

ORIGINAL PAPER

Diagnostic accuracy of a new algorithm to detect atrial fibrillation in a home blood pressure monitor

Tomoyuki Kabutoya MD | Yasushi Imai MD | Satoshi Hoshide MD  |
Kazuomi Kario MD 

Division of Cardiovascular Medicine,
Department of Medicine, Jichi Medical
University School of Medicine, Tochigi, Japan

Correspondence

Kazuomi Kario, MD, Division of Cardiovascular
Medicine, Department of Medicine, Jichi
Medical University School of Medicine,
Shimotsuke, Tochigi, Japan.
Email: kkario@jichi.ac.jp

The authors evaluated a new algorithm for detecting atrial fibrillation (AF) using a home blood pressure monitor. Three serial blood pressure values were measured by the monitor in 16 patients with AF and 20 patients with sinus rhythm. The authors defined “monitor AF in irregular pulse peak (IPP) 25” as follows: (1) IPP: [interval of pulse peak – the average of the interval of the pulse peak] \geq the average of the interval of the pulse peak $\times 25\%$; (2) irregular heart beat: beats of IPP \geq total pulse $\times 20\%$; and (3) monitor AF: two or more irregular heart beats of the three blood pressure measurements. Cutoff IPP values were set at 20% (IPP20) and 15% (IPP15). The monitor’s AF specificity was 1.0 in IPP25, IPP20, and IPP15, and its sensitivity was 0.88 in IPP25, 0.94 in IPP20, and 1.0 in IPP15. The new algorithm had high diagnostic accuracy for detecting AF and a low false-positive rate.

1 | INTRODUCTION

Atrial fibrillation (AF) is not only a major risk factor for stroke, it also causes heart failure and cardiovascular death.¹⁻⁴ AF is a common disease and the prevalence of AF increases with age.^{2,5-7} Patients with paroxysmal AF have a stroke risk that is similar to that of patients with persistent AF.⁸ However, paroxysmal AF is often not detected by standard 12-lead electrocardiography (ECG), as was shown both in patients who have undergone pacemaker implantation⁹ and those with cryptogenic stroke who have received an implantable loop recorder.¹⁰ Pulse self-examination is useful to detect AF,¹¹ but paroxysmal AF is often asymptomatic.¹²

Hypertension is an important risk factor for the onset of AF.¹³ The causes of the onset of AF are an increase in the stress of the left atrium and autonomic nervous abnormality.^{14,15} An increase in the afterload caused by hypertension causes left atrial hypertrophy and fibrosis, which are related to AF. It has been shown that a reduction in blood pressure (BP) results in a decrease in the incidence of AF.¹⁶

Two studies revealed that home BP had a higher predictive value for cardiovascular events than office BP.^{17,18} Home BP monitors are now widely used, and the Japanese Society of Hypertension (JSH) guidelines recommend the use of a home BP monitor for the control of hypertension.¹⁹ The detection of AF by a home BP monitor would provide a significant contribution to community health.

Huang and colleagues²⁰ compared irregular heart beat and ECG tracings using four BP monitors in 2009. After their report, several reports about the detection of paroxysmal AF by home BP monitors have been published. The sensitivity values were near or equal to 100%, but the specificity values were 80% to 90%,²¹⁻²⁴ and the agreement between pulse rate and heart rate was not examined simultaneously. In the present study, we confirmed the correlation between the interval of the pulse wave and QRS wave, and we evaluated a new algorithm for the detection of AF by a home BP monitor.

2 | METHODS

2.1 | Patients

We enrolled 16 patients with AF and 20 outpatients with sinus rhythm. Findings from the ECG showed AF during all three BP measurements in the patients with AF and showed sinus rhythm during all three measurements in the 20 patients with sinus rhythm.

