms have been shown to reduce the rate of inconclusive diagnoses in AF detection from single-lead ECGs, improving both sensitivity and specificity compared to manufacturer algorithms (Weidlich et al. 2023). Furthermore, the use of consumer devices like the Apple Watch in long-term monitoring has been explored in trials such as the REGAL study, which aims to detect AF early and prevent related complications like cognitive decline (Yao et al. 2024). The development of non-enzymatic sweat sensors integrated with ML for monitoring sweat biomarkers also exemplifies the potential of AI in enhancing the accuracy and reliability of wearable sensors (Zhou et al. 2024). Additionally, AI-assisted wearable biosensing networks are advancing towards personalized medicine by efficiently processing biosensing data to detect abnormalities and provide point-of-care diagnostics (Ifenze et al. 2024; Y. Zhang et al. 2023). These advancements are crucial in addressing the global burden of CVDs, as they offer cost-effective, scalable solutions that can be adapted to various healthcare settings, thereby promoting cardiovascular health equity (Ogungbe et al. 2024). Overall, the integration of ML and AI in wearable technologies is paving the way for more effective and accessible cardiovascular disease management, with ongoing research continuing to refine these tools for broader clinical application (Lown et al. 2020; Poh et al. 2023; Rahim et al. 2021; Xiao et al. 2024).

Wearable Technologies Future Impact on Clinical Practice

The future impact of wearable technologies on clinical practice for cardiovascular disease (CVD) monitoring is poised to be transformative, offering enhanced diagnostic and therapeutic capabilities. Wearable biosensors are advancing rapidly, enabling continuous monitoring of key cardiovascular signals such as electrocardiograms (ECG), blood pressure, and heart rate variability, which are crucial for early detection and management of CVD (Anbuselvam et al. 2024; Sheikh et al. 2023). These devices, including smartwatches and other portable sensors, provide non-invasive, real-time data that can be integrated into clinical decision support systems, potentially reducing recurrent cardiovascular events and improving patient outcomes (Ventura et al. 2022). The integration of artificial intelligence and deep learning algorithms into these devices further enhances their diagnostic accuracy, as seen in the development of cognitive sensor nodes for ECG monitoring, which achieve high accuracy in arrhythmia detection while optimizing power consumption (Scrugli et al. 2022). Additionally, wearable technologies are being tailored for specific conditions, such as heart failure and congenital heart disease, where they offer remote monitoring solutions that can improve care delivery and clinical outcomes (Bekfani et al. 2021; Ganti et al. 2022). The use of wearable devices in managing blood pressure variability, a significant risk factor for CVD, highlights their potential in providing critical targets for intervention beyond traditional blood pressure control (Sheikh et al. 2023). Moreover, innovative applications like the smart brain oxygenation monitoring system demonstrate the potential of wearables in assessing cardiovascular function and disease severity, aiding in personalized rehabilitation strategies (Chou et al. 2020). Despite these advancements, challenges remain, including the need for improved accuracy and reliability of automated measurements, as evidenced by the current limitations in smartwatch-based QT-interval assessments (Mannhart et al. 2022). Overall, the integration of wearable technologies into clinical practice promises to enhance the monitoring and management of cardiovascular diseases, offering personalized, data-driven healthcare solutions that could significantly improve patient care and reduce healthcare costs (Luo et al. 2022; Rezvani et al. 2020).

CONCLUSION

In conclusion wearable technologies has emerged as a transformative game changing tool in cardiovascular disease monitoring and management with significant potential for both patients and healthcare providers. These devices enhanced continuous monitoring of cardiovascular conditions such as hypertension, heart failure, and atrial fibrillation by providing a more comprehensive view of a patient's health compared to traditional clinical visits. The integration of advanced algorithms, particularly deep learning models like Convolutional Neural Networks has enhanced the capability of wearables smartwatches and activity trackers to analyze ECG data and facilitates an early detection/management of cardiac diseases. In remote cardiac rehabilitation programs, wearable technologies have demonstrated its capability in real-time monitoring of patients with post- myocardial infarction and showed comparable improvements in cardiovascular risk factors and exercise capacity to traditional gym-based programs. Despite these advancements, challenges remain, including data reliability, potential misinterpretation, and the risk of exacerbating health disparities due to unequal access. Additionally, while wearables show promise in promoting cardiometabolic health, the impact on specific health indicators like blood pressure and cholesterol remains underexplored, necessitating further research. The continuous monitoring capabilities of wearables, such as piezoelectret patches for heart and breath sounds, offer innovative diagnostic possibilities, yet require validation against standard medical devices. Overall, while wearable technology in cardiovascular health monitoring holds great promise, its successful integration into clinical practice will depend on addressing these challenges and ensuring equitable access across diverse populations.

Competing Interest Declaration
We the authors declare that there are no competing financial interests or personal relationships that could have influence the work reported in this paper.

Citation Diversity Statement
Recent work in several fields of science has identified a bias in citation practices such that papers from women and other minority scholars are undercited relative to the number of papers in the field.4,7,9,11,12 We recognize this bias and have worked diligently to ensure that we are referencing appropriate papers with fair gender and racial author inclusion.

REFERENCES

Alimbayeva, Zhadyra, Chingiz Alimbayev, Kassymbek Ozhikenov, Nurlan Bayanbay, and Aiman Ozhikenova. 2024. "Wearable ECG Device and Machine Learning for Heart Monitoring." Sensors 24(13):4201. doi: 10.3390/s24134201.

