

Comparison of Repeatability of Blood Pressure Measurements between Oscillometric and Auscultatory Methods

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Abstract

Oscillometric and auscultatory methods are two main non-invasive blood pressure measurement methods in routine examinations and monitoring. There is currently little information available on the comparison of their repeatabilities when performing more than three repeat measurements. This study aimed to provide this information. Oscillometric cuff pressure waveforms and Korotkoff sound signals were simultaneously and digitally recorded from 20 normotensive subjects. Eight repeat measurements were performed for each subject. SBP, MAP and DBP values were determined from the digitally recorded oscillometric cuff pressure and Korotkoff sound signals using oscillometric and auscultatory methods respectively.

The standard deviation of eight SBP, MAP and DBP measurements was calculated for each subject as the index of repeatability (SBP_{SD} , MAP_{SD} and DBP_{SD} respectively). The results showed that SBP from the oscillometric method were 2 mmHg higher than those from the auscultatory method ($P=0.2$). MAP and DBP values from the oscillometric method were significant lower than those from the auscultatory method (both $P<0.01$) by 7 mmHg and 6 mmHg respectively. The key results were that the repeatability indices from the oscillometric method were all greater for oscillometric measurement by 1.5 mmHg for SBP_{SD} (mean \pm SD: 4.4 ± 1.8 vs 2.9 ± 0.9 mmHg), by 1.3 mmHg for MAP_{SD} (3.6 ± 1.1 vs 2.3 ± 0.9 mmHg), and by 0.8 mmHg for DBP_{SD} (3.4 ± 1.6 vs 2.6 ± 1.0 mmHg), suggesting that the widely used oscillometric method can not replace the auscultatory method in clinical applications.

1. Introduction

Non-invasive blood pressure (NIBP) measurement plays a crucial role in routine examinations and monitoring. The auscultatory method is considered the gold standard measurement. The oscillometric method is used by the majority of automatic NIBP devices.

Although oscillometric BP devices which are sold on market have successfully fulfilled the validation protocols developed by the International Organization for Standardization, the American Association for the Advancement of Medical Instrumentation [1] or the British Hypertension Society [2], it is recognized that, even the best oscillometric BP devices that comfortably pass the requirements of established validation protocols could fail to provide accurate BP measurements for some patients [3].

Existing studies for validating the accuracy of oscillometric method usually focused on the reproducibility test between oscillometric and auscultatory methods based on two or three repeat measurements. There is currently little information available on the comparison of their repeatabilities when performing more than three repeat measurements. This study aimed to provide this information.

2. Methods

2.1. Subjects

Twenty normotensive subjects (10 male and 10 female; aged from 24 to 68 years) were studied. The detailed subject demographic information including age, height, weight and arm length are summarized in Table 1. This study received ethical permission, and all subjects gave their written informed consent.

Table 1. Demographic data for the subjects studied. Their means and standard deviations (SDs) are presented.

| Parameters | Values |
|-----------------|--------------|
| Number | 20 |
| Age (years) | 39 \pm 11 |
| Height (cm) | 172 \pm 12 |
| Weight (kg) | 70 \pm 12 |
| Arm length (cm) | 28 \pm 2 |

2.2. Blood pressure determination

As shown in Figure 1, cuff pressure and Korotkoff sound signals were synchronously and digitally recorded at a sample rate of 2000 Hz during standard BP measurement. For each subject, eight repeat measurements were performed with the recommended measurement procedure in a quiet clinical measurement room. During each measurement, the cuff pressure was quickly inflated to 200 mmHg and then linearly deflated to 20 mmHg at a rate of 2-3 mmHg/s (standard inflation) as recommended by the British Hypertension Society (BHS) [4]. All the measurements were performed by a trained and experienced observer.

The oscillometric pulses were extracted from the deflating cuff pressure signal after identifying the feet of each cardiac cycle pulse and removing the baseline cuff pressure [5]. The Korotkoff sound signals were filtered by a Butterworth band-pass filter. Figure 2 show the examples of the recorded cuff pressure, the extracted oscillometric pulses and the filtered Korotkoff sound

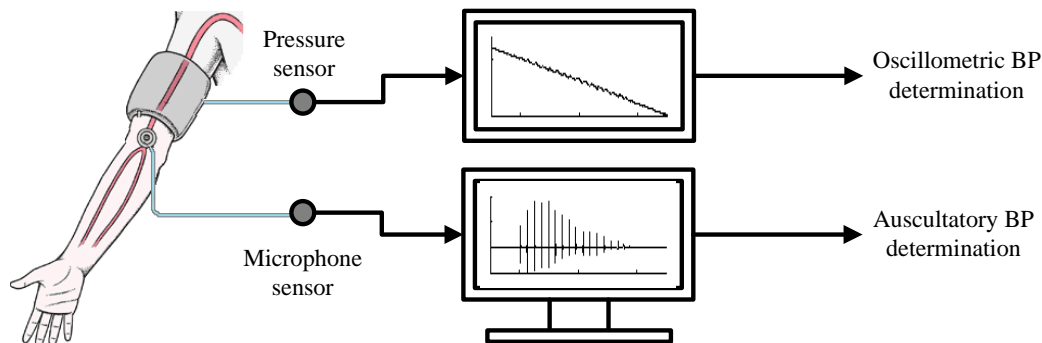


Figure 1. Diagram of blood pressure measurement system for digitally recording cuff pressure and Korotkoff sound signals. Eight repeat measurements were performed for each of all 20 subjects.

