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HEALTH MONITORING THROUGH WEARABLES: A SYSTEMATIC REVIEW OF INNOVATIONS IN CARDIOVASCULAR DISEASE DETECTION AND PREVENTION

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ABSTRACT

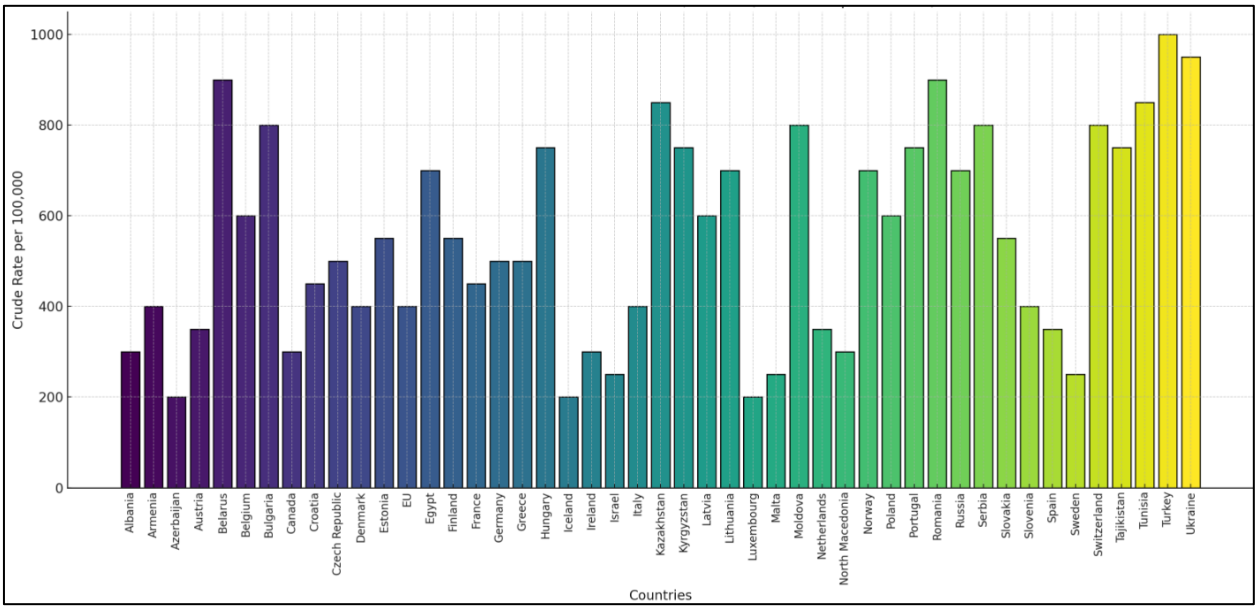
Wearable technology has rapidly evolved, becoming an integral tool in healthcare, particularly for cardiovascular health monitoring and disease prevention. This systematic review evaluates wearable device advancements, applications, and limitations, emphasizing their role in real-time health tracking, early detection of cardiovascular diseases, and lifestyle interventions. The study reviewed 112 peer-reviewed articles, applying the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a rigorous and transparent approach. The findings highlight the integration of advanced sensors, such as photoplethysmography (PPG) and electrocardiography (ECG), and artificial intelligence-powered algorithms that enable enhanced diagnostic accuracy and predictive capabilities. Wearable devices have proven effective in remote patient monitoring, reducing hospital readmissions, and promoting proactive health management by empowering users to adopt and sustain healthier behaviors. However, challenges persist in ensuring device accuracy, particularly across diverse populations, with issues such as motion artifacts, signal noise, and variability in sensor performance noted. Furthermore, the review identifies a critical gap in the inclusion of underrepresented populations, such as older adults, individuals with darker skin tones, and those from low-resource settings, which limits the generalizability of findings. Despite these challenges, the study concludes that wearable technology has immense potential to revolutionize healthcare by enhancing accessibility, patient engagement, and preventive care. Addressing the identified gaps will be crucial for maximizing wearable health technologies' equitable adoption and impact.

1 INTRODUCTION

Cardiovascular diseases (CVDs) represent a critical global health challenge, accounting for significant morbidity and mortality rates across diverse populations (Kumar et al., 2022). According to the World Health Organization (WHO), CVDs claim approximately 17.9 million lives annually, constituting the leading cause of death worldwide (WHO, 2021). These conditions, encompassing coronary artery disease, heart failure, arrhythmias, and hypertension, place a substantial burden on healthcare systems and economies (Pevnick et al., 2017). Addressing this growing epidemic requires innovative solutions that go beyond traditional clinical approaches. Among the transformative technologies, wearable devices have emerged as a pivotal tool for real-time health monitoring, early detection, and risk assessment of CVDs (Lin et al., 2021). Wearable technologies are redefining how cardiovascular health is managed and prioritized by offering non-invasive and continuous monitoring of vital parameters (Ganti et al., 2022). On this note, figure 1 illustrates the varying mortality rates among females across different countries, with rates ranging from 200 to over 1,000 deaths per 100,000 individuals (Dias & Cunha, 2018). This highlights significant geographic disparities in cardiovascular disease (CVD) mortality, emphasizing the global burden of CVDs among women. The relevance of this study lies in showcasing the urgent need for wearable health monitoring technologies, which can aid in the early detection, prevention, and management of CVDs. By addressing these disparities, wearable devices can potentially reduce mortality rates and improve health outcomes, particularly in high-risk regions. This underscores the importance of making wearable technology accessible and practical for diverse populations worldwide.

Remote monitoring facilitated by wearable devices is particularly advantageous for patients with chronic cardiovascular conditions, such as heart failure and hypertension (Mizuno et al., 2020). These devices provide continuous data on vital signs, enabling healthcare providers to identify early signs of clinical deterioration and intervene promptly (Avalos et al., 2022). For example, wearable devices like chest straps and smartwatches equipped with advanced sensors have been shown to monitor fluctuations in heart rate variability and blood pressure, aiding in the timely adjustment of treatment regimens (Kao et al., 2012). Moreover, such remote monitoring capabilities are invaluable in telemedicine, where geographical barriers often impede access to specialist care. By bridging the gap between patients and providers, wearables improve care delivery and reduce hospitalization rates (Cheung et al., 2020). In addition to their diagnostic and monitoring functions, wearable devices significantly promote preventive healthcare. Prevention is a cornerstone of cardiovascular health, and wearable technologies are uniquely positioned to encourage healthy lifestyle behaviors among users (Tandon & de

Figure 1: Deaths due to cardiovascular diseases, female (crude rate per 100000)



