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Wearable Photoplethysmography for the Detection of Paroxysmal Atrial Fibrillation after Cryptogenic Stroke: A Review of Digital Rhythm Monitoring

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Abstract

One ischaemic stroke in four ends its work-up unexplained, and in many of those patients the answer is atrial fibrillation that was simply not present while anyone was recording. Wrist-worn photoplethysmography offers months of rhythm sampling at negligible marginal cost, but it samples a pulse rather than an electrogram.

Objectives:*To review the evidence on the accuracy, yield and clinical utility of wearable photoplethysmography for identifying paroxysmal atrial l fibrillation after cryptogenic stroke, and to establish where it belongs alongside established prolonged monitoring.*

Material and Methods:*A narrative review. MEDLINE, Embase and the Cochrane Library were searched from January 2010 to May 2026 for r accuracy studies, randomised trials of prolonged monitoring, large-scale screening cohorts and society guidance. Values were extracted from the primary reports and tabulated without pooling.*

Results:*Detection is governed chiefly by how long the rhythm is watched: 3.2% with a 24-hour Holter, 16.1% with a 30-day recorder, and 12.4% % at one year rising to 30.0% at three years with an insertable monitor. Photoplethysmographic algorithms achieve pooled sensitivity and specificity near 94% and 97%; the three consumer-scale studies alerted 0.23% to 1% of users with predictive values of 84% to 98.2%. In the only randomised evaluation in stroke survivors, accuracy was 92.9% but the watch was worn on 21.2 of 30 days. Anticoagulation for device-detected atrial fibrillation cuts ischaemic stroke by about a third and raises major bleeding by three-fifths.*

Conclusion:*Wearable photoplethysmography is an entry point to the pathway, not a diagnostic test. Its value lies in extending the observation n window at a cost that permits extension, provided every positive signal is referred for electrocardiographic confirmation.*

Abbreviations:*AF – Atrial Fibrillation, ESUS – Embolic Stroke of Undetermined Source, ICM – Insertable Cardiac Monitor, PPG – – Photoplethysmography, ECG – Electrocardiogram, PPV – Positive Predictive Value.*

Keywords: *Photoplethysmography; Cryptogenic Stroke; Atrial Fibrillation; Wearable Devices; Rhythm Monitoring*

Introduction

A quarter of ischaemic strokes end their work-up without an identified mechanism. The construct of embolic stroke of undetermined source gives that group a shape: a non-lacunar infarct, no significant proximal stenosis, no major cardiac source, and so a presumed embolus of unknown origin [1,2]. It covers roughly one in six patients, who are younger than the stroke population as a whole, present with mild deficits, and recur at 4% to 5% a year [3].

The obvious inference —that an occult embolic source justifies empirical anticoagulation —has been tested three times and failed three times. Rivaroxaban was no better than aspirin and bled more [4]; dabigatran did not separate from aspirin [5]; apixaban, given to patients selected for markers of atrial cardiopathy, did not reduce

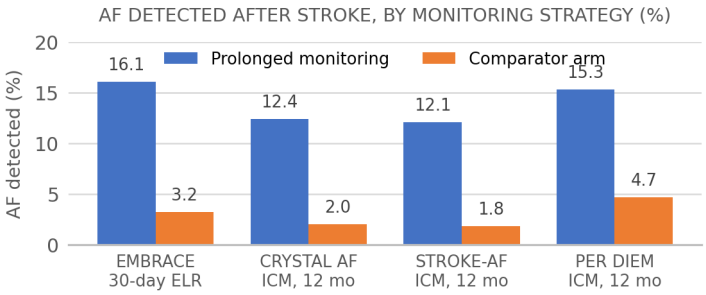

Figure 1: Atrial fibrillation detected in the randomised trials of prolonged monitoring after ischaemic stroke [7,8,9,10]. Populations and endpoints differ between trials.

Modality	Window	Signal	Principal limitation
24-hour Holter	1 day	Surface ECG	Window far shorter than the arrhythmia interval
Loop or patch recorder	14–30 days	Surface ECG	Skin tolerance; adherence falls after two weeks
Insertable monitor	Up to 3 years	Subcutaneous ECG	Invasive, costly, capacity-limited
Wrist photoplethysmography	Indefinite	Peripheral pulse	Not an electrogram; needs daily wear

Table 1: Ambulatory rhythm monitoring options after cryptogenic stroke.

recurrence [6]. The lesson is not that anticoagulation is useless here but that it works only when the target is real. Treating the label does nothing; treating documented atrial fibrillation is among the most effective interventions in vascular medicine.

