

# Agreement Between Automated and Human Measurements of Heart Rate in Patients With Atrial Fibrillation

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**Background:** The accuracy of heart rate (HR) measurement by automated blood pressure monitors in patients with atrial fibrillation (AF) remains unclear. The authors investigate the agreement between HR measurements by 2 automated devices and human counting in patients with AF. **Methods:** In 47 patients with persistent AF, HR was recorded using 2 automated blood pressure monitors: Omron M5-I and Microlife BPA100 Plus. Human counting of HR by a stethoscope was used as the reference. For each method, 3 readings were made and the mean was calculated for comparison. In addition to Wilcoxon signed rank test, the correlation between HR measurements by automated devices and human counting was determined using Spearman's rank correlation coefficient ( $r$ ), and the agreement between HR measurements by both devices and human counting was validated by the Bland-Altman plot and intraclass correlation coefficient (ICC). **Results:** Overall, we found no significant difference in HR measurements between devices and human counting (Omron vs human counting,  $81.1 \pm 11.1$  vs  $80.2 \pm 10.8$  beats per minute [bpm];  $P = .21$ ,  $r = 0.911$ ; ICC, 0.954; Microlife vs human counting,  $81.3 \pm 10.8$  vs  $80.2 \pm 10.8$  bpm;  $P = .22$ ,  $r = 0.842$ ; ICC, 0.912). However, in patients with HR greater than 80 bpm, the HR measured by the Microlife device was significantly higher than that measured by human counting ( $91.1 \pm 5.2$  vs  $87.1 \pm 8.6$  bpm,  $P = .034$ ). **Conclusion:** There was a high agreement between HR measurements by 2 automated devices and human counting, but the Microlife device may overestimate HR in AF patients with HR greater than 80 bpm.

**KEY WORDS:** atrial fibrillation, automated sphygmomanometers heart rate, human counting

Hypertension is the most common risk factor for atrial fibrillation (AF), with a prevalence rate of 1% to 2% in the general population.<sup>1,2</sup> Several trials have shown a 60% to 70% prevalence of hypertension in AF population.<sup>3,4</sup> The introduction of oscillometric

automated blood pressure (BP) monitors has simplified the task of self-monitoring of BP, and has been endorsed by several medical societies.<sup>5,6</sup> Commercialized automated oscillometric devices with specific AF-detecting algorithms have sensitivity and specificity of approximately 95% to 97% in recognition of AF.<sup>7</sup> The devices show a warning symbol on the screen when the algorithm detects irregular heartbeats, which can be used as a reliable screening instrument for early detection of AF.<sup>8–10</sup> The detection of AF could prompt patients to seek medical help for a definite diagnosis of AF. For patients

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with hypertension, AF-detecting automated BP monitors may promote daily screening of AF and prompt implementation of strategies for stroke prevention.<sup>11</sup>

Conventional sphygmomanometers are used to detect Korotkoff sounds to determine systolic and diastolic BPs manually. Automated BP monitors calculate BP by detecting oscillations transmitted from the brachial artery to the cuff.<sup>12</sup> Most automated BP monitors are validated and calibrated in subjects in sinus rhythm (SR).<sup>13</sup> Although correct measurement of BP may be difficult given the high variability of heart rate (HR) and stroke volume caused by AF,<sup>14</sup> many reports showed a high agreement in BP measurements between conventional sphygmomanometers and automated BP monitors in AF patients.<sup>14–16</sup> Frequently, automated BP monitors also provide HR measurements. Among patients in SR, the intervals between pulse waves are relatively unchanged and can be used to calculate HR while using automated oscillometric BP monitors. However, the accuracy of HR recorded by automated devices in AF patients is not clear. The present work investigated the accuracy of HR measured by automated oscillometric BP monitors in patients with AF using human counting of heartbeat derived from a stethoscope on the anterior chest as the reference.

