Inaccuracy of wrist-cuff oscillometric blood pressure devices: an arm position artefact?

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Background Despite the increasing popularity of wrist-cuff blood pressure (BP) devices, their accuracy has not been established and international guidelines do not support their use. Because arm position influences BP measurement, it is possible that conflicting reports on wrist-cuff device accuracy reflects diverse arm positions.

Method This study compared BP measured by two oscillometric devices, the upper arm-cuff OMRON HEM 705 CP and the OMRON R6 oscillometric wrist-cuff device. In the former BP was measured with the arm in two supported positions, dependent on a table (manufacturer's instructions) and horizontal (mid sternum), while the latter followed the manufacturer's instructions.

Results In contrast to the dependent arm where BP was significantly higher ($P<0.05$), the horizontal arm position with the arm-cuff produced a mean systolic and diastolic BP comparable to the wrist-cuff device where the wrist was at heart level being respectively, $137 \pm 29/80 \pm 16$ and $134 \pm 27/77 \pm 16$ mmHg. A close relationship over a wide BP range was also confirmed by least squares, least product linear regression and Bland–Altman analysis.

Conclusion This study supports the use of wrist-cuff monitors for self/home use and underlines the need for a more precise definition for arm position when using all BP devices – mercury and oscillometric. *Blood Press Monit* 10:67–71 © 2005 Lippincott Williams & Wilkins.

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Introduction

Reduced confidence in office blood pressure (BP) due to the frequency of the 'isolated office' effect has encouraged a greater reliance on ambulatory BP monitoring [1]. However, self-BP is also being used more frequently by clinicians and patients because of cost and convenience [2] and is considered to be a reasonable ambulatory BP monitoring alternative in many situations [3]. The wrist-cuff oscillometric device is a relatively new addition to the self-measurement market place and is easier to use than upper arm-cuff devices, particularly in the elderly, the handicapped, and those with large upper arms. Unfortunately wrist-cuff accuracy is questionable [4–12] with the 1999 WHO-ISH guidelines stating 'currently available home devices that measure pressure in the fingers or in the arm below the elbow should be avoided' [13]. While the subsequent guidelines from these organizations omitted any comment on self-measurement devices [14], the recent European Society of Hypertension guidelines [1], which provided a useful discussion on wrist-cuff devices, still concluded that arm-cuff devices were preferable and stated that 'wrist instruments should be considered with caution'.

Although arm position is an important component of indirect BP measurement [15,16] with all guidelines recommending that the cuff be at heart level, the interpretation of arm position by clinicians is variable [17] and probably leads to significant errors in measurement. Furthermore few published studies clearly define arm position [15] making comparisons between devices and reported studies difficult to interpret, particularly when comparing arm- and wrist-cuff devices. Therefore the aim of this study was to compare changes in arm position on BP accuracy with an oscillometric arm and a wrist-cuff device.

Methods

Normotensive and hypertensive subjects in sinus rhythm were selected. Subjects sat for at least 5 min and conversation was avoided during the experimental protocol. The non-dominant arm was used. Arm position for the wrist (OMRON R6) and upper arm (OMRON HEM 705 CP) devices were as described in the patient instruction leaflet, the former with the hand on the opposite shoulder with the extended wrist 25 mm from the body, the latter with the arm resting on a pillow placed on a table (the manufacturer now recommends an elbow flexed at 90° and resting on a table. Both recommendations produce a cuff at 'heart' level. An additional position was used for the arm-cuff device with the supported horizontal arm at mid sternal level [1].

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Duplicates of these three measurements were performed in a random order allowing 1 min between each reading. Patients were then asked for their device preference. Omron instruments were chosen because the arm-cuff device had been independently validated using established protocols [18] and the wrist-cuff device had been evaluated in several publications. There was also a presumption that the algorithms used to calculate BP might be comparable. The measurement times between the two devices were comparable.

