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ORIGINAL ARTICLE

Accuracy of wristwatch-type photoplethysmography in detecting atrial fibrillation in daily life

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Aims Detection of asymptomatic paroxysmal atrial fibrillation is challenging. Smartphone- or smartwatch-based photoplethysmography is efficient at detecting irregular rhythms using pulse waves but is too complex for older patients. We aimed to evaluate the detection accuracy of atrial fibrillation by a wristwatch-type continuous pulse wave monitor (PWM) in daily life.

Methods and results Patients at high risk of atrial fibrillation but with no history of atrial fibrillation ($n = 163$; mean $CHADS_2$ score, 1.9) and patients with known atrial fibrillation ($n = 123$, including 34 with persistent atrial fibrillation) underwent PWM and telemetry electrocardiogram recording for 3 days. Risk of atrial fibrillation was judged using the 'Kyorin Atrial Fibrillation Risk Score', a scoring system based on previously reported atrial fibrillation risk scoring systems. The PWM assessed the presence of atrial fibrillation at 30 min intervals, and the results were compared with the telemetry electrocardiogram findings. The PWMs accurately diagnosed two patients with paroxysmal atrial fibrillation in the high-risk group. The PWMs accurately diagnosed 48 of the 55 patients with atrial fibrillation in the known-atrial fibrillation group. The PWM accuracy in detecting patients with atrial fibrillation was as follows: sensitivity, 98.0%; specificity, 90.6%; positive predictive value, 69.4%; negative predictive value, 99.5%. The respective values for intervals with atrial fibrillation were 86.9%, 98.8%, 89.6%, and 98.5%.

Conclusion The wristwatch-type PWM has shown feasibility in detecting atrial fibrillation in daily life and showed the possibility of being used as a screening tool.

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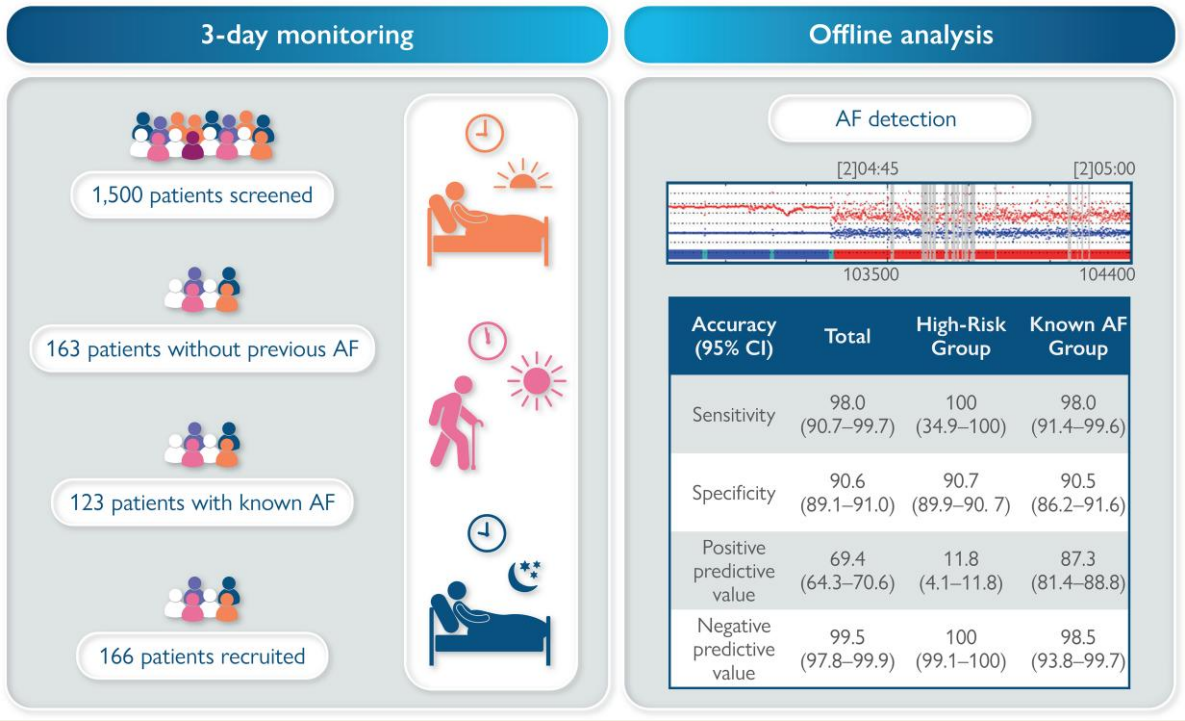
Graphical Abstract



Keywords Atrial fibrillation • Photoplethysmography • Wristwatch • Smartwatch • Mobile health technology

Introduction

Commonly affecting the older population, the incidence of atrial fibrillation (AF) has increased over the years. Patients with AF have a two-fold higher risk of mortality and five-fold higher risk of stroke than those without AF.[1,2] Resulting stroke is debilitating and often recurrent. Early diagnosis is crucial; however, detecting asymptomatic paroxysmal AF (PAF) is challenging. Long electrocardiogram (ECG) recording increases the AF detection rate.[3,4] The choice of device and monitoring duration is usually determined by symptoms and their frequency. Recent advances in mobile health technology promise early AF detection due to their non-invasiveness, simplicity, and continuous use. A recent trial with a smartphone camera-based photoplethysmography (PPG) demonstrated its feasibility in detecting AF.[5] The Apple Heart Study showed the efficacy of detecting undiagnosed AF with a smartwatch using ECG.[6] However, smartwatches and smartphones are not widely used in the older population.[7] Therefore, a simple and non-invasive wristwatch-type tool that does not require extra handling could be ideal.

