

# Discordant prevalence of hypertension using two different automated blood pressure measurement devices: a population-based study in Dar es Salaam (Tanzania)

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**Objective** The estimation of blood pressure is dependent on the accuracy of the measurement devices. We compared blood pressure readings obtained with an automated oscillometric arm-cuff device and with an automated oscillometric wrist-cuff device and then assessed the prevalence of defined blood pressure categories.

**Methods** Within a population-based survey in Dar es Salaam (Tanzania), we selected all participants with a blood pressure  $\geq 160/95$  mmHg ( $n=653$ ) and a random sample of participants with blood pressure  $<160/95$  mmHg ( $n=662$ ), based on the first blood pressure reading. Blood pressure was reassessed 2 years later for 464 and 410 of the participants, respectively. In these 874 subjects, we compared the prevalence of blood pressure categories as estimated with each device.

**Results** Overall, the wrist device gave higher blood pressure readings than the arm device (difference in systolic/diastolic blood pressure:  $6.3 \pm 17.3/3.7 \pm 11.8$  mmHg,  $P < 0.001$ ). However, the arm device tended to give lower readings than the wrist device for high blood pressure values. The prevalence of blood pressure categories differed substantially depending on which device was used, 29% and 14% for blood pressure  $<120/80$  mmHg (arm device versus wrist device, respectively), 30% and 33% for blood pressure 120–139/80–89 mmHg, 17% and 26% for blood pressure 140–159/90–99 mmHg,

12% and 13% for blood pressure 160–179/100–109 mmHg and 13% and 14% for blood pressure  $\geq 180/110$  mmHg.

**Conclusions** A large discrepancy in the estimated prevalence of blood pressure categories was observed using two different automatic measurement devices. This emphasizes that prevalence estimates based on automatic devices should be considered with caution. - *Blood Press Monit* 9:59–64 © 2004 Lippincott Williams & Wilkins.

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## Introduction

Although measurement of blood pressure with a mercury sphygmomanometer remains the gold standard for blood pressure measurement in clinical practice [1], automated electronic devices are increasingly used for environmental reasons, convenience of use and their lower susceptibility to several observer-related biases (e.g. systematic error, terminal digit preference and observer prejudice) [2,3]. Automated devices may be particularly useful in epidemiological studies as individuals with little training can perform blood pressure measurements and the comparability of results between surveys may be enhanced [4,5]. In addition, automated devices can be

used for the self-measurement of blood pressure, which may improve the management of hypertensive patients [6–8]. However, the reliability of blood pressure measurements with electronic devices depends on proper calibration, unlike mercury sphygmomanometers, which directly assess blood pressure as the height of a mercury column. Accordingly, the Association for the Advancement of Medical Instrumentation (AAMI) and the British Hypertension Society (BHS) have published recommendations for performing adequate device validation [9–11], recently updated by the European Society of Hypertension (ESH) [12].

The use of automated devices has gained increasing popularity among patients and physicians, especially the use of wrist-cuff devices, as such devices tend to be easier and more comfortable to use than devices requiring a cuff strapped around the upper arm [13,14]. In particular, convenience of use is potentially an advantage for the self-measurement of blood pressure by older individuals, and wrist-cuff devices could be useful in obese patients because measurement at wrist level is not dependent on arm circumference, a factor known to influence conventional blood pressure measurements [3,15]. However, no wrist devices have been properly validated, and their use is not yet recommended [11,14].

Indeed, although an increasing number of automated devices (at both the humeral and wrist levels) have passed some quality control tests, measurements with automated devices still show substantial deviations with regards to reference values, and biases have been found in either the entire range of blood pressure values or part of it [11,16–21]. These biases have important clinical and epidemiological consequences. At an individual level, deviations of a few mmHg may determine whether or not anti-hypertensive treatment is recommended [22], and inaccurate prevalence estimates in populations can result in inadequate public health measures.

