ORIGINAL ARTICLE

Oscillometric blood pressure measurements: differences between measured and calculated mean arterial pressure

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ABSTRACT

Mean arterial pressure (MAP) is often used as an index of overall blood pressure. In recent years, the use of automated oscillometric blood pressure measurement devices is increasing. These devices directly measure and display MAP; however, MAP is often calculated from systolic blood pressure (SBP) and diastolic blood pressure (DBP) as displayed by the device.

In this study we have analysed measured and calculated MAP, obtained by two different oscillometric BP measurement devices in two different patient cohorts.

The first cohort included 242 healthy subjects (male 40.5%, 50±13 years). BP measurements were performed with a Welch Allyn 5300P device. We found a small but significant difference between measured MAP and calculated MAP (MAP_{m-c}: -1.8 mmHg, range -5.7 to 12.9 mmHg, $p<0.001$). MAP_{m-c} showed a significant, but weak correlation with DBP and SBP.

The second cohort included 134 patients with glomerular diseases (male 63%, 50±14 years). BP measurements were performed with a Dinamap 487210 device. In this group we also observed a small difference between measured MAP and calculated MAP (+1.7 mmHg, range –15.3 to 28.2 mmHg, $p<0.001$). MAP_{m-c} correlated with age, all blood pressure indices and heart rate.

An overall analysis showed that age, SBP, DBP, and type of device are all independently related to MAP_{m-c}.

There is a significant difference between measured and calculated MAP. The difference is small on average; however, this MAP_{m-c} can be large in the individual patient. Moreover, there are differences of reported MAP between devices. Our data suggest that calculated and measured MAP cannot be used interchangeably.

KEYWORDS

Blood pressure measurement, mean arterial pressure, oscillometry

INTRODUCTION

Systemic blood pressure (BP) is one of the most important cardiovascular risk factors which is amenable for treatment. Thus far most long-term epidemiological studies have used BP values based upon auscultatory measurement with a mercury sphygmomanometer. With this technique systolic blood pressure (SBP) and diastolic blood pressure (DBP) are defined by the appearance and disappearance, respectively, of sounds over the brachial artery during deflation of the cuff (Korotkoff sounds I and V). Other indices of BP can be derived from SBP and DBP. Pulse pressure (PP) is calculated by SBP – DBP and mean arterial pressure (MAP) is calculated by DBP + 1/3 PP.

There is an ongoing debate on which of the above-mentioned BP parameters is most important in predicting cardiovascular risk and renal outcome.[1-4] Some studies suggest that MAP may be more accurate in predicting cardiovascular prognosis than other BP indices.[1,2]

Both in clinical research and clinical practice, the use of oscillometric BP measurement devices for determining BP is increasing.[5] The oscillometric BP measurement device measures oscillations from the blood vessel wall during cuff deflation. The pressure at which the oscillations are maximal is defined as MAP. The device then calculates the SBP and DBP with an algorithm.[6,7] The MAP measured oscillometry is the most reliable BP index of the oscillometric BP measurement device.[6] Although the measured MAP is reported by most devices, some researchers do not use it. Instead, they calculate the MAP from the SBP and DBP displayed by the device with the formula DBP + 1/3 PP.[8,9] Of note, some devices do not report MAP.

It is unknown if the measured MAP and calculated MAP are similar. In this study we compared the measured and calculated MAP obtained by two different oscillometric BP measurement devices in two study groups. Our data suggest that measured and calculated MAP cannot be used interchangeably.

METHODS

For this study we used archival BP data obtained with an oscillometric BP measurement device in two different patient cohorts.

Firstly we retrieved recordings of oscillometric BP measurements performed at our research unit in persons who were evaluated in the course of a screening programme for the detection of kidney disease. Participants filled in a questionnaire on medication use. Body weight and height were measured, BMI was calculated. Blood pressure was measured using an automated oscillometric device (Welch Allyn 5300P) while subjects were in a sitting position with the arm supported at heart level. Five BP readings were done at five-minute intervals.