A wristwatch-based continuous pulse wave monitor (PWM; Seiko Epson Corp., Suwa, Nagano, Japan) with an automatic AF diagnostic algorithm has shown its utility in detecting AF in patients with diagnosed AF during electrophysiological studies in the supine position and over 24 h with limited activity, respectively.[8,9] Whether the diagnostic accuracy remains high under unlimited activity and for a longer period has not been evaluated. This study aimed to evaluate the diagnostic accuracy of PWMs in daily life over 72 h in high-risk patients and those with known AF.

Methods

Study design and population

This was a prospective single-centre study conducted at Kyorin University Hospital. The study protocol was reviewed and approved by the Institutional Research Ethics Committee (R01-126, R01-184). Written informed consent was obtained from all participants. We recruited patients who were assessed for AF using the Kyorin AF Risk Score by the Cardiovascular or Endocrinology Medicine Departments at Kyorin University Hospital between October 2019 and October 2021 into two groups: the high-risk group (no AF but considered at risk) and the known-AF group (with prior AF diagnosis) (*Table 1*). This scoring system modifies the previously reported systems of the National Cerebral and Cardiovascular Centre (NCCC) and the 2016 European Society of Cardiology (ESC) Guidelines.[10,11] Risk factors adopted from both NCCC and ESC included advanced age, hypertension, overweight [body mass index (BMI) ≥25 kg/m^2), excessive drinking, current smoking, high non-high-density lipoprotein cholesterol (non-HDL-C) level, arrhythmias besides AF, coronary artery disease, and cardiac murmur, heart failure, thyroid dysfunction, diabetes mellitus, chronic obstructive pulmonary disease (COPD), obstructive sleep apnoea, chronic kidney disease (CKD), and habitual vigorous exercise.

Table 1 Kyorin AF risk score

Variable	+
Heart failure	1
Hypertension	1
Age	
60–69 years	1
70–79 years	2
≥80 years	3
Diabetes mellitus	1
Cerebral infarction	2
Vascular disease (peripheral artery disease or aortic plaque)	1
Valvular heart disease	1
Coronary artery disease (myocardial infarction or angina pectoris)	1
Hyperthyroid	1
Overweight (BMI > 25 kg/m^2)	1
COPD	
FEV1% 60–80%	1
FEV1% <60%	2
Sleep apnoea syndrome (obstructive; based on CPAP or SAS questionnaire ≥3 points)	1
CKD (Stage > 3)	1
Smoking	
Ex-smoker	1
Current smoker	1
Alcohol	
3 units/day	1
Paroxysmal atrial contraction on ECG	1

Kyorin AF risk score selects patients with a high risk of developing AF. Patients with a score of 3 or higher are considered a high risk of AF.
AF, atrial fibrillation; BMI, body mass index; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; CPAP, continuous positive airway pressure; ECG, electrocardiogram; FEV1%, percentage of forced expiratory volume in 1 s; SAS, sleep apnoea syndrome.

Table 2 SAS questionnaire

	Question	Yes
Q1	Do you snore loudly?	1.5
Q2	BMI over 25 kg/m^2?	1.5
Q3	Do you have or are you being treated for high blood pressure?	1.5
Q4	Do you feel sleepy during your waketime (during work, meetings, or driving)?	1.5
Q5	Do you wake up often during your sleep (including to urinate)?	1
Q6	Do you often feel tired, fatigued, or sleepy? Do you often have a headache in the morning?	1
Q7	Has anyone noticed that you stop breathing when you are asleep?	3

Patients with a score of 3 points or higher are considered to have SAS.
BMI, body mass index; SAS, sleep apnoea syndrome.

Clinical data were extracted from the medical records. ECGs within 30 days before enrolment were assessed. A commonly used 7-item sleep apnoea syndrome (SAS) screening questionnaire was used except in patient with diagnosed SAS (*Table 2*). SAS was suspected if the score was 3 points or higher. Serum creatinine levels within 1 year before enrolment were also documented.

High-risk group

Patients who fit the criteria were classified into the high-risk group: (i) no history of AF and (ii) Kyorin AF risk score of ≥3 points. The exclusion criteria included were as follows: (i) a history of AF; (ii) catheter or surgical ablation for AF; (iii) cardiac implantable device; and (iv) patients whom the principal investigator considered unsuitable.

Known-AF group

We also enrolled patients with known AF (PAF or persistent AF, with or without ablation for AF) to evaluate the diagnostic accuracy, given an estimated 1% prevalence of AF in the high-risk group based on a previous report.[12] AF was defined as at least one 30 s irregular rhythm without P waves. The exclusion criterion for the known-AF group was patients whom the principal investigator considered unsuitable.

Clinical data extracted from the medical records included age, sex, hypertension, heart failure, diabetes mellitus, cerebral infarction, vascular disease, coronary artery disease, hyperthyroidism, overweight (BMI > 25 kg/m^2), COPD, SAS, CKD, history of smoking, daily alcohol consumption (units), and paroxysmal atrial contraction (PAC) on previous ECGs. The $CHADS_2$ score for each patient was calculated based on clinical data.