Many studies have compared blood pressure using arm-cuff or wrist-cuff automated blood pressure devices with standard sphygmomanometers [16–21,23,24]. Most studies have, however, included few subjects over a limited range of blood pressure values. To our knowledge, no study has evaluated the impact on the estimated prevalence of blood pressure categories. The aim of this study was to compare measurements of blood pressure using an arm-cuff automatic oscillometric device and a wrist-cuff automatic oscillometric device, in a large population-based sample, in order to assess the impact on the estimated prevalence of defined blood pressure categories.

## Methods

Between November 1998 and December 1999, we conducted a cross-sectional survey of cardiovascular risk factors in the entire population aged 25–64 years in five branches of the Temeke district in Dar es Salaam, Tanzania. Survey methods, participants' characteristics and the distribution of blood pressure and other risk factors have previously been reported [25]. In this survey, all those who had a systolic (SDP)/diastolic (DBP) blood pressure  $\geq 160/95$  mmHg on the first blood pressure reading (using an arm-cuff automated device) or were taking antihypertensive treatment were identified ( $n = 653$ ). For each person with high blood pressure,

one person with blood pressure  $< 160/95$  mmHg was selected, matched by sex, age and geographical area ( $n = 662$ ).

Two years after the initial survey, these subjects were re-examined at home by four survey officers. Blood pressure was measured in the sitting position, after a rest of at least 5 min, on the left arm, at 1 min intervals. Six readings were performed: the first, second, third and sixth with a arm-cuff automated device (Visomat<sup>®</sup> OZ2, Hertia Pharma, Mannheim, Germany) [26], and the fourth and fifth with a wrist-cuff automated device (Visomat<sup>®</sup> Handy). The survey officers ('clinical officers' in the local health system) were trained to measure blood pressure with the wrist device with the wrist positioned on the chest at the heart level during the measurement. 'Arm blood pressure' was defined as the mean of the third and sixth measurements, and 'wrist blood pressure' as the mean of the fourth and fifth measurements. This sequence was chosen to avoid systematic sequential bias resulting from the decrease of blood pressure over repeated readings [27]. 'Average blood pressure' was defined as the mean of arm blood pressure and wrist blood pressure. The difference in blood pressure between the wrist and arm readings was calculated as  $\Delta BP = \text{wrist BP} - \text{arm BP}$ . Categories of blood pressure were defined according to the ESH classifications [28].

Height, weight, mid-arm circumference (MAC) and wrist circumference (WC) were measured to the nearest 0.5 cm. Weight was measured with electronic scales to the nearest 0.1 kg (Planax Automatic ST 500, Terrillon, Paris, France). Body mass index (BMI) was calculated as weight divided by height squared ( $\text{kg/m}^2$ ). Subjects were free to participate and gave informed consent. The study was approved by the Tanzanian National Institute of Medical Research and the Tanzanian Commission for Science and Technology.

Pearson correlation coefficients for the blood pressure measurements with both devices were calculated. Differences between categorical or continuous variables were tested with, respectively, the chi-square test and *t*-test. A test for trend was performed for differences of continuous variable across categories. The association of the variables of interest with systolic  $\Delta BP$  and diastolic  $\Delta BP$  was examined using multivariate linear regression. The agreement between blood pressure categories assessed with each device was tested with the kappa ( $\kappa$ ) statistic. *P*-values  $< 0.05$  were considered to be significant. Analyses were performed with SPSS 10.0 for Windows.

## Results

Of the 653 persons who had a blood pressure  $\geq 160/95$  mmHg and the 662 whose blood pressure was

< 160/95 mmHg at the time of the initial survey, 464 and 410, respectively, were traced 2 years later, these subjects ( $n = 874$ ) being considered in this study. Selected characteristics of the participants are presented in Table 1. Overall, the wrist device gave higher values than the arm device ( $P < 0.001$ ). The difference between the two devices was greater for SBP than DBP. Pearson correlation coefficients between both devices were 0.79 for SBP ( $P < 0.001$ ) and 0.74 for DBP ( $P < 0.001$ ).