For the second analysis we used BP recordings of patients with kidney disease participating in a research programme on markers of progression of glomerular disease.[10,11] In these patients approximately ten consecutive BP readings were performed at three-minute intervals with an automated device (Dinamap 487210, Critikon Tampa FL). In these patients BP was also measured by an experienced nurse using a sphygmomanometer. This 'office' reading always followed the automated measurement. The use of an ACE inhibitor, β-blocker, diuretic agent or calcium antagonist was recorded.

Calculations

The last three and five BP measurements, respectively, were used for analysis. SBP, DBP and MAP were retrieved from the printed output lists. Calculated MAP was derived from SBP and DBP using the formula DBP + 1/3 PP. PP was calculated by SBP – DBP. In each individual there were three and five pairs of calculated and measured MAP, respectively. To obtain the average difference per subject, the calculated MAPs were subtracted from the measured MAPs and these values were averaged (MAP_{m-c}). For paired comparisons we used the Wilcoxon signed-rank test, for unpaired comparisons we used the Mann-Whitney test. The MAP_{m-c} was correlated with several variables using Spearman's analysis. Multiple logistic regression was used to determine factors independently related to MAP_{m-c}. The analyses were done for the two groups separately. To evaluate the possible effect of the type of device, we also analysed the overall dataset.

All data are presented as means (±SD) or medians (range) when appropriate, All statistics were performed using SPSS software, version 14.0 (Chicago, IL). Differences were considered significant with p value <0.05.

RESULTS

Group 1

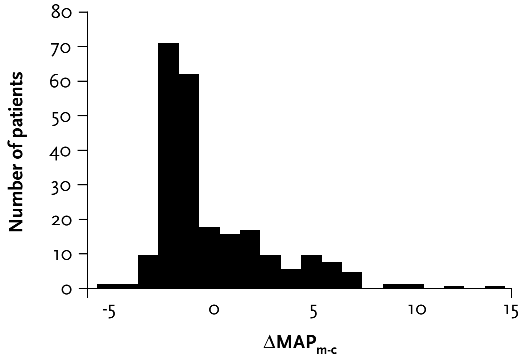
BP readings were available for 242 subjects. Their clinical characteristics are shown in *table 1*. We observed a significant difference between measured MAP and calculated MAP ($p<0.001$). The nonparametrical distribution of the MAP_{m-c} is shown in *figure 1A*. The median MAP_{m-c} amounted to -1.8 mmHg ($p<0.001$), but the difference can be large in individuals (range -5.7 to 12.9 mmHg). The MAP_{m-c} was slightly but significantly different in men and women ($p=0.008$). The median MAP_{m-c} in this group was -2.0 mmHg in male subjects and -1.7 mmHg in female subjects. Correlations of MAP_{m-c}

Table 1. *Baseline characteristics*

Variables	Group 1 (n=242) All	Group 1 Male (n=98)	Group 1 Female (n=144)	Group 2 (n=134) All	Group 2 Male (n=85)	Group 2 Female (n=49)
Age (years)	50±13	55±12	47±12	50±14	51±14	50±15
BMI (kg/m²)	25.7±4.7	26.3±3.8	25.3±5.2	27.0±4.7	26.8±4.2	28.2±5.5
Systolic blood pressure (mmHg)	121.8±14.0	126.8±13.8	118.4±13.2	131.9±25.2	132.1±25.6	131.6±24.8
Diastolic blood pressure (mmHg)	74.9±9.7	78.3±9.3	72.6±9.4	79.2±12.2	79.3±12.9	79.2±10.9
Measured mean arterial pressure (mmHg)	90.0±10.5	93.6±10.7	87.6±9.7	98.1±15.9	99.2±16.8	96.2±14.3
Antihypertensive treatment* (%)	16.1	14.3	17.4	86.6	89.4	81.6

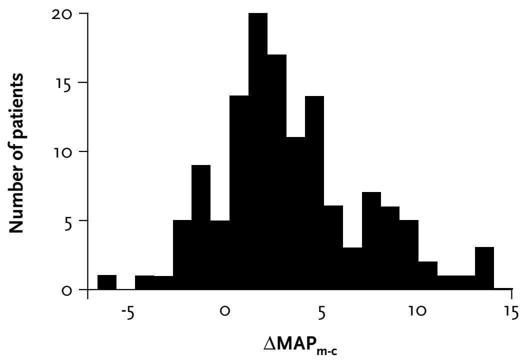
Values are expressed as means ± SD or %. *Antihypertensive treatment: use of calcium entry blockers/ACE inhibitor or angiotensin II receptor blocker/diuretic/β-blocker.