Pulse wave monitor

Details of continuous PWM have been described previously.[8] Wristwatch-based PWM can perform a 72 h continuous recording and has an automatic AF diagnostic algorithm that performs frequency analysis of the pulse waves.[8,9] *Figure 1* shows a flow chart of the algorithm. The recorded pulse waves were analysed to obtain series of pulse period (PP) values. Each PP series value was normalized by the logarithmic ratio of successive values. When a PP series had a low dispersion, the rhythm was classified as sinus rhythm. When it was highly dispersed with low randomness, the rhythm was classified as a premature contraction. When the PP series had high dispersion and variability, the rhythm was defined as AF. The PWM algorithm evaluated the reliability of the pulse wave measurements. PWM motion noise and poor skin contact were determined by signal acceleration from the device and decrease in pulse wave amplitude, respectively. For this study, rhythm assessment for AF diagnosis was performed at 30 min intervals, and AF episodes lasting ≥30 min were classified as 'PWM-diagnosed AF'. Other intervals were classified as 'non-AF'. Intervals were excluded from rhythm analyses and the study if the pulse wave measurement reliability was judged low by the algorithm. Intervals with sufficient PPG but without telemetry ECG were also discarded. The intervals started at each half hour, and a maximum of 143 intervals was obtained during the 72 h period. The analysis was performed after the 72 h recordings. *Figure 2* shows a PWM offline analysis performed at Seiko Epson.

Telemetry ECG monitoring

Duranta (ZAIKEN, Tokyo, Japan) is a telemetry one-lead ECG monitor that transmits continuous ECG waveform data to a cloud server via an iPhone, so real-time ECG can be checked.[13,14] Transmitted ECG data for diagnostic reference were analysed by cardiologists (K.S. and N.M.N.), a clinical laboratory technician (H.S.), and a certified nurse (S.I.). The telemetry ECG recordings were divided into 30 min intervals. Inadequate recordings due to noise or missing tracing were excluded

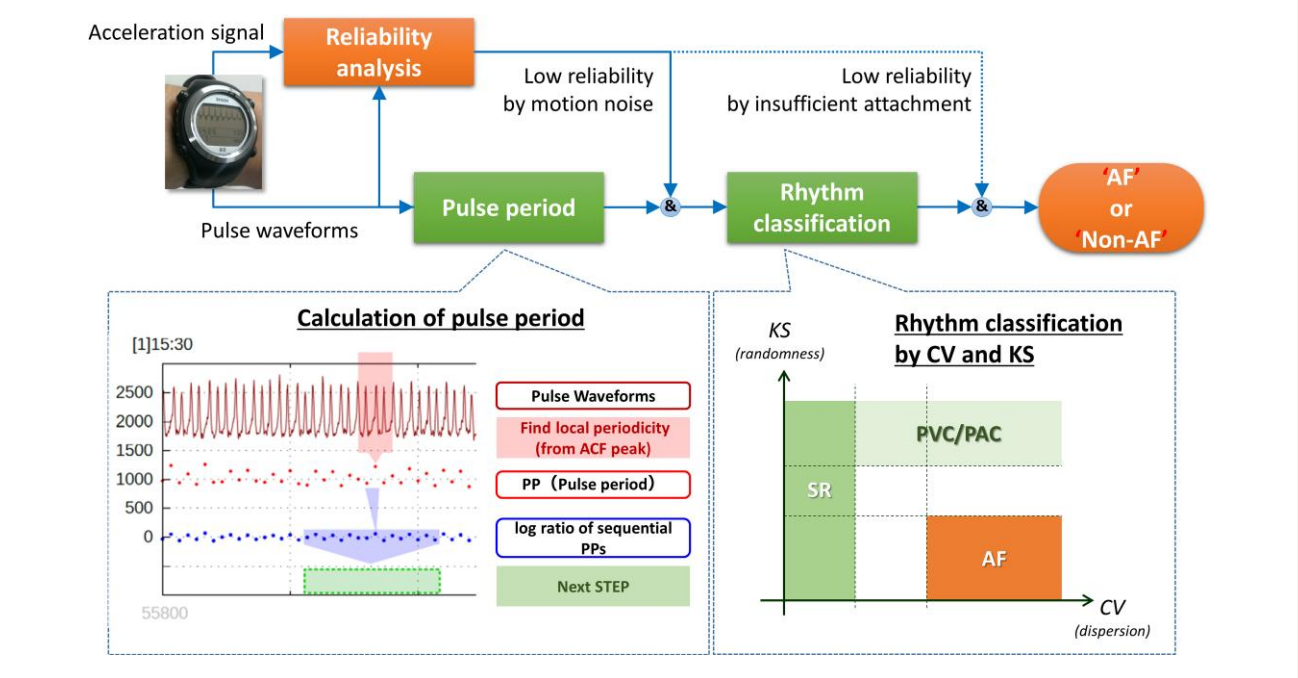


Figure 1 Pulse wave monitoring diagnostic algorithm. The recorded pulse wave is analysed to obtain a series of PP values, assumed to be the RR intervals. Then, the PP series is normalized using a logarithmic ratio of the successive values. When the PP series has low dispersion, the rhythm is classified as sinus rhythm. When the PP series has high variability and randomness (low KS), the rhythm is defined as atrial fibrillation (AF). Atrial tachycardia and atrial flutter with regular PP intervals are also classified as sinus rhythm. ACF, autocorrelation function; AF, atrial fibrillation; CV, degree of variation; KS, Kolmogorov-Smirnov difference; PAC, paroxysmal atrial contraction; PP, pulse period; PVC, paroxysmal ventricular contraction; SR, sinus rhythm.

