Comparison of wrist-type and arm-type 24-h blood pressure monitoring devices for ambulatory use

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Objective(s) **We compared a convenient, cuffless, wrist-type ambulatory blood pressure monitoring (ABPM) device (BPro) and a standard arm-type ABPM monitor under ambulatory conditions.**

Methods **Fifty normotensive and prehypertensive volunteers who had no interarm differences in BP were enrolled. The wrist and arm monitors were attached to the left wrist and the right arm, respectively, and provided readouts at 15 and 30-min intervals, respectively. Ambulatory BP levels and the extent of agreement by intraclass correlation were evaluated. In 15 of the 50 participants, we also examined values at different arm positions: heart level, above the head, and hanging at the sides.**

Results **The awake mean systolic blood pressure (SBP) values (122±13 vs. 127±11 mmHg, $P<0.01$) were significantly lower with the wrist monitor than the arm monitor, and the mean sleep diastolic blood pressure (DBP) (71±8 vs. 64±8 mmHg, $P<0.01$) was significantly higher with the wrist monitor than the arm monitor. The intraclass correlation values between the monitors were 0.54 for 24 h SBP and 0.52 for awake SBP, considered to indicate a moderate agreement. The BP values in the arm-raised position were significantly higher for the wrist monitor than for the arm monitor (SBP: 129±14 vs. 108±14 mmHg, $P<0.01$; DBP: 83±13 vs. 64±11 mmHg, $P<0.01$). However, the SBP and DBP values in the other arm positions were similar between the monitors.**

Conclusion **The wrist monitor showed fair agreement with the arm monitor in the ambulatory condition, and was stable irrespective of arm positions.** ***Blood Press Monit*** **18:57–62 © 2013 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Keywords: arm-cuff monitor, arterial tonometric monitor, comparison, wrist-type monitor

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Introduction

Ambulatory blood pressure monitoring (ABPM) is one of the most important methods for the management of hypertension. ABPM yields a variety of BP parameters including the average BP level, circadian rhythm, and BP variability. Since noninvasive ABPM was introduced in 1964 [1], arm-cuff ABPM has been used widely, but some patients find the frequent compressions of their arm by the cuff uncomfortable.

In the sphygmomanometers for self-measurement of BP, many validated wrist monitors have been used widely [2]. With respect to ABPM, a cuffless, wrist-type ABPM was developed in 2008 and validated [3] using the European Society of Hypertension (ESH) protocol [4] and the Association for the Advancement of Medical Instrumentation (AAMI) standard [5]. This monitor uses a novel but simple principle to measure BP. The wrist monitor contains a tonometer that is placed over the radial artery to capture the radial artery pulse wave form. The radial wave form height is calibrated to the brachial BP when the monitor is first applied to the wrist. All subsequent measurements of radial artery wave form height are then taken to represent variations in brachial BP. There have been no studies comparing this wrist-type monitor with the conventional arm-type monitor under ambulatory conditions. In this study, we tested the accuracy of the two different monitor types and the agreement between the BP values of the monitors.

Methods

Participants

This was a preliminary study carried out before the wrist-type monitor was to be used in clinical practice, and therefore, we enrolled 50 normotensive volunteers and prehypertensive individuals. The study participants were healthy adults, typically medical doctors, residents, and office clerks at the hospital. At baseline, we obtained informed consent from all participants. We measured their BP once in each arm sequentially at baseline in the seated position with the arm-type monitor, and we confirmed that there were no significant interarm differences in BP, that is differences of at least 10 mmHg.

