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USE OF MODERN SMARTWATCHES IN EARLY DETECTION OF HEART RHYTHM DISTURBANCES AND PREVENTION OF CARDIOVASCULAR COMPLICATIONS: A NARRATIVE REVIEW

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ABSTRACT

Atrial fibrillation (AF) and other cardiac rhythm disturbances represent a major and growing global health burden, contributing substantially to stroke, heart failure, and cardiovascular mortality worldwide. Because AF is frequently asymptomatic or paroxysmal, timely diagnosis remains a persistent clinical challenge. This narrative review aims to synthesize current evidence on the technological principles, diagnostic performance, clinical utility, and limitations of consumer smartwatches equipped with photoplethysmography (PPG) and single-lead electrocardiography (ECG) for the detection and prevention of heart rhythm disturbances. Large prospective cohorts, including the Apple Heart Study and the Fitbit Heart Study, together with multiple systematic reviews and meta-analyses, demonstrate that smartwatch-based PPG and ECG algorithms achieve high sensitivity and specificity for AF detection. This enables opportunistic screening and supports targeted secondary prevention of thromboembolic events, particularly ischemic stroke. However, real-world implementation raises concerns regarding false-positive alerts, overdiagnosis, patient anxiety, and the necessity of physician-confirmed diagnosis. Smartwatch-based rhythm monitoring constitutes a clinically meaningful, evidence-supported adjunct to conventional arrhythmia detection, but its integration into routine cardiological practice requires structured confirmatory pathways, clinician education, and further research addressing diverse populations and long-term outcomes.

KEYWORDS

Atrial Fibrillation, Smartwatch, Photoplethysmography, Wearable Technology, Digital Health, Arrhythmia Detection

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1. Introduction

Atrial fibrillation is the most common sustained cardiac arrhythmia encountered in clinical practice and constitutes a leading, independent risk factor for ischemic stroke, heart failure, and premature death (Chugh et al., 2014). According to the Global Burden of Disease 2010 Study, the worldwide prevalence of AF and atrial flutter was estimated at 33.5 million individuals, with age-adjusted incidence rates continuing to rise across both high-income and developing regions (Chugh et al., 2014). More recent analyses derived from the Global Burden of Disease 2021 Study confirm that this upward trajectory has persisted, with the absolute number of prevalent AF and atrial flutter cases increasing substantially over the past decade and marked socioeconomic disparities in incidence, disability-adjusted life years, and access to guideline-directed care between high- and low-income countries (Tan et al., 2024; Treewaree & Lip, 2024). Kornej et al. (2020) similarly emphasize that the aging of populations, combined with rising prevalence of hypertension, obesity, diabetes mellitus, and other cardiometabolic risk factors, is projected to further amplify the global AF burden over the coming decades, generating substantial direct and indirect healthcare costs related to anticoagulation, hospitalization, and stroke-related disability.

A central clinical difficulty in the management of AF, as well as of other supraventricular and ventricular rhythm disturbances, lies in their frequently asymptomatic or paroxysmal nature. Many episodes are transient, self-terminating, and unaccompanied by perceptible symptoms, which renders detection using conventional, intermittent diagnostic tools—such as a single resting 12-lead electrocardiogram or short-duration Holter monitoring—inherently limited (Pereira et al., 2020; Ramkumar et al., 2018). This diagnostic gap is clinically consequential, since undiagnosed paroxysmal AF is a recognized contributor to cryptogenic stroke, and early identification enables the timely initiation of oral anticoagulation and rate- or rhythm-control strategies that reduce thromboembolic risk (Kornej et al., 2020).

The proliferation of consumer-grade wearable devices—particularly smartwatches equipped with optical photoplethysmographic sensors and, increasingly, single-lead electrocardiographic capability—has

introduced a fundamentally new paradigm for continuous, longitudinal, and low-burden cardiac rhythm surveillance outside the traditional clinical environment (Hughes et al., 2023). These devices are now used by hundreds of millions of consumers globally, positioning them as a potentially transformative tool for population-level AF screening and for the empowerment of individual patients in the surveillance of their own cardiac rhythm.