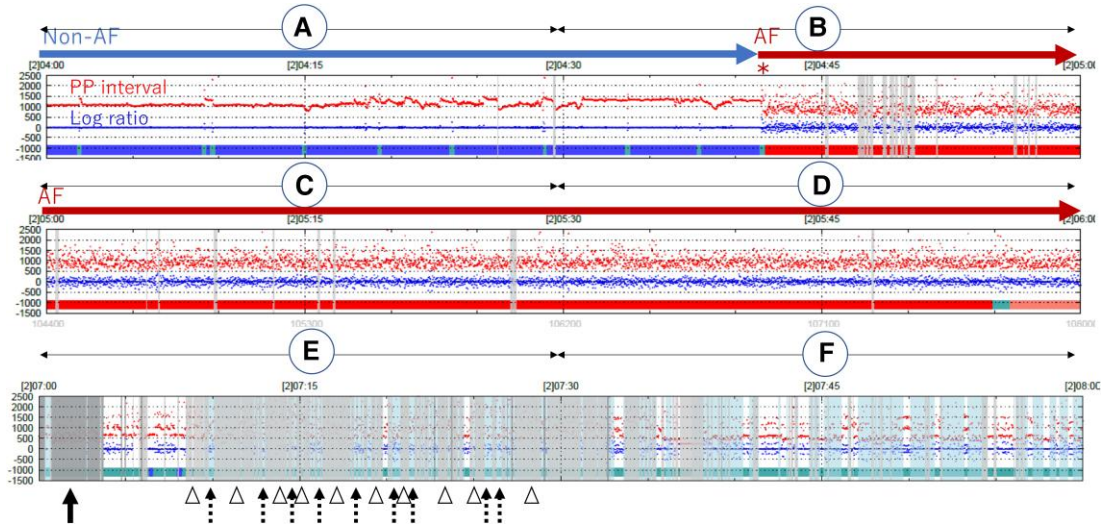


Figure 2 An example of pulse wave monitoring (PWM) analysis. PP intervals and logarithmic ratio of the successive values are shown. Interval (*A*) is classified as non-AF-based on their regular PP interval. AF starts from asterisk (*) in the middle of interval (*B*) and lasts over 30 min. Intervals (*B*), (*C*), and (*D*) are classified as AF. An arrow in interval (*E*) indicates that rhythm analysis is not performed due to poor skin contact. Arrowheads indicate poor reliability due to body motion. Dotted arrows indicate invalid analysis due to instability of the PP interval (mainly due to body motion and finger motion). Rhythm diagnosis is not performed at intervals (*E*) and (*F*). AF, atrial fibrillation; PP, pulse period.

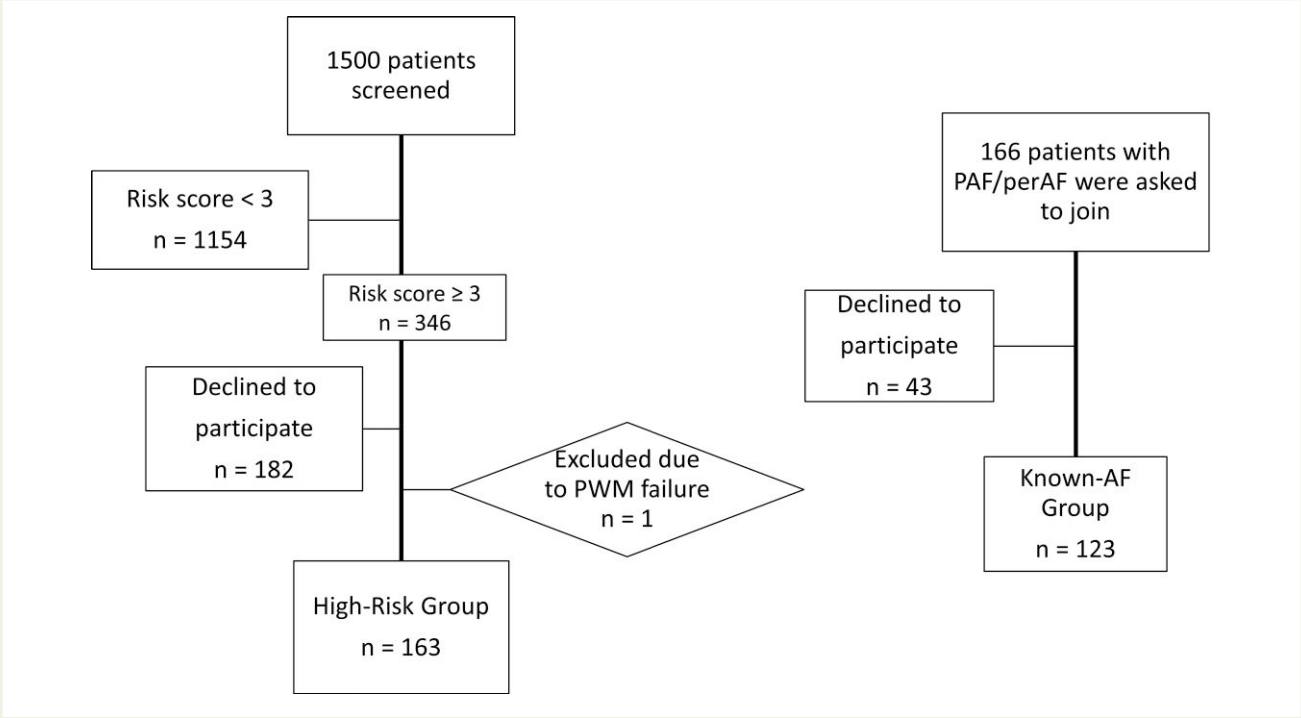


Figure 3 Flow chart of patient recruitment for the high-risk group. AF, atrial fibrillation; PAF, paroxysmal atrial fibrillation; perAF, persistent atrial fibrillation; PWM, pulse wave monitoring.

from the analysis. AF was diagnosed if it continued for ≥30 min (telemetry-diagnosed AF). Intervals were classified as 'non-AF' if they contained no AF or AF < 30 min (telemetry-diagnosed non-AF).