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Blood pressure measurements

We performed ambulatory BP monitoring with the 'wrist monitor', the BPro (HealthSTATS International, Singapore), a watch-like BP monitoring device that measures ambulatory BP using the arterial tonometric method. The wrist strap of this device contains a tonometer situated over the radial artery that samples the radial artery pulse wave. When the monitor is initially placed on the wrist, the radial wave form is calibrated to brachial BP (the monitor used to calibrate, TM-2431; A&D, Tokyo, Japan) measured in the seated position at rest. To calibrate the wrist monitor, we use measured brachial BP twice for each individual and enter the average brachial BP value into the wrist monitor. Subsequent repeated sampling of the radial artery wave form over 24 h provides a measurement of brachial BP. The BPro monitor has been validated according to the modified ESH protocol and the AAMI standard [3], but it was not recommended by the website of the dabl Educational Trust [2]. The comparator for these studies was a conventional arm-cuff monitor (TM-2431; A&D), the 'arm monitor', which measures ambulatory BP by an oscillometric method. The arm monitor uses the same algorithm as the TM-2430 arm-cuff monitor, and has been validated according to the British Hypertension Society (BHS) [6]. The average awake and sleep ambulatory BP values were calculated on the basis of the individuals' diaries.

Protocol

The individuals were seated comfortably and their BP was measured with the arm monitor. These seated brachial BP values were also used to calibrate the radial wave form captured by the wrist monitor. The arm monitor was attached to the right arm and the wrist monitor was attached to the left wrist. Ambulatory BP was measured at 15-min intervals using the wrist monitor and at 30-min intervals using the arm monitor.

BP monitoring was performed under normal ambulatory conditions. The study participants were asked to not restrict their usual daily activities, but were requested to hold their arms still during the BP measurements. The individuals were also asked to keep diaries that included the times they went to bed and woke up.

We compared the BP values measured by the wrist monitor and the arm monitor. We used the average every 15-min BP values from the wrist monitor and the every 30-min values from the arm monitor. Before the analyses, we compared the wrist BP values between the 15-min intervals and the 30-min intervals. The mean BP values of the 15-min intervals in the wrist monitor were almost identical to those of the 30-min intervals from the arm monitor (Table 1). We therefore used the every 15-min BP values from the wrist monitor.

In 15 of the 50 participants, we also examined the effect of arm position on BP readings in each monitor, testing three different arm positions: (i) horizontal at the heart level, (ii) vertical above the head, and (iii) hanging down by the individual's side (Fig. 1). The BP measurements with each monitor were performed 5 min after the participant positioned his or her arms in each position.

Statistical analysis

All statistical analyses were carried out using SPSS software, version 11.0 (IBM-SPSS, Armonk, New York, USA). Values shown are means ± SDs. The individual BP values obtained using the two monitors were evaluated as means ± SDs. The group means were compared using Student's *t*-test. The group proportions were compared using the χ^2-test. Bland–Altman plots were used for the comparisons of the two monitors [7]. The correlations between the two monitors were evaluated by Pearson's correlation coefficients and intraclass correlation (ICC) agreements. The ICC agreements between the two monitors are expressed as ICC and 95% confidence intervals.

Results

A total of 50 participants were analyzed in this study. The mean age was 32.9 ± 6.5 years. The BMI was 21.2 ± 2.4 kg/m^2 and 62% were men. Table 2 shows the success rate of BP measurements according to each type of monitor. The rate of successful BP measurements using the wrist monitor was 51% for 24 h BP, 51.5% for awake BP, and 53.8% for sleep BP, compared with 94.1, 93.5, and 98.2% using the arm monitor (all $P < 0.01$ for 24 h, awake period, and during sleep). However, because the number

Table 1 **Comparison of average blood pressure values between 30 and 15-min intervals in the wrist monitor (*n* = 50)**

	15-min intervals		30-min intervals		
	BP values	Number of measurements	BP values	Number of measurements	*P*-values
24-h SBP	119.3±12.2	2467	118.6±12.4	1194	0.02
24-h DBP	76.2±6.6	2467	75.6±6.7	1194	<0.01
Awake SBP	122.5±12.7	1811	121.7±12.2	878	0.18
Awake DBP	78.2±6.8	1811	77.7±6.9	878	0.20
Sleep SBP	111.3±13.9	656	110.5±13.4	316	0.12
Sleep DBP	71.1±7.9	656	70.4±8.6	316	0.13