That places the burden on detection. Atrial fibrillation that causes stroke is often paroxysmal, frequently asymptomatic and, by definition here, absent from the admission electrocardiogram. Detection is a sampling problem, and conventional practice samples briefly. Prolonged monitoring solves it, but the devices that monitor longest are the ones health systems can least afford to deploy widely.

Wrist-worn photoplethysmography inverts that economics. The sensor is already on millions of wrists, another month of observation costs nothing, and nothing is implanted or adhered. What it measures, though, is peripheral pulsatile blood volume rather than atrial electrical activity, and only while the wearer keeps the device on and reasonably still. This review examines what that trade buys, what it costs in certainty, and where the technique belongs after a cryptogenic stroke.

Material and Methods

Search strategy:

MEDLINE, Embase and the Cochrane Library were searched from January 2010 to May 2026. Search terms combined controlled vocabulary and free text for photoplethysmography,

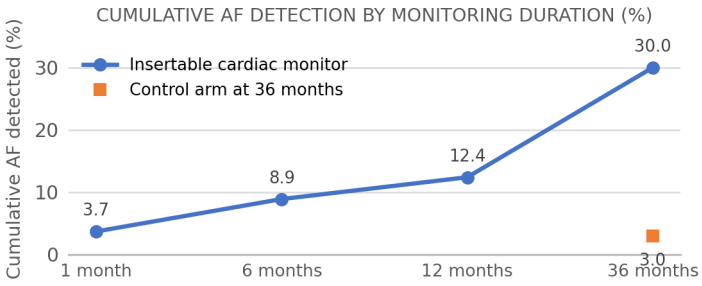

Figure 2: Cumulative detection with continuous insertable monitoring in CRYSTAL AF, by duration of observation, against the control arm at 36 months [8,11].

smartwatch, wearable device, atrial fibrillation, cryptogenic stroke, embolic stroke of undetermined source and ambulatory rhythm monitoring. Reference lists of society guidance, position papers and included reviews were hand-searched.

Eligibility and synthesis:

Randomised trials of prolonged rhythm monitoring after ischaemic stroke, diagnostic accuracy studies comparing photoplethysmographic algorithms against an electrocardiographic reference, large-scale screening cohorts and multisociety guidance were eligible. Single case reports, conference abstracts without full publication and studies of devices not commercially available were excluded. Values were extracted by one reviewer and checked by a second. The included studies differ substantially in population, reference standard, algorithm and duration of observation, so findings are presented descriptively and no pooling was attempted. No individual patient data were accessed and ethics approval was not required.

Results

Monitoring duration is the dominant variable

Four randomised trials frame the question and converge on a single point (Figure 1, Table 1). EMBRACE randomised 572 patients with a recent cryptogenic event to a 30-day event-triggered recorder or a second 24-hour Holter, finding atrial fibrillation of at least 30 seconds in 16.1% against 3.2%, with eight patients monitored per additional diagnosis [7]. CRYSTAL AF randomised 441 patients to an insertable monitor or conventional follow-up and reported 8.9% against 1.4% at six months and 12.4% against 2.0% at twelve [8].

Two later trials extended the finding beyond the cryptogenic label. STROKE-AF enrolled 496 patients whose stroke was attributed to large- or small-vessel disease and still found 12.1% against 1.8% at one year [9]; PER DIEM, comparing twelve months of implanted monitoring with 30 days of external recording in 300 patients, found 15.3% against 4.7% [10]. In both, roughly ten patients needed monitoring per additional case.