All participants wore the PWM and a telemetry ECG monitoring system continuously for 72 h and recorded a symptom diary.

Evaluation and statistical analysis

We evaluated the accuracy of 'PWM-diagnosed AF' per patient and interval using telemetry ECG as reference for confirmation. Patients were classified as having 'PWM-diagnosed AF' when at least one 30 min interval with AF was diagnosed or 'PWM-diagnosed non-AF' if no interval was diagnosed as AF by the PWM. Similarly, a patient was judged as having 'telemetry-diagnosed AF' if they had one or more intervals with telemetry-diagnosed AF or telemetry-diagnosed non-AF if they did not have any intervals with telemetry-diagnosed AF. The sensitivity, specificity, and positive and negative predictive values were calculated. The patient baseline characteristics were compared between the high-risk and known-AF groups. Continuous variables are expressed as means ± standard deviations, and categorical variables are expressed as counts and percentages of patients. Student's *t*-test analysed between-group differences for continuous variables, and the χ^2 test analysed differences for dichotomous variables. Statistical analyses were performed using EZR, version 1.54 (https://www.jichi.ac.jp/saitama-sct/SaitamaHP.files/download.html),[15] and statistical significance was set at $P < 0.05$.

Results

Patient characteristics

We screened 1500 patients in using the Kyorin AF risk score for high-risk group, and 164 patients were enrolled; however, one patient was excluded due to PWM dysfunction. For known-AF group, 166 patients were considered; 123 patients consented to participate (*Figure 3*). The known-AF group included 32 patients with persistent AF, 2 with persistent AFL, and 41 with previous AF ablation. The high-risk group comprised 163 patients; many of them were overweight or had diabetes mellitus, coronary artery, or valvular heart disease. *Table 3* shows participant baseline characteristics. The prevalence of hyperthyroidism and CKD in the known-AF group were higher than that in the high-risk group. The high-risk group had an AF risk score of 5.5 points and a $CHADS_2$ score of 1.9 points.

AF detection

In the high-risk group, telemetry ECG identified two patients with PAF (one symptomatic with AF lasting 3 h 9 min and one asymptomatic with AF lasting 14 h 27 min). PWM diagnosed AF in 17 patients, two with PAF confirmed by telemetry ECG and 15 with no AF episodes on telemetry ECG (false positives). (*Table 4*)

In the known-AF group, telemetry ECG detected 49 patients with AF lasting >30 min (17 with PAF and 32 with persistent AF). Of these, 48 patients were correctly diagnosed with AF by PWM. PWM also diagnosed AF in seven patients with no AF on telemetry ECG (false positives). (*Table 4*) Of 17 patients with PAF, 13 were asymptomatic. PWM failed to detect PAF in one patient due to rapid ventricular response with small dispersion of pulse interval.

The AF detection accuracy by PWM was as follows: high-risk group, sensitivity, 100%; specificity, 90.7%; positive predictive value, 11.8%; and negative predictive value, 100%; known-AF group, sensitivity, 98.0%; specificity, 90.5%; positive predictive value, 87.3%; and negative predictive value, 98.5%; and overall, sensitivity, 98.0%;

Table 3 Patient characteristics

Variable	High-risk group ($n = 163$)	Known-AF group ($n = 123$)	*P*-value
Age (years)	66 ± 12	67 ± 12	0.702
Female	32 (19.6)	32 (26.0)	0.252
Heart failure	26 (15.9)	31 (25.2)	0.072
Hypertension	132 (80.9)	102 (82.9)	0.757
Diabetes mellitus	78 (47.8)	29 (23.5)	<0.001
Stroke	15 (9.2)	13 (10.3)	0.694
Vascular disease	8 (4.9)	7 (5.6)	0.794
Coronary artery disease	94 (57.6)	15 (12.1)	<0.001
Valvular heart disease	17 (10.4)	4 (3.3)	0.023
Hyperthyroid	1 (0.6)	8 (6.5)	0.005
Overweight	73 (44.7)	37 (30.0)	0.014
COPD	7 (4.3)	6 (4.8)	1.000
Sleep apnoea syndrome	74 (45.3)	47 (38.2)	0.230
CKD (Stage > 3)	27 (16.5)	53 (43.0)	<0.001
Smoking	74 (45.3)	59 (48.0)	0.720
Excessive alcohol intake	6 (3.6)	10 (9.8)	0.123
Paroxysmal atrial contraction	11 (6.7)	9 (7.3)	>0.999
Kyorin AF risk score	5.5 ± 1.5	5.1 ± 2.4	0.155
$CHADS_2$ score	1.9 ± 1.0	1.8 ± 12	0.575
Previous AF ablation	0 (0)	41 (33.3)	<0.001

Values are reported as means ± standard deviations or *n* (%).
AF, atrial fibrillation; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease.