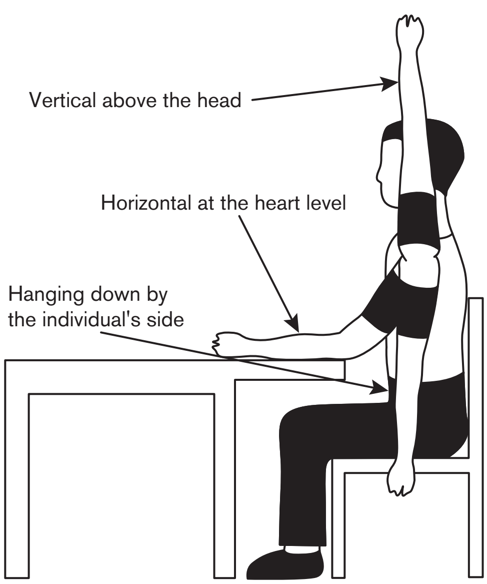
All SBP and DBP values are mmHg.
BP values are means±SDs.
DBP, diastolic blood pressure; SBP, systolic blood pressure.

of readings taken by the wrist monitor was greater, the total number of readings contributing to the 24 h BP average for each monitor was similar (wrist monitor 49 ± 10 measurements per 24 h vs. arm monitor 48 ± 3 measurements per 24 h).

The average BP values using each monitor are shown in Table 3. The awake systolic blood pressures (SBP) were significantly lower in the wrist monitor than in the arm monitor, and sleep diastolic blood pressures (DBP) were significantly higher in the wrist monitor than in the arm monitor. However, there were no significant differences in 24 h SBP, 24 h DBP, awake DBP, or sleep SBP.

Table 4 shows Pearson's correlation coefficients and the ICC agreements of BP values provided by the arm monitor and wrist monitor. All BP values from the two monitor types were significantly correlated with each other. The ICC agreements between the two monitors were moderate for the 24 h and awake SBP.

Fig. 1



Three arm positions to examine the effects of arm position. (i) Horizontal at the heart level, (ii) vertical above the head, and (iii) hanging down by the individual's side.

Figures 2 and 3 show Bland–Altman plots of the BP values provided by the two monitors. In the awake BP period, the arm monitor showed 4.5 mmHg higher SBP values and 0.8 mmHg higher DBP values than the wrist monitor. In the sleep BP period, the wrist monitor showed 2.1 mmHg higher SBP values and 7.4 mmHg higher DBP values than the arm monitor. However, there was no relationship between the difference in BP values in both monitors and the average of the BP values in both monitors. The agreement between the wrist monitor and the arm monitor values of awake and sleep BP was fair (Figs 2 and 3).

Because the arm position is critical in the use of wrist monitors, we compared the BP values of the two types of monitor in three different arm positions (Fig. 1). In the sitting position, the BP values provided by the wrist monitor and arm monitor were similar (SBP: 128 ± 15 vs. 127 ± 12 mmHg, $P = 0.54$; DBP: 82 ± 8 vs. 82 ± 9 mmHg, $P = 0.96$). Notably, in the arm-raised position, the BP values provided by the wrist monitor were significantly higher than those provided by the arm monitor (SBP: 129 ± 14 vs. 108 ± 14 mmHg, $P < 0.01$; DBP: 83 ± 13 vs. 64 ± 11 mmHg, $P < 0.01$). In the hanging-arm position, the BP values were similar between the two monitors (SBP: 127 ± 16 vs. 127 ± 14 mmHg, $P = 0.97$; DBP: 84 ± 10 vs. 82 ± 9 mmHg, $P = 0.41$). Importantly, the BP values provided by the wrist monitor were almost identical in the three arm positions.

Discussion

In this study, we compared a new, cuffless, wrist ABPM monitor with a conventional cuff ABPM monitor under ambulatory conditions. The agreement between the two types of monitor was moderate. This is the first report comparing a wrist-type and an arm-type monitor, especially under the ambulatory conditions. Although it may be unusual to compare monitors under ambulatory conditions, the relatively good agreement we found merits further discussion of the potential clinical use of ambulatory wrist monitors.