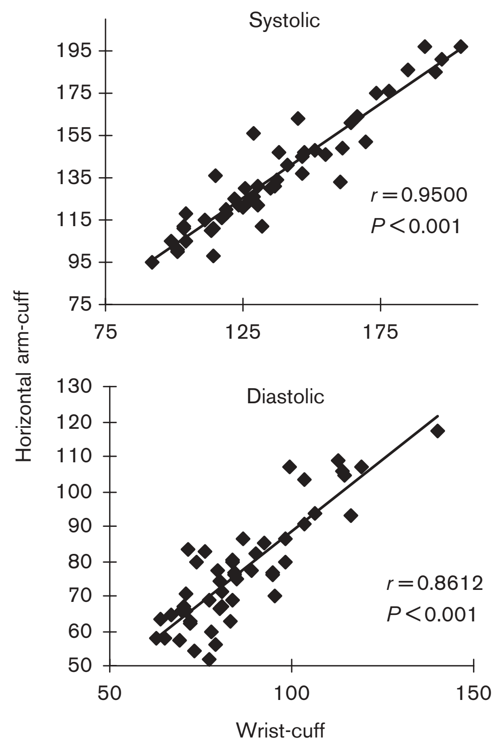
Statistical analysis

Results of different methods were compared by Students *t*-test, least squares and least product linear regression as well as the Bland–Altman method [19]. Results are expressed as mean ± standard deviation.

Results

Fifty subjects entered the study, 60% being female and 34% being hypertensive. Mean age was 57 ± 16 years. Blood pressure measured with the horizontal arm cuff were comparable to those with the wrist cuff being 137 ± 29 and 134 ± 27 mmHg systolic; 80 ± 16 and 77 ± 16 mmHg diastolic respectively (Table 1). However lowering the arm to a more dependent position increased mean systolic and diastolic BP to 142 ± 30 and 86 ± 17 mmHg ($P < 0.05$). According to least squares regression analysis there was a strong correlation between horizontal and dependent arm-cuff and wrist-cuff methods (Figs 1 and 2; Table 2), particularly with the horizontal arm ($r = 0.95$ systolic; $r = 0.86$ diastolic; $P < 0.001$). However, the least product linear regression analysis shows that while the slopes and intercepts of the systolic and diastolic regression lines for the horizontal arm and wrist cuff are not statistically different to unity and accept the hypothesis = 1 (no proportional bias) and = 0 (no fixed bias); when the dependent arm cuff was compared to the wrist-cuff device, this hypothesis was rejected at the 5% level indicating that the dependent arm-cuff produces measurements higher than the wrist cuff method (Table 2). Also the difference method of Bland and Altman demonstrated a better agreement with the horizontal arm- and the wrist-cuff device in comparison to the dependent arm (Figs 3 and 4; Table 2). Sixty-eight percent of subjects preferred the wrist monitor; only 10% preferred the arm monitor with 22% undecided. In addition arm-cuff systolic and diastolic blood pressure was significantly elevated when the horizontal arm was made dependent ($P < 0.05$).

Fig. 1



Horizontal arm-cuff compared to wrist-cuff for systolic and diastolic blood pressures.

Table 1 Hypertensive and normotensive study population characteristics and results

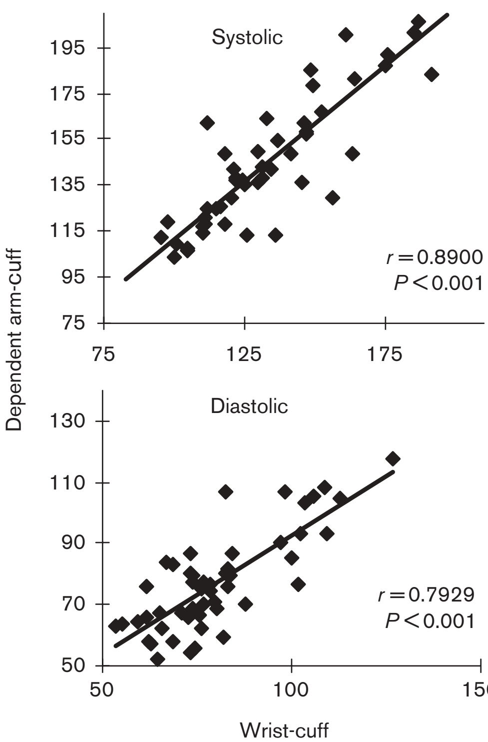
	Mean	SD
Age (years)	57	16
Arm circumference (cm)	28	5
Wrist circumference (cm)	18	3
Arm cuff dependent (mmHg)		
SBP	142	30*,†
DBP	86	17*,†
Arm cuff horizontal (mmHg)		
SBP	137	29
DBP	80	16
Wrist cuff instructions (mmHg)		
SBP	134	27
DBP	77	16

SBP, systolic blood pressure; DBP, diastolic blood pressure; $n = 50$;
*significantly different from dependent arm-cuff and horizontal arm-cuff, $P < 0.05$;
†significantly different from dependent arm-cuff and wrist-cuff, $P < 0.05$.