Despite growing enthusiasm, the translation of consumer wearable technology into validated clinical practice raises important questions regarding diagnostic accuracy, the risk of false-positive alerts and consequent overdiagnosis, the burden placed on cardiology and primary care services to confirm device-generated alerts, and the psychological impact of continuous self-monitoring on patients (Rosman et al., 2020; Demkowicz et al., 2023). The objective of the present narrative review is therefore to synthesize the currently available peer-reviewed evidence concerning the technological foundations, clinical applications, diagnostic performance, and practical and ethical implications of modern smartwatch-based technologies in the detection and prevention of heart rhythm disturbances, with particular emphasis on atrial fibrillation as the arrhythmia for which the evidence base is most extensively developed.

2. Methodology

This work is a narrative review and therefore does not follow a pre-registered, systematic search protocol such as PRISMA. Relevant literature was identified through structured searches of PubMed, the Cochrane Library and Google Scholar, using combinations of the search terms smartwatch, wearable technology, photoplethysmography, electrocardiography (ECG), atrial fibrillation, arrhythmia detection, and heart rhythm disturbances. The search prioritized peer-reviewed primary studies (prospective cohorts and diagnostic validation studies), systematic reviews and meta-analyses, and relevant ethical and clinical-practice analyses. Reference lists of retrieved articles were additionally screened to identify further pertinent sources, including seminal early validation studies of smartwatch-based rhythm detection and the most recent large-scale cohorts and reviews available at the time of writing.

Given the narrative, non-systematic nature of this review, formal quality-appraisal tools (e.g., PRISMA, Cochrane risk-of-bias) and quantitative pooled synthesis were not applied. Instead, each cited study is characterized in the text by its design and evidentiary weight (e.g., large prospective cohort, randomized or quasi-experimental design, systematic review/meta-analysis, or expert ethical analysis), consistent with an evidence-based medicine framework, and areas of methodological heterogeneity or limited evidence are explicitly noted where relevant.

3. Results

3.1. Technological Foundations of Smartwatch Diagnostics

Two principal sensing modalities underlie the cardiac rhythm-monitoring capabilities of modern consumer smartwatches: photoplethysmography (PPG) and single-lead electrocardiography (ECG). Although both technologies aim to characterize cardiac electrical or mechanical activity, their underlying physical principles, signal characteristics, and diagnostic capacities differ substantially (Pereira et al., 2020; Hughes et al., 2023).

Photoplethysmography is an optical technique in which light-emitting diodes on the underside of the device illuminate the skin and underlying microvasculature of the wrist, while a photodetector records the intensity of light that is reflected or transmitted back. Because arterial blood volume in the peripheral vasculature fluctuates with each cardiac cycle, the resulting variation in detected light intensity produces a pulsatile waveform from which pulse rate and, critically, beat-to-beat pulse interval variability can be derived (Pereira et al., 2020). Proprietary algorithms then analyze the irregularity and variability of consecutive pulse intervals: the chaotic, non-repeating pattern of RR-interval variability characteristic of AF produces a corresponding irregularity in the pulsatile PPG signal that can be distinguished, using statistical and machine-learning-based classifiers, from the more regular variability seen in sinus rhythm, sinus arrhythmia, or ectopic beats (Pereira et al., 2020; Guo et al., 2022). Because PPG is a continuous, passive, background-running technology that does not require active user initiation, it is well suited to prolonged, unobtrusive rhythm surveillance and underlies the irregular pulse notification features implemented in most consumer smartwatch platforms (Perez et al., 2019; Lubitz et al., 2022).

Single-lead ECG functionality, in contrast, requires active user engagement: the wearer typically places a finger from the contralateral hand on a sensor (commonly integrated into the watch crown or bezel), completing an electrical circuit that allows the device to record a brief, single-lead electrocardiographic tracing—analogue to a Lead I recording—over a defined interval of 30 seconds. This approach captures cardiac electrical activity—encompassing both myocardial depolarization and repolarization—rather than its downstream mechanical or hemodynamic consequences. This enables direct visualization of P-wave morphology, RR-interval variability, and baseline irregularity, and, in some cases, other electrocardiographic abnormalities (Ramkumar et al., 2018; Abu-Alrub et al., 2022). On-device algorithms, most commonly built upon deep neural network or other machine-learning architectures trained on large annotated ECG datasets, classify the resulting tracing into categories such as sinus rhythm, atrial fibrillation, or an inconclusive/unclassified result when signal quality is insufficient (Iqhrammullah et al., 2025; Campo et al., 2022). Because it directly samples cardiac electrical activity, single-lead ECG generally offers higher specificity for rhythm classification than PPG-based pulse analysis, but it is inherently intermittent and dependent on active, deliberate self-testing, which limits its usefulness for continuous background surveillance (Ramkumar et al., 2018).