**Table 1 Characteristics and blood pressure of the participants ( $n = 874$ )**

Age (years)	44.2 ± 10.5
Male gender (%)	30.3
Body mass index (kg/m <sup>2</sup> )	26.3 ± 5.2
Arm circumference (cm)	28.7 ± 3.8
Wrist circumference (cm)	16.3 ± 1.9
Average BP ≥ 140/90 mmHg or antihypertensive treatment (%)	48.6
Systolic BP (mmHg), arm-cuff device	136.0 ± 28.0
Diastolic BP (mmHg), arm-cuff device	85.7 ± 17.4
Systolic BP (mmHg), wrist-cuff device	142.3 ± 25.0
Diastolic BP (mmHg), wrist-cuff device	89.5 ± 14.9
Systolic ΔBP (mmHg)	6.3 ± 17.3***
Diastolic ΔBP (mmHg)	3.7 ± 11.8***

BP, blood pressure. ΔBP = wrist BP - arm BP. Estimates expressed as mean ± SD or percentage.

\*\*\* $P$  (for difference from 0) < 0.001.

Table 2 shows the univariate relationships between ΔBP and selected characteristics of the subjects. ΔBP was strongly related to both SBP and DBP. For low, normal and relatively high average blood pressure values, wrist readings were higher than arm readings, whereas wrist readings were lower than arm readings for higher blood pressure values (≥ 180/110 mmHg). ΔBP tended to be larger in men than in women and in younger than older age categories. Similar inverse trends were observed between ΔBP and BMI or MAC. ΔBP did not differ significantly between clinical officers (data not shown). A large variability of blood pressure was observed at the individual level with both devices. Limits of agreement, according to the Bland-Altman method [29], ranged from -28 to +41 mmHg for SBP and from -20 to +27 mmHg for DBP, suggesting large differences in blood pressure measurements between the two devices at an individual level (Fig. 1).

Multivariate analysis shows that average blood pressure was the main independent predictor of both systolic ΔBP and diastolic ΔBP (Table 3). Gender was independently associated with systolic ΔBP. BMI, age, MAC and WC were not associated with systolic ΔBP or diastolic ΔBP.

With the arm device, 41.5% of subjects were considered to be hypertensive (blood pressure ≥ 140/90 mmHg),

**Table 2 Difference in blood pressure between the wrist-cuff device and the arm-cuff device (ΔBP), according to selected characteristics of the participants**