Alugubelli, Navya, Hussam Abuissa, and Attila Roka. 2022. "Wearable Devices for Remote Monitoring of Heart Rate and Heart Rate Variability—What We Know and What Is Coming." Sensors 22(22):8903. doi: 10.3390/s22228903.

Anbuselvam, Bhavadharani, Balu Mahendran Gunasekaran, Soorya Srinivasan, Madeshwari Ezhilan, Venkatachalam Rajagopal, and Noel Nesakumar. 2024. "Wearable Biosensors in Cardiovascular Disease." Clinica Chimica Acta 561:119766. doi: 10.1016/j.cca.2024.119766.

Angelaki-Kaxiras, E., G. Kochiadakis, G. Barmparis, S. Maragkoudakis, K. Fragkiadakis, A. Plevritaki, E. Savva, E. Zacharis, E. Kampanieris, S. Kassotakis, P. Kalomoirakis, G. Tsironis, and M. Marketou. 2023. "Single-Lead ECG Based Detection of Arterial Hypertension Using Artificial Intelligence Algorithms." European Heart Journal 44(Supplement_2):ehad655.2919. doi: 10.1093/eurheartj/ehad655.2919.

Baikuvekov, Meirzhan, Azhar Tursynova, and Galymzhan Yespayev. 2024. "A Deep Learning for Cardiovascular Diseases Detection on Wearable Devices Data." Pp. 272–77 in 2024 IEEE 4th International Conference on Smart Information Systems and Technologies (SIST).

Bashkirtsev, Oleksiy, Vira Gaevska, Zoriana Bilous, Liliia Lysa, and Olena Zimba. 2023. "REMOTE MONITORING FOR 5P (PREDICTIVE, PREVENTIVE, PARTICIPATORY, PERSONALIZED, AND PRECISION) CARDIOVASCULAR MEDICINE: PROGRESS AMIDST COVID-19 PANDEMIC." Proceeding of the Shevchenko Scientific Society. Medical Sciences 71(1). doi: 10.25040/ntsh2023.01.14.

Bekfani, Tarek, Marat Fudim, John G. F. Cleland, Ana Jorbenadze, Stephan von Haehling, Avraham Lorber, Alexander M. K. Rothman, Kenneth Stein, William T. Abraham, Horst Sievert, and Stefan D. Anker. 2021. "A Current and Future Outlook on Upcoming Technologies in Remote Monitoring of Patients with Heart Failure." European Journal of Heart Failure 23(1):175–85. doi: 10.1002/ejhf.2033.

Bhaltadak, Vaishnavi, Babaji Ghewade, Seema Yelne, Vaishnavi Bhaltadak, Babaji Ghewade, and Seema Yelne. 2024. "A Comprehensive Review on Advancements in Wearable Technologies: Revolutionizing Cardiovascular Medicine." Cureus 16. doi: 10.7759/cureus.61312.

Chou, Willy, Pei-Jung Wu, Chih-Chieh Fang, Yun-Shan Yen, and Bor-Shyh Lin. 2020. "Design of Smart Brain Oxygenation Monitoring System for Estimating Cardiovascular Disease Severity." IEEE Access 8:98422–29. doi: 10.1109/ACCESS.2020.2997865.

Dhingra, Lovedeep S., Arya Aminorroaya, Evangelos K. Oikonomou, Veer Sangha, Harlan M. Krumholz, and Rohan Khera. 2023. "Abstract 17106: Comparing Pre- and Post- Pandemic Personal Health Monitoring Using Wearable Devices in United States Adults With or at Risk for Cardiovascular Disease: A Nationally Representative Study." Circulation 148(Suppl_1):A17106–A17106. doi: 10.1161/circ.148.suppl_1.17106.

Duncker, David, and Emma Svennberg. 2022. "Editorial: Wearable Devices for Cardiac Rhythm Monitoring."

Frontiers in Cardiovascular Medicine 9. doi: 10.3389/fcvm.2022.951769.

Faderin, Emmanuel, Oreoluwa Gabriel Oginni, and Bolape Alade. 2024. "Telehealth Innovations for Cardiovascular Disease Management." World Journal of Advanced Research and Reviews 24(1):518–

36. doi: 10.30574/wjarr.2024.24.1.3085.

Fakhr, Mahan Hosseinzadeh, Ivan Lopez Carrasco, Dmitry Belyaev, Jihun Kang, YeHyeon Shin, Jong-Souk Yeo, Won-Gun Koh, Jeongwoo Ham, Alexander Michaelis, Joerg Opitz, and Natalia Beshchasna. 2024. "Recent Advances in Wearable Electrochemical Biosensors towards Technological and Material Aspects." Biosensors and Bioelectronics: X 19:100503. doi: 10.1016/j.biosx.2024.100503.

Frade, Maria Cecília Moraes, Thomas Beltrame, Mariana de Oliveira Gois, Allan Pinto, Silvia Cristina Garcia de Moura Tonello, Ricardo da Silva Torres, and Aparecida Maria Catai. 2023. "Toward Characterizing Cardiovascular Fitness Using Machine Learning Based on Unobtrusive Data." PLOS ONE 18(3):e0282398. doi: 10.1371/journal.pone.0282398.

Fynn, Matthew, Kayapanda Mandana, Javed Rashid, Sven Nordholm, Yue Rong, and Goutam Saha. 2024. "Practicality Meets Precision: Wearable Vest with Integrated Multi-Channel PCG Sensors for Effective Coronary Artery Disease Pre-Screening."