2.2 | Pulse wave analysis and ECG

For each patient, three BP measurements were taken after the patient had rested for ≥ 5 minutes in the lying position and with at least 30 seconds between measurements, using a validated home BP monitor (UA-1020, A&D).²⁵ The three BPs were measured by cuff inflation to

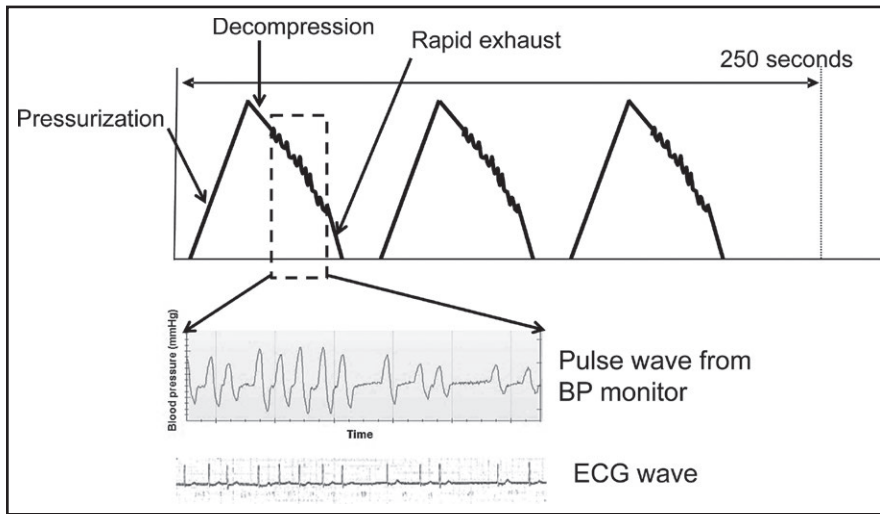


FIGURE 1 The mechanism of pulse wave analysis and the concordance between the interval of the pulse wave and QRS wave on electrocardiography (ECG). Pulse waves from the blood pressure (BP) monitor were obtained (three dotted rectangles)

a point over the patient's systolic BP, then cuff pressure was reduced gradually. The pulse wave was extracted by change of pressure after cuff deflation during each of three BP measurements. The interval of pulse waves were analyzed automatically by the UA-1020 during the decompression phase (Figure 1). We defined "monitor AF in irregular pulse peak (IPP) 25" as follows (Figure 2): (1) IPP: $|\text{interval of pulse peak} - \text{the average of the interval of the pulse peak}| \geq \text{the average of the interval of the pulse peak} \times 25\%$; (2) irregular heart beat (IHB): $\text{beats of IPP} \geq \text{total pulse} \times 20\%$; and (3) the "monitor AF (IPP25)": two or more IHB of the three BP measurements. We also confirmed the diagnostic accuracy when the cutoff IPP values were set at 20% (IPP20) and 15% (IPP15).

Simultaneously during the deflation phase of each BP measurement (when the AF detector of the device was operating), the ECG was recorded continuously in the II lead (Figure 1). We confirmed the concordance between the interval of the pulse wave and QRS wave in the ECG in five patients with AF (total 100 beats).

2.3 | Ethical issues

The internal review board of the Jichi Medical University School of Medicine approved this study. Written informed consent for the study was obtained individually from all of the patients.

2.4 | Statistical analysis

Data are shown as mean \pm SD or percentage. Student *t* test was used to analyze the continuous data of the patients with sinus rhythm and those with AF. Comparisons of parameters among the groups were made using the χ^2 test. The association between the RR interval in ECG and the pulse wave interval was assessed using Pearson correlation coefficient and a Bland-Altman graph. The sensitivity, specificity, and κ statistic for the AF diagnosis were assessed for the individual measurements for IHB and also for the monitor's detection of AF. SPSS version 20.0 software (IBM) was used for the statistical analysis. A probability value $<.05$ was considered significant.