	<i>N</i>	ΔBP, systolic	<i>P</i>	ΔBP, diastolic	<i>P</i>
Sex					
Men	265	8.4 (6.4, 10.4)		4.5 (3.2, 5.7)	
Women	607	5.4 (4.0, 6.8)	*	3.4 (2.4, 4.4)	*
Age (years)					
< 35	210	7.6 (5.2, 10.0)		4.5 (2.9, 6.1)	
35-44	263	7.0 (4.9, 9.1)		4.7 (3.3, 6.1)	
45-54	233	5.5 (3.3, 7.6)		3.0 (1.4, 4.5)	
≥ 55	166	4.9 (2.2, 7.5)	NS	2.2 (0.5, 3.9)	*
Body mass index (kg/m <sup>2</sup> )					
< 20.0	88	7.2 (4.4, 10.0)		6.7 (4.8, 8.6)	
20.0-24.9	303	6.6 (4.8, 8.4)		4.4 (3.2, 5.6)	
25.0-29.9	277	6.3 (4.4, 8.3)		3.3 (2.1, 4.6)	
≥ 30.0	204	5.5 (2.6, 8.4)	NS	2.0 (-0.1, 4.1)	**
Mid arm circumference (cm)					
< 27	237	6.9 (5.0, 8.8)		5.3 (4.1, 6.6)	
27-29	321	6.6 (5.0, 8.3)		3.6 (2.5, 4.6)	
30-32	172	4.8 (1.7, 7.8)		2.4 (0.2, 4.6)	
≥ 33	142	6.6 (3.1, 10.2)	NS	3.0 (0.6, 5.4)	*
Wrist circumference (cm)					
< 16.0	278	5.5 (3.7, 7.3)		5.0 (3.9, 6.2)	
16.0-16.9	247	6.5 (4.5, 8.5)		3.1 (1.8, 4.5)	
17.0-17.9	191	6.6 (3.8, 9.3)		2.8 (1.0, 4.7)	
≥ 18.0	156	7.3 (4.2, 10.4)	NS	3.4 (1.2, 5.6)	NS
Average BP category (mmHg)					
< 120/80	180	8.8 (7.4, 10.1)		5.7 (4.7, 6.8)	
120-139/80-89	294	9.5 (8.2, 10.8)		6.6 (5.7, 7.5)	
140-159/90-99	173	4.5 (1.9, 7.0)		2.5 (0.9, 4.1)	
160-179/100-109	118	4.5 (0.8, 8.2)		2.7 (0.3, 5.2)	
≥ 180/110	107	-1.5 (-7.2, 4.2)	***	-4.5 (-8.2, -0.8)	***

BP, blood pressure. ΔBP = wrist BP - arm BP. Estimates expressed as mean and 95% confidence interval

\* $P < 0.05$ .

\*\* $P < 0.01$ .

\*\*\* $P < 0.001$  for difference between categories (chi-square test for sex and trend test for other variables); NS, not significant.

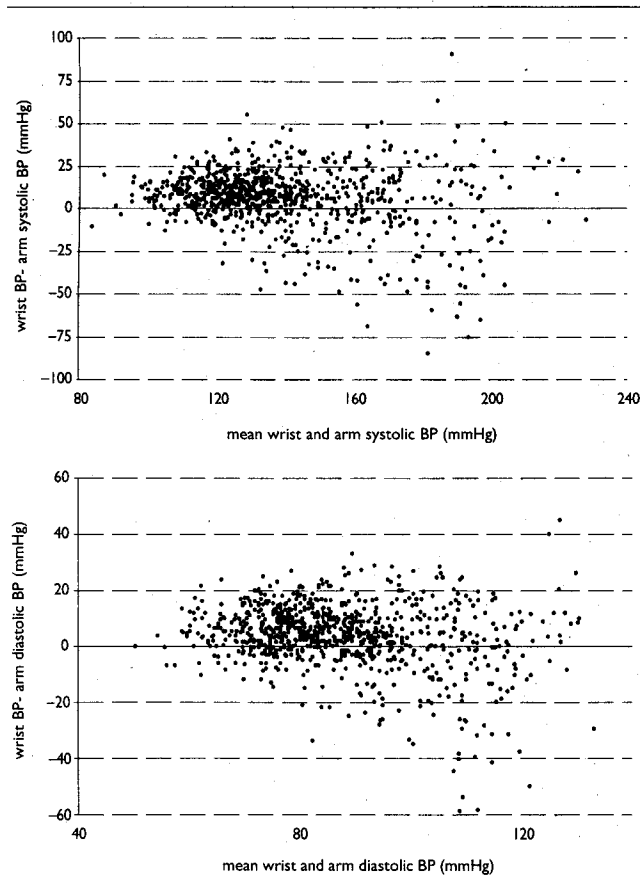
compared with 53.4% with the wrist device ( $P < 0.001$ ). Figure 2 presents the proportions of those classified in blood pressure categories based on either the arm device or the wrist device. Compared with the arm device, the wrist device gave lower proportions for low blood pressure categories and higher proportions for higher blood pressure categories ( $P < 0.001$ ): there was a trend for

subjects to be classified in higher categories with the wrist device, especially in the mid-range blood pressure categories, although the difference in prevalence was not substantial in the highest categories ( $\geq 160/100$  mmHg). Agreement between blood pressure categories based on the two devices was very poor ( $\kappa = 0.36$ ).