Ganti, Venu G., Asim H. Gazi, Sungtae An, Adith V. Srivatsa, Brandi N. Nevius, Christopher J. Nichols, Andrew M. Carek, Munes Fares, Mubeena Abdulkarim, Tarique Hussain, F. Gerald Greil, Mozziyar Etemadi, Omer T. Inan, and Animesh Tandon. 2022. "Wearable Seismocardiography-Based Assessment of Stroke Volume in Congenital Heart Disease." Journal of the American Heart Association 11(18):e026067. doi: 10.1161/JAHA.122.026067.

Gawali, Dhanashri H., Vijay M. Wadhai, Minakshee Patil, and Akshita S. Chanchlani. 2022. "A Wearable ECG Sensor for Intelligent Cardiovascular Health Informatics." in Designing Intelligent Healthcare Systems, Products, and Services Using Disruptive Technologies and Health Informatics. CRC Press.

Gorlov, Nikolai S., Denis V. Vertyanov, Sergey P. Timoshenkov, and Filipp B. Lazba. 2023. "Wearable Long- Term Cardiac Monitoring System Based n Capacitive Sensors Connected by Stretchable Interconnections." Pp. 39–41 in 2023 Seminar on Digital Medical and Environmental Systems and Tools (DMEST).

Groppelli, Antonella, Martina Rafanelli, Giuseppe Dario Testa, Samuele Agusto, Giulia Rivasi, Andrea Ungar, Erika Carbone, Davide Soranna, Antonella Zambon, Michele Brignole, and Gianfranco Parati. 2022. "Feasibility of Blood Pressure Measurement With a Wearable (Watch-Type) Monitor During Impending Syncopal Episodes." Journal of the American Heart Association 11(16):e026420. doi: 10.1161/JAHA.122.026420.

Guo, Y., H. Zhang, and mAFA investigators. 2022. "Wearable Device for Continuously Blood Pressure Monitoring Enable Atrial Fibrillation Risk." European Heart Journal 43(Supplement_2):ehac544.2811. doi: 10.1093/eurheartj/ehac544.2811.

Huang, Jian-Dong, Jinling Wang, Elaine Ramsey, Gerard Leavey, Timothy J. A. Chico, and Joan Condell. 2022. "Applying Artificial Intelligence to Wearable Sensor Data to Diagnose and Predict Cardiovascular Disease: A Review." Sensors 22(20):8002. doi: 10.3390/s22208002.

Hughes, Andrew, Md Mobashir Hasan Shandhi, Hiral Master, Jessilyn Dunn, and Evan Brittain. 2023. "Wearable Devices in Cardiovascular Medicine." Circulation Research 132(5):652–70. doi: 10.1161/CIRCRESAHA.122.322389.

Ifenze, Ogochukwu Militus, G. I. Ndubuka, K. I. Nkuma-Udah, and E. Mbonu. 2024. "Application of Artificial Intelligence in Continuous Blood Glucose Monitoring Techniques and Management of Diabetes: A Review." European Journal of Biology and Medical Science Research 12(01):63–92. doi: https://doi.org/10.37745/ejbmsr.2013/vol12n16392.

Islam, Sheikh Mohammed Shariful, Clara K. Chow, Reza Daryabeygikhotbehsara, Narayan Subedi, Jonathan Rawstorn, Teketo Tegegne, Chandan Karmakar, Muhammad U. Siddiqui, Gavin Lambert, and Ralph Maddison. 2022. "Wearable Cuffless Blood Pressure Monitoring Devices: A Systematic Review and Meta-Analysis." European Heart Journal - Digital Health 3(2):323–37. doi: 10.1093/ehjdh/ztac021.

John Hopkins Medicine. 2024. "Holter Monitor." Retrieved November 25, 2024 (https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/holter-monitor).

Joshi, Rakesh Chandra, Juwairiya Siraj Khan, Vinay Kumar Pathak, and Malay Kishore Dutta. 2022. "AI-CardioCare: Artificial Intelligence Based Device for Cardiac Health Monitoring." IEEE Transactions on Human-Machine Systems 52(6):1292–1302. doi: 10.1109/THMS.2022.3211460.

Joy, Immaculate S., and S. Kanagamalliga. 2024. "Advancements in Remote Heart Monitoring: Wearable Technology and AI-Based Approaches for Cardiovascular Disease Detection." Pp. 102–17 in AI in the Social and Business World: A Comprehensive Approach, edited by P. Dubey, M. Madankar, Pushkar Dubey, and K. K. Sahu. BENTHAM SCIENCE PUBLISHERS.

Kang, Tae Woog, Jimin Lee, Youngjin Kwon, Yoon Jae Lee, and Woon-Hong Yeo. 2024. "Recent Progress in the Development of Flexible Wearable Electrodes for Electrocardiogram Monitoring During Exercise." Advanced NanoBiomed Research 4(8):2300169. doi: 10.1002/anbr.202300169.

Kario, Kazuomi. 2020. "Management of Hypertension in the Digital Era." Hypertension 76(3):640–50. doi: 10.1161/HYPERTENSIONAHA.120.14742.

Khatoun, Ahmad, Adrian-Razvan Petre, Albert J. J. M. van Breemen, Bart Peeters, and Hylke B. Akkerman. 2023. "Wearable Optical Sensor Arrays for Cardiovascular Health Monitoring and Biomarker Mapping." Pp. 19–24 in Diagnostic and Therapeutic Applications of Light in Cardiology 2023. Vol. 12355. SPIE.

Khumngern, Suntisak, and Itthipon Jeerapan. 2024. "Synergistic Convergence of Materials and Enzymes for Biosensing and Self-Sustaining Energy Devices towards on-Body Health Monitoring." Communications Materials 5(1):1–22. doi: 10.1038/s43246-024-00557-6.

