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The Role of Wearable Devices in Cardiovascular Monitoring of Athletes: Implications for Sudden Cardiac Death Prevention

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Abstract

Background. Sudden cardiac arrest (SCA) and sudden cardiac death (SCD) in athletes are rare but devastating events. Traditional prevention relies on preparticipation cardiovascular screening, which may not identify intermittent or exercise-induced abnormalities. Wearable technologies offer continuous cardiovascular monitoring and may support early detection of potential abnormalities.

Aim. To evaluate the role of wearable devices in cardiovascular monitoring of athletes and their potential contribution to SCA/SCD prevention.

Material and methods. A narrative review was performed using PubMed, Scopus, and Google Scholar. Original studies, reviews, and consensus statements on wearable devices, arrhythmia detection, heart rate variability, and SCA/SCD in athletes were analyzed qualitatively, with emphasis on recent literature.

Results. Wearable devices based on photoplethysmography (PPG) and wearable electrocardiography (ECG) allow monitoring of cardiovascular parameters during daily activity and exercise. Wearable ECG offers greater diagnostic value for arrhythmia detection, whereas PPG enables long-term monitoring but is more susceptible to artifacts. Heart rate variability and other derived metrics may reflect autonomic regulation, although their value in predicting serious cardiac events remains uncertain. Current evidence supports wearables as adjunctive tools for symptom evaluation and longitudinal monitoring rather than standalone preventive methods.

Conclusions. Wearable technologies show promise for cardiovascular monitoring in athletes but should currently complement rather than replace established screening strategies. Further prospective studies and standardized clinical guidelines are needed to define their role in sports cardiology.

Key words: wearable devices, athletes, sudden cardiac death, cardiovascular monitoring.

1. Introduction

Sudden cardiac arrest (SCA) and sudden cardiac death (SCD) in athletes, although relatively rare, are among the most devastating events in sports medicine due to their unexpected nature and high public visibility. Reported incidence varies depending on the studied population, but SCD is consistently recognized as a leading medical cause of death during athletic participation [1,2]. The underlying etiologies are heterogeneous and include structural heart diseases such as cardiomyopathies, primary electrical disorders, and, less commonly, acquired conditions [3]. Importantly, a substantial proportion of affected individuals may be asymptomatic prior to the event, complicating early identification and risk stratification [4].

Current preventive strategies primarily rely on preparticipation cardiovascular screening, including medical history, physical examination, and, in some regions, electrocardiography (ECG) [4]. While ECG-based screening has improved detection of certain pathological conditions, its implementation continues to be controversial due to concerns regarding cost-effectiveness, false-positive results, and variability in interpretation [5]. Moreover, traditional screening represents a single time-point assessment and may fail to capture dynamic or intermittent abnormalities that develop over time or occur during exercise.

In parallel, recent years have seen rapid expansion in the use of consumer-grade wearable devices capable of continuous physiological monitoring [6,7]. Modern smartwatches and fitness trackers are equipped with sensors enabling heart rate monitoring, rhythm analysis, and estimation of autonomic function through heart rate variability (HRV) [8,9,10]. These technologies enable real-time, longitudinal assessment of cardiovascular parameters in free-living conditions, including during athletic training and competition.

Despite growing enthusiasm, the clinical utility of wearable devices in the context of SCA and SCD prevention in athletes remains incompletely defined. Several concerns remain unresolved, particularly diagnostic accuracy, susceptibility to artifacts, and false-positive findings [7,8]. Furthermore, converting large volumes of physiological data into clinically actionable insights remains challenging [6]. Therefore, this narrative review evaluates the role of wearable devices in cardiovascular monitoring of athletes, with a focus on their implications for SCA/SCD prevention.

2. Research materials and methods

This study was conducted as a narrative review focusing on wearable cardiovascular monitoring technologies in athletes and their potential role in SCA and SCD prevention. A literature search was performed using PubMed, Scopus, and Google Scholar, incorporating keywords such as “wearable devices,” “smartwatch,” “athletes,” “sudden cardiac death,” “sudden cardiac arrest,” “arrhythmia detection,” “heart rate variability,” and “cardiovascular monitoring,” combined with Boolean operators.

Articles from the past 5 years were prioritized to reflect technological advancements, although earlier seminal studies were also included where relevant. Eligible sources comprised original research, clinical studies, systematic reviews, consensus statements and review articles.