Figure 1A. *Histogram showing the difference between measured and calculated mean arterial pressure in 242 subjects*



Blood pressures recorded with Welch Allyn 5300P oscillometric device. Clearly, distribution of MAP_{m-c} is skewed.

Figure 1B. *Histogram showing the difference between measured and calculated mean arterial pressure in 132 subjects*



Blood pressures recorded with Dinamap 487210 oscillometric device. Of note, two outlaying values (-15.3 and 28.2) are not depicted.

with age, BMI, SBP, DBP, measured MAP, pulse pressure and heart rate are shown in *table 2*. Only DBP and SBP showed a significant, but weak correlation with MAP_{m-c}. In multivariable analysis it appeared that sex was not independently related to MAP_{m-c}. Both SDP and DBP were significantly related to MAP_{m-c}.

Group 2

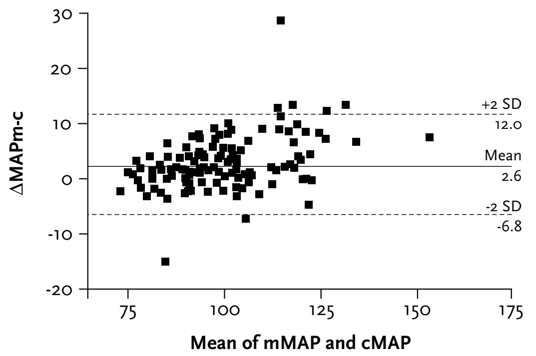
BP readings were available for 134 patients (*table 1*). In this group we also observed a significant difference between measured MAP and calculated MAP ($p<0.001$), with again a nonparametrical distribution of the MAP_{m-c} (*figure 1B*). The median MAP_{m-c} amounted to +1.67 mmHg ($p<0.001$), with a large range between individuals (-15.3 to 28.2 mmHg). *Figure 2* describes the relation between MAP_{m-c} and the mean MAP. In this group there was no difference in MAP_{m-c} between male and female subjects. All BP indices and heart rate correlated with MAP_{m-c}, although none of these correlations were very strong (*table 2*). In multivariable analysis only age ($p<0.001$) was independently related to MAP_{m-c}.

In this second patient group data on auscultatory measurement were available. There was no significant difference between the mean oscillometric SBP and the mean SBP as measured by sphygmanometry (median difference 2.1 mmHg), although the values for the individual patients were highly variable (range -31.6 to + 22.6 mmHg). We did observe a difference between DBP measured by oscillometry and auscultation, respectively, which again was very variable between the individual patients (median -0.6 mmHg, range -21.0 to +16.0 mmHg, $p=0.005$). When comparing the MAP measured oscillometrically with the MAP calculated by SBP and DBP measured by auscultation, the difference observed was median +1.5 mmHg (range -16.1 to 23.5 mmHg, $p=0.05$); for MAP calculated by oscillometry *vs* MAP calculated by auscultation, the difference was -0.3 mmHg (range -17.3 to 15.3 mmHg, $p=0.04$).

Table 2. *Correlations of MAP_{m-c} with patients characteristics*

	Group 1		Group 2	
Variables	Spearmans rho	p value	Spearmans rho	p value
Age (years)	-0.10	ns	0.38	<0.01
BMI (kg/m²)	-0.04	ns	0.13	ns
Systolic blood pressure (mmHg)	-0.16	0.01	0.31	<0.01
Diastolic blood pressure (mmHg)	-0.21	<0.01	0.29	<0.01
Measured mean arterial pressure (mmHg)	0.02	ns	0.46	<0.01
Pulse pressure (mmHg)	-0.02	ns	0.34	<0.01
Heart rate (/min)	-0.00	ns	-0.20	0.02

Figure 2. *Bland-Altman plot*



Relation between MAP_{m-c} and the mean of those mean arterial pressures for the second patient group. R=0.35; p=0.01.