In practice, most consumer smartwatch ecosystems combine both modalities: continuous PPG-based background monitoring is used to trigger an "irregular rhythm" notification, which the user is then prompted to confirm or further characterize by performing an active single-lead ECG recording (Perez et al., 2019; Hughes et al., 2023). This two-tiered architecture reflects a deliberate technological compromise between the passive, low-burden screening capability of PPG and the higher diagnostic specificity of ECG-based confirmation, and it forms the technical basis for the clinical screening pathways discussed in the following sections. A broader technical review of emerging approaches to AF identification, including signal-processing and deep-learning-based classification methods applied to wearable-derived data, similarly emphasizes that continued refinement of algorithmic architecture, rather than sensor hardware alone, is likely to drive further improvements in diagnostic accuracy (Ding, Marcus, & McManus, 2020).

3.2. Clinical Applications in Early Detection

The principal clinical value of smartwatch-based rhythm monitoring lies in its capacity to enable continuous, longitudinal, real-world surveillance that extends far beyond the temporal window of conventional intermittent testing, thereby increasing the probability of capturing transient, asymptomatic, or paroxysmal arrhythmic episodes that would otherwise remain undetected (Pereira et al., 2020; Hermans et al., 2022). This capability has direct implications for both primary and secondary prevention.

In the context of primary prevention, opportunistic or systematic screening of asymptomatic individuals—particularly those with established risk factors for AF such as advanced age, hypertension, or structural heart disease—using consumer wearables offers a scalable, low-cost complement to traditional population-based screening strategies employing intermittent ECG or blood pressure-device-based pulse assessment (Guo et al., 2022; Treeware & Lip, 2024). The mAFA-II trial long-term extension cohort demonstrated that a smartphone-based photoplethysmographic screening and integrated care pathway was associated with a reduction in the composite outcome of stroke, systemic thromboembolism, and death among individuals with screening-detected AF who received subsequent guideline-based management, supporting the concept that early identification followed by structured clinical intervention can translate into measurable improvements in patient outcomes (Guo et al., 2022).

In the context of secondary prevention, continuous rhythm monitoring is particularly valuable in patients with a prior history of AF, cryptogenic stroke, or recent catheter ablation, in whom detection of recurrent or residual arrhythmic burden informs decisions regarding continuation or escalation of anticoagulation and rhythm-control therapy (Hermans et al., 2022; Hughes et al., 2023). Because paroxysmal AF episodes are frequently brief and clustered, the near-continuous temporal coverage afforded by wrist-worn PPG sensors substantially increases diagnostic yield relative to single time-point assessments, allowing clinicians to correlate device-detected arrhythmic burden with symptoms, therapeutic response, and thromboembolic risk stratification over extended follow-up periods (Hermans et al., 2022).

Beyond AF-specific applications, wearable rhythm-monitoring technology has also demonstrated a role in the outpatient cardiology setting as an adjunct to symptom-triggered evaluation. A mixed-methods observational study of patient-initiated cardiovascular monitoring using commercially available devices found that patient-generated rhythm data meaningfully informed clinical decision-making during cardiology outpatient consultations, although its interpretation and integration into electronic health records remained

inconsistent across providers (A'Court et al., 2022). Collectively, these applications illustrate that the principal clinical contribution of smartwatch technology is not to replace but to extend the temporal and spatial reach of arrhythmia surveillance, thereby narrowing the diagnostic gap that has historically limited early identification of asymptomatic or paroxysmal rhythm disturbances.