Given the narrative design, no formal systematic protocol or meta-analysis was applied; studies were selected based on relevance and contribution to understanding wearable technologies in athletic populations. The selected literature was analyzed qualitatively, with particular attention to the diagnostic capabilities of wearable devices, arrhythmia detection, monitoring accuracy, and their potential role in early identification of cardiovascular abnormalities associated with SCD risk in athletes.

2. Research results

3.1. Sudden Cardiac Death in Athletes

Sudden cardiac death in athletes is defined as an unexpected death due to cardiac causes occurring during or shortly after physical exertion [1]. Although the absolute incidence is low, estimated at approximately 1 in 1 million to 1 in 5,000 athletes per year depending on the population and methodology, its impact is disproportionately high due to the young age and perceived health of affected individuals [1,11]

The etiological spectrum of SCD in athletes varies by age . In younger athletes (typically under 35 years), inherited and congenital conditions predominate [1]. These include hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, ion channelopathies such as long QT syndrome, and congenital coronary artery anomalies [12]. In contrast, in older athletes, atherosclerotic coronary artery disease is the leading cause [13].

Malignant ventricular arrhythmias are considered the primary mechanism underlying SCD in this population, most commonly ventricular tachycardia or ventricular fibrillation [14]. Exercise-induced physiological stress can trigger these arrhythmias, including increased sympathetic activity, dehydration, electrolyte imbalance, and hemodynamic changes [15]. Notably, such arrhythmic events can occur in individuals without prior symptoms or with previously undetected structural or electrical abnormalities [16].

One of the key challenges in preventing SCD in athletes is the often silent progression of underlying conditions. Traditional screening methods may fail to identify individuals at risk, particularly when abnormalities are intermittent, exercise-induced, or below the threshold of detection during resting evaluations. Additionally, certain physiological adaptations to training, commonly referred to as the "athlete's heart," may overlap with pathological findings, complicating interpretation [5,17].

These limitations highlight the need for complementary approaches to cardiovascular risk assessment that extend beyond single time-point evaluations. Continuous or repeated monitoring of physiological parameters, particularly during exercise, may help identify abnormal cardiovascular responses during exercise and facilitate earlier detection of potentially life-threatening abnormalities. In this context, wearable technologies have emerged as a promising tool, offering the ability to capture real-world data over extended periods.

3.2. Types of Wearable Devices and Technologies

3.2.1. Photoplethysmography (PPG)

Photoplethysmography is the most commonly used technology in consumer-grade wearables [18]. It relies on optical sensors detecting changes in blood volume within the microvasculature, allowing estimation of heart rate and, in some cases, rhythm irregularities. Its main advantage is continuous, long-term data collection with minimal user interaction.

However, PPG is susceptible to motion artifacts, variations in skin perfusion, and environmental factors, particularly during high-intensity exercise [19]. While it may indicate rhythm irregularities, it lacks the specificity required for definitive arrhythmia diagnosis [20].

3.2.2. Wearable Electrocardiography (ECG)

Wearable ECG technology provides direct measurement of cardiac electrical activity and enables more accurate detection of arrhythmias. Many modern devices offer single-lead ECG recordings, typically user-initiated, while some systems allow intermittent or near-continuous monitoring [10,21].

Compared to PPG, ECG offers greater diagnostic value, but its use in athletes is limited by intermittent recordings and the potential to miss transient or exercise-induced arrhythmias. Continuous ECG solutions are less practical in routine athletic settings. Additionally, ECG interpretation requires expertise due to physiological adaptations in athletes [8].

3.2.3. Advanced Physiological Metrics

Wearables increasingly provide derived metrics such as heart rate variability (HRV), resting heart rate trends, and sleep parameters. HRV, a marker of autonomic nervous system balance, is widely used to assess training load and recovery [10].

Although alterations in autonomic tone may be associated with arrhythmic risk, the clinical value of HRV-derived metrics remains uncertain, particularly under non-stationary conditions such as exercise or motion. Their interpretation is further complicated by methodological heterogeneity, susceptibility to motion artifacts and other physiological confounders, as well as the lack of standardized measurement and analysis protocols [22].

3.3. Clinical Applications in Athletes

Wearable devices offer several potential applications in the cardiovascular monitoring of athletes. Although their role in preventing SCD is unproven, they may support earlier detection of abnormalities and improve understanding of physiological responses to exercise [6].

3.3.1. Detection of Arrhythmias

One of the most relevant clinical applications of wearable technology is arrhythmia detection [20]. Devices equipped with PPG or ECG functions can identify irregular heart rhythms and prompt further evaluation [9].

