Automated Blood Pressure Measurement: Reasons for Measurement Variability Uncovered

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Abstract

The most common automated blood pressure devices determine systolic, diastolic and mean arterial blood pressure (SBP, DBP and MAP) by analysing the oscillometric pulse waveform. The aim of this study was to assess the variability of the amplitude of oscillometric pulse waveform characteristics at SBP, DBP and MAP.

Sixty oscillometric waveforms from twenty subjects were analysed. Manual SBP and DBP were obtained with a manual sphygmomanometer, from which manual MAP was calculated from the empirical equation. Automated MAP was estimated from the maximum oscillometric pulse. The oscillometric pulse amplitudes, normalised to the maximum pulse, at above SBP, SBP, MAP, DBP and below DBP were then determined. The cuff pressures at half the maximum oscillometric pulse amplitude were also measured.

There were significant differences in normalised oscillometric pulse amplitude between SBP and DBP (mean±SD: 0.45±0.10 vs 0.80±0.12, P<0.001), and between manual and automated MAP (0.89±0.09 vs 1.00±0, P<0.001).

Manual SBP (118±11 mmHg) and DBP (76±9 mmHg) were significantly different from the cuff pressures at half the maximum oscillometric pulse amplitude (117±12 mmHg and 66±10 mmHg), with the paired differences of 1±5 mmHg (P<0.05) and 10±7 mmHg (P<0.001) respectively. Significant differences between manual and automated MAP were also observed, with the paired difference of 3±6 mmHg (P<0.001).

In conclusion, there are large variations in the pulse characteristics at SBP, DBP and MAP. This complicates a reliable automatic estimation of these values.

1. Introduction

High blood pressure is a cause of morbidity and mortality. Measurement of blood pressure is one of the most common clinical measurements made by General Practitioners, Hospital Physicians and other healthcare providers. People also regularly measure their own blood pressures at home. But the accuracy of those measurements is still in doubt [1-2].

The most common automated devices use the oscillometric technique, in which a cuff containing an air bladder is wrapped round the upper limb. During deflation, the oscillations in the cuff pressure begin above systolic blood pressure (SBP) and continue below diastolic blood pressure (DBP). These oscillations are caused by the pulse radiating down the artery producing pressure changes in the air bladder [3-5]. These small pressure changes, known as oscillometric pulses, are greatest at mean arterial pressure (MAP) and become smaller at both lower and higher cuff pressures [6].

SBP, DBP and MAP are often determined by analysing the oscillometric pulse waveform using empirical algorithms [7]. Many algorithms, not divulged by the manufacturers of automated devices, use the systolic and diastolic characteristic ratios, which are the amplitudes of the oscillometric pulse at the cuff pressure of SBP and DBP, divided by the maximum oscillometric pulse amplitude [8, 9]. However, there is little information available on how pressures relate to the features extracted from oscillometric waveforms.

The aim of this study was to assess the variability of the amplitude of oscillometric pulse waveform characteristics at SBP, DBP and MAP.

2. Methods

2.1. Subjects

Twenty healthy subjects, with no known cardiovascular disease, were studied. There were 10 male and 10 female subjects, with ages in the range 22 to 71 years. This study received ethical permission, and all subjects gave their written informed consent to participate in the study.

2.2. Blood pressure measurements

Blood pressure measurements were undertaken in a quiet room. Prior to the measurement, the subject was asked to have a 5 min rest in order to allow cardiovascular stabilization. The subject was then seated in a chair with their feet on the floor and with arm supported at heart level.

Manual SBP and DBP were obtained with a manual sphygmomanometer, simultaneously by two trained observers, agreeing within 4 mmHg. The average from the two observers was used as the reference SBP and DBP for that subject. Manual MAP was then calculated from the empirical equation: MAP=DBP+(SBP-DBP)/3.

Three repeat measurements were performed for each subject. During each measurement, the cuff pressure was deflated at 2-3mmHg/s and recorded to a data capture computer at a sample rate of 2000 Hz.

2.3. Oscillometric waveform analysis

Interactive software was developed with the application of Matlab 7.0 to perform off-line oscillometric waveform analysis. The oscillometric pulses were extracted from the cuff pressure, deflated from 150 mmHg to approximately 40 mmHg over the duration of 40 s, as shown in Figure 1.