## Methods

### Study Population

We performed a cross-sectional study of 47 patients with persistent AF in a single center. Inclusion criteria were being older than 20 years, presence of AF confirmed by electrocardiography before measurement, and completion of written informed consent for participation. All patients were enrolled in our outpatient clinics and were ambulatory and stable. Exclusion criteria were hemodynamic or respiratory instability, moderate to severe aortic insufficiency, and upper arm circumferences of less than 26 cm or greater than 35 cm. The restriction of upper arm circumstances is in accordance with the American Heart Association recommendation for a standard cuff bladder.<sup>5</sup> The study period was from January 1, 2014, to January 31, 2016.

From each patient, we obtained demographic variables such as age; gender; associated comorbidities such as congestive heart failure, coronary artery disease, valvular heart disease, hypertension, peripheral artery disease, diabetes mellitus, stroke, hyperlipidemia, hyperthyroidism, chronic kidney disease, and smoking status; and medications currently used including aspirin, anticoagulants, amiodarone, digoxin, renin-angiotensin system blockades,  $\alpha$ -blockers,  $\beta$ -blockers, calcium channel blockers, diuretics, nitrates, oral antidiabetic drugs, and statins. The CHA<sub>2</sub>DS<sub>2</sub>-VASc score (congestive heart failure, hypertension, age  $\geq$  75 years

[2 points], diabetes, stroke [2 points], vascular disease, age of 65–74 years, and female gender) was calculated to estimate the stroke risk.<sup>17</sup>

### Study Protocol

Electrocardiography was performed to confirm the presence of AF in each patient. The procedure was explained to each patient, and a written informed consent was obtained. Before BP measurement, upper arm circumferences were measured to allow the correct choice of cuff size. We used 2 automated oscillometric BP monitors, Omron M5-I Professional (Medizintechnik, Mannheim, Germany) and Microlife BPA100 Plus (Microlife, Heerbrugg, Switzerland), according to the manufacturers' instructions. Both devices have been validated according to the European Society of Hypertension International Protocol or Association for the Advancement of Medical Instrumentation.<sup>18–20</sup> Regarding AF detection, the Microlife devices had built-in AF-detecting algorithms, showing the warning symbol on the screen if AF was detected, whereas the Omron devices were conventional automated oscillometric BP monitors. Each patient underwent HR measurement by human counting and 2 automated devices.

Patients sat at a table in a quiet room with adequate resting for 30 minutes before measurement. The protocol is presented in Table 1.

Measurements were separated by 5-minute intervals. Three rounds of measurement were performed to obtain the average HRs. Each measurement of BP was taken in the same arm to ensure consistency and accuracy.

**TABLE 1** The Study Protocol

Human counting of heartbeats by a stethoscope on the anterior chest for 1 min.
5-min interval
Test device 1 (Omron M5-I)
5-min interval
Test device 2 (Microlife BPA100 plus)
5-min interval
Human counting of heartbeats by a stethoscope upon anterior chest for 1 min
5-min interval
Test device 2 (Microlife BPA100 plus)
5-min interval
Test device 1 (Omron M5-I)
5-min interval
Human counting of heartbeats by a stethoscope upon anterior chest for 1 min
5-min interval
Test device 1 (Omron M5-I)
5-min interval
Test device 2 (Microlife BPA100 plus)

The measurement of BP was taken in the same arm in each step.

## Statistical Analysis

The continuous variables are expressed as mean (standard deviation) and/or median (interquartile range), and the categorical variables are expressed as number and percentage. Comparison of HRs between automated devices and human counting was performed by Wilcoxon signed rank test because the numerical value of HR was not normally distributed. The correlation was determined using the Spearman's rank correlation coefficient ( $r$ ). The intraclass correlation coefficient and the Bland-Altman plot were used to determine the agreement between measurements from automated devices and human counting. We also performed a subgroup analysis with stratification on manually counted HR greater than or less than 80 bpm.

## Results

Totally, 47 patients were enrolled, of which 42 (89%) were detected as having AF by Microlife and 5 (11%) were not. The baseline characteristics of the study subjects are shown in Table 2. Among the 47 enrolled

patients, the mean age was 76.2 years, with male dominance (59.5%). The average BP was 146/81 mm Hg. As for the comorbidities, 42.5% of the studied patients had hypertension, 31.9% had diabetes, and 25.5% had hyperlipidemia/smoking status. The average CHA<sub>2</sub>DS<sub>2</sub>-VAsC score was 2.8; 46.8% of the studied patients were prescribed with anticoagulants, and 38.3% were prescribed with aspirin. Regarding HR control, 55.3% of the patients received  $\beta$ -blockers, 34% received digoxin, and 25.5% received calcium channel blockers.

