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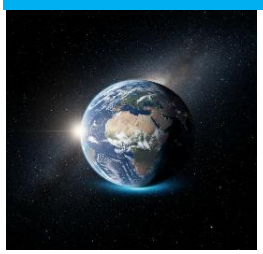

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Fitness Trackers and Other Wearable Devices in Cardiology for Prevention, Screening and Diagnosis of Arrhythmias: Focus on Atrial Fibrillation

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Abstract

Background: Atrial fibrillation (AF) is the most common sustained arrhythmia worldwide and a major cause of ischaemic stroke, heart failure, and cardiovascular mortality. Due to its frequently asymptomatic and paroxysmal nature, many cases remain undiagnosed until serious complications occur. This diagnostic challenge is particularly relevant in physically active individuals, as arrhythmias may be triggered or exacerbated during sports and exercise. Traditional monitoring methods have important limitations in sensitivity, duration, and long-term patient acceptability.

Aim: This narrative review evaluates the current evidence on fitness trackers and other wearable devices in the prevention, screening, and diagnosis of atrial fibrillation, focusing on clinical performance, patient-centred aspects, limitations, and applications in sports and exercise.

Material and Methods: A comprehensive narrative review was performed, incorporating the 2024 ESC Guidelines, major clinical trials, meta-analyses, and recent studies on photoplethysmography (PPG) and single-lead ECG technologies across various wearable form factors.

Results: Wearable devices, including smartwatches, adhesive patches, and smart textiles, achieve high diagnostic accuracy for AF detection (sensitivity and specificity frequently 90–97%). They improve identification of subclinical and silent AF in high-risk and physically active populations and provide markedly better comfort and adherence during sports and exercise. Key challenges include motion artefacts, false-positive alerts, and the scarcity of large randomised trials with hard clinical outcomes.

Conclusions: Wearable technologies have the potential to transform AF care from reactive treatment of complications to proactive, personalised prevention. While already clinically valuable, widespread adoption requires overcoming technical barriers and confirming long-term benefit in robust outcome trials.

Keywords: Atrial fibrillation, Wearable devices, Digital health, Screening, Prevention, Photoplethysmography, Single-lead ECG, Remote monitoring, Fitness trackers, Sports cardiology

1. Introduction

Atrial fibrillation (AF) represents one of the most prevalent cardiac disorders and the most common sustained arrhythmia globally. It significantly affects healthcare systems at both primary and secondary care levels. The condition arises from chaotic electrical activity within

the atria, resulting in irregular ventricular contractions and loss of coordinated atrial contribution to ventricular filling [1].

Recent estimates indicate that approximately 59.7 million people worldwide were living with AF in 2019 [2]. The number of new cases has been doubling every few decades, and projections suggest that overall prevalence will continue to rise sharply in the coming years [3]. This increase is driven primarily by population ageing, the growing burden of modifiable risk factors and comorbidities such as hypertension, obesity, diabetes mellitus and heart failure, greater disease awareness, and advances in detection methods. The lifetime risk of developing AF reaches nearly one in three among older adults, while community-based studies in the United States have reported prevalence rates as high as 5.9% [4].

A substantial proportion of AF episodes occur without noticeable symptoms, often termed „silent AF". As a result, many individuals remain undiagnosed until they experience a major complication, most commonly ischaemic stroke or heart failure. This diagnostic gap, together with the steadily increasing epidemiological burden, underscores the urgent need for systematic early screening and preventive strategies. Prompt identification of AF allows timely initiation of oral anticoagulation therapy, which can reduce the risk of stroke by roughly two-thirds. Moreover, proactive and ongoing management of modifiable risk factors and comorbidities, which is now recognised as the foundational element of AF care, has the potential to delay or prevent disease onset, limit its progression, and improve long-term prognosis irrespective of symptoms or thromboembolic risk profile [1].

Against this background, fitness trackers and other wearable devices offer a powerful, scalable, and cost-effective approach to population-wide screening, early diagnosis, and upstream prevention of atrial fibrillation (AF). These technologies have become particularly valuable for individuals engaged in regular sports and exercise, where traditional ECG monitoring often fails due to motion artefacts, limited portability, or interference with vigorous movement. By enabling continuous heart rhythm assessment in real-world settings, wearables allow for the early detection of exercise-induced arrhythmias that might otherwise remain undetected during brief clinical evaluations. Furthermore, they provide a unique opportunity to simultaneously monitor cardiac rhythm and objective training load, such as daily step counts and training volume, shifting the focus toward a more proactive and personalised model of cardiovascular care in active populations [5–9].