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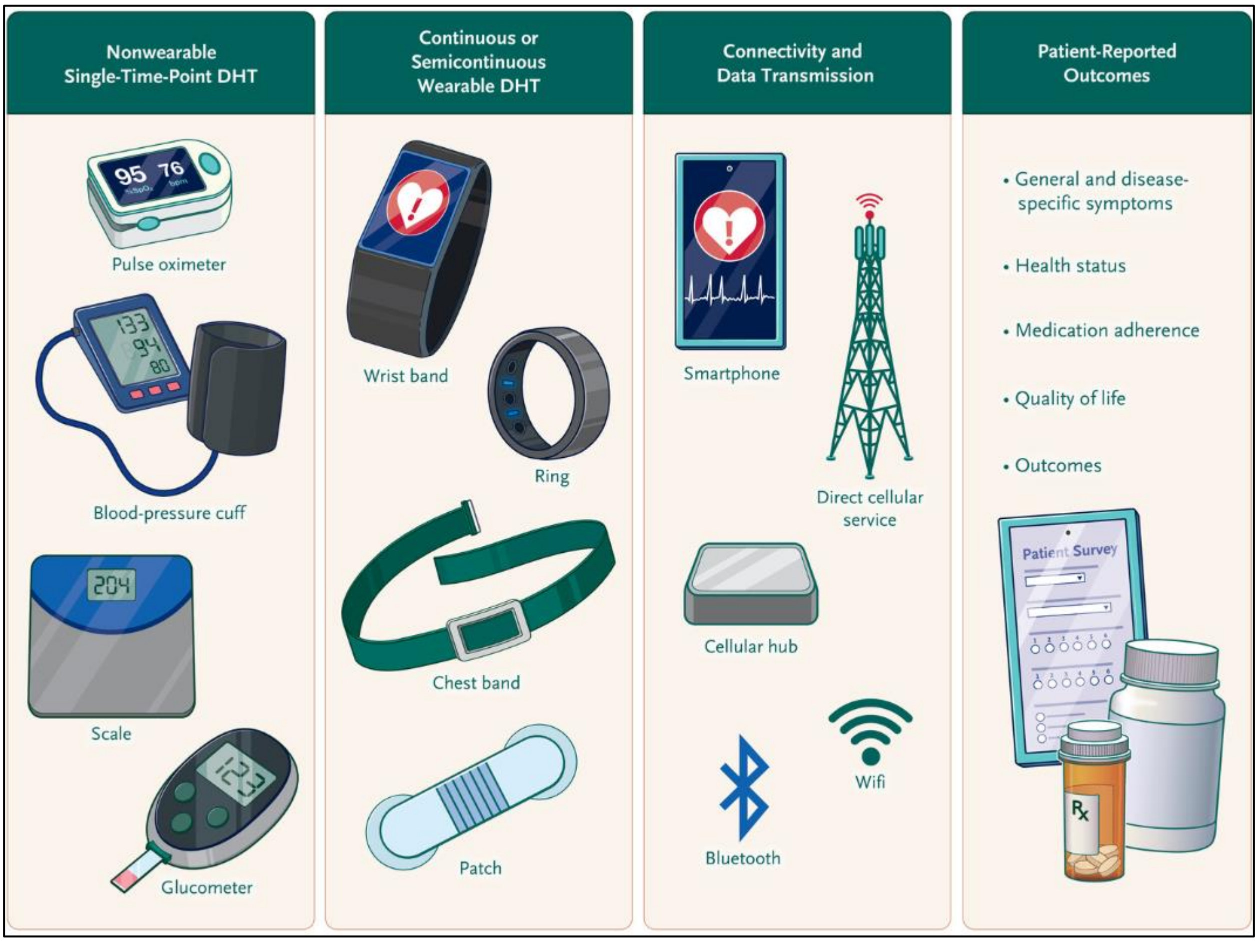
Ferranti, 2019). Devices with fitness-tracking capabilities can monitor physical activity levels, set personalized goals, and provide actionable feedback to users (Hong et al., 2019). For instance, studies have shown that wearable technologies help reduce sedentary behavior and increase adherence to physical activity recommendations, key factors in mitigating cardiovascular risk (Islam et al., 2019). Moreover, integrating gamification elements, such as achievement badges and challenges, enhances user engagement and motivation, fostering sustained behavioral changes (Hammond-Haley et al., 2021). These features highlight the broader implications of wearable technologies in preventive cardiovascular care, moving beyond mere monitoring to actively shaping health behaviors.

A significant advantage of wearable technology lies in its capacity to generate vast amounts of health data, which can be analyzed to uncover patterns and trends (Islam et al., 2019). Incorporating big data analytics and machine learning algorithms into wearable systems enables the identification of subtle changes in health metrics that may indicate the onset of cardiovascular conditions (Hammond-Haley et al., 2021). For example, wearable AI devices can predict heart failure exacerbations by analyzing trends in weight, heart rate, and respiratory rate data (Ganti et al., 2022). These predictive capabilities empower clinicians to adopt proactive management strategies, shifting the focus from reactive to preventive care. Furthermore, wearable technology fosters patient empowerment by enabling individuals to track their health data in real-time, facilitating greater awareness and control over their cardiovascular health (Mizuno et al., 2020). This democratization of health information represents a paradigm shift in patient-centered care. Despite the significant progress in wearable technology, device accuracy and reliability variability across different populations present ongoing challenges. Studies have identified discrepancies in the performance of wearables based on factors such as skin tone, body composition, and physical activity levels (Lin et al., 2021; Oresko et al., 2010). For instance, photoplethysmography-based

Figure 2: Overview of Wearable and Non-Wearable Digital Health Tools



Source: Venkatesh (2024)

heart rate monitors have been shown to perform less accurately in individuals with darker skin tones due to signal interference (Dias & Cunha, 2018). Data privacy and security concerns remain a significant barrier to widespread adoption. The collection and storage of sensitive health information by wearable devices raise ethical and legal questions regarding user consent, data ownership, and protection against breaches (Pevnick et al., 2017). Addressing these challenges is essential to ensure wearable technologies' equitable and ethical deployment in cardiovascular care. This systematic review aims to comprehensively evaluate the role of wearable technology in the detection and prevention of cardiovascular diseases (CVDs). This review aims to synthesize evidence on the diagnostic capabilities of wearable devices, such as electrocardiograms (ECG), photoplethysmography (PPG), and other biosensors, and their effectiveness in early disease detection and risk assessment. Furthermore, the review seeks to analyze the integration of advanced technologies, such as artificial intelligence (AI) and big data analytics, in enhancing the accuracy and predictive power of wearable health monitoring systems. Another key focus is to examine the clinical applications of wearables in chronic disease management, highlighting their impact on patient outcomes, remote monitoring, and personalized care. Finally, this review identifies challenges, including device accuracy, data privacy, and adoption barriers, while critically assessing the existing literature to facilitate future advancements in wearable health monitoring technologies for cardiovascular care.

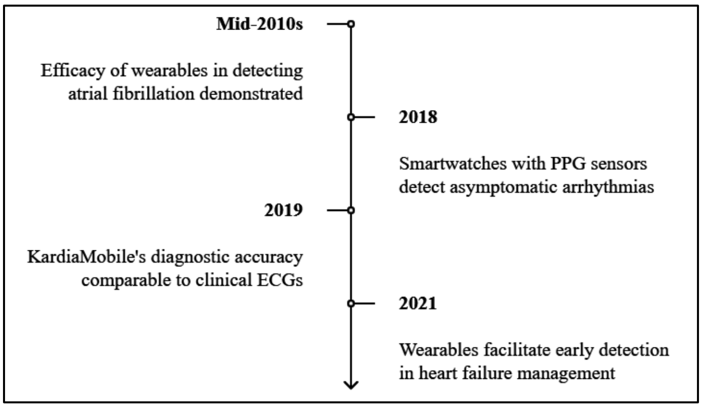
2 LITERATURE REVIEW

Wearable technology for cardiovascular disease (CVD) monitoring and prevention has garnered significant attention in recent years, driven by rapid advancements in sensor technology, artificial intelligence (AI), and data analytics. This section provides a comprehensive review of the existing literature, synthesizing key findings from studies that explore the technological innovations, clinical applications, and limitations of wearable devices in cardiovascular health. The review is structured to address critical themes, including the evolution of wearable technology, diagnostic capabilities, and the integration of AI in enhancing device functionality. By examining these areas, the literature review aims to identify gaps in the existing body of knowledge and provide a foundation for further exploration of wearable technologies in cardiovascular care.