Among the 47 enrolled patients, the mean HR measured by human counting was  $80.2 \pm 10.8$  bpm. We found no significant difference in HR measurements between the 2 automated devices and human counting (Omron vs human counting,  $81.1 \pm 11.1$  bpm,  $P = .21$ ; Microlife vs human counting,  $81.3 \pm 10.8$  bpm,  $P = .22$ ). After stratifying the patients based on human-counting HR greater than or less than 80 bpm, we found higher HRs measured by Microlife in comparison with human counting in patients with human-counting HR greater than 80 bpm ( $91.1 \pm 5.2$  vs  $87.1 \pm 8.6$  bpm,  $P = .034$ ) (Table 3).

**TABLE 2** Patient Demographics, Comorbidities, Medications, and Risk Score for Stroke

Variables	All	AF identified by Microlife	AF not Identified by Microlife
Patients, n	47	42	5
Age, mean (SD), y	76.2 (9.4)	75.2 (8.2)	78.3 (7.6)
Male, %	59.5	57.1	80.0
Blood pressure, mm Hg	146/81	141/84	151/75
Human-counting HR	$80.2 \pm 10.8$	$79.6 \pm 11.6$	$90.5 \pm 10.2$
Comorbidities, n (%)			
CHF	7 (14.8)	5 (11.9)	2 (40.0)
CAD	8 (17.0)	7 (16.7)	1 (20.0)
VHD	6 (12.7)	6 (14.3)	0
HTN	20 (42.5)	18 (32.9)	2 (40.0)
PAD	2 (4.2)	1 (2.4)	1 (20.0)
DM	15 (31.9)	12 (28.6)	3 (60.0)
Stroke	8 (17.0)	8 (9.0)	0
Hyperlipidemia	12 (25.5)	9 (21.4)	3 (60.0)
Hyperthyroidism	4 (8.5)	4 (9.5)	0
CKD	6 (12.7)	4 (9.5)	2 (40.0)
Smoking	12 (25.5)	11 (26.2)	1 (20.0)
Medications, n (%)			
Aspirin	18 (38.3)	16 (38.1)	2 (40.0)
Anticoagulants	22 (46.8)	21 (50)	1 (20.0)
Amiodarone	3 (6.3)	2 (4.8)	1 (20.0)
Digoxin	16 (34.0)	14 (33.3)	2 (40.0)
ACEIs/ARBs	18 (38.3)	15 (35.7)	3 (60.0)
$\alpha$ -Blockers	5 (10.6)	5 (11.9)	0
$\beta$ -Blockers	26 (55.3)	23 (54.8)	3 (60.0)
CCBs	12 (25.5)	10 (23.8)	2 (40.0)
Diuretics	17 (36.1)	16 (38.1)	1 (20.0)
Nitrates	6 (12.7)	5 (11.9)	1 (20.0)
OADs	9 (19.1)	6 (14.3)	3 (60.0)
Statins	10 (21.2)	9 (21.4)	1 (20.0)
Risk score for stroke			
CHA <sub>2</sub> DS <sub>2</sub> -VAsC	2.8	2.8	2.9

Abbreviations: ACEIs, angiotensin-converting-enzyme inhibitors; AF, atrial fibrillation; ARBs, angiotensin receptor blockers; CAD, coronary artery disease; CCB, calcium channel blocker; CHF, congestive heart failure; CKD, chronic kidney disease; DM, diabetes mellitus; HTN, hypertension; OAD, oral antidiabetic drug; PAD, peripheral artery disease; VHD, valvular heart disease.