Wearable devices, encompassing smart devices (such as smartwatches and fitness trackers), adhesive wearable patches, chest straps and biotextiles equipped with single-lead electrocardiography (ECG) or photoplethysmography (PPG) sensors, have emerged as a promising solution by enabling convenient, long-term heart rhythm assessment directly in the patient's daily environment, including during sports and fitness activities. ECG-based wearables achieve over 90% accuracy in detecting atrial fibrillation, while also allowing identification of other arrhythmias such as atrial flutter or QT prolongation. PPG approaches, in turn, facilitate passive, near-continuous monitoring through ubiquitous smartphone cameras, even during physical exercise [10,11]. These commercial technologies (predominantly smart devices, wristbands and patches, with 58% holding FDA clearance) have become a cornerstone of AF screening and monitoring, offering high diagnostic accuracy in real-world ambulatory settings, including fitness routines [11].

In contrast to the 12-lead ECG, which remains the gold standard but is limited by in-clinic acquisition and short recording duration, wearable and remote devices overcome these barriers through patient-initiated, prolonged monitoring. Even intermittent 30-second recordings accumulated over time achieve detection rates comparable to 24-hour Holter monitoring, while continuous patch-based systems significantly increase diagnostic yield for paroxysmal and silent episodes, particularly during sports activities [6,12]. Self-administered home-based solutions such as smartphone-compatible ECG devices or wearable patches empower patients, address the limitations of traditional „spot checks" and markedly improve early detection of undiagnosed AF compared with routine care or delayed monitoring, particularly in high-risk groups [13,14].

These technologies are evolving at a remarkable pace, with each new generation offering improved sensor accuracy, longer battery life and more sophisticated artificial intelligence algorithms. However, it is crucial to critically evaluate whether these rapid advancements genuinely translate into better diagnostic performance and clinical outcomes. In an era when many patients are reluctant to attend in-person consultations, face long waiting lists or cannot afford repeated specialist visits, such low-effort, home-based devices provide an accessible, opportunistic alternative that can be used during routine daily activities without disrupting everyday life. Consequently, fitness trackers and wearable devices open the possibility of truly integrated, patient-centred care across the entire AF continuum, from upstream prevention

through risk-factor tracking to large-scale population screening for silent AF, precise diagnosis, monitoring and even support for Hospital-at-Home care models [15].

2. Methods and Devices for Atrial Fibrillation Screening

In recent years the market has seen a rapid influx of new technologies designed to monitor heart rhythm, most notably fitness trackers and smartwatches. Although robust data on their influence on hard clinical outcomes remain limited, these tools show clear potential for identifying AF. Their broader effects on clinical practice, healthcare costs, regulation and health policy therefore deserve thorough further evaluation [1].

AF detection technologies can be broadly categorised into two groups: those that record an electrical electrocardiographic (ECG) signal and those that rely on non-electrical optical methods, primarily photoplethysmography (PPG).

2.1. Photoplethysmography (PPG) vs. Electrocardiography (ECG) in Wearable Devices

Contemporary wearable devices mainly employ either PPG or ECG to detect arrhythmias. ECG continues to serve as the reference standard because it directly captures the heart's electrical activity and provides detailed waveform information. PPG, by contrast, stands out for its simplicity, complete non-invasiveness and ability to perform passive, near-continuous monitoring with almost no active input from the user. Pooled analyses indicate that PPG-based AF detection reaches sensitivity and specificity in the range of 91.6–97.4% and 95.9–97.5%, respectively, values that are high yet generally slightly lower than those achieved by ECG-based systems [16–18]. Hybrid solutions that combine both technologies are becoming increasingly popular, using PPG for broad, continuous screening and ECG for definitive confirmation.

Importantly, any irregular rhythm detected by PPG or another screening method must be verified by a physician interpreting either a single-lead or continuous ECG recording lasting at least 30 seconds, or a standard 12-lead ECG, before a formal diagnosis of AF can be established [1].