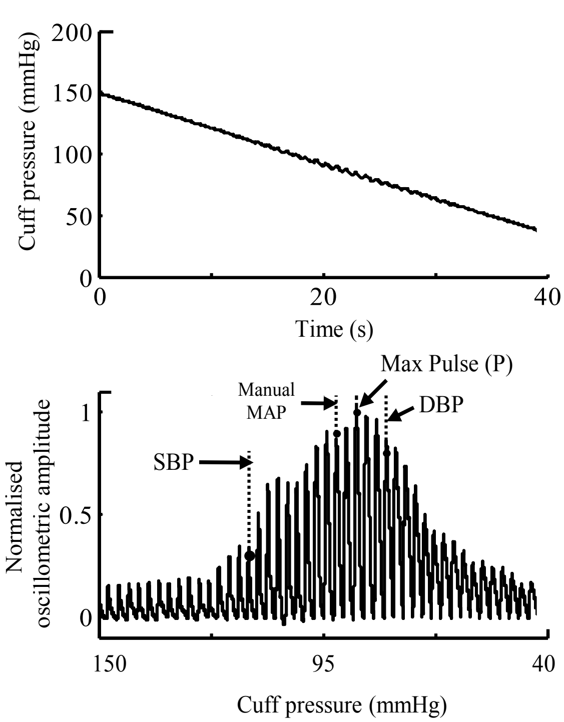

Figure 1. One typical example of cuff pressure (top) and extracted oscillometric pulse waveform (bottom).

The maximum oscillometric pulse was taken to determine automated MAP, also known as Max Pulse (P) in Figure 1. In order to compare the non-calibrated oscillometric waveforms from different subjects, the oscillometric pulse amplitudes were normalised to the maximum value. The normalised amplitudes and associated cuff pressures of the following peaks of the oscillometric pulses were then measured:

- The oscillometric pulses at cuff pressure above SBP (150 mmHg) and below DBP (40 mmHg).
- The first and last oscillometric pulses whose normalised amplitude is larger than 0.5.
- The oscillometric pulses associated with SBP, DBP and MAP.

2.4. Data and statistical analysis

The means and standard deviations (SDs) of the normalised amplitudes and cuff pressures of the above-mentioned oscollometric pulses were calculated from the 60 oscillometric waveforms. Within-subject variability was calculated from the SD of the three repeat measurements, and also expressed as a coefficient of variability (100×SD/mean, %).

The normalised oscillometric pulse amplitude between the pulses at cuff pressure above SBP and below DBP, between the pulses associated with SBP and DBP and between manual and automated MAP were compared. The cuff pressures at half the maximum oscillometric pulse amplitude were then compared with manual SBP and DBP.

All differences were for paired values in each subject, and all statistical analysis were performed on paired data by using SPSS software package (SPSS Inc.). A value of $P<0.05$ was considered statistically significant.

3. Results

3.1. Overall pulse amplitude and cuff pressure information

The overall means and SDs of normalised oscillometric pulse amplitudes were 0.20±0.07 (at above SBP), 0.45±0.10 (at SBP), 0.89±0.09 (at manual MAP), 0.80±0.12 (at DBP) and 0.20±0.10 (at below DBP), as shown in Figure 2. Their corresponding mean within-subject SD variabilities were 0.05, 0.06, 0.06, 0.06 and 0.03, with coefficients of variability of 25%, 13%, 6%, 8% and 17%.

The means±SDs of SBP and DBP were 118±11 mmHg and 76±9 mmHg. They were 90±8 mmHg and 87±10 mmHg for the manual and automated MAPs. The cuff pressures at half the maximum oscillometric pulse amplitude were 117±12 mmHg and 66±10 mmHg respectively at high and low pressure region.

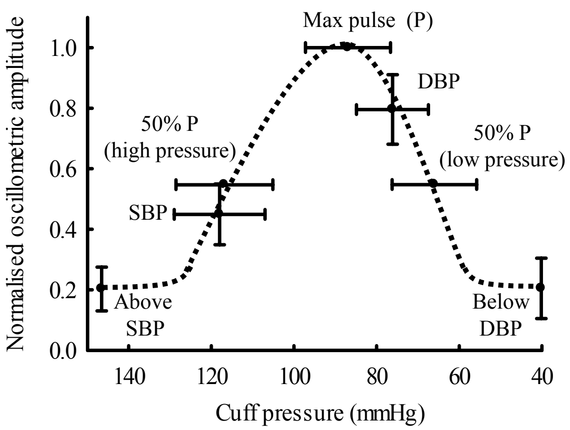

Figure 2. Means and SDs of the normalised pulse amplitudes and associated cuff pressures from different oscillometric pulses. A virtual smooth envelope is artificially drawn based on the values obtained and our experienced observation on oscillometric waveforms.

3.2. Comparison of oscillometric pulse amplitude

There was no significant difference in normalised amplitude between the pulses at cuff pressure above SBP and below DBP, as shown in Figure 3. It also showed that the normalised oscillometric pulse amplitude associated with manual SBP was significantly different from that for DBP (almost half, $P<0.001$).