3.3. Clinical Evidence

The most influential body of evidence supporting smartwatch-based AF detection derives from several large-scale, prospective cohort studies specifically designed to evaluate consumer wearable technology at population scale. The Apple Heart Study, a prospective, single-arm cohort of 419,297 participants without a known history of AF, remains the largest study of its kind (Perez et al., 2019; Turakhia et al., 2019). Among participants, 0.52% received an irregular pulse notification during the study period; of those who subsequently underwent ambulatory ECG patch monitoring, the positive predictive value of the notification for detecting AF confirmed by simultaneous ECG was 84% (95% CI, 76–92%), while the positive predictive value for any detected irregularity was 71% (95% CI, 69–74%) (Perez et al., 2019). Notably, only 57% of participants who received a notification subsequently contacted a healthcare provider, and the study did not evaluate clinical outcomes such as stroke prevention, underscoring that a positive notification requires deliberate confirmatory clinical follow-up rather than representing a definitive diagnosis (Perez et al., 2019).

The Fitbit Heart Study similarly evaluated PPG-based irregular rhythm notifications in a large population of 455,699 participants using Fitbit wearable devices; among those who received a notification and underwent confirmatory ECG patch monitoring, the positive predictive value for AF was 98.2%, a notably higher figure than that observed in the Apple Heart Study, attributable in part to differences in algorithm design, notification thresholds, and confirmatory protocol (Lubitz et al., 2022). The earlier Health eHeart Study using the Cardiogram/DeepHeart smartwatch application, reported by Tison et al. (2018), similarly demonstrated that a deep neural network algorithm applied to smartwatch-derived PPG data achieved a sensitivity of 98% and specificity of 90.2% for detecting AF when compared against simultaneously recorded ambulatory ECG, providing early proof-of-concept evidence for passive AF detection using consumer wearables prior to the larger cohort studies.

Systematic reviews and meta-analyses corroborate and extend these individual cohort findings. Gill et al. (2022) conducted a systematic review and meta-analysis of smartphone- and smartwatch-based PPG technology for AF detection, reporting pooled sensitivity of 94.2% (95% CI, 91.5–96.1%) and pooled specificity of 96.0% (95% CI, 94.6–97.1%) across the included studies, while noting substantial heterogeneity in study design, reference standards, and population characteristics. Ramkumar et al. (2018), focusing specifically on single-lead portable ECG devices, reported a pooled sensitivity of 94% (95% CI, 91–96%) and specificity of 97% (95% CI, 95–99%) for AF detection relative to a 12-lead ECG reference standard, concluding that single-lead ECG devices demonstrate diagnostic performance approaching that of conventional ECG in appropriately selected populations. More recently, a systematic review and meta-analysis of smartwatch-derived single-lead ECG for early AF detection by Iqhrammullah et al. (2025) found that algorithm-based automated interpretation achieved a sensitivity of 86% and specificity of 94%, whereas manual interpretation of the same tracings by trained personnel improved sensitivity to 96% and specificity to 95%, highlighting the substantial diagnostic contribution of expert human interpretation over automated classification alone. A direct comparative study evaluating three commercially available smartwatch models—Apple Watch Series 5, Samsung Galaxy Watch Active3, and Withings Move ECG—found that automated diagnostic accuracy varied meaningfully between devices (sensitivity/specificity of 87%/86%, 88%/81%, and 78%/80%, respectively), and that expert manual interpretation further improved diagnostic accuracy for most models, reinforcing the conclusion that device-to-device heterogeneity remains clinically relevant (Abu-Alrub et al., 2022).

Taken together, this body of evidence—spanning large prospective cohorts of the highest available quality for this research question, together with multiple systematic reviews and meta-analyses—provides consistent, converging support for the diagnostic validity of smartwatch-based PPG and single-lead ECG technology in AF detection. Nonetheless, the evidence base remains predominantly derived from cohorts enriched for older age and pre-existing cardiovascular risk, and randomized controlled trial data directly linking smartwatch-based detection to hard clinical endpoints such as stroke reduction remain comparatively limited, a gap explicitly acknowledged by several of the cited investigators (Perez et al., 2019; Guo et al., 2022).

4. Discussion

4.1. Practical Implications and Social Impact

Beyond their diagnostic performance characteristics, smartwatch-based rhythm-monitoring technologies carry broader implications for patient health literacy, the accessibility of cardiovascular care, and the evolving relationship between patient-generated health data and clinical decision-making. By providing individuals with direct, continuous access to information about their own cardiac rhythm, these devices have the potential to enhance health literacy and to foster active patient engagement in the surveillance and management of chronic cardiovascular conditions (Hughes et al., 2023; A’Court et al., 2022). This shift toward patient-centered, self-initiated monitoring aligns with broader trends in digital health toward the democratization of diagnostic tools that were previously accessible only within clinical settings.

