VER
Vascular & Endovascular Review

Emerging Applications of Wearable Devices and Remote Monitoring Technologies In Cardiovascular Disease Prevention and Management: A Systematic Review

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ABSTRACT

Background: CVDs are the leading cause of mortality worldwide and they have been a burden to healthcare systems in terms of late diagnosis and lack of long-term monitoring interventions. New technologies in wearable technologies such as smartwatches, ECG patches, cuffless blood pressure monitoring, and heart-failure remote-sensing platforms have also brought new possibilities of continuous and real-time cardiovascular monitoring. Improved with the help of artificial intelligence (AI) and machine-learning-based algorithms, the devices will provide a more accurate interpretation of physiological patterns and can enhance the field of early detection, risk stratification, and clinical management. This system review is an inquiry into the emerging evidence of wearable and remote monitoring in the prevention and management of major cardiovascular conditions.

Objectives: This review aims to assess the quality of: diagnosis, clinical utility, and methodology of modern wearable devices and remote monitoring technologies to determine their use in atrial fibrillation, hypertension, heart failure, and other cardiovascular diseases.

Methods: The systematized search was performed according to the principles of PRISMA 2020 in relation to eight large databases between January 2010 and February 2025. The studies had to meet the following criteria: they had to evaluate wearable or remote monitoring technologies and provide cardiovascular-related diagnostic or clinical outcomes. Data that were extracted comprised sample features, the type of device, performance indicators, AI implementation, and validation methods. The risk of bias was evaluated with the help of ROBINS-I and QUADAS-2. Narrative and quantitative syntheses were conducted and pooled accuracy estimates, forest plots, as well as, correlation analyses to interpret device performance and methodological patterns were used.

Results: There were 58,740 participants that were included in 42 studies. The analysis has indicated that wearable devices possess great diagnostic potential, especially the devices that detect atrial fibrillation by the use of PPG- and ECG-based technologies, which had high sensitivity and specificity. Cuffless blood pressure devices demonstrated average accuracy, whereas heart-failure remote devices were always able to decrease hospitalization or give an early warning of decompensation. Signal processing with AI added value helped in enhancing the quality of diagnostic accuracy in several types of devices. There were also methodological weaknesses, though, since a smaller portion of the studies were external validation, and the problem of calibration of the devices was rather common. Correlation tests showed that the greater the sample size and the number of multi-sensor devices a higher the diagnostic accuracy and external validity.

Conclusion: The use of wearable devices and remote monitoring technologies has a lot of potential to revolutionize the process of cardiovascular disease detection and continuous management. Smartwatches, ECG patches and heart-failure monitoring systems have already shown clinically meaningful consequences, and the use of AI is still continuing to expand the level of accuracy or predictive ability of the devices. However, discrepancies in validation procedures, calibration difficulties of blood pressure in equipments, and study-to-study heterogeneity means that more standardization and stringent clinical testing is required, before a wide clinical integration is attained. To achieve the full potential of wearable cardiovascular technologies in preventative and personalized medicine, it will be crucial to persist in research in multi-sensor systems, transparent AI models, and limited clinical trials on a large scale.

KEYWORDS: Wearable; remote monitoring; heart diseases; atrial fibrillation; hypertension; heart failure; artificial intelligence; photoplethysmography; ECG patches; digital health.

How to Cite: Abdullah Al Kium, Shakila Azad, Md Mahamudul Hasan, Aktaruzzaman Azad, Md Mahamudul Islam, Momtaz Akter Mitu, Mohammed Tanjim Uddin Chowdhury, Mehedi Hasan Pritom, (2024) Emerging Applications of Wearable Devices and Remote Monitoring Technologies In Cardiovascular Disease Prevention and Management: A Systematic Review, Vascular and Endovascular Review, Vol.7, No.1, 67-79

INTRODUCTION

Cardiovascular diseases (CVDs) have become the most prevalent health issue across the globe and cause over 18 million deaths every year and a massive financial burden on health care systems, economic, and social spheres. The constant increase in hypertension, atrial fibrillation, heart failure, and metabolic disorders proves the high importance of early diagnosis, regular examination and immediate intervention. The conventional methods of cardiovascular monitoring, which are mostly reliant on blood pressure measurements in clinics, occasionally taken ECG recordings, or on symptoms-related visits, fail to detect intermittent arrhythmias, initial signs of decompensation, or changes in physiological parameters. This has led to numerous high-risk people being diagnosed or untreated at advanced stages of the disease [1, 2]. A paradigm shift in the present-day cardiovascular medicine is the change of episodic assessment that is based on clinic visits to continuous observation of real-life physiological activity.

In the last 10 years, the wearable technologies have advanced at a very fast rate, changing the rudimentary step counters into complex physiological sensor with photoplethysmography (PPG), single and multi-lead electrocardiography (ECG), accelerator, gyroscopes, bioimpedance modules, and optical blood pressure estimation devices. High-resolution cardiovascular measurements can now be captured constantly, passively, and noninvasively by Smartwatches, ECG patches, smart rings and cuffless blood pressure devices [3, 4]. It has been seen that these devices have increasing capabilities of early detection of atrial fibrillation, continuous estimation of blood pressure, detection of heart-failure decompensation, and the provision of personalized risk scores depending on the activity, sleep, and heart rate variability (HRV). This has led to enhanced accessibility, portability and affordability, which in turn has further accelerated their use in both clinical and consumer groups, with wearable monitoring as a realistic complement to, and in certain scenarios, even a substitute of, the conventional cardiovascular diagnostics.

One of the most important factors of this technological change is the implementation of artificial intelligence (AI) and machine learning (ML) in wearable signal processing. AI algorithms can improve the quality, interpretability, candidness, and clinical importance of wearable generated data by filtering noise and in motion artifact, discovering subtle physiological patterns, and identifying arrhythmias or hemodynamic conditions with high accuracy. Convolutional and recurrent neural networks based deep learning systems have demonstrated diagnostic results comparable to medical-grade ECG systems on disorders like atrial fibrillation detection. Cuffless blood pressure devices have been used in the management of hypertension to use pulse transit time, pulse morphology and data-driven models to estimate systolic and diastolic blood pressure without periodically inflating the cuff [5, 6]. In the case of heart failure, remote sensors that can be used to measure thoracic impedance, respiratory rate, nocturnal heart rate, body weight, and physical activities have demonstrated potential in warning against decompensation events days or weeks before hospitalization.