Table 4 Results of the 3-day monitoring period on pulse wave monitoring and telemetry ECG

Variable	AT/AF by ECG	Non-AF by ECG	Total
High-risk group			
AF by PWM	2 (2 PAF)	15	17
Non-AF by PWM	0	146 (2 PAT)	146
Total	2	161	163
Known-AF group			
AF by PWM	48 (16 PAF, 32 perAF)	7	55
Non-AF by PWM	1 (1 PAF)	67 (4 PAT, 2 perAFL)	68
Total	49 (17 PAF/AT, 32 perAF)	74	123

AF, atrial fibrillation; AT, atrial tachycardia; ECG, electrocardiogram; PAF, paroxysmal atrial fibrillation; PAT, paroxysmal atrial tachycardia; perAF, persistent atrial fibrillation; perAFL, persistent atrial flutter, PWM, pulse wave monitoring.

specificity, 90.6%; positive predictive value, 69.4%; and negative predictive value, 99.5%.

Other tachyarrhythmias detected on telemetry ECG

In the high-risk group, two patients had paroxysmal AT on telemetry ECG (one with a 50 min episode and one with repeated episodes for 9 h 22 min); these episodes were classified as non-AF due to their rhythm regularity. However, abrupt changes in pulse wave intervals were detected (*Figure 4*).

In the known-AF group, four patients had paroxysmal AT and two patients had persistent AFL on telemetry ECG; these episodes were diagnosed as non-AF by PWM due to their rhythm regularity.

Intervals with AF detected by PWM

Owing to the battery lifespan, continuous recording time for PWM was limited to 72 h. The total recording time in all 286 patients was 20 241.9 h, with an average of 70.8 ± 6.0 h. Reasons for shorter recording times included unexpected battery depletion ($n = 14$), incorrect operation by patients ($n = 6$), and wristband break ($n = 1$). A total of 40 055 intervals were obtained. Of these, 7022 intervals were excluded due to insufficient PWM monitoring. Thus, 33 033 intervals (82.5%) were eligible for comparison with telemetry ECG. Another 6963 intervals (17.4%) were excluded due to insufficient telemetry ECG; therefore, 26 070 intervals (65.1%) were analysed (*Figure 5*). PWM accuracy in detecting intervals with AF was as follows: high-risk group, sensitivity, 100%; specificity, 99.0%; positive predictive value, 5.5%; and negative predictive value, 100%; known-AF group, sensitivity, 86.9%; specificity, 98.5%; positive predictive value, 95.2%; and negative predictive value, 95.6%; and overall, sensitivity, 86.9%; specificity, 98.8%; positive predictive value, 89.6%; and negative predictive value, 98.5%.

False diagnosis by PWM

Seventy-two patients had PWM-detected AF, of which 22 were false positives. Reasons for false positives included noise due to poor PWM-skin contact ($n = 7$), body motion artefacts ($n = 8$), Wenckebach atrioventricular block ($n = 1$), significant sinus arrhythmia ($n = 6$), frequent PACs ($n = 11$), paroxysmal ventricular contractions (PVCs; $n = 1$), and other factors ($n = 2$). Some patients had multiple causes. With adequate skin contact, PWM correctly diagnosed PAC and PVC as 'non-AF'; however, the PWM diagnosis was false positive if skin contact was inadequate, or motion noise was present. Reasons for false-negative diagnoses were AF with a rapid ventricular response and relatively little irregularity ($n = 1$).

Symptom diary

In the high-risk group, six patients experienced palpitations during monitoring: PAF ($n = 1$), AT ($n = 1$), frequent PVCs ($n = 1$), and sinus rhythm ($n = 3$) on telemetry ECG.

In the known-AF group, 13 patients experienced palpitations during the study: PAF ($n = 5$), persistent AF ($n = 2$), AT ($n = 1$),