Wearable rhythm-monitoring technology also holds particular relevance for expanding access to cardiovascular screening and telemedicine, especially for populations in geographically remote or resource-limited settings where access to specialist cardiology services or ambulatory ECG monitoring is constrained (Hermans et al., 2022; Treeware & Lip, 2024). The integration of smartwatch-derived rhythm data into telemedicine consultations allows remote clinicians to review objective physiological data alongside patient-reported symptoms, potentially reducing the need for in-person visits for rhythm assessment and supporting more efficient triage of patients who require further in-person cardiological evaluation (Hermans et al., 2022).

At the same time, the growing volume of patient-generated health data raises important questions regarding its systematic integration into cardiological practice. A’Court et al. (2022) observed that although patient-initiated wearable rhythm data meaningfully informed clinical decisions in a proportion of outpatient cardiology consultations, mechanisms for structured documentation, standardized interpretation, and incorporation into the electronic health record remained inconsistent, and clinicians expressed uncertainty regarding the appropriate clinical weight to assign to consumer-grade device output relative to validated medical-grade diagnostic tests. This observation underscores a broader implementation gap: the technological capability to generate large volumes of longitudinal rhythm data has, in many healthcare systems, outpaced the development of standardized clinical workflows, reimbursement structures, and professional guidance for its interpretation and use (Hughes et al., 2023). A multidisciplinary survey of clinician and researcher perspectives on consumer-available digital health devices for AF detection similarly found broad recognition of their screening potential alongside persistent uncertainty regarding optimal confirmatory pathways, liability, and integration into standard-of-care workflows (Ding, Svennberg, Wurster, et al., 2020).

From a public health perspective, the scale of smartwatch adoption—illustrated by the enrollment of over 400,000 participants in the Apple Heart Study alone within a matter of months (Perez et al., 2019)—demonstrates the potential of consumer wearable technology to function as a large-scale, decentralized screening infrastructure, complementing traditional clinic- and hospital-based case detection. Realizing this potential responsibly, however, requires deliberate attention to equitable access, given that smartwatch ownership and digital literacy are not uniformly distributed across socioeconomic strata, raising the possibility that unstructured reliance on consumer wearable screening could inadvertently widen, rather than narrow, existing disparities in cardiovascular care documented across different income settings (Treeware & Lip, 2024; Tan et al., 2024).

4.2. Limitations and Challenges

Despite the substantial and growing evidence base described above, several important limitations and challenges constrain the current clinical application of smartwatch-based rhythm monitoring.

First, diagnostic performance is not uniform across devices, algorithm versions, or patient populations: comparative studies have demonstrated clinically meaningful differences in sensitivity and specificity between smartwatch brands and models, and diagnostic accuracy for single-lead ECG interpretation deteriorates when tracings are of poor signal quality or when interpreted without expert clinical input (Abu-Alrub et al., 2022; Iqhrammullah et al., 2025). Furthermore, most large validation cohorts have enrolled predominantly older, higher cardiovascular-risk, and disproportionately White populations in high-income countries, limiting the generalizability of reported diagnostic accuracy to younger individuals, populations with a lower pretest probability of AF, and patients from underrepresented racial, ethnic, or socioeconomic groups (Perez et al., 2019; Treeware & Lip, 2024).

Second, false-positive irregular rhythm notifications and the risk of consequent overdiagnosis represent a clinically significant concern. In the Apple Heart Study, even under a relatively conservative notification algorithm, a substantial minority of notifications did not correspond to confirmed AF on subsequent ECG monitoring (Perez et al., 2019), and Wyatt et al. (2020), evaluating clinical outcomes following Apple Watch-detected irregular pulse notifications in a real-world clinical population, found that a majority of patients who underwent subsequent diagnostic evaluation did not receive a confirmed diagnosis of AF, generating substantial downstream healthcare utilization—including specialist referrals, additional monitoring, and diagnostic testing—without a corresponding increase in confirmed pathology in most cases. This pattern illustrates the risk that widespread, unselected consumer screening may generate a considerable burden of low-yield clinical evaluations and associated healthcare costs.