The three-year follow-up of CRYSTAL AF makes the relationship explicit (Figure 2). Cumulative detection in the

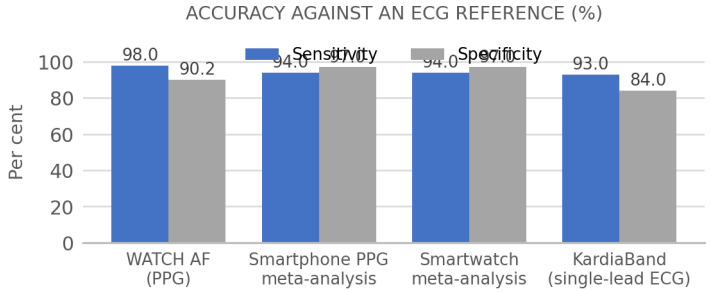

Figure 3: Sensitivity and specificity of photoplethysmographic algorithms against an electrocardiographic reference, with a single-lead wristband for comparison [14,15,16,17].

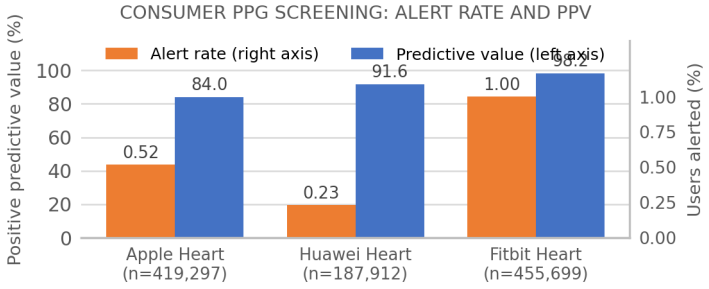

Figure 4: Alert rate and positive predictive value in the three consumer screening studies [12,18,19]. Confirmatory endpoints differ; see Table 2.

Study	Enrolled	Alert rate	PPV	Confirmatory test
Apple Heart [18]	419,297	0.52%	0.84	ECG patch, median 13 days after alert
Huawei Heart [19]	187,912	0.23%	91.6%	Clinical review and ECG
Fitbit Heart [12]	455,699	1.0%	98.2%	One-week ECG patch, concurrent

Table 2: Large-scale screening studies of consumer photoplethysmographic devices. Predictive values are not directly comparable: endpoint, algorithm and timing of the confirmatory recording all differ.

monitored arm was 3.7% at one month, 8.9% at six, 12.4% at twelve and 30.0% at 36 months, against 3.0% in the control arm [11]. The curve does not plateau within the life of the device. Detection is a property of the observation window more than of the technology, which is why a modality that can be worn indefinitely deserves attention even if each sample is less reliable.

Two features of these episodes matter for what follows. Most are silent — 74% of those found in the first six months of CRYSTAL AF caused no symptoms — so symptom-triggered recording cannot substitute [11].

How photoplethysmography works, and where it degrades

A photoplethysmographic sensor illuminates the skin and measures light returned from the microvascular bed. Each cardiac cycle produces a pulse wave, and the interval between successive peaks stands in for the R-R interval. Algorithms look for what fibrillation does to that series: loss of regularity, and a distribution of intervals no sinus rhythm generates. Implementations analyse overlapping multi-minute windows and require a run of consecutive irregular windows before alerting, trading sensitivity for a tolerable false alarm rate [12].

The technique fails in predictable ways. Motion corrupts the waveform, so most systems sample during inactivity and discard segments the accelerometer flags as contaminated, which is why wear during sleep contributes disproportionately to yield. Perfusion matters: cold peripheries, oedema and a loose fit all attenuate the signal. Most importantly, the pulse interval is a downstream surrogate. Frequent atrial or ventricular ectopy produces the same irregularity as fibrillation, and a secondary analysis of the largest screening study found that among notified participants without atrial fibrillation on subsequent patch monitoring, 40% had some other arrhythmia — ectopy predominating [13]. A photoplethysmographic alert identifies an irregular pulse. It does not identify atrial fibrillation.

Accuracy against an electrocardiographic reference

Formal accuracy studies are consistently favourable (Figure 3). The WATCH AF trial recorded smartwatch pulse waveforms alongside mobile electrocardiography in 672 hospitalised patients and reported sensitivity of 98.0% and specificity of 90.2% in its validation cohort, with a C-statistic of 0.97 [14]. Two meta-analyses give a similar picture from different literatures: pooled sensitivity of 94% and specificity of 97% across 17 studies of smartphone-camera photoplethysmography, and comparable figures across 20 smartwatch studies [15,16]. Single-lead electrocardiographic wristbands, a useful comparator, performed slightly worse in the earliest head-to-head work, with 93% sensitivity and 84% specificity against physician interpretation [17].