**TABLE 3** Mean Values of Heart Rate Measured by Automated Devices and Human Counting

	Human Counting		Automated Devices				
	HR, bpm	Omron			Microlife		
		HR, bpm	D, bpm <sup>a</sup>	P <sup>b</sup>	HR, bpm	D, bpm <sup>a</sup>	P <sup>b</sup>
All, mean (SD)	80.2 (10.8)	81.1 (11.1)	+0.8 (0.41)		81.3 (10.8)	+1.6 (0.58)	
Median (IQR)	80 (73–86)	82 (73–87)		.21	82 (75–89)		.22
Manually measured HR < 80 bpm, n = 22							
Mean (SD)	71.7 (9.2)	72.2 (2.5)	+0.5 (0.22)		71.6 (7.4)	−0.1 (0.23)	
Median (IQR)	71 (65–76)	73 (64–81)		.18	77 (63–81)		.41
Manually measured HR ≥ 80 bpm, n = 25							
Mean (SD)	87.1 (8.6)	88.2 (6.9)	+1.8 (1.51)		91.1 (5.2)	+4.2 (2.53)	
Median (IQR)	85 (80–93)	86 (82–92)		.45	88 (82–95)		.034

Abbreviations: bpm, beats per minute; HR, heart rate; IQR, interquartile range.

<sup>a</sup>Difference between automatic devices and human counting.

<sup>b</sup>Compared with human counting using Wilcoxon signed rank test.

Overall, the Spearman's rank correlation coefficients ( $r$ ) between the HRs measured by the 2 automated devices and human counting were high (Omron vs human counting,  $r = 0.911$ ; Microlife vs human counting,  $r = 0.842$ ) (Table 4; Figure 1A, B). However, we found a relatively weak correlation between the HRs measured by Microlife device and human counting ( $r = 0.538$ ) in patients with human-counting HR greater than 80 bpm (Table 4 and Figure 1F). Most of the intraclass correlation coefficients between different measurements were higher than 0.85 except in patients with human-counting HR greater than 80 bpm (intraclass correlation coefficient, 0.775) (Table 5). The Bland-Altman plot shows a positive bias of HR indicating an overestimation by Microlife in patients with human-counting HR greater than 80 bpm (Figure 2).

## Discussion

In this study, we used 2 different automated BP monitors to measure HRs for AF patients. One was Omron, which is one of the most widely used automated BP monitors across Europe and Asia, and the other was Microlife BPA-100, which is equipped with a specific AF detection algorithm. In general, we found a high agreement of HR measurements between the 2 automated BP monitors and human counting in patients with AF. Nevertheless, a relatively weak correlation between HRs measured by Microlife and human counting was noted in patients with human-counting HR greater than 80 bpm. The Microlife BPA-100 automated BP monitor overestimated HRs in AF patients with a higher HR.

With an automated device, patients can measure both their BP and HR. Although investigators have suggested that there was no impact on the accuracy of BP measurement using automated devices in patients