Wrist-type ambulatory blood pressure monitoring monitors

Although the use of a brachial cuff BP monitor is a standard method to measure BP and various hypertension

Table 2 Numbers and percentages of successful blood pressure readings by wrist monitor and arm monitor ($n = 50$)

	Wrist monitor			Arm monitor			
	Number of successful measurements	Number of measurements	Success rate of BP measurement (%)	Number of successful measurements	Number of measurements	Success rate of BP measurement (%)	*P*-values
24 h	49±10	96±0	51.0	48±3	51±2	94.1	<0.01
Awake	37±9	72±6	51.5	35±4	38±4	93.5	<0.01
Sleep	13±7	24±5	53.8	12±3	12±3	98.2	<0.01

Successful measurements and numbers of measurements are means±SDs.
BP, blood pressure.

Table 3 Comparison of average blood pressure levels provided by a wrist monitor and an arm monitor ($n=50$)

	Wrist monitor	Arm monitor	*P*-values
24-h SBP (mmHg)	119±12	122±11	0.07
24-h DBP (mmHg)	76±7	75±7	0.37
Awake SBP (mmHg)	122±13	127±11	<0.01
Awake DBP (mmHg)	78±7	79±8	0.49
Sleep SBP (mmHg)	111±1	109±13	0.28
Sleep DBP (mmHg)	71±8	64±8	<0.01

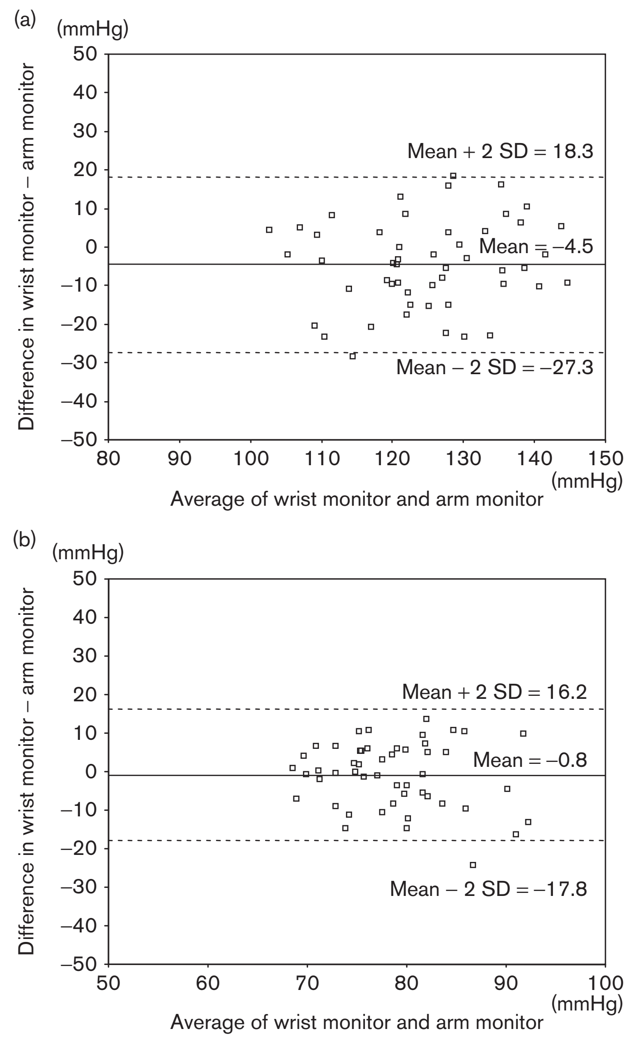
Data shown are means±SDs.
DBP, diastolic blood pressure; SBP, systolic blood pressure.

Table 4 Correlations between the wrist monitor and the arm monitor ($n=50$)

	Pearson's correlation coefficients	*P*-values	ICC (95% CI)	*P*-values
Average 24-h SBP	0.54	<0.01	0.54 (0.31–0.71)	0.38
Average 24-h DBP	0.30	0.03	0.37 (0.10–0.58)	0.95
Average awake SBP	0.55	<0.01	0.52 (0.29–0.70)	0.33
Average awake DBP	0.34	0.02	0.46 (0.21–0.65)	0.92
Average sleep SBP	0.39	<0.01	0.29 (0.009–0.52)	0.83
Average sleep DBP	0.28	0.05	0.29 (0.01–0.53)	0.97

CI, confidence interval; DBP, diastolic blood pressure; ICC, intraclass correlation coefficients; SBP, systolic blood pressure.
P-values show the difference from ICC agreement 0.5 as a reference.