2.2. Single-Lead ECG Technology

Single-lead (lead-I equivalent) ECG recorders overcome many constraints of traditional monitoring by allowing patients to initiate and extend recordings in everyday settings. Even

when used intermittently, accumulated 30-second strips can achieve detection rates comparable to 24-hour Holter monitoring, while continuous single-lead systems markedly improve identification of paroxysmal and asymptomatic episodes [6,19]. Across multiple studies, pooled sensitivity and specificity of handheld and wearable single-lead ECG devices reach 89–97% and 95–99%, respectively, figures that approach the performance of a 12-lead ECG while offering far greater accessibility and patient autonomy [6,20].

2.3. Contemporary Wearable Form Factors

Modern wearable solutions come in several practical designs, each with specific strengths:

- **Smartwatches** (Apple Watch, Samsung Galaxy Watch, Fitbit, Garmin and others) integrate continuous PPG monitoring with on-demand single-lead ECG. Major validation trials have reported positive predictive values for confirmed AF ranging from 84% (Apple Heart Study, n>419 000) to 98.2% (Fitbit Heart Study) [5,16].

- **Adhesive ECG patches** enable uninterrupted recording for up to 14 days and consistently deliver the highest diagnostic yield (3.9–5.3%) for previously undetected AF, surpassing conventional Holter monitors in both detection rate and wearer comfort [12,21].

- **Smart rings** benefit from stable finger placement and minimal motion artefacts but currently rely almost exclusively on PPG and lack ECG capability in most models [16].

- **Smart textiles/biotextiles** embed conductive electrodes directly into everyday clothing, supporting monitoring periods of weeks to months with excellent comfort, washability and long-term adherence compared with patches or Holter systems [7].

Smartphone-based PPG applications and chest straps represent additional low-cost options that achieve pooled sensitivity/specificity of approximately 96%/97% [22].

2.4. Diagnostic Performance and Comparative Effectiveness

Systematic reviews and meta-analyses demonstrate consistently strong performance across wearable platforms, with no statistically meaningful difference in overall diagnostic yield between PPG and single-lead ECG approaches in most direct comparisons [17,23]. PPG technologies generally excel in sensitivity and population-scale accessibility, while ECG-based

patches and smartwatches provide superior specificity and immediate confirmatory rhythm strips. Continuous patch monitoring currently yields the highest detection rates, followed by single-lead ECG and PPG devices [21]. In everyday practice, wearable monitoring substantially outperforms single 12-lead ECG or simple pulse palpation, especially for intermittent and silent AF, and has been linked to higher rates of appropriate oral anticoagulation initiation [1,12]. Performance may decline modestly in older adults because of motion artefacts, arterial stiffness or skin changes, which highlights the importance of choosing the right device for each patient's profile and clinical scenario [24].

While wearable devices are effective for atrial fibrillation (AF) screening under resting conditions, their signal quality and heart rate accuracy may be compromised during high-intensity exercise due to motion artefacts and irregular RR intervals [25]. Moreover, because the ventricular response in AF is inherently irregular, heart rate may be an unreliable marker for prescribing or monitoring exercise intensity in this population; breathing frequency has therefore been proposed as a more physiologically robust alternative [26].

2.5. Artificial Intelligence Algorithms in Wearable AF Detection

The integration of large-scale datasets and artificial intelligence tools is exerting a growing influence on the field of cardiac electrophysiology. Sophisticated algorithms are now being developed to enhance automated recognition of atrial fibrillation from both PPG and ECG signals generated by wearable devices. Although these tools already achieve impressive technical accuracy, their true clinical value and applicability across diverse real-world populations have yet to be fully established. When properly integrated, AI-driven analysis may eventually allow dynamic, continuous, patient-led monitoring that can guide treatment adjustments in real time [1].

A recent meta-analysis of 26 studies reported pooled sensitivity of 94.8% and specificity of 97.0% for AI algorithms applied to wearable signals, with deep neural networks clearly outperforming traditional machine-learning methods [27]. Deep-learning models maintain robust performance even during daily activities and in ambulatory conditions [18,28]. Nevertheless, important challenges persist in the areas of data quality, external validation, motion artefact handling, algorithm transparency, clinical integration, and ethical considerations surrounding continuous remote monitoring [1]. Addressing these issues will be

essential before AI-enhanced wearables can be widely adopted as part of routine, proactive AF care.