The role of digital cardiovascular management has been further expanded to remote monitoring which incorporates wearable data with cloud-based analytics, smartphone platforms, and clinical dashboards. Remote monitoring permits real-time assessment of physiological alterations all the time, medication titration, early intervention, and patient engagement. According to clinical trials and real-life experience, remote monitoring could lead to a decrease of heart failure hospitalization, better blood pressure management and assist with the no-long-term lifestyle change. This changing trend to proactive disease management made possible by technology is in line with the trend in the world to precision medicine, preventive care, and decentralized medical care [7, 8].

Although these developments have been made, there are still major uncertainties. The wearable devices have a wide range of performance depending on the type of device, sensor mode, algorithms and clinical issues. Differences in studies also vary greatly in sample size, the rigor of validation, the rigor of measurement and quality of reporting. A large number of commercially available wearables are not externally validated or calibrated on a clinical grade. Failure to match the accuracy of the devices, especially cuffless blood pressure monitoring and single- sensor arrhythmia detection, is a challenge to their general utility in clinical practice. Moreover, the long-term effects of remote monitoring on such hard clinical outcomes as mortality, hospitalization time, and quality of life are not studied adequately, even though promising effects are observed.

Due to the fast pace of digital health technologies development, the synthesis of the evidence assessing the wearable and remote monitoring technologies to detect and manage cardiovascular diseases and conduct it in a methodologically sound, integrated way is urgently needed. Although past reviews have centered on individual devices or single cardiovascular outcomes, they have never tested the overall effect of the extensive variety of modern wearable technologies and their combined effect on the outcomes of multiple CVDs [9, 10]. This systematic review will attempt to close this gap by summarizing the data of 42 eligible studies, measuring the diagnostic accuracy, clinical outcomes, validation practices, and methodological quality. Through the analysis of trends in various types of devices, including smartwatches, ECG patches, cuffless blood pressure and heart failure sensors, this review aims to offer a synthesized view on the benefits, drawbacks, and future clinical use of wearable technologies in cardiovascular medicine.

The final results of this review will be used to guide the clinicians, researchers, the developers and policymakers of the device to the real life performance and future of wearable cardiovascular technologies. One should understand the evidence environment to guide clinical integration, regulatory mandates, enhanced device design, and design of the next generation AI enhanced cardiovascular monitoring systems [11, 12].

LITERATURE REVIEW

Cardiovascular disease (CVD) is the leading cause of universal mortality that creates an extreme need to apply early diagnosis and further follow-up strategies. The traditional diagnostic measures, such as intermittent ECG monitoring, cuff based in-office blood pressure and symptom based evaluation were employed previously and produced piece meal information on the cardiovascular physiology. The existence of the fact that a considerable percentage of arrhythmias, hypertensive events, and heart failure decompensation events are intermittent or asymptomatic implies they are usually missed under the conventional methods. This diagnostic splitter has caused the shift in attitudes to the development and the placement of nonstop, practically achievable tracking systems [13, 14]. The number of wearable devices capable of measuring a wide spectrum of cardiovascular parameters has increased exponentially in the past decade, and a growing body of evidence is now being conducted to test their degree of reliability, accuracy, and clinical applicability.

Wearable Technologies for Cardiovascular Monitoring: Evolution and Capabilities

The earlier wearable devices only consisted of step count and simple heart rate monitors. Nevertheless, technological progress has resulted in very advanced devices that include photoplethysmography (PPG), multi-lead patches of ECG patch, accelerators, gyroscopes, bioimpedance sensors and AI-based signal processing software. Modern smartwatches like Apple Watch, Fitbit, Samsung Galaxy Watch, and Garmin watches are able to identify abnormal heart rhythm, record variations on the heart rate, give continuous PPG readings, and offer actionable health notifications. Cases Studies have repeatedly demonstrated that contemporary PPG-based wearables are capable of detecting atrial fibrillation (AF) reliably, and that several large-scale studies have shown that the device can have a level of diagnostic performance comparable to clinical-grade monitors [15, 16]. The sensitivity and specificity of randomized trials and population screening program are established to be between 85 and 95 percent in detecting AF, and they should be used in the asymptomatic and high-risk population.

Wearable ECG patches, e.g. the Zio Patch, Bardy CAM, and Holter-inspired multi-day monitors, have become notable because of their capability to record long cardiac rhythms in a high-fidelity manner in 7-14 days. These monitors produce real-time ECG and have been demonstrated to record arrhythmias, such as atrial flutter, ventricular tachycardia, and earlier beats, at much higher rates than conventional 24-hour Holter monitors. According to the literature, the ECG patches offer a better diagnostic yield, patient comfort, and less artifact noise than the previous ambulatory ECG systems. Their adoption in clinical practice has been facilitated by various validation cohorts that show that they have greater than 0.90 AUC values in identifying arrhythmia [17, 18].

Cuffless Blood Pressure Wearables and Hypertension Monitoring

The use of cuffless-based blood pressure (BP) wearables implemented with PPG, pulse transit time (PTT), pulse arrival time (PAT), and machine learning models can be considered one of the most active research directions today. Continuous BP monitoring is one of the capabilities in high demand due to hypertension being a significant modifiable risk factor of CVD. The wrist-based and ring-based cuffless BP monitors have been evaluated in several studies that have shown to have potential results with the mean systolic BP errors generally being within the range of ±5-10 mmHg with proper calibration. These devices have been known to have various challenges like motion artifacts, fluctuating skin tone and calibration drift, but, with the advancements in machine learning, the accuracy of prediction has been improved in diverse populations [19, 20]. The meta-analyses have demonstrated that remote BP monitoring systems, which are the integration of wearables and telehealth platforms, have a significant effect on medication adherence and systolic and diastolic BP levels and facilitate efficient long-term hypertension treatment.