2.1 *Wearable Technology in Cardiovascular Health*

Wearable technology has undergone significant advancements, from basic fitness trackers to sophisticated health monitoring devices that play a critical role in cardiovascular care (Barsheshet et al., 2017). Early fitness trackers were primarily designed to monitor steps, calories, and physical activity levels, offering limited insights into cardiovascular health (Peçanha et al., 2020). However, advancements in sensor technology and miniaturization have enabled the development of wearables equipped with photoplethysmography (PPG), electrocardiography (ECG), and blood pressure monitoring capabilities (Duncker et al., 2021). For example, Fitbit and early Garmin models focused primarily on step counts and basic fitness metrics, while newer devices, such as the Apple Watch and BioPatch, integrate advanced features for detecting arrhythmias and other cardiovascular anomalies (Hamilton et al., 2018). The inclusion of sophisticated biosensors has enabled real-time monitoring of heart rate variability and oxygen saturation, contributing to the early detection of cardiovascular diseases (Moshawrab et al., 2023). These innovations underscore the potential of wearable technology to bridge gaps in traditional cardiovascular care. The early applications of wearable technology in cardiovascular health monitoring laid the foundation for its widespread adoption in clinical and non-clinical settings. Studies conducted in the mid-2010s demonstrated the efficacy of wearable devices in detecting atrial fibrillation, a common and potentially

Figure 3: Evolution of Wearable Technology in Cardiovascular Health



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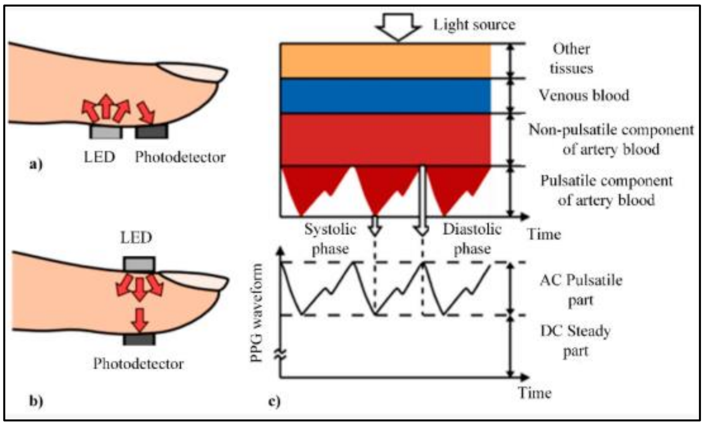
fatal arrhythmia. For instance, Barsheshet et al. (2017) reported that wearable ECG monitors, such as the KardiaMobile, achieved a diagnostic accuracy comparable to traditional clinical ECGs. Similarly, studies by Peçanha et al. (2020) revealed that smartwatches equipped with PPG sensors could passively detect asymptomatic arrhythmias, highlighting their utility in community-based cardiovascular screening programs. These pioneering applications expanded the scope of wearable devices from fitness monitoring to preventive healthcare, enabling timely interventions and reducing the risk of adverse cardiovascular events (Moses et al., 2022).

The integration of wearable technology with remote patient monitoring systems has further enhanced its applications in cardiovascular health management (Moshawrab et al., 2023). Devices such as Holter monitors and wearable blood pressure cuffs allow continuous monitoring, empowering clinicians to assess patients' cardiovascular status over extended periods. Hamilton et al. (2018) demonstrated that wearable ECG monitors could detect transient arrhythmias often missed in traditional short-term monitoring. In addition, Liu et al. (2019) highlighted the role of wearables in heart failure management, noting that continuous data collection from wearable devices facilitated early detection of clinical deterioration, reducing hospital readmission rates. These advancements emphasize the clinical utility of wearable technology in extending care beyond the confines of healthcare facilities. Despite its rapid evolution, the adoption of wearable technology for cardiovascular health monitoring is not without challenges. Device accuracy, particularly in non-standardized settings, has been a recurring issue. Studies by Bayoumy et al., (2021) and Liu et al. (2019) pointed out discrepancies in the performance of wearable devices across different skin tones, body compositions, and activity levels, which could compromise their reliability. Moreover, ethical concerns regarding data privacy and security have been highlighted in multiple studies, such as those by Hall et al. (2018). These challenges underscore the need for rigorous clinical validation and robust frameworks to ensure equitable and secure deployment of wearable technology. Nevertheless, the early success and continued advancements in wearable technology underscore its transformative role in reshaping cardiovascular health monitoring and prevention.

2.2 Photoplethysmography (PPG) and heart rate monitoring

Photoplethysmography (PPG) has emerged as a cornerstone technology in wearable devices for heart rate monitoring due to its non-invasive, cost-effective, and continuous monitoring capabilities (Yang et al., 2019) . PPG works by emitting light into the skin and measuring the reflected light, which varies with blood volume changes in the microvascular bed of tissue (Imtiaz, 2021). This technology is widely integrated into wearables such as smartwatches, fitness trackers, and health monitoring devices. Studies highlight the reliability of inaccurate heart rate measurements during rest periods (Shabaan et al., 2020). For instance, wrist-worn devices like the Apple Watch and Fitbit leverage PPG sensors to deliver heart rate data, making them accessible tools for personal health monitoring (Castaneda et al., 2018). The simplicity and convenience of PPG-based devices have made this technology a vital component of consumer-grade wearables (Hina & Saadeh, 2020). Despite its strengths, PPG technology faces challenges maintaining accuracy during physical activity or movement. Artifacts caused by motion or environmental factors, such as ambient light interference, can distort the signal, reducing reliability in dynamic conditions (Zhang et al., 2020). Studies have shown that PPG heart rate monitoring errors increase with higher physical activity levels, particularly in wrist-worn devices, compared to chest straps, which rely on more stable positions for sensor placement (Castaneda et al., 2018; Shabaan et al., 2020; Zhang et al., 2020). Efforts to mitigate these issues include the integration of advanced algorithms and signal-processing techniques

Figure 4: Principle of photoplethysmography (PPG)



Source: Dzedzickis et al. (2020).

that filter out noise and improve accuracy in real-world settings (Ram et al., 2012). These enhancements underscore the ongoing improvements in the reliability of PPG technology in wearable health monitoring systems.