Lastly, we performed an analysis of the combined data of the oscillometric BP readings in both groups. In multivariate analysis age, SBP, DBP, and type of device were independently related to MAP_{m-c}.

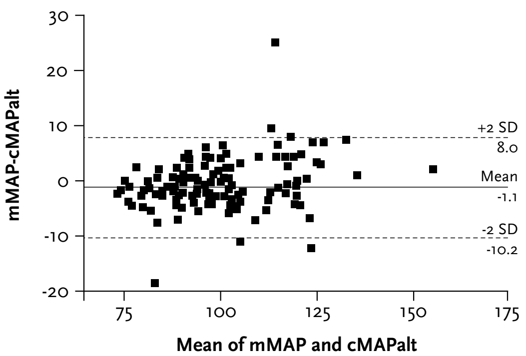
DISCUSSION

We found a small but significant difference between the measured and calculated MAP in oscillometric BP readings. The measured MAP was lower than the calculated MAP in the first cohort, while it was higher than the calculated MAP in the second cohort. The difference between measured and calculated MAP was dependent on age, SBP and DBP. Of note, the observed differences were also clearly dependent on the BP measurement device (Welch Allyn *vs* Dinamap). It has been shown before that although all devices on the market have passed an obligatory test protocol, the accuracy of different devices can vary.[5,12]

Although the differences between measured and calculated MAP seem small, large differences have been observed in individuals. Variability will be even larger when using only one single BP measurement (*table 3*). Therefore, we feel that measured and calculated MAP cannot be used interchangeably. We were unable to find important determinants of the difference between measured and calculated MAP. Although SBP and DBP were related to MAP_{m-c} in group 1, and age and BP in group 2, these factors can only explain the variation in MAP to a limited extent.

Recently, the method of calculating the MAP has been debated. Bos *et al.* showed that the well-known formula of MAP = DBP + 1/3 PP underestimates the 'real' MAP, with larger underestimations at higher pressures.[13] A new formula of DBP + 0.4 PP was suggested and was validated for a large range of BP values.[14] Use of this new formula results in a higher value of the calculated MAP. To determine if the application of this new formula would affect our conclusions, we reanalysed the data of our second patient cohort. In this new analysis the difference between measured and calculated MAP became negative (median -1.6 mmHg, range –18.8 to +24.8 mmHg); however, the difference remained statistically significant (p=0.007). Thus, the use of the new formula does not nullify the difference between calculated and measured MAP in oscillometry (*figure 3*).

Figure 3. *Bland-Altman plot*



Relation between the difference of measured mean arterial pressures (MAPs) and the MAP calculated by the alternative formula (mMAP-cMAPalt) and the mean of those MAPs for the second patient group. r=0.26; p=0.01.

Table 3. *MAP_{m-c} (mmHg) for the consecutive BP measurements*

		MAP_{m-c} 1	MAP_{m-c} 2	MAP_{m-c} 3	MAP_{m-c} 4	MAP_{m-c} 5
Group 1	Mean ±SD	-0.6±3.2	-0.4±3.8	-0.7±5.1	NA	NA
	Median (range)	-1.7 (6-17)	-1.7 (-7-16)	-1.0 (-17-21)	NA	NA
Group 2	Mean ±SD	1.9±6.4	2.5±6.2	2.6±7.4	2.2±5.6	2.4±5.4
	Median (range)	1.7 (-17-24)	1.5 (-18-25)	2.2 (-27-25)	1.0 (-12-18)	2.7 (-12-18)

NA = not available.