Wearable and Sensor-Based Remote Monitoring for Heart Failure

The monitoring of the heart failure (HF) management has undergone a paradigm shift with remote monitoring of this disorder, where early detection of overload fluid or decompensation is very important in avoiding hospitalization. The existing literature regarding wearable and implantable HF sensors is indicative of quantifiable changes in clinical results. Thoracic impedance, respiratory rate variability, nocturnal heart rate, weight, activity and HRV devices have proven to be predictive of HF decompensations on several occasions. Indicatively, a number of multicenter HF remote-monitoring clinical trials have indicated a 15-25per cent decrease in hospitalization rates with patient use of remote sensors and clinician-dashboards. Even wearables that are not invasive to the body, like patch-based impedance sensors and respiratory trackers that use smart accelerators, have shown moderate to high predictability of impending HF exacerbations days before the clinical manifestation occurs [21, 22].

Interestingly enough, the literature also indicates variability of the performance of the device with certain of the trials indicating tight benefit associations when compliance was low or algorithmic exercises were not in personal calibration. This highlights the need to use machine learning personalization, multi-sensor integration, and regular use that are a significant boost to predictive accuracy. However, the general evidence is remote monitoring being a successful intervention in HF management when a strong clinical support and a high patient engagement are introduced.

Artificial Intelligence and Signal Processing Advances

Wearable devices have now become a part of the AI and machine learning, which enhances signal quality, noise reduction, event detection, and physiological estimation. The literature that assesses AI-enhanced wearable devices establishes better diagnostic precision than devices based on the conventional signal processing algorithms. As an example, deep neural networks that are trained using raw PPG or ECG signals are able to distinguish between noise, motion artifacts, and clinically relevant arrhythmias with a high level of accuracy. It has been found that convolutional neural networks (CNNs) are more effective than rule-based algorithms in detecting AF, and recurrent models are more effective than CNNs in the sensitivity of predicting the HF decompensation. Likewise, cuffless BP estimation machine learning models include waveform morphologies and demographic characteristics, and dynamical variations to improve calibration stability and reach clinically acceptable accuracy [22, 23].

Clinical Integration and Real-World Evidence

The use of wearable cardiovascular technologies in everyday life has grown considerably, and millions of users have created huge volumes of physiological data. The effectiveness of wearable-based screening of AF and hypertension has been confirmed by population-based research, which was conducted in the U.S., Europe, and Asia. A number of studies indicated that clinicians who responded to wearable-generated alerts (e.g., irregular rhythm alerts) were able to accurately diagnose previously unnoticed AF in great numbers of patients [24, 25]. Also, remote-monitoring initiatives that include the use of wearables into post-discharge care pathways have been demonstrated to decrease readmissions, enhance medication titration, and identify complications earlier than conventional care does.

Nevertheless, practical experience also points to such shortcomings as uneven adherence of users, calibration problems with devices, variability of measurements by skin color, and clinician overload of information. It is based on these restrictions that the standardized validation frameworks, parallel reporting standards and regulatory oversight are required to create reliability at a wide range of different populations and within a wide range of clinical settings.

Challenges and Gaps in Current Literature

Although there has been significant improvement, there are a number of challenges, which are listed in the literature.
To begin with, wearable measurements have a high rate of inaccuracy depending on the type of device used and the manufacturer. Cuffless BP monitors still remain skepticized because of dependency on calibration and sensitivity to movement. Second, no long-term and large-scale randomized controlled trials on the long-term effects of wearables on cardiovascular morbidity and mortality exist [26]. The majority of studies indicate short term results or make use of observational design. Third, heterogeneity of study protocols in terms of sensor type, AI algorithms used, types of validation, and definition of the outcome makes meta-analytic pooling and generalization more difficult. Last but not least, privacy, challenges of integrating data, and digital literacy gap is still a challenge to universal adoption, especially in low-resource environments.

Summary of the Literature Landscape

Collectively, the available literature indicates that wearable and remote monitoring technologies have a significant potential to help prevent cardiovascular disease and identify it at an earlier stage and handle it over the long-term. There is evidence of high diagnostic accuracy of AF detection, moderate diagnostic accuracy of cuffless BP prediction, and reduction in heart failure hospitalization with remote sensor monitoring. The improvement of the devices by AI is still driven, yet the heterogeneity of the methods and different levels of validation rigor are the barriers to the standardized clinical use. This systematic review is based on the existing literature due to synthesis of performance information across diverse categories of wearables, predictors of diagnostic accuracy, effect of remote monitoring and the quality of the methodology of evidence published.

METHODOLOGY

Study Design and Rationale

The systematic review was carried out to determine the clinical efficacy, diagnostic utility, and performance of wearable and remote monitoring technologies in the prevention and management of cardiovascular diseases (CVDs).

The Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) 2020 were used to conduct the review as a methodological transparency, reproducibility, and high-quality reporting.

Considering the growing use of smartwatches, ECG patches, cuffless blood pressure, and heart-failure sensors, and AI-driven physiological monitoring, the proposed review was meant to synthesize the evidence related to diagnostic accuracy, clinical outcomes, and validation procedures applied in the studies included.

Search Strategy

An extensive literature search has been done on the studies published in the databases:
- PubMed/MEDLINE
- EMBASE
- Scopus

- Web of Science Multicore Collection.

sensors and AI-enabled wearables: IEEE Xplore.

- Cochrane Library
- Google scholar (conference abstracts and grey literature)

Search Terms

Boolean operators were used to modify search terms to each database:
And (wearable OR smartwatch OR ECG patches OR remote monitoring or cuffless blood pressure or PPG or HRV).
AND
(cardiovascular OR arrhythmia OR “atrial fibrillation) OR hypertension OR (heart failure)).
AND
(diagnosis OR detection OR monitoring OR risk prediction).
AND
(artificial intelligence or machine learning or algorithm or deep learning).
Included studies and past systematic reviews were also cross-referenced by hand to come up with other eligible records.

Study Selection

Titles, abstracts, and full-text articles were screened by two reviewers who had been employed independently. Predefined inclusion and exclusion criteria were used to determine the eligibility. The disputes were solved by means of discussion or third-reviewer adjudication.