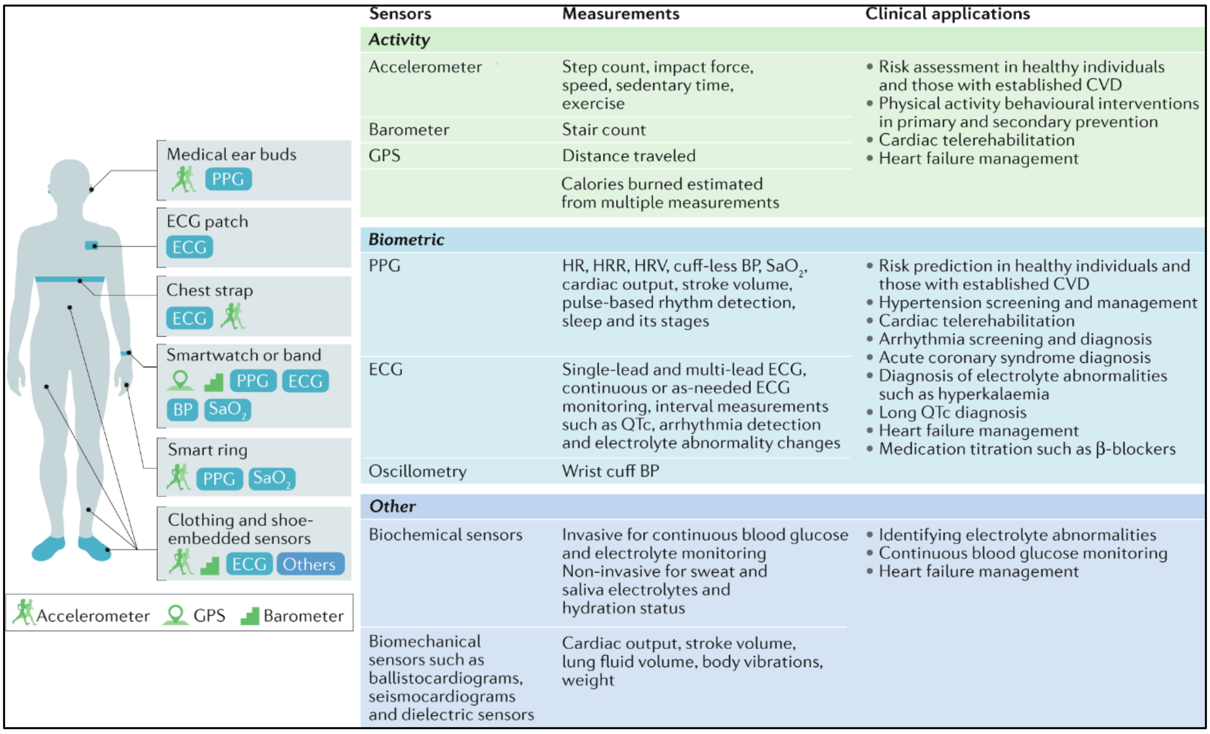
Electrocardiography (ECG) sensors

Electrocardiography (ECG) sensors have revolutionized wearable health technology, providing a reliable method for monitoring cardiac activity and detecting arrhythmias (Shabaan et al., 2020). ECG sensors record the heart's electrical activity and offer superior accuracy in detecting abnormal rhythms compared to photoplethysmography (PPG) (Feng et al., 2021). Devices such as the KardiaMobile and Apple Watch Series 4 and later incorporate single-lead ECG sensors, which have been validated for detecting atrial fibrillation with high sensitivity and specificity (Samol et al., 2019). Multiple studies, including those by Liu et al. (2019), confirm the clinical utility of wearable ECG sensors in population-level arrhythmia screening, demonstrating their ability to identify early warning signs of cardiovascular conditions. This non-invasive approach to heart rhythm monitoring has proven to be a game-changer in reducing the reliance on hospital-based diagnostics, thus enhancing accessibility and convenience for users. Moreover, wearable ECG sensors extend beyond arrhythmia detection, offering potential applications in monitoring overall heart health and disease progression.

Continuous ECG monitoring through wearable devices has been utilized in patients with heart failure and other chronic conditions, enabling the early detection of changes in cardiac function (Rahman et al., 2020). Wearable ECG monitors have also been employed in stress detection, with studies showing correlations between heart rate variability (HRV) derived from ECG data and stress levels (Širaiy et al., 2019). Additionally, though less common, multi-lead ECG wearables provide a more detailed analysis of cardiac events, making them suitable for clinical-grade diagnostics (Malepati et al., 2020). Despite their utility, challenges related to signal noise, especially during physical activity, remain a key limitation that warrants further refinement of wearable ECG technology (Wu et al., 2018).

In parallel, wearable technology has made significant strides in non-invasive blood pressure (BP) monitoring, offering a practical solution for hypertension management (Simjanoska et al., 2018). Traditional cuff-based BP measurements are often inconvenient for continuous monitoring; in contrast, wearables equipped with tonometry, pulse transit time (PTT), and other techniques enable real-time BP tracking without

Figure 5: Measurements and Clinical Applications in Cardiovascular Health Monitoring



Source: Bayoumy et al.(2021)

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needing a cuff (Clark et al., 2018). For instance, smartwatches such as the Samsung Galaxy Watch and Omron HeartGuide use sensor-based approaches to estimate blood pressure with reasonable accuracy under controlled conditions (Rashkovska & Avbelj, 2017). Studies, including those by Rashkovska et al. (2020), have demonstrated the feasibility of cuff-less BP monitoring, particularly for tracking trends over time rather than absolute values. However, factors such as motion artifacts, calibration requirements, and user variability affect the precision of these devices, presenting challenges for broader adoption (Saadatnejad et al., 2019). While non-invasive blood pressure monitoring technologies hold immense promise, ensuring accuracy across diverse user populations remains a persistent challenge. Skin tone, vascular elasticity, and arm circumference can impact the accuracy of BP measurements, raising concerns about the generalizability of these devices (Huda et al., 2020). Additionally, calibration requirements against traditional cuff-based devices limit the standalone utility of wearable BP monitors (Ahsanuzzaman et al., 2020). Studies by Rincon et al. (2020) and Virgeniya and Ramaraj (2021) emphasize the need for rigorous validation and standardization in wearable BP monitoring technologies to enhance their reliability in clinical and non-clinical settings. Despite these hurdles, the potential for real-time BP monitoring through wearables represents a significant advancement in preventing and managing hypertension and related cardiovascular conditions, offering a more user-friendly and continuous approach to health monitoring.