Fig. 2



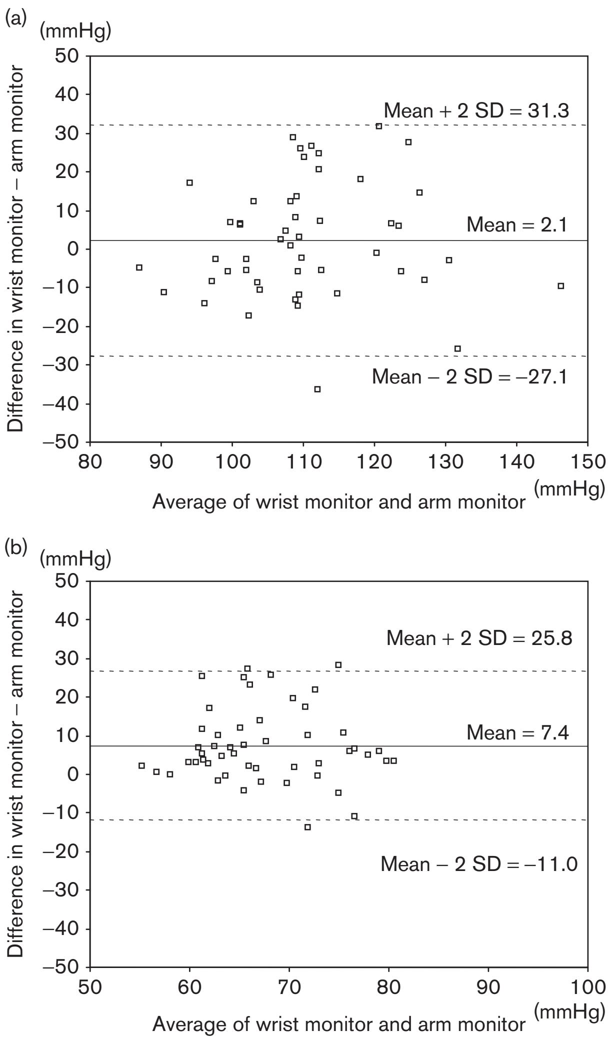
Average awake (a) SBP and (b) DBP values as Bland–Altman plots. The arm monitor showed 4.5 mmHg higher SBP values and 0.8 mmHg higher DBP values than the wrist monitor. DBP, diastolic blood pressure; SBP, systolic blood pressure.

guidelines recommend using a brachial cuff BP monitor, there are some advantages to the wrist-type BP monitors [8]. Wrist monitors do not require the removal of clothing for a cuff application, and they are easy to wear, particularly in the winter, because long-sleeved clothing can be used with a wrist monitor, but not with an arm-cuff monitor. Another advantage of wrist monitors is that they can even be used for obese patients for whom an appropriate arm-cuff size is not available. A large cuff should be used to measure BP in the obese with large arm circumferences, but the upper arms are sometimes tapered, in which case the cuff will not fit properly. Because the wrist size is more similar between obese and nonobese individuals, the wrist-type BP monitor measurements are not affected by body size.

Almost all wrist-type home-use BP monitors are the 'cuff' type, which uses a cuff-oscillometric algorithm. The disadvantage of the wrist cuff-type monitor is the inconsistency of BP readings for different wrist positions. That is, the BP value for an arm position higher than the heart will likely be lower than that at the heart level, and BP values for an arm position lower than the heart may be higher. This variability can be avoided if the wrist is always at the heart level when the readings are taken, but it is often difficult for patients to fix their wrists at the heart level as they go about their daily lives. In fact, it was noted that the SD of a wrist cuff-type BP monitor was large [9]. However, modern wrist cuff-type monitors provide good performance, and there are over 30 wrist cuff-type BP monitors that have passed the AAMI, BHS, or EHS validation protocol [2].

The algorithm of the wrist-type ABPM monitor we used in the present study is an arterial tonometric algorithm. The principle is that a single transducer that is held manually over the radial artery records the wave form of SBP and DBP when an artery is partially compressed against the radius bone. Our present findings show that the BP values provided by this wrist monitor are the same in different arm positions and are thus not affected by the position of the arms.