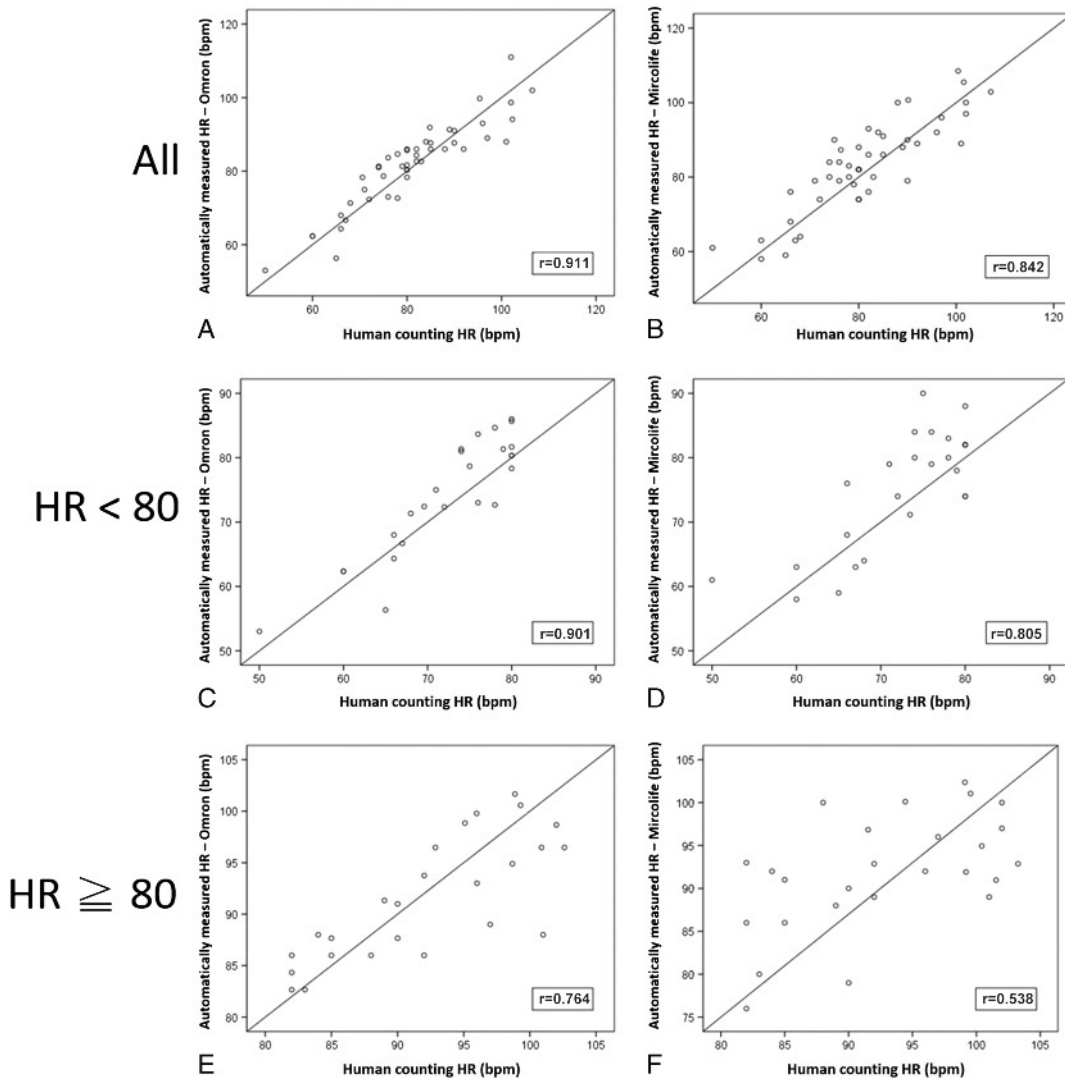
with sustained AF, literature regarding the accuracy of HR measured by automated devices was scarce.<sup>16,21,22</sup> Vazquez-Rodriguez et al<sup>16</sup> reported a high correlation between the measurement of HRs by Philips SureSigns VS1 (Philips Medical Systems, Andover, Massachusetts) and a manual method determined by measuring central pulse for 1 minute, either in SR or AF rhythm. Our study showed similar results in that both the Omron and Microlife devices had high consistency with human counting method in HR measurement.

Wiesel et al<sup>8</sup> developed an algorithm for AF detection, which has been integrated into the Microlife BPA-100. This algorithm can calculate the irregularity index of a patient's pulse, which is defined as the standard deviation of the time intervals between successive heartbeats divided by the mean of the intervals for the total number of beats analyzed. The average time interval of the last 10 beats, during deflation of cuff, is used for calculation of HRs. However, intervals that are 25% shorter or longer than that of the average are discarded.<sup>10</sup> When patients with AF have a rapid ventricular rate, a heartbeat occurring with a very short time interval after the preceding beat may have a

**TABLE 4** Spearman's Rank Correlation Coefficient ( $r$ ) Between Heart Rate Measured by Automated Devices and Human Counting

	All		HR < 80 bpm		HR ≥ 80 bpm	
	$r$	$P$	$r$	$P$	$r$	$P$
Omron and human counting	0.911	<.001	0.901	<.001	0.764	.002
Microlife and human counting	0.842	.015	0.805	.013	0.538	.022

Abbreviations: bpm, beats per minute; HR, heart rate.