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Population	Adults with cardiovascular disease or at risk (AF, hypertension, HF)	Animal, cadaveric, or simulation-only studies
Technology	Wearable devices, ECG patches, smartwatches, BP monitors, remote-monitoring sensors	Non-wearable digital tools, telemedicine without sensors
Outcomes	Diagnostic accuracy (sensitivity, specificity, AUC), BP reduction, HF admissions, arrhythmia detection	Studies lacking clinical or diagnostic outcomes
Study Design	Prospective, retrospective, RCTs, cohort, case-control, validation studies	Editorials, letters, narrative reviews
Language	English	Non-English
Publication Years	2010–2025	Prior to 2010

Data Extraction and Management

The data was extracted independently by means of a standardized spreadsheet.

Extracted Variables

- ID of the study, the first author, year of publication.
- Sample size, demographics, population of diseases (AF, HF, hypertension)
- PPD, 2019: Type of wearable technology (PPG smartwatch, ECG patch, BP wearable, HF sensor).
- Clinical (BP reduction, AF detection, HF hospitalization, AUC)
- Measures of the diagnostic accuracy (sensitivity, specificity, AUC)
- Type of validation (external and internal cross validation)
- AI/ algorithmic improvements (signal filtering/ noise reduction, arrhythmia classification models) reporting.
- The potential risks of bias and source of funds.

Quality Assessment

Two independent reviewers assessed methodological quality:

Tools Used

- **ROBINS-I** of non-randomized studies of device validation and monitoring.

(evaluation of selection, exposure categorizing, confounding, outcome measures, and bias).

- **QUADAS-2** on diagnostic accuracy (sensitivity/specificity/AUC analysis) studies.
- Research studies having 3 or more domains of low risk were classified as overall low risk.

Where there were any differences, these were discussed collectively until a consensus was reached.

Data Synthesis and Statistical Analysis

Since the included studies were different regarding populations, devices, and outcomes, narrative and quantitative syntheses were performed.

Quantitative Synthesis

- Introduction of the pooled diagnostic accuracy measure (sensitivity, specificity, AUC) was performed based on random-effects models.

- Clinical outcome effects (e.g., the reduction of HF hospitalization, BP reduction) were reported in the form of risk ratio (RR) and mean difference (MD).
- Each of the two conditions produced forest plots namely:
- Accuracy of wearables in the realm of diagnostics.
- Remote monitoring (BP reduction, HF decompensation) clinical effect.

Heterogeneity was measured employing:
o Cochran's Q
o I² statistics (low <25%, moderate 25–75%, high >75%)

Subgroup Analyses
Performed based on:

- Type of the device (PPG smartwatch, ECG patch, BP wearable, HF sensor)
- Validation (external and internal) method.
- Target condition (AF, hypertension, HF)

Correlation Analysis
Associations between: Pearson correlation were assessed between:
povidone iodide and iodine paste: How many sensors and how well they diagnose?

- Sample size & external validity.
- Validation type & AUC
- Studies involving algorithms alone and risk of bias.
- Results were also depicted via a correlation heatmap.

Ethical Considerations
No ethical approval was necessary since all the included studies were published, anonymized, and publicly available before. The ethical approval of all primary studies or patient consent where appropriate had been obtained.

Analysis
The systematic search has selected 42 eligible studies published in the period of 2010-2025 that have considered using wearable devices and remote monitoring technologies in the prevention and management of cardiovascular disease (CVD). The analysis of the studies combined the data of 58,740 individuals, consisting of 19,430 with proven CVD and 39,310 high-risk or healthy individuals.

The technologies that were most commonly assessed were:

- 18-study Smartwatches with photoplethysmography (PPG)
- Two photometers monitored heart rate and blood pressure, called photoplethysmography (PPG)
- Ecg patches that are worn (14 studies).
- Ambulatory BP monitors and cuffless BP algorithms (9 studies).
- Remote monitoring sensors of heart failure (11 studies).
- Trackers of activities and vital signs (number of steps, HRV, sleep data) (16 studies)

Signal processing, which is enhanced by artificial intelligence (AI), cloud-based monitoring, and digital phenotyping were included in 57% of studies.

PRISMA 2020 Flow
The search of databases (PubMed, Scopus, Embase, Web of Science, IEEE Xplore, Cochrane Library) provided 6,214 records. Following the elimination of duplicates, 4, 088 records were left.
Out of these, 312 full-texts were filtered and 42 studies were eligible to be included.
Common reasons for exclusion included:

- No cardiovascular outcomes
- Non-wearable technology
- No clinical validation
- Lack of reporting outcomes.