3. Human Factors, Patient Comfort and Adherence in Wearable Technologies for Atrial Fibrillation

Successful long-term use of wearable devices for atrial fibrillation (AF) screening and monitoring depends not only on technical accuracy but also on how well the technology fits into patients' daily lives. Factors such as comfort, ease of use, and overall user experience play a decisive role in whether patients continue wearing the device long enough to detect infrequent paroxysmal or silent episodes.

Patient preference and real-world acceptability are markedly higher for modern wearable solutions than for traditional monitoring methods. In a direct comparison, 98% of participants strongly preferred a 72-hour adhesive ECG patch over a standard 24-hour Holter monitor, citing the absence of wires and greater freedom of movement [29]. Similarly, textile-based ECG garments with dry, flexible electrodes embedded in stretchable fabrics have shown excellent user acceptability: up to 79% of patients reported preferring them over conventional Holter monitors, while skin irritation occurred in fewer than 3% of cases. These garments were well tolerated during rest, physical activity and sleep, supporting significantly better long-term compliance [7].

The integration of wearable technologies into sports and fitness activities substantially enhances patient comfort and long-term adherence. Smart textiles, adhesive ECG patches, and wrist-worn devices are generally well tolerated during high-intensity exercise and sleep, with nearly four out of five users favouring them over traditional Holter monitoring systems. Such acceptability is particularly important for detecting sporadic paroxysmal episodes that may arise in relation to physical exertion [7,25].

Beyond comfort, effective implementation of wearable technologies requires genuine user-centered design and attention to behavioural science. A systematic review of 55 studies on mobile health interventions for AF found that although most trials assess usability during early feasibility stages, very few incorporate true user-centered design principles during device development or address long-term behavioural change [30]. Patient experiences, contextual factors (e.g., lifestyle, work demands) and changes in user needs over time are frequently

overlooked. As a result, many promising devices fail to achieve sustained engagement in everyday settings.

Behavioural strategies, such as personalised feedback, gamification and goal-setting, show promise in improving adherence and encouraging beneficial lifestyle modifications. Mapping these approaches against the UK Medical Research Council framework for complex interventions reveals that most efforts focus on the individual (micro) and community (meso) levels, while broader societal (macro) interventions remain almost absent. Although these techniques appear helpful in the short term, their long-term efficacy in chronic conditions such as AF still requires further rigorous evaluation [30].

Taken together, these findings underline that the future success of wearable-based AF screening, prevention and diagnosis will depend as much on human factors and patient-centred design as on improvements in sensor accuracy and artificial intelligence. Devices that combine high diagnostic performance with excellent comfort, intuitive use and behavioural support are far more likely to achieve the sustained adherence necessary for meaningful clinical impact at the population level.

4. Screening and Prevention of Atrial Fibrillation: Opportunities Offered by Wearable Technologies

Fitness trackers and other wearable technologies have fundamentally changed the landscape of atrial fibrillation (AF) screening and prevention by enabling convenient, prolonged and patient-centred rhythm monitoring outside the hospital environment. They support both opportunistic and systematic strategies and facilitate early detection of both symptomatic and silent forms of the arrhythmia [1].

4.1. Tools and Approaches to AF Screening

Contemporary AF screening tools span a broad spectrum, from simple pulse palpation and standard 12-lead ECG to advanced wearable solutions. Among ECG-based devices, adhesive patches (up to 14 days), smart textiles/biotextiles (up to 30 days) and consumer smart devices (30-second recordings) play an increasingly important role. On the non-ECG side, PPG implemented in smartwatches, smartphone applications and chest straps enables passive, near-continuous monitoring with minimal patient effort. These consumer-grade technologies

complement traditional methods and are now widely recognised as valuable components of modern screening programmes [1,24].

4.2. **Prolonged versus Single-Timepoint Screening**

Single-timepoint („snapshot") assessments, such as a single 12-lead ECG or brief pulse check, are easy to perform but frequently miss paroxysmal and asymptomatic episodes. Prolonged or continuous monitoring with wearable devices consistently achieves higher diagnostic yield, particularly in high-risk groups. Studies in elderly populations have shown that continuous single-lead ECG recording detects AF in 6% of participants, compared with only 2% using intermittent 30-second handheld recordings performed four times daily [1,31]. This advantage becomes even more pronounced when monitoring extends over days or weeks.