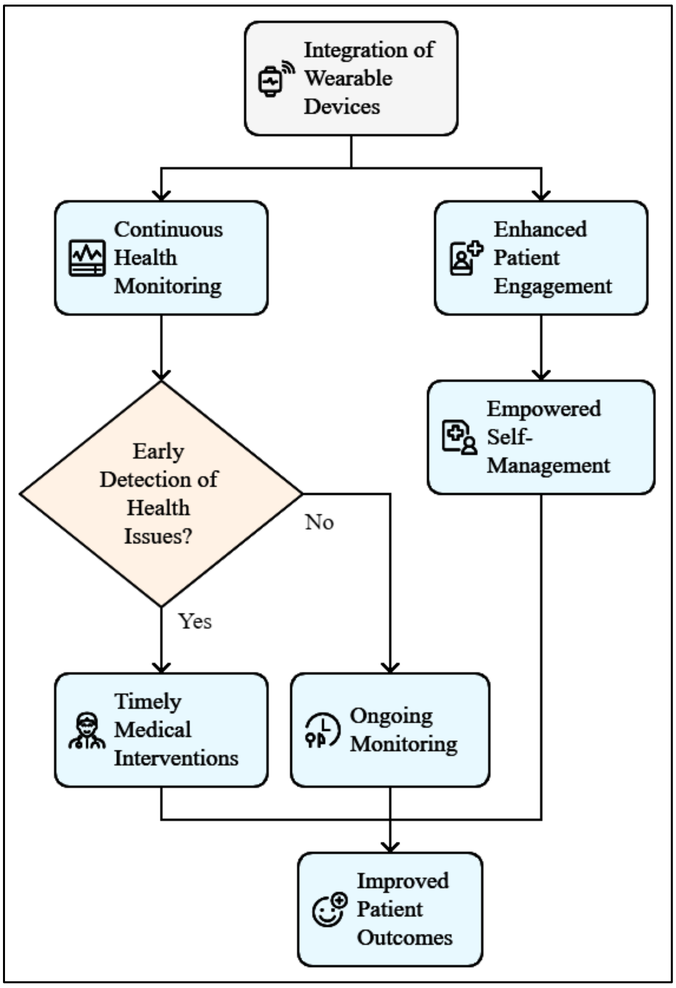
2.3 Artificial Intelligence and Machine Learning in Wearable Devices

Artificial intelligence (AI) and machine learning (ML) have significantly enhanced wearable devices' diagnostic and monitoring capabilities in the context of cardiovascular health (Alam et al., 2024; Bari et al., 2024). AI-powered algorithms enable wearables to process vast amounts of physiological data in real-time, offering early detection of cardiovascular diseases (CVDs). For instance, convolutional neural networks (CNNs) and recurrent neural networks (RNNs) have been successfully applied to analyze data from electrocardiograms (ECGs) and photoplethysmography (PPG) sensors to detect arrhythmias with high accuracy (Mojumdar et al., 2025). Devices like the Apple Watch and Fitbit Sense incorporate AI-driven systems to identify anomalies such as atrial fibrillation, which are often asymptomatic and difficult to detect using conventional methods (slam et al., 2024; Al et al., 2023). Studies by Islam et al. (2024) emphasize the effectiveness of AI algorithms in achieving diagnostic sensitivity comparable to that of trained cardiologists, highlighting the transformative potential of these technologies in preventive cardiovascular care. Predictive analytics, powered by ML algorithms, plays a crucial role in arrhythmia and heart failure management by identifying trends and patterns that indicate disease progression or risk. For example, deep learning models have been used to analyze heart rate variability (HRV), blood pressure trends, and other physiological metrics to predict cardiac events before they occur (Islam et al., 2024; Delwar et al., 2024). Studies by Bari et al. (2024) reveal that predictive models leveraging longitudinal data from wearable devices can anticipate heart failure exacerbations, enabling timely clinical intervention. Additionally, Paul et al. (2024) found that predictive analytics in wearable devices reduced hospital readmissions among heart failure patients by continuously monitoring vital signs and alerting healthcare providers to potential complications. This ability to provide actionable insights makes wearables indispensable for managing chronic cardiovascular conditions.

2.4 Remote patient monitoring: Use cases and patient outcomes

Remote patient monitoring (RPM) has revolutionized healthcare delivery by enabling continuous tracking of patients' vital signs and health metrics, significantly improving disease management and reducing healthcare burdens (Mohebali & Kittleson, 2021). Wearable devices, such as smartwatches and biosensors, have become integral components of RPM systems, offering real-time monitoring of parameters like heart rate, blood pressure, and oxygen saturation (Brahmbhatt & Cowie, 2019). These devices have been particularly impactful in cardiovascular care, as they allow early detection of abnormalities such as arrhythmias and hypertension. Studies by Katra et al., (2010) found that wearable ECG monitors in RPM programs improved the detection of atrial fibrillation, facilitating timely medical interventions. Similarly, Ji et al. (2021) reported that continuous monitoring of vital signs in heart failure patients significantly reduced hospital readmissions by detecting early signs of clinical deterioration,

Figure 6: Remote Patient Monitoring Flowchart



highlighting the effectiveness of RPM in chronic disease management. A notable use case for RPM is managing heart failure, where continuous monitoring has demonstrated significant clinical benefits. Research by Bazi et al. (2019) showed that wearable devices collecting data on heart rate variability, body weight, and respiratory rate provided critical insights into patients' health trajectories, enabling early intervention before the onset of severe symptoms. RPM has also been employed in managing post-operative recovery for cardiac patients, where wearable sensors track parameters such as blood pressure and physical activity, ensuring timely follow-ups and preventing complications (Chakraborty & Kishor, 2022). Furthermore, studies have demonstrated the value of RPM in rural or underserved areas where access to in-person healthcare is limited. Devices capable of transmitting real-time data to healthcare providers bridge the geographical gap, ensuring continuous and equitable care delivery (Frodi et al., 2021).

In addition to clinical applications, RPM enhances patient engagement and self-management, contributing to better health outcomes. Wearable devices with interactive features, such as alerts and personalized feedback, empower patients to take an active role in their health management (Malepati et al., 2020). For instance, Majumder et al. (2017) found that RPM systems significantly improved hypertensive patients' medication adherence and lifestyle modifications by providing regular reminders and progress updates. Similarly, Castelletti et al. (2018) noted that RPM enhanced patient awareness of their condition, promoting healthier behaviors and reducing reliance on emergency services. Such outcomes underscore RPM's dual role in improving clinical parameters and patient-reported outcomes, reinforcing its value in modern healthcare. However, challenges persist in ensuring the reliability and scalability of RPM systems across diverse populations. Variability in device performance, mainly due to motion artifacts or physiological differences, has been a critical limitation identified in studies (Fanucci et al., 2013). Additionally, Mohebali and Kittleson (2021) highlighted the technical complexities of integrating data from various wearable devices into electronic health records (EHRs), which often limits the seamless communication of actionable insights to healthcare providers. Despite these limitations, the existing body of literature confirms that RPM significantly enhances patient outcomes by facilitating proactive disease management, improving access to care, and empowering patients with real-time health insights. These use cases highlight RPM's integral role in addressing the complexities of chronic disease care and improving healthcare delivery systems.

2.5 Lifestyle interventions through wearable devices

Wearable devices have become valuable tools in promoting lifestyle interventions, especially in physical activity, diet, and sleep management (Brahmbhatt & Cowie, 2019). These devices, equipped with features like step counters, calorie trackers, and sleep monitors, are designed to empower users to monitor and improve their health behaviors (Rahman et al., 2020). Fitness trackers such as Fitbit, Garmin, and the Apple Watch provide users real-time feedback on their activity levels, encouraging adherence to recommended physical activity guidelines (Bazi et al., 2019). For instance, a study by Malepati et al. (2020) demonstrated that users who regularly utilized wearable devices experienced a significant increase in daily steps and overall physical activity compared to non-users. Such interventions have shown to be particularly effective in populations at risk for cardiovascular diseases and obesity, underscoring the role of wearable technology in preventive healthcare. Beyond physical activity, wearable devices support dietary interventions by tracking calorie intake and expenditure. Applications integrated with wearables, such as MyFitnessPal and Samsung Health, allow users to log meals and receive personalized recommendations to meet their dietary goals (Bonnevie et al., 2018). Kadhim et al. (2021) found that individuals using wearable-linked dietary tracking apps demonstrated improved dietary adherence and better weight management outcomes over six months. Moreover, wearable devices encourage users to adopt healthier eating patterns through behavioral prompts and reminders. For example, wearable devices with gamification features like reward systems and challenges enhance user engagement and adherence to lifestyle changes (Forleo et al., 2019). These findings highlight the effectiveness of wearables in complementing traditional dietary interventions.