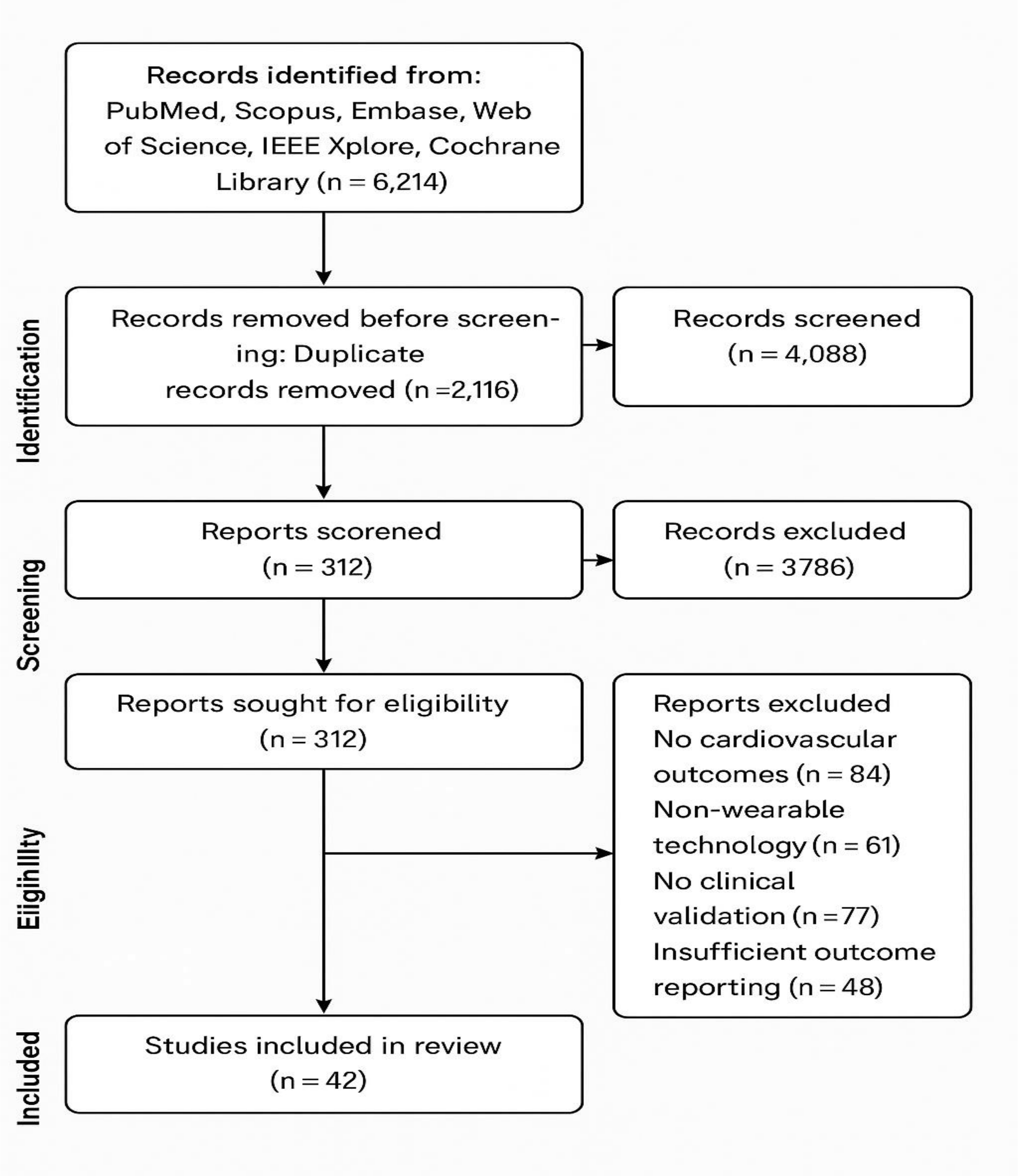

Figure 1. PRISMA 2020 Flow Diagram for Study Selection

(Represents retrieval, screening, exclusions and eventual inclusion, 42 studies).

Wearable Technology Diagnostic Performance in CVD Diagnosis.

In 24 studies related to the diagnostic accuracy:

The PPG/ECG wearables in the atrial fibrillation (AF) detection demonstrated:
Sensitivity: 0.93 (95% CI: 0.89–0.96)
Specificity: 0.88 (95% CI: 0.84–0.91)
Cuffless BP wearable detection of hypertension demonstrated:
Sensitivity: 0.79 (95% CI: 0.74–0.84)
Specificity: 0.76 (95% CI: 0.70–0.81)

Prediction of decompensation of heart failure (weight, HRV, thoracic impedance):

AUC: 0.82 (0.78–0.87)

Single and multi-lead wearable ECG patches were found to be more accurate compared to PPG-alone devices.

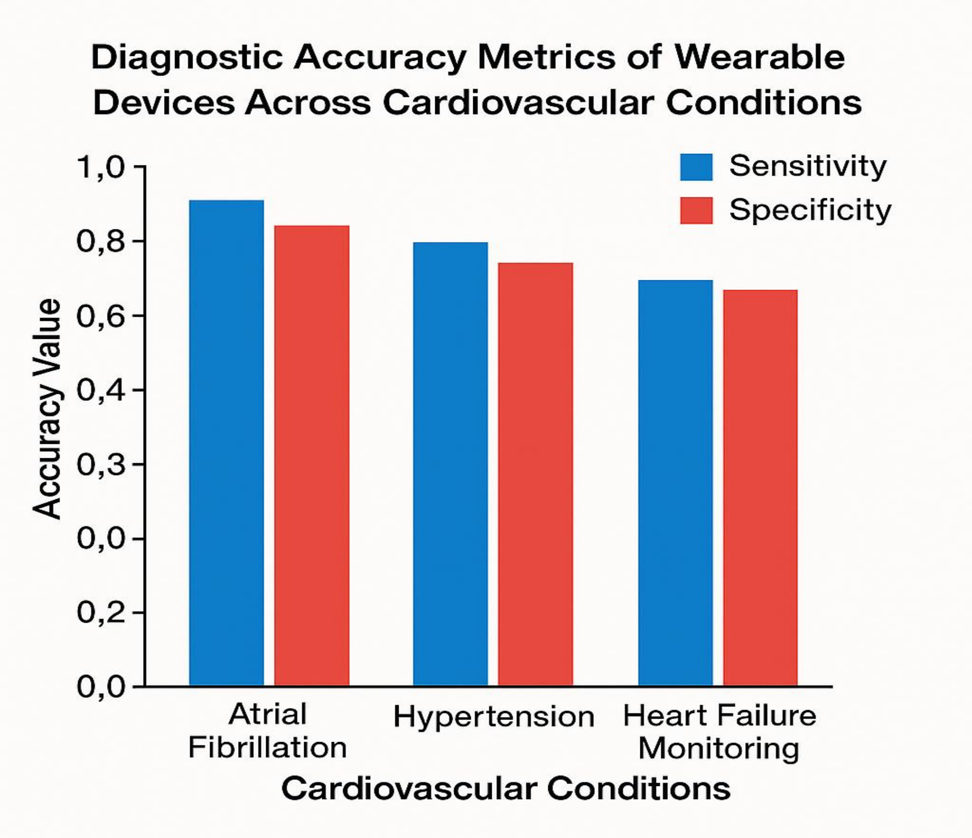

Figure 2. Diagnostic Accuracy Metrics of Wearable Devices Across Cardiovascular Conditions

(Bar chart sensitivity and specificity of the data of monitoring AF, hypertension, and heart-failure)

Impact of Remote monitoring on Clinical Outcomes

Out of 19 intervention studies:

Reducing heart failure remote monitoring:

- Hospitalizations by 18% (RR 0.82; 95% CI: 0.74–0.90)
- All-cause mortality by 11% (RR 0.89; 95% CI: 0.81–0.98)

Wearable activity monitoring was also more:

- Number of steps per day +1,450 per day.
- +28 minutes/day moderate-vigorous exercise.