4.3. **Detection of Subclinical and Silent AF in High-Risk Populations**

A large proportion of AF episodes are asymptomatic and would remain undetected without extended monitoring. Wearable technologies have proven especially effective in revealing this hidden burden. In the NOMED-AF study using a wearable vest system, silent AF was identified in 9% of individuals with diabetes versus 7% without [32]. Likewise, in diabetic patients with chronic kidney disease, wearable ECG patch monitoring revealed a nearly threefold higher rate of newly detected AF (7.3% vs 2.3%), with most episodes being subclinical [1,33].

In older adults – the population with the highest AF prevalence – single-lead ECG wearables achieve sensitivity and specificity of 87–100% and 82–100%, respectively, while PPG-based devices reach 67–98% sensitivity and 83–98% specificity [1,22,24].

4.4. **Wearables in Postoperative Atrial Fibrillation Surveillance**

Postoperative AF often occurs after hospital discharge and is frequently silent. Smartphone-based PPG monitoring for 6 weeks after cardiac surgery increased detection of new AF or atrial flutter more than ten-fold (18.5% vs 1.9%) and led to a five-fold higher rate of therapeutic interventions, including anticoagulation and rhythm control [34]. A recent scoping review confirmed that wearable and handheld ECG devices significantly improve post-discharge detection and reduce unplanned emergency visits [20]. Ongoing trials, such as

THOFAWATCH, are further evaluating continuous smartwatch monitoring in thoracic surgery patients [35].

4.5. **Wearables in Secondary Prevention after Cryptogenic Stroke**

In patients with cryptogenic stroke, prolonged monitoring is essential to identify underlying paroxysmal AF. Wearable ECG devices (patches, vests, belts) have demonstrated new AF detection rates of approximately 20.7%, with performance comparable to traditional Holter monitoring but superior comfort and feasibility for longer use [1,36].

4.6. **Supporting Primary Prevention**

Wearables not only detect AF but also actively support primary prevention by delivering continuous feedback on modifiable risk factors such as physical activity, heart rate trends and sleep quality. This complements guideline-recommended lifestyle interventions – optimal blood pressure control, maintenance of normal body weight, regular moderate physical activity and reduction of excessive alcohol intake – which carry the highest level of recommendation for preventing incident AF in the general population [1].

Increasing physical activity levels through structured use of fitness trackers has emerged as a promising strategy in atrial fibrillation management. In patients undergoing catheter ablation, the BE-ACTION trial demonstrated that fitness trackers significantly increased daily step counts, and when combined with regular motivational support, further improved walking distance without increasing arrhythmia recurrence. These findings suggest that wearable-based exercise promotion, particularly when supported by behavioural intervention, can be safely incorporated into post-procedural care [37].

In summary, wearable devices have evolved into versatile clinical tools that enhance both the sensitivity of AF screening and the effectiveness of preventive strategies across diverse patient populations and care settings.

5. Limitations, Challenges and Future Directions

Although wearable devices have demonstrated impressive diagnostic performance in atrial fibrillation (AF) screening and prevention, several important limitations and implementation challenges must be acknowledged before they can be widely adopted into routine clinical practice.

5.1. **Limitations of Current Evidence**

Most of the current evidence derives from observational studies and relatively short-term trials in selected populations. Large-scale randomised controlled trials powered for hard clinical outcomes such as stroke, mortality or healthcare utilisation remain scarce, particularly for consumer-grade wearable devices in low-risk or general populations [1,21,38]. Many validation studies, particularly those evaluating photoplethysmography, have been limited by small sample sizes and high selection bias, resulting in unrealistically high performance estimates that may not translate well to real-world settings [1,17,18]. In addition, the clinical significance of very low-burden, device-detected subclinical AF remains uncertain, and it is not yet clear which patients truly benefit from early anticoagulation triggered by wearable alerts [36,39,40].

5.2. **Technical and Clinical Challenges**

Signal quality is a persistent limitation of wearable devices, particularly during physical activity, in elderly or multimorbid patients, and in individuals with darker skin tones. Motion artefacts, poor skin contact, low-perfusion states and concurrent ectopic beats frequently result in false-positive or inconclusive readings, thereby increasing the workload of manual ECG over-reading by clinicians [18,24,28,41]. PPG-based algorithms are particularly vulnerable in these situations, while even single-lead ECG devices occasionally fail to detect very brief or low-amplitude episodes [17,42]. In inpatient settings, although upper-arm PPG wearables have shown good performance, interpretability is still limited to approximately 77% of recording time [28].