**FIGURE 1.** Correlation of heart rate measurements between automated devices and human counting according to the Spearman's rank correlation coefficient (*r*). A, Omron and human counting. B, Microlife and human counting. C, Omron and human counting in subjects with a manually measured heart rate of less than 80 bpm. D, Microlife and human counting in subjects with a manually measured heart rate of less than 80 bpm. E, Omron and human counting in subjects with a manually measured heart rate of greater than 80 bpm. F, Microlife and human counting in subjects with a manually measured heart rate of greater than 80 bpm. Abbreviations: bpm, beats per minute; HR, heart rate.

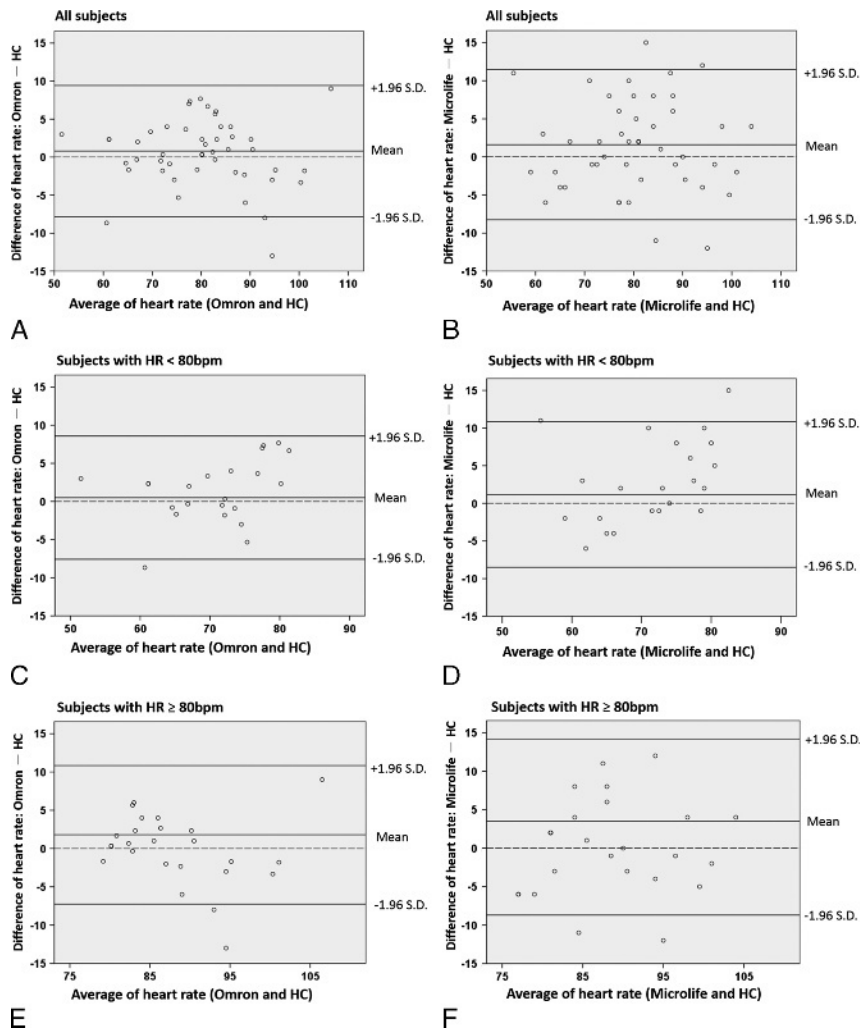
markedly diminished stroke volume, resulting in no detectable pulse. Therefore, the time interval between heartbeats may be overestimated because of the undetectable pulse between beats. These erroneously measured longer time intervals will then be discarded during calculation of the irregular index and HR. As a result, the calculation algorithm incorporated in the Microlife device may overestimate the HR in AF patients with a higher HR, as observed in our study. Of note, 5 patients in this study with documented AF were missed by the AF detection algorithm. Although this occurred in a small number of patients, this should be examined and validated in a large sample. On the other hand, our analysis showed the sensitivity of the Microlife device as 89.3%, which was much lower than

those reported in previous validation studies (sensitivity, 93.9%–98.7%).<sup>23</sup> However, in the primary care setting, the reported sensitivity of the Microlife device was 83% (95% confidence interval, 63%–95%).<sup>24</sup>

**TABLE 5** Intraclass Correlation Coefficient Between Heart Rate Measured by Automated Devices and Human Counting

	All	HR < 80 bpm	HR ≥ 80 bpm
Omron and human counting	0.954	0.932	0.876
Microlife and human counting	0.912	0.881	0.775

Abbreviations: bpm, beats per minute; HR, heart rate.