2.3. Data and statistical analysis

The mean values of the SBP, MAP and DBP from the eight repeat measurements were calculated separately for oscillometric and auscultatory methods for each subject for comparing the BP determination difference between the two methods. The standard deviation (SD) values of the SBP, MAP and DBP from the eight repeat measurements were calculated separately for the two methods for each subject to compare the BP measurement repeatability between the two methods. These SD values were used as the repeatability indices (denoted as SBP_{SD} , MAP_{SD} and DBP_{SD} respectively).

Paired t test was used for the comparisons of BP determination difference and BP measurement repeatability. A value of $P < 0.05$ was considered statistically significant.

signal.

As shown in Figure 2, for the oscillometric method, mean arterial pressure (MAP) was obtained from the maximum oscillometric pulse. Oscillometric SBP and DBP were determined from the closest oscillometric pulse above the thresholds of characteristics ratio. Amoore *et al* has reported that the mean characteristic ratios were 0.49 for SBP and 0.72 for DBP respectively [6]. So in this study, the baseline cuff pressure corresponding to 50% of maximum oscillometric pulse in the high pressure range and 70% of maximum oscillometric pulse in the low pressure range during cuff deflation were used to determine the oscillometric SBP and DBP respectively.

For the auscultatory method, SBP and DBP were determined by replaying the Korotkoff sound signals to a trained listener. The appearance and disappearance of Korotkoff sounds are associated with auscultatory SBP and DBP respectively. Auscultatory MAP was determined using the typical formula: $MAP = DBP + (SBP - DBP)/3$.

3. Results

3.1. BP determination difference between oscillometric and auscultatory methods

Table 2 showed that SBP values from the oscillometric method were slightly higher than those from the auscultatory method but not significantly ($P = 0.2$). However, MAP and DBP values from the oscillometric method were significant lower than those from the auscultatory method (both $P < 0.01$). Specifically, BP values were lower from oscillometric measurement by 7 mmHg for MAP and by 6 mmHg for DBP.

3.2. BP measurement repeatability between oscillometric and auscultatory methods

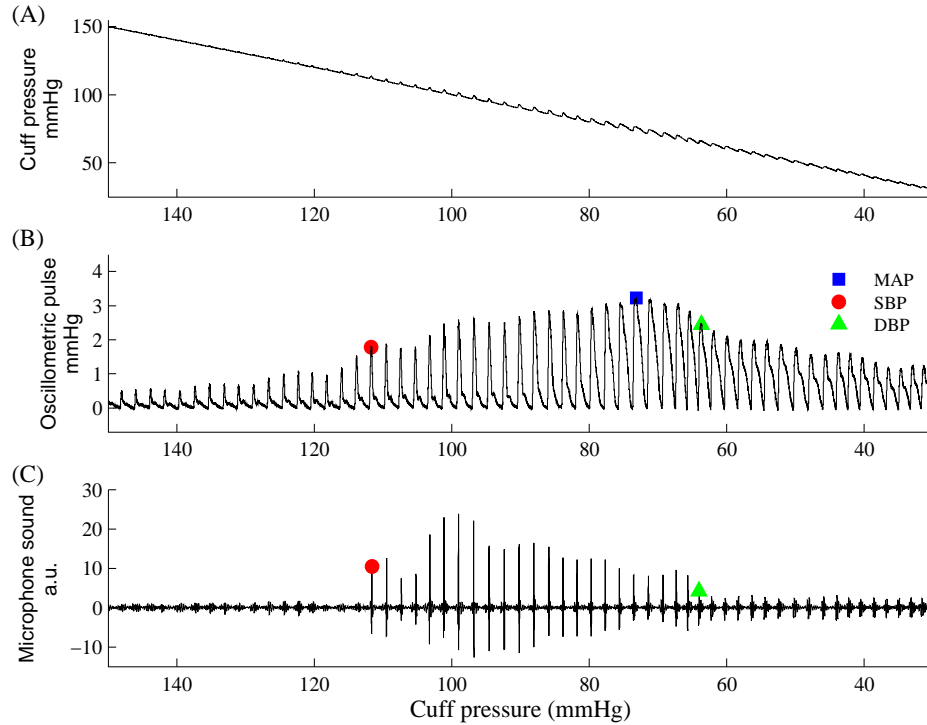


Figure 2. Examples of the BP determination from both oscillometric and auscultatory methods. (A) the recorded cuff pressure, (B) the extracted oscillometric pulse from cuff pressure and (C) the filtered Korotkoff sound signal.