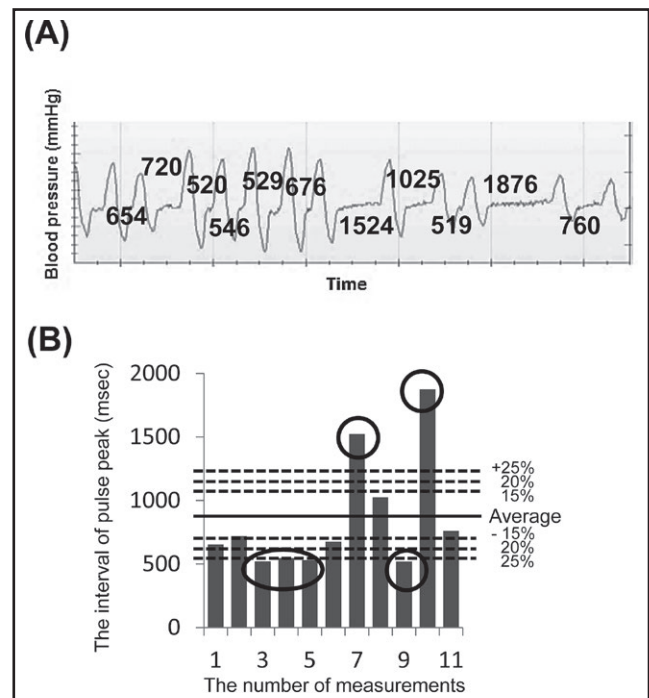


FIGURE 2 The atrial fibrillation detection algorithm and an example of irregular heart beat (IHB). A, The pulse peak record. The numbers indicate the interval of the pulse wave (ms). B, An example of IHB. The six encircled bars were judged as irregular pulse peak (IPP). The six beats of IPP were more than $20\% \times 11$ beats

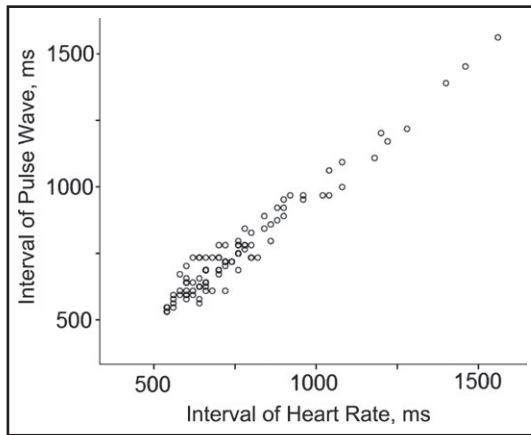
3 | RESULTS

The clinical characteristics of the patients with AF and those with sinus rhythm are summarized in Table 1. The age and sex distributions of the two groups were similar. The association between the RR interval on ECG and the pulse wave interval is illustrated in Figure 3. The correlation was very good ($R = .98$, $P < .001$) and the pulse wave interval measured by the home BP monitor reflected the RR interval

TABLE 1 Patient characteristics

	Sinus rhythm (n = 20)	AF (n=16)	P Value
Age, y	63 ± 11	66 ± 10	.36
Men, %	75	88	.49
Systolic BP, mm Hg	127 ± 17	128 ± 12	.82
Diastolic BP, mm Hg	77 ± 11	82 ± 9	.23
Pulse rate, beats per min	65 ± 11	78 ± 14	.003

Abbreviations: AF, atrial fibrillation; BP, blood pressure.

**FIGURE 3** The association between the interval of the pulse wave and heart rate

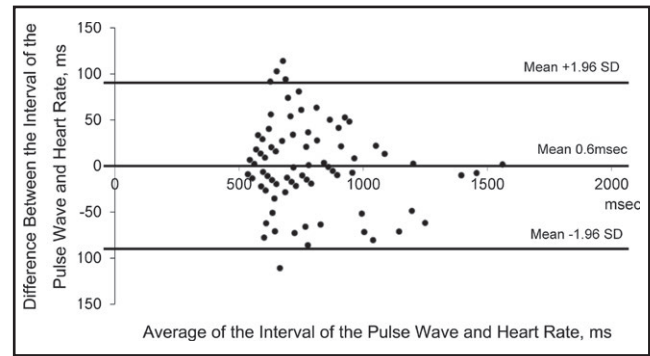
correctly. Figure 4 shows the Bland-Altman plot of the RR interval on ECG and the pulse wave interval values.

The accuracy for detecting IHBs was as follows (Table 2): the specificity was 1.0 in IPP25 and IPP20, and the sensitivity was 0.69 to 0.88 in IPP25 and 0.88 to 0.94 in IPP20. In IPP15, the specificity was 0.95 to 1.00 and the sensitivity was 1.0. One case of

TABLE 2 Accuracy of the monitor for detecting IHB

	Reading	IHB diagnosis +/-	Sensitivity	Specificity	κ
IPP 25%	First	14/22	0.88	1.00	0.89
	Second	11/25	0.69	1.00	0.71
	Third	14/22	0.88	1.00	0.89
IPP 20%	First	14/22	0.88	1.00	0.89
	Second	14/22	0.88	1.00	0.89
	Third	15/21	0.94	1.00	0.94
IPP 15%	First	16/20	1.00	1.00	1.00
	Second	17/19	1.00	0.95	0.94
	Third	16/20	1.00	1.00	1.00

Abbreviations: IHB, irregular heart beat; IPP, irregular pulse peak.