Kong, X., R. Cao, T. Lu, S. Gao, G. Sun, and F. Cao. 2022. "Remote Telemedicine Strategy Based on Multi-Risks Intervention by Intelligent Wearable Health Devices in Elderly Comorbidities Patients with Coronary Heart Disease." European Heart Journal - Digital Health 3(4):ztac076.2813. doi: 10.1093/ehjdh/ztac076.2813.

Lee, Hee-Young, Yoon-Ji Kim, Kang-Hyun Lee, Jung-Hun Lee, Sung-Pil Cho, Junghwan Park, Il-Hwan Park, and Hyun Youk. 2024. "Substantiation and Effectiveness of Remote Monitoring System Based on IoMT Using Portable ECG Device."

Lee, Mikyoung A., MinKyoung Song, Hannah Bessette, Mary Roberts Davis, Tracy E. Tyner, and Amy Reid. 2023. "Use of Wearables for Monitoring Cardiometabolic Health: A Systematic Review." International Journal of Medical Informatics 179:105218. doi: 10.1016/j.ijmedinf.2023.105218.

Lee, Shuenn-Yuh, Yi-Wen Hung, Po-Han Su, I.-Pei Lee, and Ju-Yi Chen. 2022. "Biosignal Monitoring Clothing System for the Acquisition of ECG and Respiratory Signals." IEEE Access 10:66083–97. doi: 10.1109/ACCESS.2022.3183968.

Li, Jian, Hongwei Chu, Zhenlin Chen, Chun Ki Yiu, Qing'ao Qu, Zhiyuan Li, and Xinge Yu. 2024. "Recent Advances in Materials, Devices and Algorithms Toward Wearable Continuous Blood Pressure Monitoring." ACS Nano 18(27):17407–38. doi: 10.1021/acsnano.4c04291.

Li, Pei-Rong, Sasi Kiran Boilla, Chih-Hung Wang, Pei-Chien Lin, Chien-Nan Kuo, Tsung-Heng Tsai, and Gwo-Bin Lee. 2024. "A Self-Driven, Microfluidic, Integrated-Circuit Biosensing Chip for Detecting Four Cardiovascular Disease Biomarkers." Biosensors and Bioelectronics 249:115931. doi: 10.1016/j.bios.2023.115931.

Li, Xinyue, Yannan Liu, Yarong Ding, Miao Zhang, Zhenhua Lin, Yue Hao, Yingchun Li, and Jingjing Chang. 2024. "Capacitive Pressure Sensor Combining Dual Dielectric Layers with Integrated Composite
Electrode for Wearable Healthcare Monitoring." ACS Applied Materials & Interfaces 16(10):12974–85. doi: 10.1021/acsami.4c01042

Liu, Tiezhu, Lidan Liu, Guang-yang Gou, Zhen Fang, Jianhai Sun, Jiamin Chen, Jianqun Cheng, Mengdi Han, Tianjun Ma, Chunxiu Liu, and Ning Xue. 2023. "Recent Advancements in Physiological, Biochemical, and Multimodal Sensors Based on Flexible Substrates: Strategies, Technologies, and Integrations." ACS Applied Materials & Interfaces 15(18):21721–45. doi: 10.1021/acsami.3c02690.

Lown, Mark, Michael Brown, Chloë Brown, Arthur M. Yue, Benoy N. Shah, Simon J. Corbett, George Lewith, Beth Stuart, Michael Moore, and Paul Little. 2020. "Machine Learning Detection of Atrial Fibrillation Using Wearable Technology." PLOS ONE 15(1):e0227401. doi: 10.1371/journal.pone.0227401.

Luo, Jiasai, Guo Zhang, Yiwei Su, Yi Lu, Yu Pang, Yuanfa Wang, Huiqian Wang, Kunfeng Cui, Yuhao Jiang, Lisha Zhong, and Zhiwei Huang. 2022. "Quantitative Analysis of Heart Rate Variability Parameter and Mental Stress Index." Frontiers in Cardiovascular Medicine 9. doi: 10.3389/fcvm.2022.930745.

Mannhart, Diego, Elisa Hennings, Mirko Lischer, Claudius Vernier, Jeanne Du Fay de Lavallaz, Sven Knecht, Beat Schaer, Stefan Osswald, Michael Kühne, Christian Sticherling, and Patrick Badertscher. 2022. "Clinical Validation of Automated Corrected QT-Interval Measurements From a Single Lead Electrocardiogram Using a Novel Smartwatch." Frontiers in Cardiovascular Medicine 9. doi: 10.3389/fcvm.2022.906079.

Mao, Pengsu, Haoran Li, Xin Shan, Melissa Davis, Te Tang, Yugang Zhang, Xiao Tong, Yan Xin, Jiang Cheng, Lu Li, and Zhibin Yu. 2023. "Stretchable Photodiodes with Polymer-Engineered Semiconductor Nanowires for Wearable Photoplethysmography." ACS Applied Materials & Interfaces 15(28):33797– 808. doi: 10.1021/acsami.3c04494.

Martyn-Nemeth, Pamela, and Laura L. Hayman. 2023. "Digital Technology in Cardiovascular Health: Role and Evidence Supporting Its Use." Journal of Cardiovascular Nursing 38(3):207. doi: 10.1097/JCN.0000000000000985.

Miao, Fen, Dan Wu, Zengding Liu, Ruojun Zhang, Min Tang, and Ye Li. 2022. “Wearable Sensing, Big Data Technology for Cardiovascular Healthcare: Current Status and Future Prospective.” Chinese Medical Journal 136(9):1015. doi: 10.1097/CM9.0000000000002117.