**Discussion**

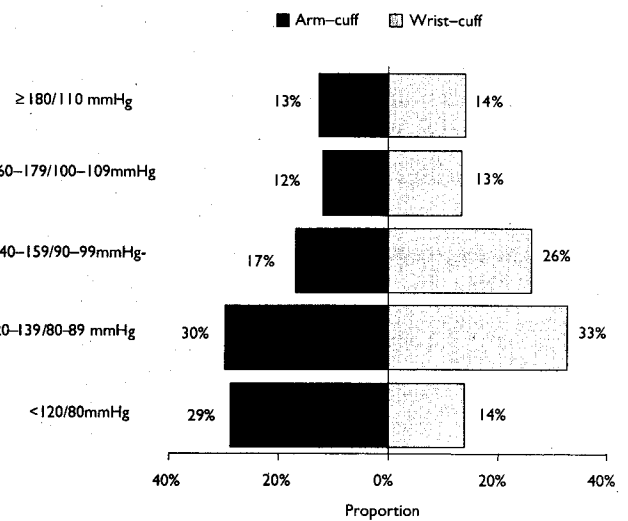
This study shows that blood pressure was higher with the wrist-cuff device for the low, normal and relatively high range of blood pressure, but tended to be lower for higher blood pressure, when compared with values with the arm-cuff device. Except for this strong relationship with blood pressure level, the difference in blood pressure between both devices ( $\Delta$ BP) depended only marginally on other factors such as sex, BMI and MAC. Consequently, the difference between blood pressure measurements

**Fig. 1**



Bland-Altman plot of agreement between blood pressure (BP) readings with the arm-cuff and wrist-cuff devices.

**Fig. 2**



Proportions of persons in each blood pressure category using the arm-cuff or the wrist-cuff device.

**Table 3 Association between the difference in blood pressure between the wrist-cuff device and the arm-cuff device ( $\Delta$ BP) and selected variables**

	Systolic BP ( $R^2=0.05$ )			Diastolic BP ( $R^2=0.06$ )		
	Regression coefficient	95%, CI	P	Regression coefficient	95%, CI	P
Average BP (mmHg)	-0.14	-0.19, -0.09	***	-0.17	-0.22, -0.11	***
Sex (men versus women)	3.61	0.94, 6.27	**	1.54	-0.26, 3.34	NS
BMI ( $\text{kg}/\text{m}^2$ )	-0.04	-0.42, 0.34	NS	-0.15	-0.41, 0.10	NS
Age (year)	0.01	-0.11, 0.12	NS	-0.03	-0.11, 0.05	NS
Arm circumference (cm)	0.14	-0.33, 0.62	NS	0.08	-0.25, 0.40	NS
Wrist circumference (cm)	0.22	-0.46, 0.89	NS	-0.01	-0.46, 0.45	NS
Constant	18.17	4.43, 31.90	*	21.12	11.79, 30.44	***

BMI, body mass index; BP, blood pressure.  $\Delta$ BP=wrist BP-arm BP.

\* $P < 0.05$ ,

\*\* $P < 0.01$ ,

\*\*\* $P < 0.001$ . NS, not significant.

obtained with the two devices had a large and differential impact on the estimation of the proportion of subjects within the blood pressure categories.