Table 2. Blood pressures (SBP, MAP and DBP) determined from both oscillometric and auscultatory methods.

| Indices | Oscillometric | Auscultatory | <i>P</i> value |
|------------|---------------|--------------|----------------|
| SBP (mmHg) | 107±9 | 105±10 | 0.2 |
| MAP (mmHg) | 74±7 | 81±7 | <0.01 |
| DBP (mmHg) | 63±6 | 69±7 | <0.01 |

Table 3 shows that all three repeatability indices (SBP_{SD}, MAP_{SD} and DBP_{SD}) from the oscillometric method were higher than those from the auscultatory method. As shown in Figure 3, the differences for SBP_{SD} and MAP_{SD} were statistically significant (both $P < 0.01$) between the two methods while the difference for DBP_{SD}

was not ($P = 0.1$). Specifically, repeatability indices were all greater for oscillometric measurement by 1.5 mmHg for SBP_{SD} (mean±SD: 4.4±1.8 vs 2.9±0.9 mmHg), by 1.3 mmHg for MAP_{SD} (3.6±1.1 vs 2.3±0.9 mmHg), and by 0.8 mmHg for DBP_{SD} (3.4±1.6 vs 2.6±1.0 mmHg).

Table 3. The results of repeatability indices (SBP_{SD}, MAP_{SD} and DBP_{SD}) from both oscillometric and auscultatory methods.

| Indices | Oscillometric | Auscultatory | <i>P</i> value |
|--------------------------|---------------|--------------|----------------|
| SBP _{SD} (mmHg) | 4.4±1.8 | 2.9±0.9 | <0.01 |
| MAP _{SD} (mmHg) | 3.6±1.1 | 2.3±0.9 | <0.01 |
| DBP _{SD} (mmHg) | 3.4±1.6 | 2.6±1.0 | 0.1 |

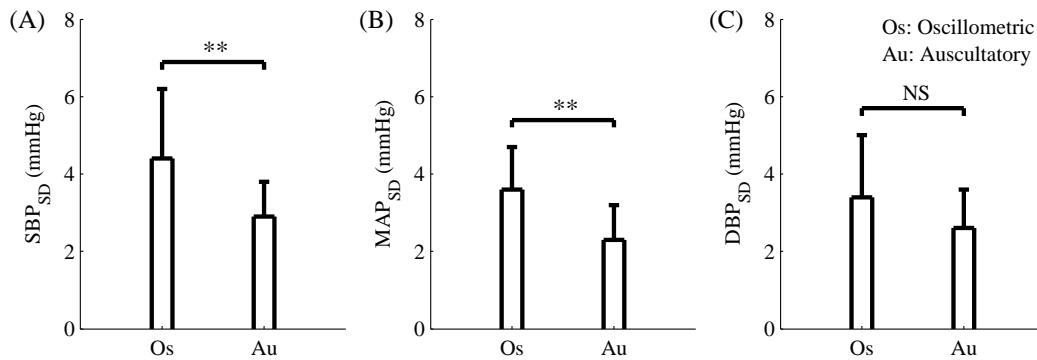


Figure 3 Mean+SD of the three repeatability indices for both oscillometric and auscultatory methods: (a) SBP_{SD}, (b) MAP_{SD} and (c) DBP_{SD}. 'NS': statistical significance $P \geq 0.05$, '***': statistical significance $P < 0.01$.

4. Discussion and conclusion

It has been found in this study that BP values determined from oscillometric method were different with these from the auscultatory method. Previous study in [7] has reported that SBP did not have significant difference between the oscillometric and auscultatory methods but the DBP was significantly higher by 3.6 mmHg when using oscillometric method [7], which was opposite with our current finding. However, Landgraf *et al* reported a 2 mmHg lower DBP values [8]. The different conclusion could be caused by different algorithms used for oscillometric BP determination. In this study, we used the fixed characteristic ratios of 0.5 for SBP and 0.7 for DBP, which were close to the mean systolic and diastolic characteristics ratios of 0.48 and 0.71 reported by Amoore *et al* [6]. In order to achieve better accuracy, characteristics ratios could be fine-tuned to reduce the BP determination differences between oscillometric and auscultatory method.

More importantly, this study demonstrated that auscultatory method is more stable than oscillometric method using the data from eight repeat measurements, and confirmed that the oscillometric method for BP determination based on characteristics ratios is not reliable enough for replacing the auscultatory method in clinical applications.

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