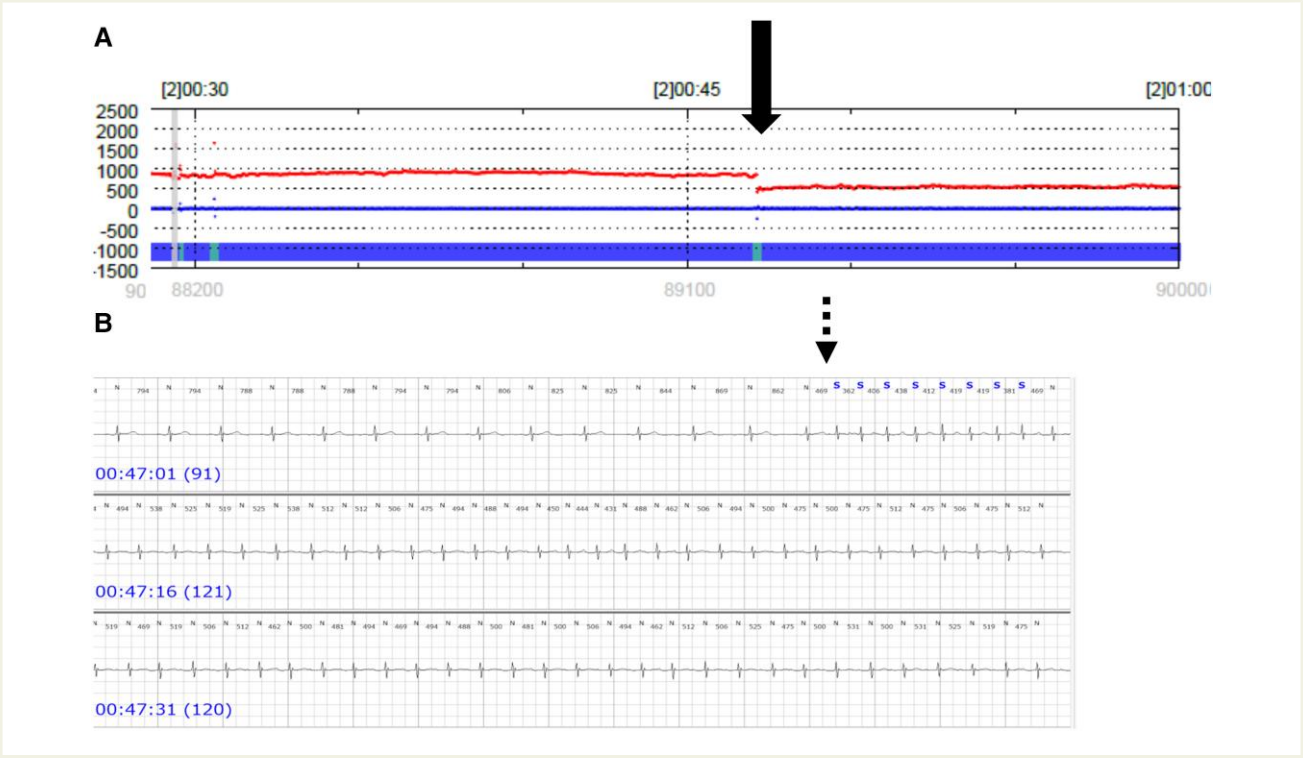


Figure 4 An example of a false-negative diagnosis. (*A*) PWM recordings; (*B*) Telemetry ECG recordings. PWM detects a sudden decrease in the pulse period interval (bold arrow), and atrial tachycardia is confirmed by telemetry (dotted arrow). As the rhythm diagnosis is based on the dispersion and randomness of the pulse period interval, this rhythm is not diagnosed as AF. AF, atrial fibrillation; ECG, electrocardiogram; PWM, pulse wave monitor.

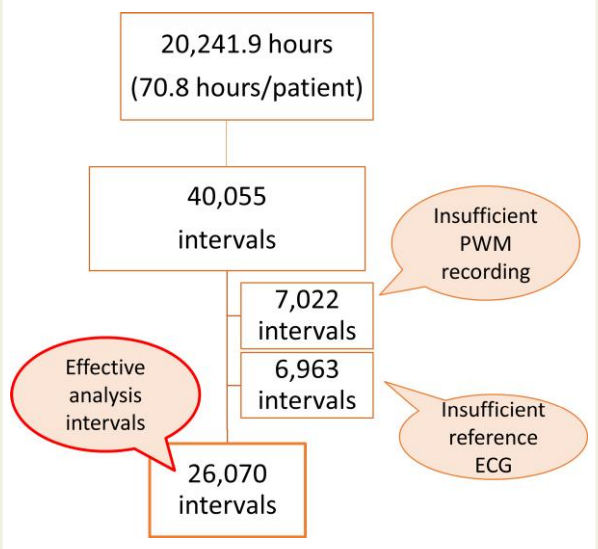


Figure 5 Flow chart of interval-based analysis. PWM recorded a maximum of 72 h in each patient. The total recording time in all 286 participants was 20 241.9 h. Intervals with insufficient PWM (7022 intervals; 17.5%) or ECG recordings (6.963 intervals; 17.4%) were excluded, so the analysis was performed on 26 070 intervals (65.1%). ECG, electrocardiogram; PWM, pulse wave monitor.

persistent AFL ($n = 1$), sinus tachycardia ($n = 1$), and normal sinus rhythm ($n = 3$) on telemetry ECG.

Thus, PWM was able to detect one asymptomatic PAF patient in the high-risk group and 12 asymptomatic PAF patients in the known-AF group.

Discussion

Accuracy of AF detection by PWM

Studies have reported the accuracy of PPG with a smartphone camera (sensitivity, 89.9%; specificity, 99.1%)[5] and a smartwatch coupled with a deep neural network in patients who underwent cardioversion for AF (sensitivity, 98.0%; specificity, 90.2%) and outpatients (sensitivity, 67.7%; specificity, 90.2%).[16] However, ECG and PPG in these studies were recorded over a short period upon symptom onset. PPGs with long-term efficacy have recently been reported. Avram *et al.* demonstrated the feasibility of detecting AF by PPG on a smartwatch. The participants wore both a smartwatch and wearable ECG for 28 days (sensitivity, 87.8%; specificity, 97.4%); however, the participants included both patients with and without AF. Accuracy based on patient characteristics remains unknown.[17] Väliaho *et al.*[18] demonstrated the accuracy of PPG in detecting AF. However, the study setting was limited; participants were inpatients and wore wristband type PPG for only 24 h. Therefore, the long-term efficacy and utility of PPG in daily life have not been fully evaluated.

The wristwatch-type PWM with an automatic AF diagnostic algorithm using frequency analysis allows continuous 3-day recording without charging and has a comparable accuracy, suggesting its utility in AF screening.[8] Owing to low prevalence of AF in the high-risk group, we recruited 123 patients for the known-AF group. Fifty-one patients had AF over the 3-day period. The diagnostic accuracy of PWM was adequate for clinical use. In the high-risk group, the positive predictive value was low; however, false positives included arrhythmias requiring ECG confirmation, such as frequent PAC/PVC with high burden and Wenckebach-type atrioventricular block. Thus, PWM can help select patients who require more detailed ECG monitoring. Longer battery life may improve AF detection.