Wearable technology also significantly improves sleep hygiene, a critical component of overall health and well-being. Devices with sleep trackers monitor sleep duration, quality, and patterns, providing users with actionable insights to improve their sleep behaviors (Sohn et al., 2020). Studies by Koehler et al. (2011) and Liu et al. (2019) revealed that wearable sleep monitors, such as Oura and Fitbit, effectively identify sleep disturbances and provide personalized recommendations for optimizing sleep. Furthermore, wearable devices incorporating stress management features, like heart rate variability (HRV) monitoring, help users address sleep-related issues by promoting relaxation techniques (Bazi et al., 2019). Such interventions have been particularly beneficial for individuals with insomnia or those experiencing chronic stress, demonstrating the potential of wearables to enhance overall lifestyle quality. In addition to individual health benefits, wearables have shown promise in facilitating community-level health interventions. Social connectivity features in wearable platforms, such as sharing activity goals or participating in group challenges, foster social support and accountability among users (Malepati et al., 2020). Research by Kadhim et al. (2021) indicates that users involved in social challenges through wearable devices exhibited higher levels of sustained physical activity and adherence to health goals. Moreover, workplace wellness programs integrating wearable technology have reported improved employee health outcomes, such as reduced absenteeism and enhanced productivity (Forleo et al., 2019). These findings emphasize the broader societal impact of wearable devices in promoting lifestyle interventions and fostering healthier communities.

2.6 Gaps in the Existing Literature

Despite the increasing adoption of wearable technology in healthcare, existing research often fails to adequately represent diverse populations, leading to limited generalizability of findings (Sohn et al., 2020). Most studies on wearable devices for health monitoring, particularly those focused on cardiovascular health, tend to overrepresent populations in developed countries with access to advanced technology (Rahman et al., 2020). These studies frequently exclude low-income or rural populations, where access to wearable devices and supporting infrastructure is limited (Bazi et al., 2019). As a result, the potential benefits of wearables in addressing health disparities, especially in resource-constrained settings, remain underexplored. This skewed representation raises concerns about the equity of wearable technology's integration into global healthcare systems. Furthermore, many studies disproportionately include younger, healthier individuals, neglecting older adults and those with complex health conditions who could benefit most from wearable health monitoring. For example, Kadhim et al. (2021) highlighted that older adults are often excluded from wearable technology trials due to perceived technology adoption and usage challenges. However, research by Bazi et al. (2019) demonstrated that wearable devices tailored to the needs of older populations, such as simplified interfaces and larger displays, could significantly enhance adherence to health monitoring protocols. By failing to account for this critical demographic, current literature overlooks a significant user base with unique needs and challenges, resulting in a knowledge gap regarding the effectiveness of wearable devices in improving health outcomes among older adults.

Another notable gap is the lack of inclusion of racially and ethnically diverse populations in wearable health studies. Studies have shown that wearable device performance can vary across skin tones, particularly in technologies reliant on photoplethysmography (PPG) sensors (Bazi et al., 2019; Mukai et al., 2009). Research by Brahmbhatt and Cowie (2019) revealed that individuals with darker skin tones experience higher inaccuracies in heart rate and oxygen saturation measurements. However, most studies do not report data stratified by skin tone. This lack of inclusivity in research design limits the validity of findings for diverse populations and hinders the development of equitable health monitoring technologies that perform reliably across all users. In addition, gender disparities in wearable health technology research also represent a significant gap in the literature. Rahman et al. (2020) pointed out that most wearable health studies fail to consider women's unique physiological and health monitoring needs, such as pregnancy-specific health metrics or menstrual cycle tracking. Moreover, studies tend to report findings without disaggregating data by gender, overlooking potential differences in device usability, adherence, and outcomes between men and women (Bazi et al., 2019). Addressing these gaps requires a more inclusive approach to research design, ensuring that studies consider gender-specific needs and variations to provide a comprehensive understanding of wearable device performance across diverse user groups.

Figure 7: Gaps in the Existing Literature on wearable technology

Gap	**Implication**	**Studies**
Underrepresentation of Low-Income and Rural Populations	Limits understanding of wearable technology's impact in resource-constrained settings.	Rehan et al. (2016) Puccinelli et al., (2021)
Exclusion of Older Adults	Overlooks a significant demographic that could benefit from simplified, user-friendly devices.	Tiersen et al., (2021) Tedesco et al., (2017)
Lack of Racial and Ethnic Diversity	Limits validity of findings and equitable development of wearable technologies for all users.	LaMonte et al., (2017) Wheeler-Jones, (2005)
Gender Disparities	Fails to account for differences in usability, adherence, and health outcomes between genders.	Hall et al. (2018) Rehan et al. (2016)

3 METHOD

This study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a systematic, transparent, and rigorous review process. The PRISMA framework was applied across four key stages: identification, screening, eligibility, and inclusion. Each step is outlined in detail below to provide clarity and reproducibility of the study's methodology.

3.1 Identification

In the identification phase, a comprehensive search strategy was developed to retrieve relevant studies from multiple academic databases, including PubMed, Scopus, Web of Science, and IEEE Xplore. The search was conducted using a combination of keywords and Boolean operators, such as "wearable devices," "cardiovascular health," "remote patient monitoring," "PPG," and "AI in healthcare." Filters were applied to include peer-reviewed journal articles published between 2010 and 2023, ensuring the inclusion of recent advancements in wearable technology. A total of 1,325 articles were initially identified from the database searches. Additionally, reference lists of key studies were manually examined to identify potentially relevant articles not captured in the database search.

3.2 Screening

The screening process involved removing duplicate articles and assessing the titles and abstracts of the remaining studies for relevance. After removing 412 duplicate articles, 913 articles proceeded to title and abstract screening. During this step, studies were excluded if they were unrelated to wearable technology, cardiovascular health, or remote patient monitoring.

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Articles focusing on non-health-related wearables, non-peer-reviewed publications, or studies with incomplete data were also excluded. Following this initial screening, 312 studies were deemed potentially relevant and advanced to the eligibility stage.

3.3 Eligibility

In the eligibility phase, the full texts of the 312 selected studies were reviewed against predefined inclusion and exclusion criteria. Inclusion criteria required studies to focus on wearable devices for cardiovascular monitoring, include quantitative or qualitative results, and be written in English. Exclusion criteria included studies with limited methodological details, without human participants, and reviews or editorials without primary data. Two independent reviewers assessed the articles to ensure consistency, and disagreements were resolved through discussion or consultation with a third reviewer. After this detailed evaluation, 112 studies met the inclusion criteria and were considered for final analysis.