Discussion

A closer arm- and wrist-cuff systolic and diastolic BP correlation is produced by making the cuffed upper arm horizontal (mid sternum) in accordance with European Society of Hypertension guidelines [1] in contrast to the dependent arm position required by the manufacturer and supported by the practical guidelines of the American Heart Association [20] which states 'when a patient is seated placing the arm on a nearby table top a little above waist level will result in a satisfactory position'. While published guidelines do not support the general use of wrist devices because some studies found such devices failed to reach the required validation criteria, it is likely that arm position influenced some of these study results making device evaluation difficult. While heart level is always a stated objective, precise published information on arm position is often not forthcoming in many published hypertension studies [15] including those where wrist devices were compared to arm-cuffs. Furthermore arm position 'is not uniformly and unequivocally defined' when national and international guidelines were recently evaluated [15]. This probably explains why a recent audit of specialists, generalists and nurses found a wide range in arm-cuff preference for sitting and standing BP [17]. In particular only 8 and 4% chose the horizontal arm position while sitting and standing respectively. While a recent study supported the significant effect of arm position on arm-cuff blood pressure using auscultatory and oscillometric devices, it also found that the higher the blood pressure the greater the error, particularly for systolic blood pressure [16]. This was also true for ambulatory blood pressure monitoring and emphasizes the clinical importance of this issue and the need for an agreed standard for arm position.

Fig. 2



Dependent arm-cuff compared to wrist-cuff for systolic and diastolic blood pressures.

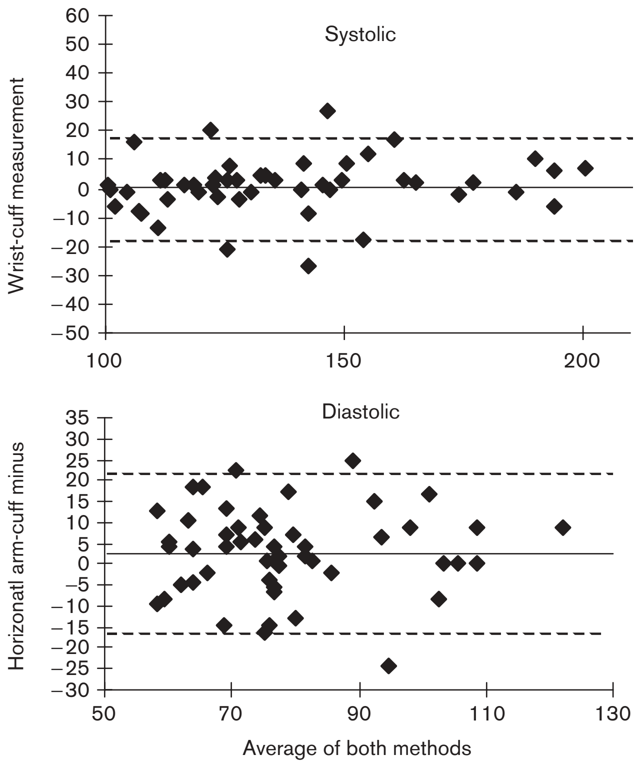
It is presumed that a mercury arm-cuff sphygmomanometer and an OMRON R3 wrist device were at heart level where the wrist device more closely reflected intra-arterial (axillary) BP than the mercury device since subjects were studied supine [4]. A more recent study demonstrated that an OMRON HEM-60 wrist device produced a mean systolic and diastolic BP within 2 mmHg of a mercury sphygmomanometer; however, neither cuff positions were clearly defined with mention of a stand or pillow for the arm and the body position was not stated [12]. Rogers *et al.* [6] compared an OMRON R3 with a mercury device and while a mean systolic/diastolic increase of 5.87/5.5 mmHg was observed in 20 hypertensives and a mean decrease of 3.2/4.2 mmHg occurred in 20 normotensives, no fixed or proportional bias was found between the methods with least product regression analysis. The arm position in this study was probably dependent with both devices since the arm was resting on a table, sometimes with a pillow. Mean systolic and diastolic BP was not significantly different when the OMRON HEM-601 wrist device was compared to an OMRON 707 upper arm device with the wrist device being closer to the arm-cuff comparator than the other 11 devices tested [12]. Again arm position for both devices was not defined. While only a limited BP range was evaluated when central arterial was compared to peripheral BP in supine patients, the wrist device (NAIS-MATSUSHITA) was found to be relatively inaccurate for the lower diastolic pressures [5]. Unfortunately aortic and peripheral pressures are not identical. Zweiker *et al.* [7]