Additionally, 82.5% of the intervals acquired by PWM over 3 days was analysable, which was higher than the 52.5%–59.5% of 24 h reported by Väliaho *et al.*[18], indicating device reliability.

AF risk score

Multiple scoring systems are used to predict the development of AF. Chamberlain *et al.*[19] reported that age, height, smoking status, systolic blood pressure, hypertension treatment, precordial murmur, left ventricular hypertrophy, left atrial enlargement, diabetes, coronary heart disease, and heart failure were risk factors for both Black and White patients. Schnabel *et al.*[20] reported that age, sex, BMI, systolic blood pressure, hypertension treatment, PR interval, clinically significant cardiac murmur, and heart failure were associated with AF. Kokubo *et al.* developed a risk score for AF incidence in the Japanese population that included age, sex, hypertension, overweight, excessive drinking, coronary artery disease, high non-HDL-C level, and arrhythmias besides AF. Patients with a score of 12 or ≥16 points had a respective 12% and 27% predicted 10-year probability of developing AF.[10]

In the Apple Heart Study (419 297 participants; mean age, 41 ± 13 years), irregular pulse was detected in 0.52%. In 450 participants who completed post-monitoring ECG, 153 participants had new AF.[6] Intermittent ECG recordings over 2 weeks in the STROKESTOP study identified AF in 3% of participants, aged 75–76 years, without history of AF.[21] In the mSToPS trial using 2-week continuous ECG monitoring, new AF was detected in 6.7 per 100 person-years among individuals with a median CHA_2DS_2-VASc score of 3.0.[22] In Framingham Heart Study, the lifetime risk of developing AF in persons of European ancestry aged 55 years was 33–37%.[23,24] The prevalence of AF in Japan is 2.1–2.7% in individuals in their 70 s and 2.8–3.2% in those in their 80 s, which are lower than in Europe.[25–27] The REAL-AF-based study revealed that previously unknown AF was documented at a rate of 3.7% per year among Japanese patients with a CHA_2DS_2-VASc score ≥1.0 using 14-day external loop monitoring.[12]

Based on these studies, to identify high-risk patients, we developed the Kyorin AF risk score, which incorporates CHA_2DS_2-VASc score variables, COPD, SAS, CKD, drinking, and smoking. In our study, new AF was detected in two patients in the high-risk group (1.2%) during the 3-day monitoring period.

The merit of the wristwatch-type PWM

According to stroke prevention guidelines, continuous ECG monitoring for 30 days is recommended to detect AF in patients after an acute ischaemic stroke or transient ischaemic attack with no apparent cause.[28] During the 30-day recording, ECG patches can cause skin irritation, and battery change is frequently required. In contrast, the wristwatch-type PWM can be worn continuously for 72 h. It requires 3.5 h for a full battery charge; otherwise, no additional operation is needed.

The number of smartphone users has increased but remains low in the older population in Japan. The Japanese Ministry of Internal Affairs and Communications reported that only 24.3% of those aged 70 years or older use smartphones or tablets.[7] Insufficient digital literacy is another barrier. However, a wristwatch-type PWM can be worn like any wristwatch and has a longer battery life than the standard smartwatch. The battery life of the PWM in this study lasted up to 3 days, although the current model has a battery life of 7 days. Hence, a wristwatch-type PWM is ideal for screening asymptomatic AF, especially in the older population.

Future aspects

Simple, convenient, and affordable, PWM devices may benefit high-risk patients who need closer ECG monitoring in populations. Guidelines on handling and interpreting the results are must be provided.[29,30]

Information collected by Seiko Epson PWM, including exercise quality and duration, the number of steps, and consumed calories, can be used by public health nurses and dietitians to guide patients with borderline lifestyle-related diseases. In AF screening, integration of a pulse monitoring algorithm and individualized goals into the system can enable PWM to directly advise patients via automated messages.

Limitations

Patients in this study wore both a PWM and telemetry ECG for 72 h daily. Artefacts due to body motion and poor PWM-skin contact were the main causes of ambiguous PP interval recordings. Of 40 055 intervals recorded by PWM, 7022 (17.5%) were excluded due to insufficient data. Notifications for artefacts and device adjustment can be developed to improve the recording. In addition, future technology could provide better noise elimination.

As PWM judges the rhythm based on the irregularity of the pulse interval, the current algorithm could not diagnose AT or AFL; however, sudden onsets and offsets were clearly recorded. With an improved algorithm to detect such sudden changes in pulse interval, the diagnosis of other paroxysmal tachycardias could be made.

In this study, false positive results were observed with frequent PACs or PVCs and Wenckebach-type atrioventricular block, which could not be distinguished by PWM and required ECG confirmation.

Additionally, ECG confirmation is needed for definitive diagnosis of AF in current guidelines.[31] Patients with PWM-diagnosed AF require a follow-up ECG for rhythm confirmation; however, the timing and duration of monitoring remains unsolved. ECGs with a long duration such as 2-week patch-type ECGs, telemetry ECG monitors, and event recorders would be suitable.

Finally, an 'AF episode' was defined in this study as AF lasting at least 30 min; the results may differ based on episode duration.

Conclusions

The wristwatch-type continuous PWM is useful in detecting AF in patients with previously diagnosed AF, but its utility in screening should be established in future study.

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Data availability

The data supporting the study are available upon reasonable request from the corresponding author.

Consent

Written informed consent was obtained from all participants.

Lead author biography

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