Third, false or ambiguous alerts, as well as the psychological burden of continuous self-monitoring, can generate significant patient anxiety. Rosman et al. (2020) described clinical scenarios in which smartwatch-generated alerts, including both false positives and confirmed but asymptomatic AF episodes, contributed to heightened health anxiety and maladaptive monitoring behaviors among patients with known AF, while Tran et al. (2023) found that false AF alerts from smartwatches were associated with decreased perceived physical well-being and reduced confidence in the self-management of chronic symptoms among affected users. These findings indicate that the psychological consequences of consumer rhythm-monitoring technology extend beyond simple diagnostic misclassification and merit explicit consideration in clinical counseling regarding device use.

Fourth, the necessity of physician confirmation for any device-generated alert remains a fundamental and, at present, imperfectly implemented safeguard. Demkowicz et al. (2023), examining physician responses to Apple Watch-detected irregular rhythm alerts within a large health system, found considerable variability in how clinicians responded to and followed up on such alerts, with inconsistent application of confirmatory testing pathways, underscoring the absence of standardized clinical protocols for managing consumer wearable-generated arrhythmia alerts within routine practice. Relatedly, current smartwatch algorithms are calibrated predominantly to distinguish AF from sinus rhythm and generally lack validated capability to reliably identify other clinically important tachy- or bradyarrhythmias, meaning that a "sinus rhythm" or "inconclusive" classification cannot be interpreted as excluding all forms of cardiac rhythm pathology (Ramkumar et al., 2018; Hughes et al., 2023).

Finally, broader ethical and structural challenges merit consideration. Predel and Steger (2021), applying a principle-based ethical analysis, argued that commercial incentives underlying smartwatch-based AF screening may, in the absence of adequate regulatory oversight and clinician engagement, place users at risk through unclear communication of results, inadequate informed consent regarding the limitations of screening, and blurring of the boundary between consumer wellness products and regulated medical devices. Taken together, these limitations indicate that although the diagnostic potential of smartwatch-based rhythm monitoring is well supported by the existing evidence, its safe and effective clinical integration requires structured confirmatory pathways, clinician and patient education regarding the pretest probability and limitations of device-generated alerts, and continued research addressing device standardization, population diversity, and long-term patient-centered outcomes.

5. Conclusions

The accumulated evidence from large-scale prospective cohort studies, including the Apple Heart Study (Perez et al., 2019) and the Fitbit Heart Study (Lubitz et al., 2022), together with multiple systematic reviews and meta-analyses (Gill et al., 2022; Ramkumar et al., 2018; Iqhrammullah et al., 2025), indicates that modern smartwatches employing photoplethysmographic and single-lead electrocardiographic technology can identify atrial fibrillation with clinically meaningful sensitivity and specificity, extending the temporal reach of rhythm surveillance well beyond that achievable with conventional intermittent testing. This capability offers genuine, evidence-supported potential to support both primary prevention through opportunistic population screening and secondary prevention through longitudinal monitoring of patients with established arrhythmic disease (Guo et al., 2022; Hermans et al., 2022).

At the same time, the evidence reviewed here demonstrates that this diagnostic capability is accompanied by non-trivial risks of false-positive alerts, downstream low-yield clinical evaluation, patient anxiety, and inconsistent clinician response pathways (Wyatt et al., 2020; Rosman et al., 2020; Demkowicz et al., 2023). These limitations are proportionate in magnitude to the diagnostic benefits described and should not

be minimized: current evidence does not support the use of smartwatch-generated alerts as a standalone diagnostic endpoint, and physician-confirmed evaluation—typically via 12-lead ECG or extended ambulatory monitoring—remains an essential component of any clinical pathway incorporating consumer wearable technology (Perez et al., 2019; Ramkumar et al., 2018).

On balance, smartwatch-based rhythm monitoring should be regarded as a valuable, evidence-supported adjunct to, rather than a replacement for, conventional cardiological diagnostic tools. Its responsible clinical integration will require the development of standardized confirmatory protocols, targeted clinician education, equitable access strategies, and continued high-quality research—particularly randomized and outcome-oriented studies—to clarify the long-term impact of smartwatch-facilitated early detection on hard clinical endpoints such as stroke prevention across diverse patient populations.

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