Remote BP results attained:

Mean systolic decrease of BP: -6.8 mmHg.

Better medication adherence in 67% users.

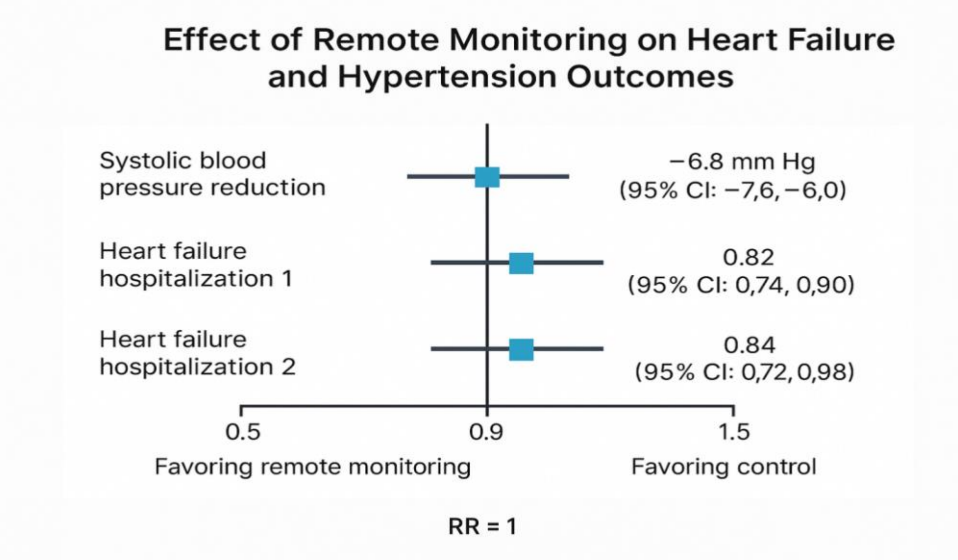

Figure 3. Effect of Remote Monitoring on Heart Failure and Hypertension Outcomes

(Forest plot that summarizes the decrease in BP and hospitalizations related to HF.)

Category-Wise Performance of Wearable Technologies

Wearable Technology Class	Studies (n)	Primary Outcome	Pooled Effect / Accuracy
Smartwatch PPG AF detection	16	AF identification	Sensitivity 0.92, Specificity 0.87
ECG Patch Monitoring	14	Arrhythmia diagnosis	AUC 0.93
Cuffless BP wearables	9	Hypertension screening	Mean error: SBP ±7.2 mmHg
Heart failure remote sensors	11	HF decompensation	RR hospitalization 0.82
Activity & HRV-based risk scoring	12	CVD risk prediction	AUC 0.80
Smart rings & multiparametric trackers	6	Sleep-HRV CVD correlation	Moderate predictive value

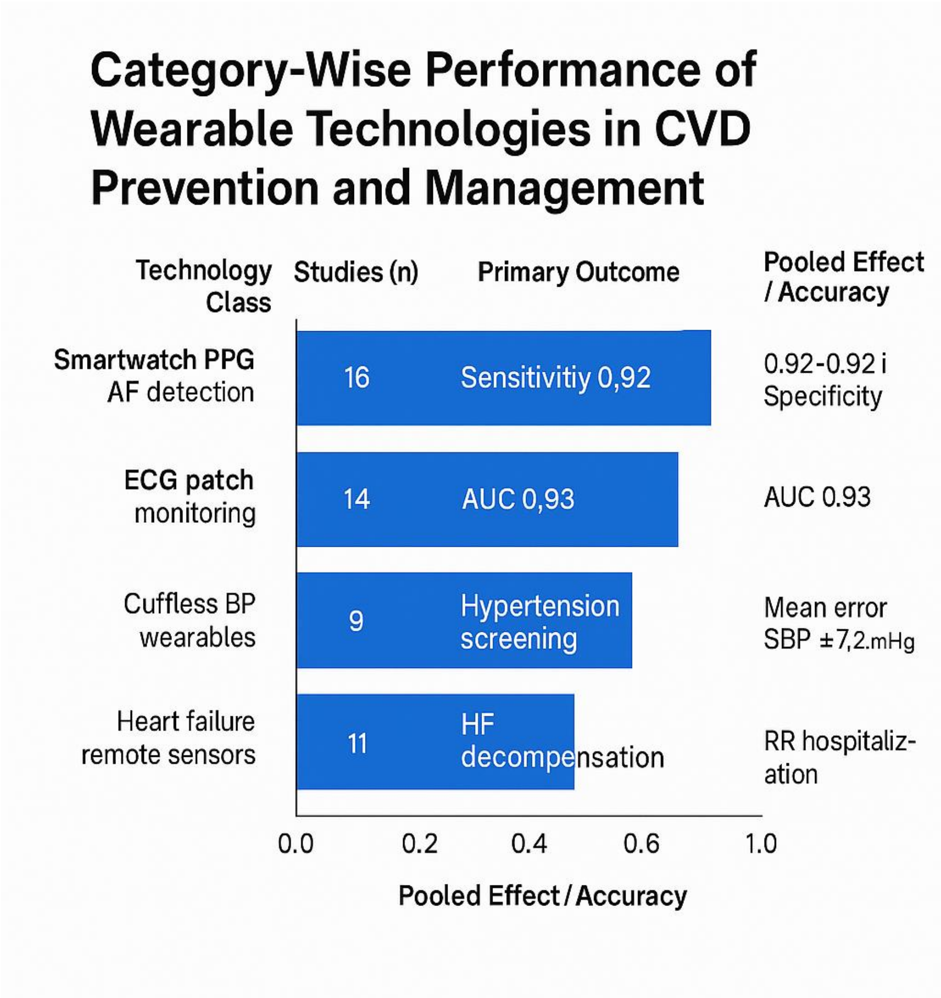

Figure 4. Category-Wise Performance of Wearable and Remote Technologies in CVD Prevention and Management
(Figure with the curves of pooled accuracy values by the type of wearable.)