Several factors can account for the difference in blood pressure reading depending on which device was used. Physiologically, SBP is expected to be higher and DBP lower in the peripheral arteries as peripheral wave reflection is responsible for a narrower and higher systolic peak [14,30]. Among other possible factors, our study showed that age, MAC or WC and BMI were not significant predictors of this difference. Gender, however, was a determinant for the difference in SBP between the two devices, whereas no association was noted for DBP. We cannot think of a straightforward explanation for this finding, which has not, to our knowledge, been reported in other similar studies. Readings with wrist devices are prone to error related to the position of the arm (a 5 cm lower arm position, for example, resulting in a 4 mmHg increase in blood pressure) [31]. The survey officers were trained to perform blood pressure measurement properly, but in some instances wrist readings might have been made at a level lower than the heart, leading to some blood pressure overestimation with this device. Finally, one potential limitation of our study is that only one size of cuff was used for mid-arm blood pressure measurement. However, an analysis restricted to subjects with an MAC of less than 32 cm gave similar results.

The discrepancy between readings with the two devices used in this study may relate to improper calibration. The arm device used in our study tended to underestimate the standard (mercury sphygmomanometer) measurement of blood pressure and showed unsatisfactory performance in a validation study in hypertensive subjects [26]. Until recently, no wrist-cuff device has been properly validated [6,11] except for some of the latest models [e.g. Omron RX (Omron Corporation, Tokyo, Japan) and Nissei WS-310 (Nissei Seimitsu Sokki, Ca, Ltd, Gunma, Japan)], which have attained the BHS but not the AAMI requirements for validation [32]). Several studies have evaluated the accuracy of other wrist devices [16–21]. Wrist blood pressure consistently differed from the standard measurements, albeit not in a consistent manner: some devices under-estimated [11,16] or over-estimated blood pressure [19], whereas others over-estimated low blood pressure and under-estimated high blood pressure [18].

To our knowledge, no study has compared a wrist-cuff automated device with an arm-cuff automated device, except for that of Dieterle *et al.* [26], which compared the Omron R3<sup>®</sup> wrist device and the Visomat<sup>®</sup> OZ2 arm device (the later being also used in our study). In contrast to our findings, the wrist device gave lower blood pressure

measurements than the arm device, but the authors found a similar dependency of  $\Delta$ BP with the level of blood pressure.

Our findings show that the wrist device gave higher blood pressure readings in patients with low, normal or relatively high blood pressure, but lower readings of blood pressure in patients in the highest range of blood pressure. Consequently, we found a greater prevalence of hypertension (blood pressure  $\geq$  140/90 mmHg) based on readings with the wrist device than with the arm device. Moreover, a substantial proportion of persons with low blood pressure using the arm device were categorized into intermediate blood pressure categories (120–139/80–89 mmHg and 140–159/90–99 mmHg) using the wrist device. This resulted in an inflated prevalence of these intermediate blood pressure categories based on the wrist device as opposed to the arm device.

This differential bias has important clinical implications. On one hand, normotensive patients (based on readings with the humeral device) would be labelled as hypertensive (based on readings with the wrist device). Labelling healthy persons as sick patients can result in detrimental consequences [33,34], the unnecessary prescription of antihypertensive medications and increased medical costs. On the other hand, blood pressure readings tend to be lower with the wrist device than with the arm device in patients in the highest range of blood pressure, which can lead to an under-treatment of high cardiovascular risk patients. Hence, patients with high values could be wrongly reassured and patients with low values wrongly worried. The impact of this systematic difference in blood pressure readings between two devices at high blood pressure values would be somewhat attenuated in clinical practice as blood pressure tends to decrease in individual patients over repeated readings over several visits.

Finally, this study was not designed to demonstrate whether one device was better than the other since we could not compare the devices' readings with measurements with those of a standard mercury sphygmomanometer. Instead, our purpose was to assess differences in the prevalence of blood pressure categories as a consequence of discrepancies between readings with two different automated devices. This issue is important because of the increasingly frequent use of automated devices in clinical practice [1] and epidemiological studies [5,25]. Admittedly, the significance of our findings is limited to the devices we have tested. Because accuracy in blood pressure measurement is a prerequisite for the detection and control of hypertension, our findings further emphasize the critical importance of a proper calibration of electronic instruments over the whole range of blood pressure values.

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