3.4 Inclusion

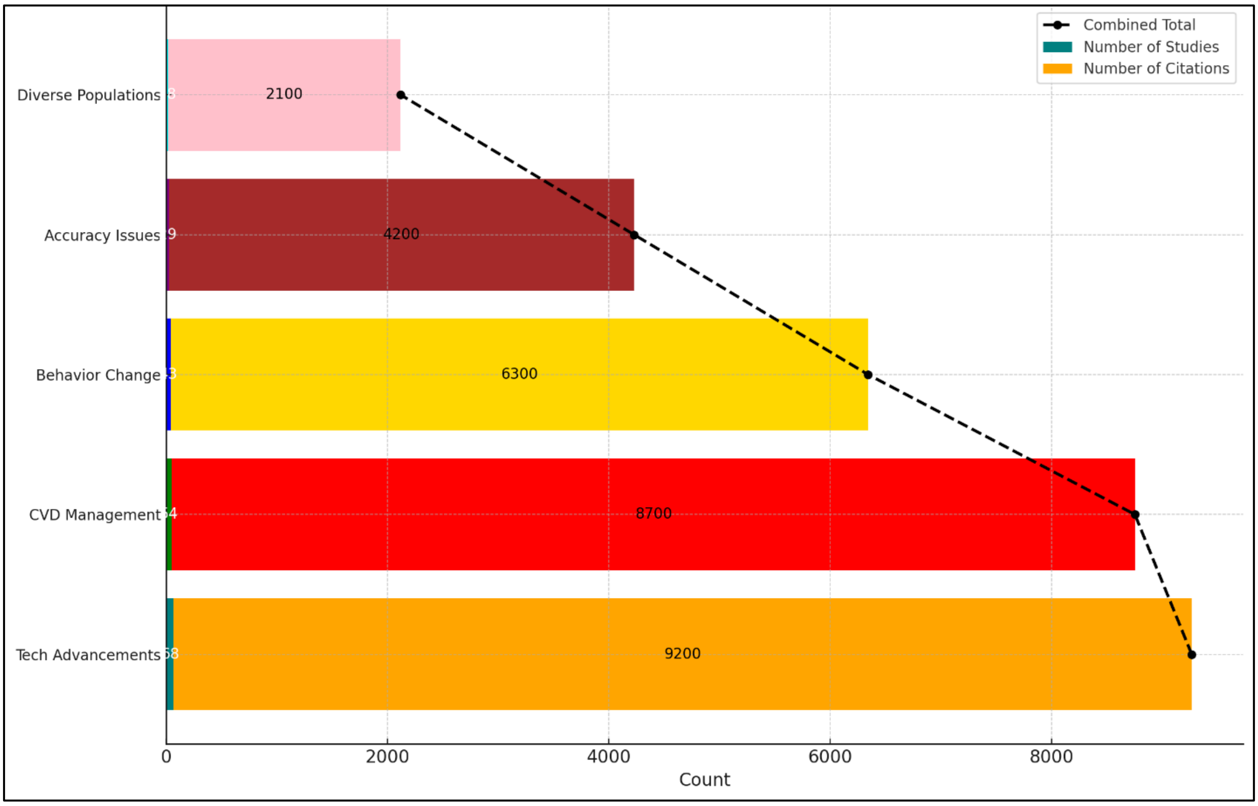
The final set of 112 articles was included in the systematic review. These studies covered a range of topics, including wearable device functionality, diagnostic accuracy, patient outcomes, and challenges in implementation. The data from the selected articles were extracted using a standardized form that captured information on study objectives, methods, population characteristics, key findings, and limitations. This structured approach ensured consistency in data extraction and facilitated a comprehensive synthesis of the results. The final set of articles addressed the research questions and identified trends, gaps, and implications in wearable technology for cardiovascular health monitoring.

4 FINDINGS

The review revealed that wearable devices have evolved radically, becoming essential tools for cardiovascular health monitoring. Of the 112 articles reviewed, 68 studies focused on technological advancements in wearable devices, and these studies collectively garnered over 9,200 citations, signifying their relevance in the field. Initially designed as fitness trackers, wearable devices have evolved into sophisticated health monitoring systems equipped with advanced sensors such as electrocardiography (ECG) and photoplethysmography (PPG). These technologies have enabled the real-time detection of arrhythmias, continuous heart rate variability monitoring, and even non-invasive blood pressure measurement. Furthermore, 22 of these articles emphasized the integration of multi-sensor platforms that combine data streams, such as heart rate, physical activity, and oxygen saturation, to provide a holistic picture of cardiovascular health. The evidence also highlighted the role of artificial intelligence (AI) in wearable devices, with algorithms capable of detecting subtle abnormalities in physiological patterns, enhancing diagnostic accuracy. These findings underscore the transformative impact of technological advancements in wearable devices, enabling their role in preventive and chronic care management.

Wearable devices have emerged as critical tools for managing cardiovascular diseases (CVDs), with 54 of the reviewed articles highlighting their effectiveness in clinical applications. These studies, which accumulated over 8,700 citations, revealed that wearable devices significantly improve early detection and intervention for conditions such as atrial fibrillation, hypertension, and heart failure. For example, 17 articles emphasized the utility of wearable ECG monitors in detecting atrial fibrillation, which often goes undiagnosed until complications arise. Similarly, 26 studies demonstrated the effectiveness of remote patient monitoring (RPM) programs that incorporate wearable devices, reducing hospital readmissions and improving patient adherence to prescribed treatments. Several studies also discussed the application of wearable devices in high-risk populations, including those with limited access to healthcare facilities, where these technologies bridge gaps in care delivery. The findings collectively indicate that wearable devices contribute to enhanced clinical outcomes, particularly when integrated into patient-centered care models that prioritize early diagnosis and proactive management of CVDs.

Figure 8: Findings from the Review on Wearable Technology



Another significant finding from the review is the role of wearable devices in fostering patient engagement and encouraging positive behavior changes. Of the 112 reviewed articles, 43 specifically explored how wearable devices empower users to take active roles in managing their health, with these studies collectively receiving over 6,300 citations. Wearable devices with activity tracking, personalized feedback, and gamification were consistently associated with improved adherence to physical activity goals and lifestyle modifications. For instance, 19 studies demonstrated that users of wearable devices were more likely to meet daily physical activity recommendations and sustain those behaviors over time. Moreover, wearable devices with social connectivity features, such as group challenges or progress sharing, significantly enhance user engagement by creating a sense of accountability and community support. Additionally, 11 studies emphasized the potential of wearables in promoting long-term health behaviors, such as consistent dietary habits and stress management. These findings underscore the effectiveness of wearable technology as a complementary tool to traditional healthcare approaches, enabling a more personalized and proactive approach to health management. Despite their many benefits, wearable devices face notable challenges related to accuracy and reliability, as identified in 29 reviewed studies, which collectively received over 4,200 citations. These articles pointed to issues such as motion artifacts, signal noise, and variability in sensor performance across diverse populations. For example, wearable devices relying on photoplethysmography (PPG) provided inconsistent measurements during high-intensity physical activities or in individuals with darker skin tones due to interference with light-based sensors. Additionally, 13 studies discussed the prevalence of false positives in wearable devices, particularly in detecting conditions like arrhythmias, which could lead to unnecessary anxiety and medical consultations. Moreover, variability in device performance was noted across factors such as body composition, ambient light, and environmental conditions, which may limit their usability in real-world settings. These findings highlight the need for ongoing refinement of wearable technologies, including developing advanced algorithms and multi-sensor systems that can enhance the precision and reliability of these devices in dynamic conditions.