**FIGURE 2.** Agreement of heart rate measurements between automated devices and human counting according to the Bland-Altman plot. A, Omron and human counting. B, Microlife and human counting. C, Omron and human counting in subjects with a manually measured heart rate of less than 80 bpm. D, Microlife and human counting in subjects with a manually measured heart rate of less than 80 bpm. E, Omron and human counting in subjects with a manually measured heart rate of greater than 80 bpm. F, Microlife and human counting in subjects with a manually measured heart rate of greater than 80 bpm. Abbreviations: bpm, beats per minute; HC, human counting.

Increasing attention has been given to home BP monitoring because it is more closely correlated to ambulatory BP monitoring<sup>6,25</sup> and more predictive of adverse outcomes.<sup>26–28</sup> Automated BP monitors have the advantage of minimizing interobserver bias and being convenient to use. In addition, patient self-monitoring of BP at home can improve BP control and compliance.<sup>29</sup> The importance of AF screening is increasingly being recommended by most cardiovascular societies, particularly for those 65 years or older or stroke survivors.<sup>1,2,7</sup> Because hypertension affects up to 90% of patients with AF and the concept of opportunistic screening has evolved, BP machines with AF detection algorithms have become a reasonable and recommended instrument.<sup>7</sup> For patients with persistent AF, rate control is an integral part of treatment that improves AF-related symptoms. The HR targets are classified into the lenient (<110 bpm) and stricter (<80 bpm) rate con-

trol targets. Holter 24-hour monitoring has been recommended for assessment of adequacy of HR control.<sup>2</sup> Although the Holter monitor permits the detection of baseline rhythm and HRs during rest, sleeping and ambulation, the bulkiness of the device, and its inconvenience limit its clinical application. Automated home BP monitors could help AF patients provide their HR data for clinical decision-making.

Our study showed 2 important findings. The first one was the high accuracy of 2 automated BP monitors in the measurement of HR, which justified their clinical use for HR recordings in patients with AF. Therefore, clinicians could adjust the dosage of medications for HR control based on the daily HR data from automated BP monitors. The second finding was that the Microlife device seemed to overestimate the HR by nearly 4 bpm compared with human counting in patients with a higher HR. Current guidelines suggest strict HR control

### What's New and Important

- Our results showed high agreement between automatic devices and human counting of HR in patients with AF.
- In AF patients with a heart rate greater than 80 bpm, the automatic device may overestimate HR in AF patients.

for symptomatic AF patients, recommending a cutoff value of 80 bpm.<sup>1,2</sup> When symptomatic AF patients provided their daily HR recordings measured by the Microlife devices and the averaged HR was greater than 80 bpm, the interpretation should be made with caution because of the possible overestimation of HR by the Microlife device. Clinicians might have to arrange further continuous ECG monitors, such as Holter monitor or skin patch recorder, to more accurately measure the HR.

### Limitations

This study has some limitations to be acknowledged. First, the study was limited to HR measurements by Omron M5-I and Microlife BPA-100 plus. Whether the results could be extrapolated to other devices is unknown. Second, only 1 investigator performed human HR counting, as well as the operation of automated devices, and the investigator was not blinded to the results. Third, we assumed that there was little change in HR in the resting state. The human counting and automated measurements were not obtained simultaneously. Fourth, patients with extreme tachycardia (HR > 120 bpm) were not present in our cohort, and the conclusion of this study may not be applied to those patients. Finally, we only included participants whose arm circumferences were appropriate for use of a normal adult-size BP cuff.

### Conclusions

There is high agreement in HR measurement between a conventional BP monitor (Omron M5-I), AF-detecting BP monitor (Microlife BPA-100), and human counting in the presence of AF. Although being equipped with a specific algorithm for AF detection, the Microlife device overestimated HR in AF patients with a resting HR of more than 80 bpm.

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