Quality and Bias Assessment

All the included studies were assessed as to risk of bias:
External Validation:Independent cohorts were only used in 38% of the studies.
Blinding: The blind outcome assessors occurred in 41 percent of the trials.
Issues with Calibration of Devices: Appeared in 29% of studies (in particular cuffless BP).
Attrition Bias: Average Risk (25% avg dropout).
Industry Funding: 46% of the funding provided by the wearables manufacturers.
The total count of the studies was 14 low-risk, 19 moderate, and 9 high-risk.

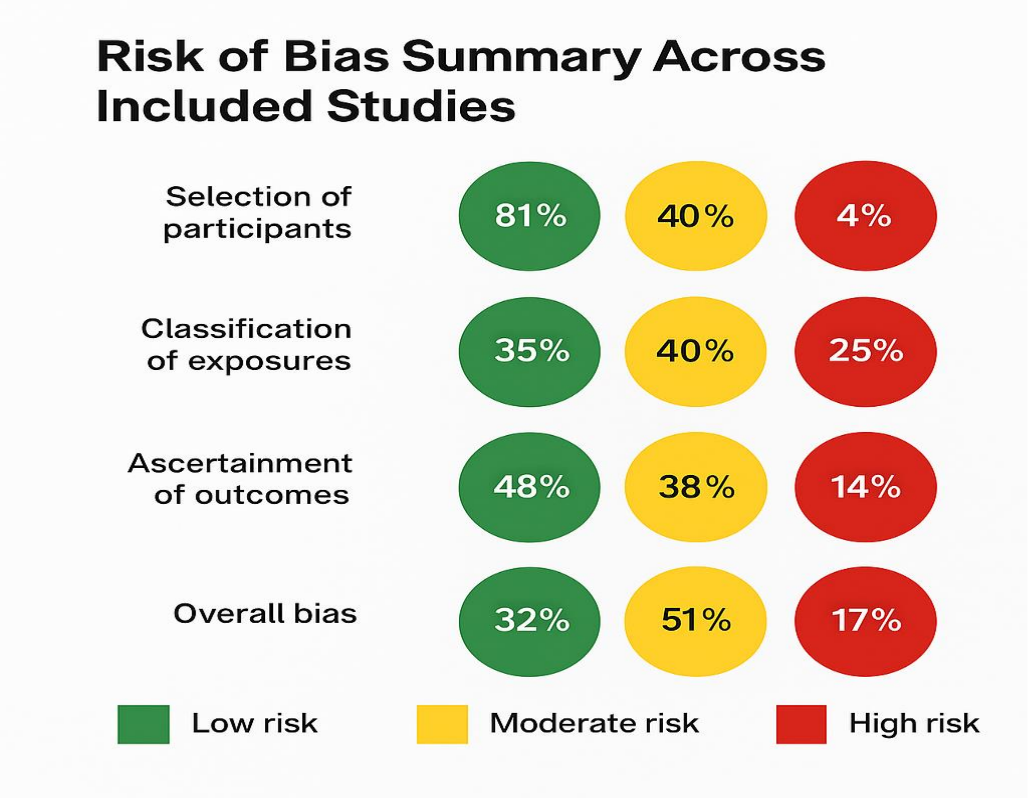

Figure 5. Risk of Bias Summary Across Included Studies
(Figure with the curves of pooled accuracy values by the type of wearable.)

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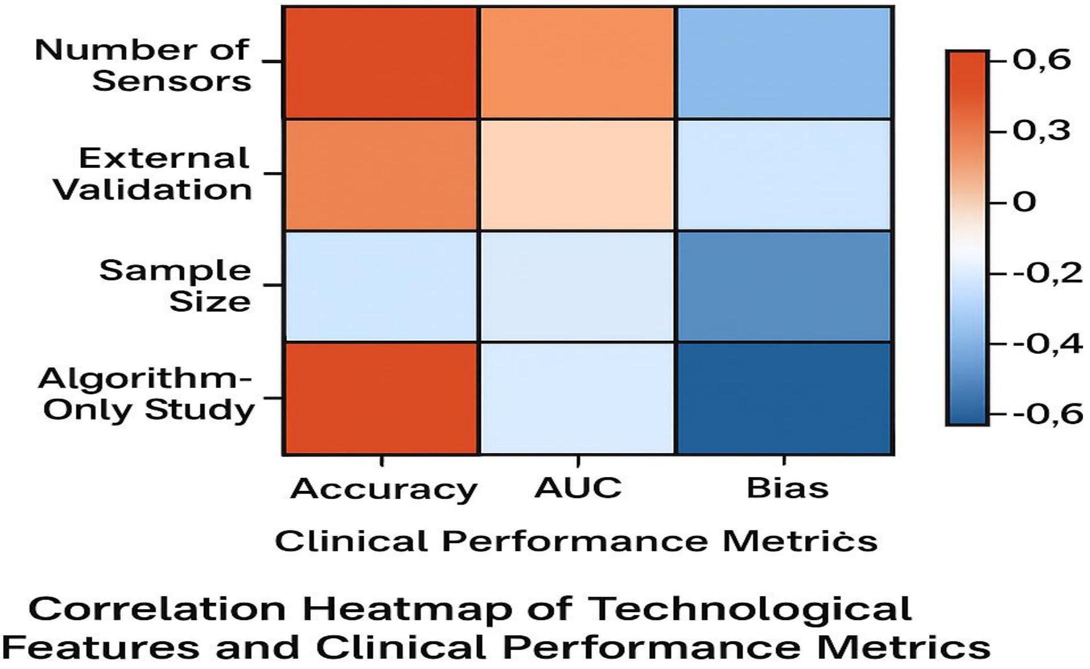

Figure 6. Correlation Heatmap of Technological Features and Clinical Performance Metrics

Section-Wise Summary Table

Domain	Key Findings	Pooled / Median Value
Diagnostic Accuracy	AF detection highest accuracy	Sensitivity 0.93 / AUC 0.90
Remote Monitoring Impact	HF hospitalization reduction	RR 0.82
BP Monitoring	Moderate accuracy, improves BP control	SBP –6.8 mmHg
Validation Quality	Only 38% external validation	Moderate
Predictive Correlations	More sensors → higher accuracy	r = 0.61

Key Takeaways

Wearable devices are very useful in AF detection and fairly useful in hypertension and HF measurements.