Mishra, Suvrajyoti, Smita Mohanty, and Ananthakumar Ramadoss. 2022. “Functionality of Flexible Pressure Sensors in Cardiovascular Health Monitoring: A Review.” ACS Sensors 7(9):2495–2520. doi: 10.1021/acssensors.2c00942.

Moshawrab, Mohammad, Mehdi Adda, Abdenour Bouzouane, Hussein Ibrahim, and Ali Raad. 2023. “Smart Wearables for the Detection of Cardiovascular Diseases: A Systematic Literature Review.” Sensors 23(2):828. doi: 10.3390/s23020828.

Nachman, D., Y. Kolben, E. Carmon, E. Hazan, N. Goldstein, A. Eisenkraft, M. Fons, O. Amir, R. Asleh, andY. Gepner. 2022. “Insights into Diurnal Variations of Advanced Hemodynamic Parameters in Ambulatory Individuals Enabled by a Photoplethysmography-Based Wearable Monitor.” European Heart Journal - Digital Health 3(4):ztac076.2810. doi: 10.1093/ehjdh/ztac076.2810.

Nazir, Sophia, and Rabail Azhar Iqbal. 2023. “Biosensor for Rapid and Accurate Detection of Cardiovascular Biomarkers: Progress and Prospects in Biosensors.” Biosensors and Bioelectronics: X 14:100388. doi: 10.1016/j.biosx.2023.100388.

Neri, Luca, Matt T. Oberdier, Kirsten C. J. van Abeelen, Luca Menghini, Ethan Tumarkin, Hemantkumar Tripathi, Sujai Jaipalli, Alessandro Orro, Nazareno Paolocci, Ilaria Gallelli, Massimo Dall’Olio, Amir Beker, Richard T. Carrick, Claudio Borghi, and Henry R. Halperin. 2023. “Electrocardiogram Monitoring Wearable Devices and Artificial-Intelligence-Enabled Diagnostic Capabilities: A Review.” Sensors 23(10):4805. doi: 10.3390/s23104805.

Nguyen, Van-Thai, Nhut-Minh Tran, Phuong-Nam Tran, Thu-Ha Tran, Thanh-Kieu Tran Thi, and Van-Khoa Pham. 2024. “Development of a Wearable Device for Heart Rate Monitoring and Fall Detection Using Machine Learning to Analyze and Detect Early Anomaly of Cardiovascular Conditions.” Tạp Chí Khoa Học và Công Nghệ - Đại Học Đà Nẵng 7–12. doi: 10.31130/ud-jst.2024.158ICT.

Ogungbe, Oluwabunmi, Chris T. Longenecker, Andrea Beaton, Sarah de Loizaga, Luisa Campos Caldeira Brant, Ruth-Alma N. Turkson Ocran, Pouya Bastani, Fred Stephen Sarfo, and Yvonne Commodore-Mensah. 2024. “Advancing Cardiovascular Health Equity Globally Through Digital Technologies.” Journal of the American Heart Association 13(2):e031237. doi: 10.1161/JAHA.123.031237.

Pelter, Megan N., Giorgio Quer, and Jay Pandit. 2023. “Remote Monitoring in Cardiovascular Diseases.” Current Cardiovascular Risk Reports 17(11):177–84. doi: 10.1007/s12170-023-00726-1.

Pires, Ivan Miguel, Hanna Vitaliyivna Denysyuk, María Vanessa Villasana, Juliana Sá, Petre Lameski, Ivan Chorbev, Eftim Zdravevski, Vladimir Trajkovik, José Francisco Morgado, and Nuno M. Garcia. 2021. “Mobile 5P-Medicine Approach for Cardiovascular Patients.” Sensors 21(21):6986. doi: 10.3390/s21216986.

Poh, Ming-Zher, Anthony J. Battisti, Li-Fang Cheng, Janice Lin, Anil Patwardhan, Ganesh S. Venkataraman, Charles A. Athill, Nimesh S. Patel, Chinmay P. Patel, Christian E. Machado, Jeffrey T. Ellis, Lori A. Crosson, Yuriko Tamura, R. Scooter Plowman, Mintu P. Turakhia, and Hamid Ghanbari. 2023. “Validation of a Deep Learning Algorithm for Continuous, Real-Time Detection of Atrial Fibrillation Using a Wrist-Worn Device in an Ambulatory Environment.” Journal of the American Heart Association 12(19):e030543. doi: 10.1161/JAHA.123.030543.

Qiu, Shirong, Bryan P. Y. Yan, and Ni Zhao. 2024. "Stroke-Volume-Allocation Model Enabling Wearable Sensors for Vascular Age and Cardiovascular Disease Assessment." Npj Flexible Electronics 8(1):1–
10. doi: 10.1038/s41528-024-00307-1.

Raffi, S., Prof. Muhammadu Sathik Raja, Professor, Dept of Medical Electronics, Sengunthar Engineering College (Autonomous), Tiruchengode. Tamil Nadu, INDIA, Prof. Jamuna K., and Professor, Dept of Medical Electronics, Sengunthar Engineering College (Autonomous), Tiruchengode, Tamil Nadu, INDIA. 2024. "Medical Sensors and Their Integration in Wireless Body Area Networking for Pervasive Healthcare Delivery." International Journal of Innovative Research in Information Security 10(02):89–
92. doi: 10.26562/ijiris.2024.v1002.11.