Fig. 3



Average sleep (a) SBP and (b) DBP values as Bland–Altman plots. The wrist monitor showed 2.1 mmHg higher SBP values and 7.4 mmHg higher DBP values than the arm monitor. DBP, diastolic blood pressure; SBP, systolic blood pressure.

As the data in Table 3 show, the differences in awake SBP readings between the wrist and the arm monitors were large because of the extensive movement of the arm in the daytime and its influence on the arm monitor. An arterial tonometric monitor records arterial waveforms and BP values are calculated from the waveforms. The BP values obtained with the arterial tonometric method are not affected by the hydrostatic effect of differences in the position of the wrist relative to the heart, and thus the BP value does not change with different arm positions [10]. Another advantage of the wrist monitor is that it is comfortable during BP measurement. The wrist monitor records the BP without compression of the wrist for every BP measurement.

One disadvantage of the wrist monitor is that it can become dislodged during BP measurements under ambulatory conditions. If the sensor moves to an inadequate position, the measurement fails. In fact, in the present study, the success rate of BP measurement was as low as 50%. However, this could be an overestimation because most of the individuals in this study were medical staff who were physically very active when they wore the monitors. We would likely obtain a better success rate using this monitor in less active (i.e. older or more sedentary) individuals. In fact, the success rate of BP measurement was 49.8% for medical staff and 61.5% for office clerk. Even so, the wrist monitor was able to obtain almost the same number of readings as the arm monitor when we set the measurement interval at 15 min. Although the wrist monitor requires twice the measurements of BP compared with the arm monitor, this could be acceptable because the measurements by the wrist monitor were less uncomfortable for the individuals. The wrist monitor is compact and easy to wear, and can also be used in individuals who cannot use an arm monitor.

Method of comparison

In this study, the agreement in the BP values between the wrist monitor and the arm monitor was not always good under the ambulatory condition. One possible explanation for this is that the BP measurement intervals of the wrist and the arm monitors were different, and the timing of the BP measurements was not strictly the same. The wrist monitor starts BP measurements just after the individual sets it, and then measures BP every 15 min. The arm monitor was set to measure BP every 30 min in this study. Most of the BP values in these devices were not taken at the same time; the time difference was at 7 min at a maximum. Second, various factors – such as noise, muscle contraction, and displacement of the monitor from the correct position – might have affected the difference in the BP values under the ambulatory conditions.

There are some reports of comparison studies between a noninvasive brachial cuff-type ABPM and an intra-arterial BP to clarify the accuracy of the cuff-type ABPM under ambulatory and resting conditions [11,12]. These reports indicated that the cuff-type ABPM showed more different BP values from the intra-arterial BP under the ambulatory condition than at rest. It is possible that the measurements provided by an arm-type ABPM, even as a reference, can fluctuate under the ambulatory condition, especially when the individuals move their arms. This hydrostatic effect is not seen with the wrist monitor. As shown in Table 3, the awake SBP readings of the wrist monitors and arm monitors were significantly different ($P < 0.01$). However, the huge differences in BP values between the wrist monitor and the arm monitor were within the range of random variation rather than indicating a failure of comparison.

There are some limitations to this study. First, as described above, the timing of BP measurements by the two monitors was not exactly the same. It was not possible to synchronize the monitors because we used different types of monitors. If the timing can be set to be exactly the same, the agreement could be improved [13]. However, the timing of the BP measurement was not crucial for this study, because we compared the average BP values and not single readings. Second, the success rate of BP measurements by the wrist monitor was significantly lower than that of the arm monitor. However, this can be overcome by a higher sampling frequency. Third, the participants in the study were normotensive and prehypertensive individuals; we did not compare BP values in individuals with high BP. However, this study was a preliminary investigation conducted before the use of the wrist monitor in clinical practice, and further examinations of this monitor's utility for hypertensive individuals are necessary.

Conclusion

Under the ambulatory condition, the BP values provided by the wrist monitor showed fair agreement with those provided by the arm monitor. This new monitor could be used for 24 h BP measurement.

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Conflicts of interest

There are no conflicts of interest.

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