In athletes, arrhythmias may include premature ventricular contractions, supraventricular tachycardias, and, less commonly, malignant ventricular arrhythmias. Detection accuracy depends largely on the technology used. PPG-based systems can identify irregular pulse patterns but cannot reliably distinguish arrhythmia types [20]. Exercise-induced arrhythmias may therefore remain undetected unless monitoring occurs during symptoms.

3.3.2. Monitoring Training Load and Autonomic Balance

Wearables are widely used to monitor training load and recovery through heart rate, HRV, and sleep metrics. These parameters reflect autonomic nervous system activity and physiological stress [10].

Changes in autonomic balance, such as increased sympathetic activity or reduced parasympathetic tone, may contribute to arrhythmogenesis. Longitudinal HRV monitoring may therefore provide indirect insight into cardiovascular status [23]. However, the relationship between these measures and serious cardiac events is not well established, and current evidence does not support HRV as a reliable predictor of malignant arrhythmias.

While wearables may increase awareness of physiological changes and encourage timely medical evaluation, their role in predicting SCA remains uncertain.

3.4. Limitations and Challenges

Despite the increasing popularity and technological progress of wearable devices, several limitations restrict their current role in preventing SCA and SCD in athletes.

A major concern is the risk of false-positive findings. Devices based on photoplethysmography may incorrectly detect irregular rhythms because of motion artifacts, signal noise, or normal physiological variability. In athletes, where heart rate fluctuations are common, this may lead to unnecessary anxiety, additional testing, and increased healthcare utilization without clear benefit [24,25].

False-negative results are also problematic. Wearables may fail to identify transient or exercise-induced arrhythmias, particularly when monitoring is intermittent or user-activated, as with ECG-enabled devices. As a result, clinically significant abnormalities can remain undetected, creating false reassurance [6].

An additional challenge is the lack of standardization between devices and measurement methods [10,19,21]. Manufacturers use proprietary algorithms for heart rate, HRV, and arrhythmia analysis. This variability limits comparability and raises concerns about reliability, especially because many algorithms have not been fully validated in athletes.

Interpretation of wearable-derived data also remains difficult. Large volumes of physiological information may be challenging for both users and clinicians to assess, particularly when distinguishing normal athletic adaptations from pathological findings. The absence of standardized clinical guidelines further complicates integration into routine cardiovascular evaluation [6].

Currently available evidence does not yet clearly demonstrate that wearable devices reduce the incidence of SCA or SCD in athletes. To date, most studies have focused on feasibility, diagnostic accuracy, or detection of relatively benign arrhythmias, with limited data on clinically relevant outcomes [4,24].

Overdiagnosis is another concern, as detection of clinically insignificant abnormalities may trigger unnecessary investigations, psychological stress, and financial burden, particularly in young athletes [24]. Practical issues such as adherence, comfort, battery life, and cost may also limit real-world effectiveness.

Wearable technologies can support cardiovascular monitoring, but their role in preventing SCD in athletes remains complementary rather than definitive. Careful data interpretation and integration with established clinical practice are essential to maximize benefits while minimizing unintended consequences.

3.5. Integration with Traditional Screening

Wearable technologies should complement, not replace, traditional cardiovascular screening. Their main advantage lies in longitudinal monitoring, which may help detect intermittent abnormalities or provide additional data in individuals with borderline findings [6].

They are particularly useful in symptom-driven evaluation, enabling rhythm recording during palpitations or dizziness. They may also support follow-up in athletes with known cardiovascular conditions. However, interpretation must be contextual, and standardized guidelines for integration are currently lacking [26].

3.6. Future Directions

The continued development of wearable technologies is likely to expand their role in cardiovascular monitoring and potentially improve the prevention of SCA and SCD in athletes. Several areas of progress may shape their future clinical value.

Artificial intelligence is likely to become increasingly important in wearable-based cardiovascular assessment [27]. Machine learning algorithms may identify subtle patterns in large volumes of physiological data, improving arrhythmia detection and potentially enabling earlier recognition of individuals at increased risk [28,29]. However, their effectiveness will depend on access to high-quality datasets that adequately represent athletic populations [7].

Further improvements in sensor technology should improve wearable accuracy. Better signal quality, reduced motion artifacts, and multi-sensor platforms may enhance both PPG and wearable ECG systems [7,22]. Future devices could additionally monitor parameters such as respiratory rate, estimated blood pressure, or biochemical markers, providing a broader assessment of cardiovascular status [30].