These numbers carry the caveats their authors attach. Almost all derive from supervised recordings in patients with a high prevalence of the target condition, often around cardioversion, where the arrhythmia is sustained and the trace is clean. No study in the smartphone literature satisfied every methodological criterion, and its authors judged the reported accuracy optimistic [16]. Free-living performance is the relevant quantity and is far less well characterised.

What happens at population scale

Three studies have deployed these algorithms across hundreds of thousands of users, and are more instructive than any accuracy statistic (Figure 4, Table 2). The Apple Heart Study enrolled 419,297 participants; over a median of 117 days, 2,161 (0.52%) received an irregular pulse notification, and among 450 returning an analysable patch, atrial fibrillation was present in 34%, with a positive predictive value of 0.84 [18]. The Huawei Heart Study screened 187,912 individuals, notified 0.23%, and confirmed atrial

fibrillation in 87.0% of those followed up, with a positive predictive value of 91.6% [19]. The Fitbit Heart Study enrolled 455,699 participants, generated detections in 1%, and reported a positive predictive value of 98.2% for concurrent atrial fibrillation on a one-week patch, holding at 97.0% in those aged 65 or over [12].

The gap between an 84% and a 98.2% predictive value is instructive rather than contradictory: endpoints, algorithms and the interval to confirmatory recording all differ. What the three share is the shape of the result. Alerts are rare, and enrichment for genuine arrhythmia among those alerted is high compared with unselected patch screening, where yield sits below 5% [20]. In a young population most alerts still arise in people who will never have a stroke —but that is a statement about pre-test probability, and a cryptogenic stroke cohort inverts it.

Evidence in stroke survivors specifically

Almost none of the screening literature comes from the population this review concerns. The Pulsewatch trial is the exception: 120 ischaemic stroke survivors of mean age 65 were randomised to a smartwatch and smartphone system alongside an electrocardiographic patch, or to the patch alone. It achieved 92.9% accuracy against cardiologist-adjudicated patch recordings and, the finding that matters most, participants wore the watch on 21.2 of 30 days [21]. The system had been co-designed with stroke survivors and their caregivers to maximise acceptability, so the shortfall in wear time is close to a best case. Roughly a third of the monitoring window was lost.

Adherence, not accuracy, is the binding constraint. A device with 95% sensitivity worn 70% of the time detects less than one with 85% sensitivity worn continuously, and the post-stroke population is the group least habituated to wearable technology: older, often with hemiparesis affecting one wrist, sometimes cognitively or visually impaired, frequently without a compatible smartphone. Yield projected from implanted-device trials, which record without cooperation, will overstate what a wrist sensor delivers.

From an alert to a treatment decision

Suppose the alert is genuine and an electrocardiogram confirms brief atrial fibrillation. What follows is less settled than the screening literature implies. Two randomised trials of anticoagulation for device-detected subclinical atrial fibrillation reported apparently divergent results: NOAH-AFNET 6 found no benefit from edoxaban and more bleeding and death in 2,536 patients [22], while ARTESiA, in 4,012, found apixaban cut stroke or systemic embolism from 1.24% to 0.78% per patient-year while major bleeding rose from 1.12% to 1.53% [23]. A study-level meta-analysis reconciled them: anticoagulation reduces ischaemic stroke by about 32% and raises major bleeding by about 62% —a real but finely balanced trade [24].

Tier	Candidate	Instrument	Action on a positive
Inpatient	All ischaemic stroke	Telemetry and 12-lead ECG	Anticoagulate on ECG diagnosis
First-line ambulatory	Cryptogenic stroke	14–30 day patch or loop recorder	Anticoagulate on ECG diagnosis
High probability	Atrial ectopy, atrial enlargement, raised natriuretic peptide	Insertable cardiac monitor	Adjudicate episode, then anticoagulate
Extended surveillance	Lower probability, implant declined or unavailable	Service-issued wrist photoplet hysmography	Refer for confirmatory ECG recording

Table 3: A tiered monitoring pathway after cryptogenic stroke, consolidating the randomised trials and current society guidance.