Table 2 **Least square and least product regression analysis and the method of difference for device comparison**

	Least square		Least product		Method of difference	
Device	*r*	*p*	α 95% CI	β 95% CI	Mean ± SD	Limit of agreement
Systolic BP						
Horizontal versus wrist-cuff	0.95	< 0.001	− 6.7 to 18.4	0.86–1.04	0.99 ± 9.45	− 17.9 & 19.9
Dependent versus wrist-cuff	0.89	< 0.001	− 29.4 to 11.5	1.01–1.30	57 ± 14.19	− 16.8 & 40
Diastolic BP						
Horizontal versus wrist-cuff	0.86	< 0.001	− 10.5 to 16.3	0.83–1.18	3.01 ± 10.39	− 17.77 & 23.79
Dependent versus wrist-cuff	0.79	< 0.001	− 19.3 to 5.2	1.1–1.12	9.25 ± 8.62	− 8.0 & 26.5

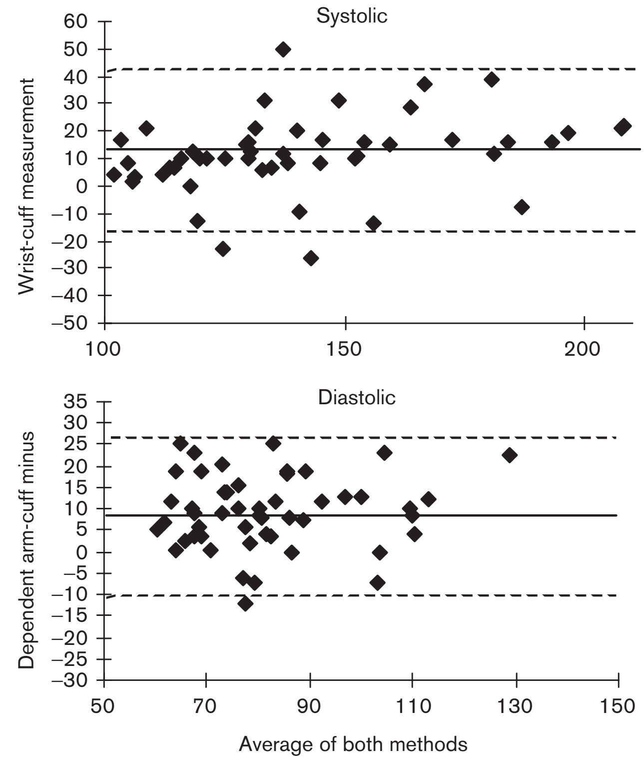
CI, confidence interval; BP, blood pressure.

Fig. 3



Comparison of systolic and diastolic blood pressure readings. Bland–Altman plot showing the between-device difference in measurements against the mean of both methods.

Fig. 4



Comparison of systolic and diastolic blood pressure readings. Bland–Altman plot showing the between-device difference in measurements against the mean of both methods.

found the Klock wrist device unreliable when compared to a mercury sphygmomanometer, however again arm position was not clearly stated. Uen *et al.* [11] found the Braun wrist device to record pressures comparable to ambulatory BP monitoring.

Despite preliminary evidence that wrist position influences wrist device results [12] a crossover design in 43 subjects where a wrist monitor with a position sensor was compared to one without, no significant differences were detected [11].

While differences between various oscillometric upper arm and wrist devices are likely, the former including ambulatory BP monitors, an important issue must be the acceptability of some error given the clear benefits of such instruments both to patients and clinicians. Because mercury devices have their own reliability problems and are of little benefit in the home, it was thought appropriate to compare the wrist device with another commonly used oscillometric arm-cuff device used to measure self/home BP. By ensuring that the arm-cuff was at heart level rather than relatively dependent, systolic and diastolic pressures became comparable to wrist measurements over a wide range of systolic and diastolic pressures. Thus this study suggests that wrist devices can produce reliable and accurate results when compared to a commonly used and validated arm-cuff device. Furthermore a review of the published literature suggests that contradictory reports may reflect incorrect arm position and underlines the need for a clear and unambiguous international standard for arm position. Regardless of the pronouncements of national and international organizations, the general public including many of our subjects prefers wrist devices, a preference that is reflected in the market place [12,21].

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