**FIGURE 4** Bland-Altman plot of the interval of the pulse wave and heart rate values

sinus rhythm was judged as IHB in the IPP15 setting. The second measurement was judged as IHB, but the first and third readings were not IHB. Monitor AF was defined as two or more IHBs of three BP measurements. The patient had only one IHB and thus was not classified as having monitor AF. Therefore, the specificity of the second reading in IPP15 was 0.95 (Table 2). However, all of the first and third readings in the patients with sinus rhythm were judged as sinus rhythm, and the specificities of both the first and third readings in IPP15 were 1.0. Monitor AF was purposefully defined as two or more IHBs of three BP measurements to avoid false-positive judgment, as would have occurred otherwise in this case. The monitor's accuracy for diagnosing AF is summarized in Table 3. The specificity of the monitor-diagnosed AF was 1.0 in IPP25, IPP20, and IPP15, and the sensitivity was 0.88 in IPP25, 0.94 in IPP20, and 1.0 in IPP15.

4 | DISCUSSION

The judgment of IHD at 100% specificity was obtained by IPP15, and the detection of AF at 100% specificity was obtained by both IPP20 and IPP15. The frequency of paroxysmal AF varies, and the detection rate increased in accord with the length of the observation period.^{9,10} Self-measured home BP can be taken every day and over a long term,

TABLE 3 Accuracy of the monitor for diagnosing AF

	Monitor detection AF +/-	Sensitivity	Specificity	κ
IPP 25%	14/22	0.88	1.00	0.89
IPP 20%	15/21	0.94	1.00	0.94
IPP 15%	16/20	1.00	1.00	1.00

Abbreviations: AF, atrial fibrillation; IPP, irregular pulse peak.

and thus the longer a home BP monitor is used, the more likely it is that paroxysmal AF will be detected.

A stroke event is often the first event of AF,²⁶ and screening and anticoagulation therapy for asymptomatic AF is useful to prevent stroke.²⁷ Pulse palpation is useful to detect AF,²⁸ but most instances of paroxysmal AF may not be detected. Pulse self-examination is a useful technique to detect paroxysmal AF,¹¹ but it might be inaccurate compared with home BP monitoring.

Hypertension is a major risk factor for the onset of AF,¹³ and BP reduction is useful to suppress AF.¹⁶ Home BP values are a better predictor of mortality and cardiovascular events compared with office BP,^{29,30} and thus the control of home BP is important. In Japan, roughly 40 million home BP devices are being used,³¹ and thus when the AF detection algorithm described in the present study is adapted, more individuals with asymptomatic AF will be identified. Hypertension is also a major risk for stroke in patients with AF,³² and patients with asymptomatic AF with hypertension have a high stroke risk. Increased BP is associated with cardiovascular events in patients with AF.³³ Thus, the necessary control of home BP could be greatly aided by the use of a home BP monitor.

The specificity of an AF detection algorithm of home BP monitor values was 80% to 90% in earlier studies,²¹⁻²⁴ and false-positive readings were observed. In the present study, the accuracy of IHD at IPP20 was 100% in three measurements. Our goal herein was to reduce false-positive results. When the cutoff was IPP15, sinus rhythm was judged as AF one time with three measurements. In their analysis, Stergiou and colleagues²² found that when two abnormal readings of three measurements were required to diagnose AF, the specificity increased. In this study, the specificity also benefited from defining monitor AF as two or more IHBs of three BP measurements. If the cutoff is set as IPP15, respiratory arrhythmia and premature beats might be overdiagnosed as AF. To detect AF, the cutoff level (IPP15 or IPP20) must be further investigated to obtain the best sensitivity and specificity.

5 | STUDY LIMITATIONS

This study has some limitations. First, arrhythmias other than AF were not included. Further studies including arrhythmias other than AF and more cases are needed to further evaluate the AF detection algorithm. Second, the specific definitions for IPP and IHB were not validated; thus, we compared three different IPP cutoff levels (15%, 20%, and 25%). The optimal level of IPP and IHB should be investigated by further studies.

6 | CONCLUSIONS

Our new algorithm for a home BP monitor had high diagnostic accuracy for detecting AF. The quality of the control of hypertension might be improved in terms of the detection of AF by using the algorithm equipped in a home BP monitor at IPP15 and IPP20 after further evaluations of sensitivity and specificity.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare related to this study.

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