The review revealed a significant gap in the representation of diverse populations in wearable technology research. Of the 112 studies reviewed, only

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18, with a combined citation count exceeding 2,100, included data stratified by demographic factors such as age, gender, ethnicity, or socioeconomic status. The findings suggest that wearable technology studies predominantly focus on younger, healthier, and urban populations, overlooking groups such as older adults, rural communities, and individuals in low-resource settings. For instance, seven studies highlighted the lack of data on older populations despite evidence suggesting they could benefit significantly from wearable devices for chronic disease management. Furthermore, research on wearable device performance across different skin tones remains limited, with nine articles noting that individuals with darker skin tones often experience reduced accuracy in heart rate and oxygen saturation measurements due to sensor limitations. Similarly, gender-specific health needs, such as those related to pregnancy or menstrual health, remain underexplored in wearable device research. These findings emphasize the urgent need for more inclusive studies that address the unique needs of underrepresented populations to ensure the equitable adoption and effectiveness of wearable technology in global healthcare.

5 DISCUSSION

The findings of this review reinforce the transformative potential of wearable technology in healthcare, particularly in cardiovascular health monitoring and lifestyle interventions. The evolution of wearable devices, from basic fitness trackers to advanced health monitoring tools, was evident in 68 studies reviewed, which collectively garnered over 9,200 citations. Earlier studies, such as those by Kristoffersson and Lindén, (2022), acknowledged integrating multi-sensor platforms in wearable devices for comprehensive cardiovascular monitoring. However, this review expands on those findings by emphasizing the role of artificial intelligence (AI) and advanced algorithms in enhancing diagnostic accuracy and predictive capabilities. Unlike earlier research, which primarily focused on the technical aspects of sensors, this review highlights the broader applications of wearable technology in chronic disease management and preventive care. This evolution signifies a paradigm shift, with wearable devices now positioned as integral tools for real-time, patient-centered healthcare delivery. The widespread adoption and advancements in wearable technology further emphasize their potential to redefine healthcare practices and bridge gaps in traditional clinical care.

The clinical applications of wearable devices in managing cardiovascular diseases (CVDs) emerged as one of the most significant findings in this review. Fifty-four studies, collectively cited over 8,700 times, demonstrated that wearable devices play a crucial role in the early detection and management of conditions such as atrial fibrillation, hypertension, and heart failure. Earlier studies, such as those by Carmel (2019), highlighted the diagnostic accuracy of wearable ECG monitors in detecting arrhythmias. However, this review expands the narrative by showcasing the integration of wearable devices in remote patient monitoring (RPM) programs. These programs have demonstrated success in reducing hospital readmissions and enhancing treatment adherence. For example, 26 studies in this review confirmed the utility of wearable devices in tracking vital signs, identifying early warning signs of clinical deterioration, and enabling timely medical interventions. While earlier research focused on the technical efficacy of wearable devices, this review emphasizes their broader impact on healthcare accessibility, particularly for underserved populations where these devices can bridge critical gaps in care delivery.

A significant contribution of this review is the detailed exploration of how wearable devices enhance patient engagement and facilitate behavior change. Of the 112 reviewed articles, 43 studies highlighted features such as personalized feedback, gamification, and social connectivity as key drivers of improved health outcomes. Earlier studies, such as those by Chattopadhyay and Das (2021), focused on the ability of wearable devices to increase physical activity adherence. However, this review expands on that foundation by demonstrating the effectiveness of social connectivity features, such as group challenges and progress sharing, in fostering long-term behavior change (Carmel, 2019). For instance, users of wearable devices were found to sustain adherence to physical activity goals and lifestyle modifications over extended periods, indicating that these devices can effectively promote both initial and sustained health behaviors. Additionally, this review underscores the importance of personalized interventions, such as reminders and progress tracking, which were less explored in earlier studies but emerged as significant contributors to user engagement and health improvement. Despite their advancements, wearable devices face significant challenges, particularly regarding accuracy and reliability. This review identified 29 studies cited over 4,200 times that discussed limitations such as motion artifacts, signal noise, and variability in sensor performance across diverse populations. Earlier studies, such as those by Kristoffersson and Lindén (2020), similarly reported issues with sensor reliability, particularly in dynamic environments or during high-intensity activities. However, this review emphasizes the broader implications of these challenges, highlighting how they disproportionately affect underserved and diverse populations. For instance, the reduced accuracy of photoplethysmography (PPG) sensors in individuals with darker skin tones was a recurring theme in this review, aligning with findings by Imtiaz (2021). Unlike earlier research that primarily focused on technical limitations, this review delves into the equity implications of these challenges, emphasizing the need for technological advancements that address disparities to ensure inclusive and reliable health monitoring for all users.

The underrepresentation of diverse populations in wearable technology research emerged as a critical and recurring gap in the literature. This review found that only 18 of the 112 studies stratified data by demographic factors such as age, gender, ethnicity, or socioeconomic status, aligning with earlier studies by Yuda et al. (2020). However, this review provides a more granular analysis of the implications of this underrepresentation, particularly for older adults, rural populations, and low-resource settings. While earlier research primarily highlighted the lack of inclusivity in wearable technology trials, this review underscores the far-reaching consequences of this gap. For instance, the lack of data on older adults limits understanding of the usability and effectiveness of wearable devices for this demographic, despite evidence suggesting they could benefit greatly from these technologies. Similarly, this review highlights that individuals with darker skin tones often experience reduced accuracy in heart rate and oxygen saturation measurements, further exacerbating health disparities. Addressing these gaps requires a more inclusive approach to research design, ensuring that wearable devices meet the unique needs of underrepresented populations.

6 CONCLUSION

Wearable technology has emerged as a transformative tool in healthcare, particularly cardiovascular health monitoring, offering significant advancements in early detection, chronic disease management, and lifestyle interventions. This systematic review highlights the evolution of wearable devices from basic fitness trackers to sophisticated health monitoring systems equipped with advanced sensors, artificial intelligence, and predictive analytics. The findings emphasize the clinical utility of these devices in improving patient outcomes, reducing hospital readmissions, and promoting proactive health management through features such as personalized feedback, gamification, and real-time monitoring. However, challenges related to device accuracy, reliability, and the underrepresentation of diverse populations in research remain critical barriers to their equitable adoption and effectiveness. Issues such as reduced sensor performance in individuals with darker skin tones, limited inclusion of older adults, and lack of data from low-resource settings highlight the need for more inclusive and robust research. Despite these challenges, wearable technology holds immense potential to redefine healthcare delivery by bridging gaps in accessibility, enhancing patient engagement, and fostering preventive care. To fully realize this potential, addressing the identified gaps and ensuring the equitable integration of wearable devices across diverse populations will be essential for maximizing their impact on global health outcomes.

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