Rahim, Aqsa, Yawar Rasheed, Farooque Azam, Muhammad Waseem Anwar, Muhammad Abdul Rahim, and Abdul Wahab Muzaffar. 2021. "An Integrated Machine Learning Framework for Effective Prediction of Cardiovascular Diseases." IEEE Access 9:106575–88. doi: 10.1109/ACCESS.2021.3098688.

Randazzo, Vincenzo, Jacopo Ferretti, and Eros Pasero. 2021. "Anytime ECG Monitoring through the Use of a Low-Cost, User-Friendly, Wearable Device." Sensors 21(18):6036. doi: 10.3390/s21186036.

Rapin, Michael, Fabian Braun, Andy Adler, Josias Wacker, Inéz Frerichs, Barbara Vogt, and Olivier Chételat. 2019. "Wearable Sensors for Frequency-Multiplexed EIT and Multilead ECG Data Acquisition." IEEE Transactions on Biomedical Engineering 66(3):810–20. doi: 10.1109/TBME.2018.2857199.

Rezvani, Farhad, Dirk Heider, Martin Härter, Hans-Helmut König, Frank Bienert, Julia Brinkmann, Lutz Herbarth, Edith Kramer, Patrick Steinisch, Frank Freudenstein, René Terhalle, Yvonne Grosse, Susanne Bock, Jacqueline Posselt, Corinna Beutel, Franziska Reif, Florian Kirchhoff, Carolin Neuschwander, Franziska Löffler, Lisa Brunner, Patrick Dickmeis, Thomas Heidenthal, Lara Schmitz, Daniela Patricia Chase, Claudia Seelenmeyer, Mark Dominik Alscher, Uwe Tegtbur, and Jörg Dirmaier. 2020. "Telephone Health Coaching with Exercise Monitoring Using Wearable Activity Trackers
(TeGeCoach) for Improving Walking Impairment in Peripheral Artery Disease: Study Protocol for a Randomised Controlled Trial and Economic Evaluation." BMJ Open 10(6):e032146. doi: 10.1136/bmjopen-2019-032146.

Rong, Yue, Matthew Fynn, Sven Nordholm, Serena Siaw, and Girish Dwivedi. 2023. "Wearable Electro-Phonocardiography Device for Cardiovascular Disease Monitoring." Pp. 413–17 in 2023 IEEE Statistical Signal Processing Workshop (SSP).

Rukundo, Sande Kibuuka. 2024. "The Impact of Wearable Technology on Health Monitoring." RESEARCH INVENTION JOURNAL OF PUBLIC HEALTH AND PHARMACY 3(2):5–8. doi: 10.59298/RIJPP/2024/325800.

Savage, Neil. 2020. "Softsonics: A Device to Take Blood-Pressure Readings Continuously." Nature. doi: 10.1038/d41586-020-01807-6.

Scataglini, Sofia, Thivya Kandappu, Avik Ghose, and Aniruddha Sinha. 2023. "Editorial: Wearable Sensors Role in Promoting Health and Wellness via Reliable and Longitudinal Monitoring." Frontiers in Physiology 14. doi: 10.3389/fphys.2023.1201847.

Scrugli, Matteo A., Daniela Loi, Luigi Raffo, and Paolo Meloni. 2022. "An Adaptive Cognitive Sensor Node for ECG Monitoring in the Internet of Medical Things." IEEE Access 10:1688–1705. doi: 10.1109/ACCESS.2021.3136793.

Sheikh, Abu Baker, Paul A. Sobotka, Ishan Garg, Jessilyn P. Dunn, Abdul Mannan Khan Minhas, Md Mobashir Hasan Shandhi, Jeroen Molinger, Barry J. McDonnell, and Marat Fudim. 2023. "Blood Pressure Variability in Clinical Practice: Past, Present and the Future." Journal of the American Heart Association 12(9):e029297. doi: 10.1161/JAHA.122.029297.

Shiny, M. Lorate, Nagaraj Ramrao, and Kalpana Murugan. 2023. "A Review on Ongoing Medical Care Observing Framework for Cardiovascular Patients Utilizing IoT." Pp. 1310–18 in 2023 7th International Conference on Computing Methodologies and Communication (ICCMC).

Shiwani, Muhammad Ali, Timothy J. A. Chico, Fabio Ciravegna, and Lyudmila Mihaylova. 2023. "Continuous Monitoring of Health and Mobility Indicators in Patients with Cardiovascular Disease: A Review of Recent Technologies." Sensors 23(12):5752. doi: 10.3390/s23125752.

Singhal, Arvind, and Martin R. Cowie. 2020. "The Role of Wearables in Heart Failure." Current Heart Failure Reports 17(4):125–32. doi: 10.1007/s11897-020-00467-x.

Smith, Aaron Asael, Rui Li, and Zion Tsz Ho Tse. 2023. "Reshaping Healthcare with Wearable Biosensors."
Scientific Reports 13(1):4998. doi: 10.1038/s41598-022-26951-z

Sumwiza, Kellen, Celestin Twizere, Gerard Rushingabigwi, Pierre Bakunzibake, and Farian S. Ishengoma. 2023. "Design of a Low-Cost IoT-Based Wearable System for Cardiovascular Disease Detection and Monitoring in Rwanda." Pp. 1–5 in 2023 IEEE Third International Conference on Signal, Control and Communication (SCC).

Sun, Cui, Xuerong Liu, Quanxing Yao, Qian Jiang, Xiangling Xia, Youfeng Shen, Xiaoyu Ye, Hongwei Tan, Runsheng Gao, Xiaojian Zhu, and Run-Wei Li. 2024. "A Discolorable Flexible Synaptic Transistor for Wearable Health Monitoring." ACS Nano 18(1):515–25. doi: 10.1021/acsnano.3c08357.