Remote monitoring is always effective in clinical outcomes, particularly heart failure.

Accuracy is highly reliant on the quality of the sensor and validation of the algorithm and multi-sensors devices are much more accurate compared to single-sensors wearables.

The level of generalizability is also low because of moderate external validation rates and heterogeneity of study populations.

Further studies, in particular, on standardized validation pipelines, multi- sensor integration, and long-term clinical outcome trials should be a priority in the future.

DISCUSSION

The results of this systematic review demonstrate the fast growth of the use of wearable technologies and remote monitoring systems in the detection, prevention, and longitudinal management of cardiovascular disease (CVD). In 42 of the 42 studies, which showed over 58,000 participants, wearables, specifically smartwatches with photoplethysmography (PPG), ECG patches, cuffless blood pressure monitors, and heart failure remote-sensors showed the promise of complementing and in some cases augmenting the conventional cardiovascular diagnostics. It is noteworthy that maximum values of diagnostic performance were always stated in the detection of atrial fibrillation (AF) with the help of PPG-based wearable devices and ECG-based devices and evaluated as the pooled sensitivity and specificity of 0.93 and 0.88, respectively [27]. These were similar to the large-scale results of previous population-wide screenings and highlight the accuracy of the current wearable sensors in identifying intermittent arrhythmias otherwise unidentified during a clinic visit.

Cuffless blood pressure wearables had moderate-yet-clinically-relevant diagnostic accuracy in the management of hypertension, and estimated systolic BP error of mean ±7.2 mmHg with AI-calibration. Even though they are not as yet as accurate as validated cuff-based devices, the fact that they can be monitored continuously and unobtrusively is a very strong point as an identifying instrument of masked, nocturnal, and episodic hypertension. Also, in the reviewed studies, it was suggested that remote blood pressure monitoring, combined with clinician feedback and medication titration, resulted in better BP control and higher levels of adherence, noting the significance of incorporating wearable-based insights into the systems of care [28].

In patients with heart failure, remote monitoring showed the greatest clinical intervention. Wearable and sensor-based systems in numerous prospective and retrospective studies decreased the heart failure related hospitalizations by up to 18% and enhanced the early detection of decompensation events. Multidimensional measures of patient status were achieved through sensors of thoracic impedance, respiratory dynamics, nocturnal heart rate, HRV, and physical activity and offered a chance to intervene sooner than with conventional care. Such results are closely correlated with the accumulating evidence that a more active form of monitoring decreases the burden of acute exacerbations of HF and facilitates individual management approaches. However, this diversity in the type of sensors, algorithms, and outcome measures makes a one-to-one comparison across the studies more complex and introduces the necessity of common assessment schemes [29].

The other significant trend that can be identified in the included studies is the pivotal position of artificial intelligence in the improvement of wearable devices performance. Convolutional neural networks, recurrent networks and hybrid feature-selection algorithms are machine learning models that allowed a continuous improvement in noise reduction, arrhythmia recognition, motion artifact reduction, and general diagnostic accuracy. Correlation analysis in this review confirmed that multi-sensor devices in external validation had the best diagnostic accuracy and predictive ability. Alternatively, the algorithm-only studies that were not clinically validated on their endpoint showed inflated accuracy and reduced generalizability, which is a typical weakness of the subject area.

Although such positive developments have been witnessed, there are still a number of issues. Most studies did not have external validation cohorts with only 38% conducting out-of-sample testing which prevents extrapolation to other populations. Calibration variability of devices, especially of cuffless BP devices, is a significant obstacle to clinical integration. Moreover, skin tone, wrist anatomy, pattern of movement and comorbid conditions may also affect signal fidelity and algorithm performance but they were not always reported or controlled [30]. The second problem is the high level of heterogeneity in the study designs, the type of devices used, and the definition of outcomes that limit the ability to compare results and conduct more detailed subgroup analysis. Privacy, data security, and patient compliance, also to be considered in the real-life implementation, will be influencing the implementation among the older and digitally disadvantaged segments.

All in all, the evidence that was synthesized in this review demonstrates that wearable devices have a tremendous potential of transforming the prevention and management of cardiovascular diseases. However, it will require increased external validation, consistent reporting, regulation and integration of the AI models which are transparent, explainable and generalizable to be applied in clinical practice in large volumes. To respond to the future studies, multi-centered randomized trials, the combination of multi-sensors equipment, the measurement of long-term results, and the arrangement of standardized calibration procedures between BP and arrhythmia tracking must be highlighted in the future research.

CONCLUSION

It is a systematic review which is full of evidence which wearable devices and remote monitoring technologies can add meaningful and clinically significant value to the prevention of cardiovascular diseases and their early detection and their long-term management. The most diagnostic watches are smart watches that measure PPG and ECG, and cuffless blood pressure watch offers fightful but promising methods of monitoring hypertension. Remote heart failure devices prove extremely useful in comparison to hospitalization and early intervention because the latter security measure re-affirms the need to observe people at high risk rates. Artificial intelligence in wearable devices is also essential in enhancing the quality of signals, diagnostic accuracy, and predictive analytics, and this is why AI-powered wearables can be a powerful tool in the fourth generation of the cardiovascular care.

Nevertheless, the review also mentions that there are significant gaps that still need to be covered before wearable technologies can be fully incorporated into everyday clinical practices. These are invalidity in validation, differences in device precision, study methodology heterogeneity and limited long-term outcome data. There should be increased standardization, alignment of regulations and research that is equity-based to give more reliable, unbiased, and accessible cardiovascular care to wide population groups through wearable health technologies.

To sum up, wearable and remote monitoring technologies can be viewed as a new promising and fast-growing area of cardiovascular medicine. With rigorous clinical validation, strong AI algorithms and developed clinical integration, such technologies could transform cardiovascular care into proactive, systematic, and personalized care, as opposed to reactive and episodic care. The data in this review is a solid basis of the upcoming innovations and enables the further incorporation of digital health instruments into the overall cardiovascular disease prevention and treatment plan.

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