Two qualifications carry that finding into the post-stroke setting. Both trials enrolled patients with implanted devices, in whom the arrhythmia burden is measured continuously and accurately, not inferred from an intermittently worn optical sensor. And both enrolled patients in whom the arrhythmia was an incidental finding rather than the sequel to a stroke. That device-detected episodes carry any stroke risk at all was established in pacemaker cohorts [25], and absolute risk after a cryptogenic stroke is higher than in either setting, so the balance struck in these trials is not the balance that applies here. Screening also has to answer for its downstream effects. The LOOP study randomised 6,004 high-risk individuals and tripled both detection (31.8% against 12.2%) and anticoagulation (29.7% against 13.1%), yet the reduction in stroke or systemic embolism did not reach significance (4.5% against 5.6%; hazard ratio 0.80) [26]. Finding more atrial fibrillation is not the same as preventing more strokes.

Burden is the missing variable. Most subclinical episodes are short and sporadic, and loop recorder data show that brief runs often do not progress [29]. An intermittently worn optical sensor cannot measure burden at all, leaving a binary alert where the trials that inform treatment used continuous measurement.

Guidance has settled into a consistent position. European and American documents recommend prolonged monitoring after cryptogenic stroke and accept consumer devices as a means of initial detection, while insisting that anticoagulation follow an electrocardiographic diagnosis rather than an optical one [27,28]. The European Heart Rhythm Association puts it directly: these wearables are a screening front end, and a positive signal triggers a recording, not a prescription [30,31]. Cost-effectiveness modelling reaches acceptable ratios only when confirmatory testing and the consequences of false positives are built into the pathway [32].

Discussion

The evidence supports a narrower claim than enthusiasts make and a broader one than sceptics allow. Wearable photoplethysmography does not compete with the insertable

monitor on diagnostic grounds: it is less accurate, not continuous, and dependent on a patient doing something daily. It competes on the patient-months of observation a service can afford. Since detection scales with duration far more strongly than with per-sample fidelity, a modality that is mediocre but sustainable can outperform one that is excellent but rationed.

The arrangement this suggests is a tiered pathway rather than a choice (Table 3). Patients at highest probability —older, with atrial enlargement, frequent atrial ectopy on the admission Holter, or raised natriuretic peptides —warrant an implanted monitor, since the pre-test probability justifies the cost [33]. Those at lower probability, or who decline an implant or face a long wait, are candidates for wrist-worn monitoring as an extension of the window rather than a replacement. Every alert goes for confirmatory recording, and a negative wearable period never excludes the diagnosis.

Three things would have to be true for this to work, and none is established. Adherence would need active support rather than assumption. Confirmatory pathways would need capacity, since an alert that waits six weeks for a patch has lost most of its value. And the treatment threshold for brief, wearable-detected atrial fibrillation would need trials in this population rather than extrapolation from implanted-device cohorts whose burden measurement is not comparable.

The equity argument deserves stating plainly. Consumer devices are owned disproportionately by younger, wealthier and more digitally confident people, so a pathway resting on personal ownership would widen existing disparities. Only the version in which the service issues the device preserves the cost advantage without that cost, and it is the one worth evaluating [31,32].

Study limitations

This is a narrative rather than a systematic review: studies were selected against stated criteria but without duplicate screening of the full yield, and no risk-of-bias instrument was applied. Accuracy estimates derive predominantly from supervised recordings in enriched populations and almost certainly overstate free-living performance. The randomised monitoring trials used electrocardiographic devices, so their yield data reach photoplethysmography by inference. Only one randomised study has evaluated wrist-worn detection in stroke survivors, and it was not powered for yield. Algorithms are proprietary and revised without notice, so pooled estimates describe a moving target. The review addresses detection alone.

Conclusion

After a cryptogenic stroke, the probability of finding atrial fibrillation depends mainly on how long the rhythm is observed, and conventional practice observes it briefly. Wearable photoplethysmography extends that window at a cost that makes extension realistic, and its accuracy against an electrocardiographic reference is adequate for screening. It is not adequate for diagnosis: an irregular pulse is not a diagnosis, ectopy reproduces the signal, and the device works only when worn. As the first tier of a pathway in which every alert generates a confirmatory recording and adherence is actively supported, it is a reasonable addition to secondary prevention. As a substitute for electrocardiographic confirmation, or as grounds for anticoagulation, it is not.

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