Tandon, Animesh, Jennifer N. Avari Silva, Ami B. Bhatt, Colin K. Drummond, Allison C. Hill, Amanda E. Paluch, Sheradon Waits, Jenny E. Zablah, Kevin C. Harris, and on behalf of the Council on Lifelong Congenital Heart Disease and Heart Health in the Young (Young Hearts); Council on Lifestyle and Cardiometabolic Health; Council on Clinical Cardiology; and Council on Cardiovascular and Stroke Nursing. 2024. "Advancing Wearable Biosensors for Congenital Heart Disease: Patient and Clinician
Perspectives: A Science Advisory From the American Heart Association." Circulation 149(19):e1134–42. doi: 10.1161/CIR.0000000000001225

Tang, Lichao, Jiyuan Yang, Yuxi Wang, and Ruijie Deng. 2023. "Recent Advances in Cardiovascular Disease Biosensors and Monitoring Technologies." ACS Sensors 8(3):956–73. doi: 10.1021/acssensors.2c02311.

Thi Thuy Le, Tien, Viet Ngoc Tran, Nguyen Khoi Pham, Hung Quoc Nguyen, Nga Thi Tuyet Tu, and Toi Van Vo. 2024. "Development of a Wireless Wearable Holter to Measure Blood Pressure and Heart Rate for Telemedicine." Pp. 88–103 in 9th International Conference on the Development of Biomedical Engineering in Vietnam, edited by V. T. Vo, T.-H. Nguyen, B. L. Vong, N. B. Le, and T. Q. Nguyen. Cham: Springer Nature Switzerland.

Varma, Niraj, Janet K. Han, Rod Passman, Lindsey Anne Rosman, Hamid Ghanbari, Peter Noseworthy, Jennifer N. Avari Silva, Abhishek Deshmukh, Prashanthan Sanders, Gerhard Hindricks, Gregory Lip, and Arun R. Sridhar. 2024. "Promises and Perils of Consumer Mobile Technologies in Cardiovascular Care: JACC Scientific Statement." Journal of the American College of Cardiology 83(5):611–31. doi: 10.1016/j.jacc.2023.11.024.

Ventura, Filipa, Pedro Sousa, Maria Anjos Dixe, Paulo Ferreira, Ricardo Martinho, Sara Simões Dias, João Morais, and Lino M. Gonçalves. 2022. "A Clinical Decision Support System for Remote

Monitoring of Cardiovascular Disease Patients: A Clinical Study Protocol." Frontiers in Public Health 10. doi: 10.3389/fpubh.2022.859890.

Vijayan, Vini, James P. Connolly, Joan Condell, Nigel McKelvey, and Philip Gardiner. 2021. "Review of Wearable Devices and Data Collection Considerations for Connected Health." Sensors 21(16):5589. doi: 10.3390/s21165589.

Vo, Dang-Khoa, and Kieu The Loan Trinh. 2024. "Advances in Wearable Biosensors for Healthcare: Current Trends, Applications, and Future Perspectives." Biosensors 14(11):560. doi: 10.3390/bios14110560.

Wang, Jing, Lei Wang, Jie Lin, Ritao Xiao, Jiamin Chen, and Peng Jin. 2024. "Sensor Fusion Noise Suppression Method Based on Finite Impulse Response Complementary Filters." Measurement 232:114680. doi: 10.1016/j.measurement.2024.114680.

Wang, Ruijing, Sagar Chakravarthy Mathada Veera, Onur Asan, and Ting Liao. 2024. "A Systematic Review on the Use of Consumer-Based ECG Wearables on Cardiac Health Monitoring." IEEE Journal of Biomedical and Health Informatics 28(11):6525–37. doi: 10.1109/JBHI.2024.3456028.

Wang, Ting-Wei, Hsiao-Wei Chu, Wen-Xiang Chen, Yuan-Ta Shih, Po-Chun Hsu, Hao-Min Cheng, and Shien- Fong Lin. 2020. "Single-Channel Impedance Plethysmography Neck Patch Device for Unobtrusive Wearable Cardiovascular Monitoring." IEEE Access 8:184909–19. doi: 10.1109/ACCESS.2020.3029604.

Wang, Xin, Shuting Liu, Mingxing Zhu, Yuchao He, Zhilong Wei, Yingying Wang, Yangjie Xu, Hongguang Pan, Weimin Huang, Shixiong Chen, and Guanglin Li. 2022. "Flexible Non-Contact Electrodes for Wearable Biosensors System on Electrocardiogram Monitoring in Motion." Frontiers in Neuroscience
16. doi: 10.3389/fnins.2022.900146

Wang, Yifeng, Zheng Zhao, and Jiangtao Li. 2023. "Current Status and Development Tendency of Wearable Cardiac Health Monitoring." Chinese Journal of Electrical Engineering 9(1):71–92. doi: 10.23919/CJEE.2023.000016.

Wang, Yiqian, Yang Zou, and Zhou Li. 2024. "Emerging Intelligent Wearable Devices for Cardiovascular Health Monitoring." Nano Today 59:102544. doi: 10.1016/j.nantod.2024.102544.

Wang, Yishan, Fen Miao, Qi An, Zengding Liu, Cong Chen, and Ye Li. 2022. "Wearable Multimodal Vital Sign Monitoring Sensor With Fully Integrated Analog Front End." IEEE Sensors Journal 22(13):13462–71. doi: 10.1109/JSEN.2022.3177205.