Integration with healthcare systems will likely become increasingly important [31]. Seamless transmission of wearable-derived data into electronic health records could support faster and more informed clinical decisions, although issues such as data overload, privacy, and management of abnormal findings will need to be addressed [7].

Future research needs to focus on large prospective investigations assessing clinically meaningful outcomes. Demonstrating that wearables can reduce SCA incidence or improve survival will be crucial for wider acceptance in sports cardiology. Standardized guidelines for interpretation and clinical application will also be necessary [26].

Wearable devices show significant potential, but their transition from consumer technologies to clinically validated tools will require further research, technological refinement, and careful integration into medical practice.

3.7. Practical Implications for Clinicians and Athletes

From a practical perspective, wearable devices may support cardiovascular monitoring in athletes, but their role should be clearly defined to avoid misinterpretation and overreliance [24].

For clinicians, wearable-derived data can provide useful context in selected cases, especially when evaluating intermittent symptoms such as palpitations, dizziness, or unexplained fatigue. ECG-enabled devices may help capture rhythm disturbances during symptoms and improve diagnostic yield. However, these findings should always be interpreted within the broader clinical context and confirmed with standard diagnostic methods when necessary [24].

Wearable technologies are widely used to monitor heart rate during rest and physical activity and may support health monitoring, clinical research, and exercise interventions. These devices can provide useful physiological information for consumers, researchers, and clinicians, particularly during physical activity and longitudinal monitoring. However, differences in accuracy between devices and activity conditions indicate that wearable-derived data should be interpreted cautiously when used for health-related or clinical decision-making [32].

Notably, wearable devices are not diagnostic tools and should not replace formal medical evaluation [27]. Athletes should seek professional assessment if they experience concerning symptoms or repeated abnormal readings. Conversely, isolated or non-specific alerts should not automatically trigger extensive investigations without clinical correlation [24].

In summary, wearable technologies can serve as a valuable adjunct in the cardiovascular care of athletes when used appropriately, supporting rather than replacing established clinical assessment and decision-making.

4. Discussion

The growing use of wearable technologies has introduced new possibilities for cardiovascular monitoring in athletes and may influence future strategies for SCA and SCD prevention. Unlike traditional preparticipation screening, wearable devices allow continuous assessment of physiological parameters during training and daily activity, potentially improving detection of intermittent or exercise-induced abnormalities.

Among available technologies, wearable ECG systems appear to offer the greatest clinical relevance because they directly record cardiac electrical activity. In contrast, PPG-based systems are more susceptible to motion artifacts and inaccurate rhythm notifications, particularly during intense exercise. Although metrics such as HRV may provide information regarding autonomic balance and training adaptation, their value in predicting malignant arrhythmias or sudden cardiac events remains uncertain.

An important issue is the balance between early detection and overdiagnosis. Wearables may identify asymptomatic rhythm disturbances, but many findings are clinically insignificant and may lead to unnecessary anxiety and additional investigations. False-negative results may also provide false reassurance, emphasizing that wearable devices cannot replace established cardiovascular assessment.

At present, wearable devices appear more useful for identifying selected abnormalities and supporting clinical evaluation than for true prediction of sudden cardiac events Further improvements in sensor accuracy, algorithm validation, and prospective clinical studies are necessary to determine their future role in SCA and SCD prevention in athletes.

5. Conclusions

Wearable devices are increasingly sophisticated tools for cardiovascular monitoring in athletes, offering advantages in longitudinal data collection and arrhythmia detection. However, they should not be used as standalone tools for SCA/SCD prevention due to limitations in accuracy, interpretation, and evidence.

At present, they are best considered complementary to established screening strategies. Future research should focus on prospective studies assessing clinical outcomes and on developing standardized frameworks for their integration into sports cardiology practice.

Disclosure

All authors have read and approved the final version of the manuscript for publication

Author Contributions

Conceptualization, R.W. and N.S.; methodology, P.T.; software, J.F.; validation W.P. and M.S.; formal analysis K.R.; investigation, K.Z.; resources M.S.; data curation B.B.; writing—original draft preparation K.R.; writing—review and editing R.W. and K.R.; visualization W.P.; supervision N.S.; project administration, P.T.; funding acquisition R.W. All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflicts of interest.

Declaration of the Use of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT for the purpose of language editing and grammar correction of the English text to improve readability and linguistic accuracy. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the substantive content of the publication.

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