Despite their promise, current approaches to exercise quantification remain suboptimal in endurance populations. A major limitation highlighted in recent sports cardiology literature is the predominant reliance on self-reported questionnaires, with limited use of objective heart-rate monitoring. Furthermore, there is substantial heterogeneity in the reporting of FITT (Frequency, Intensity, Time, and Type) variables, and only a minority of studies capture all necessary components required for comprehensive training load assessment. As sports cardiology advances toward precision medicine, integrating wearable-derived data with structured training-log platforms may help standardize exercise dose quantification and better define safe training thresholds [43].

5.3. **Implementation and Societal Barriers**

Integration into existing healthcare workflows poses practical difficulties, including increased physician interpretation time, alarm fatigue, data privacy concerns, and limited interoperability with electronic health records [6,15]. False-positive notifications can generate unnecessary anxiety, additional investigations and healthcare costs, especially in low-pretest-probability groups [16,39]. Disparities in digital literacy, socioeconomic status and access to devices further risk widening health inequalities rather than reducing them [30,42]. Regulatory approval, cost-effectiveness and equitable reimbursement models also remain incompletely resolved [21,36].

5.4. **Future Directions and Research Priorities**

Future development should focus on several key areas. Improved signal-processing algorithms (particularly deep learning models robust to motion and diverse skin types), multimodal sensing (combining PPG, ECG and additional physiological signals), and better battery life and washable smart textiles will enhance usability and accuracy [7,11,18]. Co-design with patients and clinicians from the earliest stages, together with behavioural science techniques, is essential to improve long-term adherence and translate detection into meaningful clinical benefit [15,30]. Large, pragmatic randomised controlled trials evaluating wearable-enabled screening pathways on hard clinical outcomes (stroke reduction, mortality and cost-effectiveness) are urgently needed, particularly in high-risk populations such as patients after cardiac or thoracic surgery and those with cryptogenic stroke [21,34–36,44,45]. Seamless integration of wearable data with electronic health records and the development of standardised clinical decision pathways will be critical for safe and scalable implementation of these technologies in routine practice [15,38].

Addressing these challenges will determine whether wearable technologies fulfil their potential to shift AF care from reactive treatment to truly proactive, personalised prevention.

6. Conclusion

Fitness trackers and other wearable devices have emerged as a transformative technology in the prevention, screening, and diagnosis of atrial fibrillation. By enabling convenient, prolonged, and patient-centred heart rhythm monitoring during daily life, including sports and fitness activities, outside traditional healthcare settings, they address many longstanding limitations of conventional methods, including the low sensitivity of single-timepoint assessments to the poor

acceptability of prolonged Holter monitoring. Across diverse clinical scenarios, including population screening, post-operative surveillance, cryptogenic stroke evaluation, and primary prevention in high-risk individuals, wearables consistently demonstrate high diagnostic accuracy, improved detection of subclinical and silent AF, and the potential to facilitate earlier therapeutic intervention.

This review highlights that while technical performance of current-generation smartwatches, patches, and textile-based systems is already clinically meaningful, their ultimate value will depend on successful integration into structured care pathways, thoughtful attention to human factors, and rigorous validation in large-scale outcome trials. When combined with appropriate patient selection, physician oversight, and seamless data integration with electronic health records, fitness trackers and wearable technologies offer a realistic opportunity to shift the paradigm of AF management from reactive treatment of complications to truly proactive, personalised prevention.

This paradigm shift is particularly relevant in physically active and athletic populations, in whom arrhythmias often manifest in relation to exercise and training load. By capturing both heart rhythm and objective markers of physical activity in real-world conditions, wearable technologies bridge the gap between sports cardiology and routine clinical care. Their value lies not only in detection, but in enabling safer, individualized exercise strategies that align rhythm monitoring with lifestyle and performance goals.

In the coming years, as sensor technology, artificial intelligence algorithms, and healthcare system integration continue to mature, fitness trackers and wearable devices are poised to become a cornerstone of modern cardiology, not merely as consumer gadgets, but as powerful clinical tools that can meaningfully reduce the global burden of atrial fibrillation and its devastating complications.

Disclosure

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