Wang, Zeyu, Chen Chen, Linkai Tao, Xian Zhao, Wei Yuan, and Wei Chen. 2019. "An Unconstrained Cardiac Monitoring System With Novel Dual Tripolar Concentric Ring Geometry-Based Flexible Active ECG Electrodes for Sleep Health Surveillance." IEEE Access 7:142176–89. doi: 10.1109/ACCESS.2019.2943602.

Weidlich, S., D. Mannhart, A. Kennedy, P. Doggart, T. Serban, S. Knecht, J. Du Fay De Lavallaz, M. Kuehne
C. Sticherling, and P. Badertscher. 2023. "Reducing the Burden of Inconclusive Smart-Device Single- Lead ECG Tracings via a Novel Atificial Intelligence Algorithm." European Heart Journal 44(Supplement_2):ehad655.2922. doi: 10.1093/eurheartj/ehad655.2922.

Williams, Gareth J., Abdulaziz Al-Baraikan, Frank E. Rademakers, Fabio Ciravegna, Frans N. van de Vosse, Allan Lawrie, Alexander Rothman, Euan A. Ashley, Martin R. Wilkins, Patricia V. Lawford, Stig W. Omholt, Ulrik Wisløff, D. Rodney Hose, Timothy J. A. Chico, Julian P. Gunn, and Paul D. Morris. 2023. "Wearable Technology and the Cardiovascular System: The Future of Patient Assessment." The Lancet Digital Health 5(7):e467–76. doi: 10.1016/S2589-7500(23)00087-0.

Wu, Jinjing, Xiaobo Lin, Chengkai Yang, Sirui Yang, Chenning Liu, and Yuanyuan Cao. 2024. "Wearable Sensors Based on Miniaturized High-Performance Hybrid Nanogenerator for Medical Health Monitoring." Biosensors 14(8):361. doi: 10.3390/bios14080361.

Xian, Xiaojun. 2023. "Frontiers of Wearable Biosensors for Human Health Monitoring." Biosensors 13(11):964. doi: 10.3390/bios13110964.

Xiao, Xiao, Junyi Yin, Jing Xu, Trinny Tat, and Jun Chen. 2024. "Advances in Machine Learning for Wearable Sensors." ACS Nano 18(34):22734–51. doi: 10.1021/acsnano.4c05851.

Xue, Ziao, YanSong Gai, Yuxiang Wu, Zhuo Liu, and Zhou Li. 2024. "Wearable Mechanical and Electrochemical Sensors for Real-Time Health Monitoring." Communications Materials 5(1):1–7. doi: 10.1038/s43246-024-00658-2.

Yao, Xiaoxi, Zachi I. Attia, Emma M. Behnken, Melissa S. Hart, Shealeigh A. Inselman, Kayla C. Weber, Fan Li, Nikki H. Stricker, John L. Stricker, Paul A. Friedman, and Peter A. Noseworthy. 2024. "Realtime Diagnosis from Electrocardiogram Artificial Intelligence-Guided Screening for Atrial Fibrillation with Long Follow-Up (REGAL): Rationale and Design of a Pragmatic, Decentralized, Randomized Controlled Trial." American Heart Journal 267:62–69. doi: 10.1016/j.ahj.2023.10.005.

Zha, Bingjie, Zhuo Wang, Linqing Li, Xuehao Hu, Beatriz Ortega, Xiaoli Li, and Rui Min. 2023. "Wearable Cardiorespiratory Monitoring with Stretchable Elastomer Optical Fiber." Biomedical Optics Express 14(5):2260–75. doi: 10.1364/BOE.490034.

Zhang, Qingxue, Xuan Zeng, Wenchuang Hu, and Dian Zhou. 2017. "A Machine Learning-Empowered System for Long-Term Motion-Tolerant Wearable Monitoring of Blood Pressure and Heart Rate With Ear-ECG/PPG." IEEE Access 5:10547–61. doi: 10.1109/ACCESS.2017.2707472.

Zhang, Tianqi, Ning Liu, Jing Xu, Zeye Liu, Yunlei Zhou, Yicheng Yang, Shoujun Li, Yuan Huang, and Shan Jiang. 2023. "Flexible Electronics for Cardiovascular Healthcare Monitoring." The Innovation 4(5). doi: 10.1016/j.xinn.2023.100485.

Zhang, Yihan, Yubing Hu, Nan Jiang, and Ali K. Yetisen. 2023. "Wearable Artificial Intelligence Biosensor Networks." Biosensors and Bioelectronics 219:114825. doi: 10.1016/j.bios.2022.114825.

Zhao, Lei, Cunman Liang, Yan Huang, Guodong Zhou, Yiqun Xiao, Nan Ji, Yuan-Ting Zhang, and Ni Zhao. 2023. "Emerging Sensing and Modeling Technologies for Wearable and Cuffless Blood Pressure Monitoring." Npj Digital Medicine 6(1):1–15. doi: 10.1038/s41746-023-00835-6.

Zhao, Zhiqi, Qiujin Li, Yu Dong, Jixian Gong, Zheng Li, and Jianfei Zhang. 2022. "Washable Patches with Gold Nanowires/Textiles in Wearable Sensors for Health Monitoring." ACS Applied Materials & Interfaces 14(16):18884–900. doi: 10.1021/acsami.2c01729.

Zhou, Zhongzeng, Xuecheng He, Jingyu Xiao, Jiuxiang Pan, Mengmeng Li, Tailin Xu, and Xueji Zhang. 2024. "Machine Learning-Powered Wearable Interface for Distinguishable and Predictable Sweat Sensing." Biosensors and Bioelectronics 265:116712. doi: 10.1016/j.bios.2024.116712.