To our knowledge only Smulyan *et al.* have evaluated the difference between calculated MAP and measured MAP in oscillometric BP measurement (Colin Medical Instrument device).[15] These authors studied patients who underwent a coronary angiography, and observed a weak correlation between the difference in MAP and age (r=0.32). This finding is similar to our finding in the second group (r=0.38) but not to the first group (r=-0.10). The difference between the findings of Smulyan *et al.* and the findings in our first group might be explained by the difference in population. In Smulyan's study there were more men (50%), the subjects were on average older (mean age 60.4 years) and 85% of the subjects used medication for the treatment of cardiovascular disease, whereas in our first group of 'healthy' persons, this was only 16.1%. Our second group had more men (63%), higher BPs and all subjects were patients with kidney disease, so this population may be more like that of Smulyan, explaining the similarity in outcome.

The oscillometric BP measurement device has been compared with intra-arterial BP measurement and with sphygmomanometer BP readings. Loubser *et al.* compared BPs obtained with oscillometric (Dinamap 1845) and intra-arterial methods in postoperative hypertensive patients.[16] In that study the MAP did not significantly differ between the two methods. In contrary, the SBP was underestimated largely (19 mmHg) by the oscillometric method. In further analysis this appeared to be due to large underestimation in hypertensive patients (SBP >160 mmHg), while in the normotensive range (SBP <140) there was no significant difference. In addition, the DBP was significantly overestimated (6 mmHg) by the oscillometric device and this difference remained fairly constant throughout all pressure ranges. Gorback *et al.* performed a comparable study in anaesthesia patients (oscillometric BP measurement (Dinamap 1846SX) *vs* intra-arterial BP readings).[17] They showed the same tendency to underestimated SBP at higher pressures (-9 mmHg), but they could not confirm the overestimation of the DBP. Both DBP and MAP did not significantly differ between the two measurement methods. However, in individual patients the differences were unpredictable and varied from large overestimation to large underestimation for all BP indices (-34 mmHg to +17 mmHg). This large individual variability (from -30 to 25 mmHg) was also found by Pace and East, who compared oscillometric (Dinamap 845XT) and intra-arterial BP readings in patients who underwent elective surgery.[18] Furthermore, they did not find a significant overall difference in SBP and MAP, but confirmed the overestimation (6 mmHg) of the DBP as found by Loubser.

Comparisons of the standard mercury sphygmomanometer and intra-arterial BP show an underestimation of SBP (6 to 10 mmHg) and an overestimation of DBP (2 to 8 mmHg).[19,20]

In most cardiovascular risk studies a sphygmomanometer was used to assess the risk of BP level. Therefore BPs obtained by oscillometry have been compared with sphygmomanometer BPs. For this purpose the American Association for the Advancement of Medical Instrumentation (AAMI) and the British Hypertension Society (BHS) have both designed a protocol for the validation of oscillometric BP measurement devices by comparing sphygmomanometer BP with oscillometry BPs. The values of the oscillometric BP readings and of the sphygmomanometer readings are compared for SBP and DBP. The oscillometric device is graded 'A' if the difference in read pressure is smaller than 5 mmHg in 60%, smaller than 10 mmHg in 85% and smaller than 15 mmHg in 95% of the readings.

Clearly, these validation studies are developed with the goal to make sure that an oscillometric BP measuring device displays the same SBP and DBP values as a sphygmomanometer in one individual. This is convenient when using guidelines based on sphygmomanometer readings. However, it cannot be excluded that oscillometry measures a different kind of physiological variable of BP than sphygmomanometers do. Smulyan *et al.* found that MAP obtained by oscillometry correlated better with intra-aortal pressure than other BP indices. If oscillometrically measured BP does mark a different kind of physiological variable, this would be masked by adjusting the algorithms to mimic sphygmomanometer outcome, in order to achieve an 'A' grading in validation.

Researchers using an oscillometric device for obtaining MAP should be aware of the difference in calculated and measured MAP. Therefore, researchers should describe their method of obtaining MAP with an oscillometric device precisely, especially describing the use of measured MAP or calculated MAP.

In this study we have not calculated relative risks for calculated and measured MAP, nor have we compared the oscillometric measurements with sphygmomanometer or intra-arterial BP readings. Therefore, we can not conclude which MAP is the best to use. We did find a relatively large range in the difference between calculated and measured MAP for the individual patient obtained from oscillometric BP measuring. With that finding, we want to emphasise the importance of describing the method of determining MAP when using an oscillometric BP measurement device in research.

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