Figure 4 showed that the normalised amplitude of the pulses associated with manual MAP was significantly smaller than that of the maximum oscillometric pulses (automated MAP), with a paired difference of -0.11±0.09 ($P<0.001$).

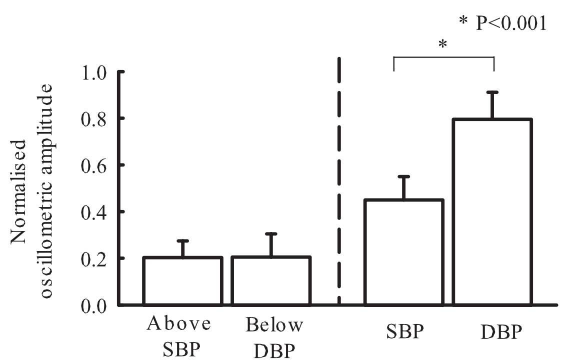

Figure 3. Paired comparisons of normalised oscillometric pulse amplitude between the pulses at cuff pressure above SBP and below DBP (left) and between the pulses associated with manual SBP and DBP (right).

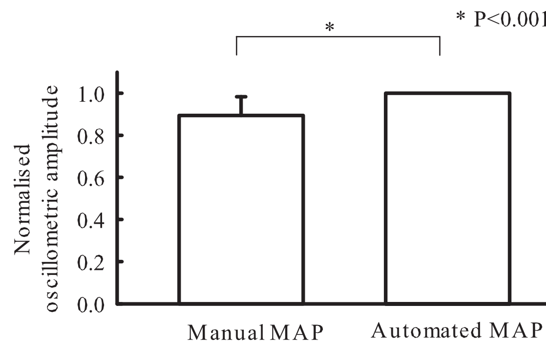

Figure 4. Paired comparison of normalised oscillometric pulse amplitude between manual and automated MAP.

3.3. Comparison of cuff pressure

As shown in Figure 5, the cuff pressures associated with the oscillometric pulses having half maximum amplitude were significantly different from SBP and DBP, with the mean paired difference±SD of -1±5 mmHg ($P<0.05$) and -10±7 mmHg ($P<0.001$) respectively.

Significant difference between manual and automated MAP was also observed, with the paired difference±SD of 3±6 mmHg ($P<0.001$), as shown in Figure 6.

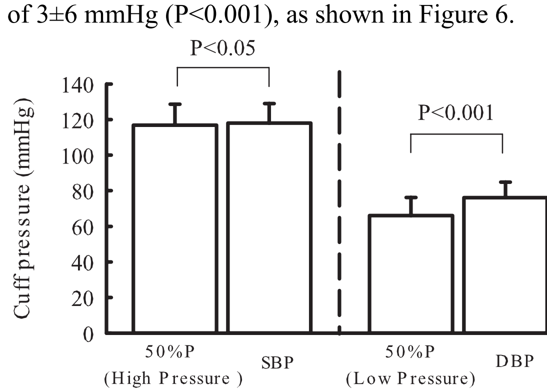

Figure 5. Paired comparisons between cuff pressures associated with the oscillometric pulses having half maximum amplitude and SBP and DBP.

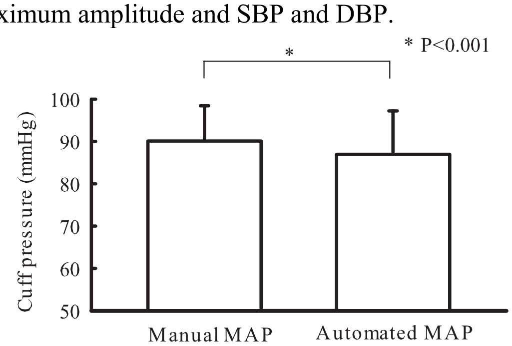

Figure 6. Paired comparison of manual and automated MAP.

4. Discussion and conclusions

The normalised oscillometric pulse amplitudes at SBP, DBP and MAP were determined. The mean oscillometric pulse amplitudes at SBP and DBP were 0.45 and 0.80, which was similar to the published systolic and diastolic characteristic ratio reported by Geddes et al. and Amoore et al. [8, 9]. However, it varied significantly, with the within-subject and between-subject SD variabilities of 0.06 and 0.10. Although it is generally accepted that these variabilities are associated with the conditions and environment in which blood pressure measurements are made [10, 11], as well as other physiological and biomechanical factors [12, 13], the relationship between the different causes and the variability of the oscillometric pulse amplitude needs to be further investigated.

Next, although the principle of producing oscillations at above SBP and below DBP regions is different [14], their normalised oscillometric pulse amplitudes were statistically similar. However, in this present study, only one oscillometric pulse above SBP and below DBP was used for analysis. More work needs to be followed up to obtain regional pulse amplitude quantification and then do comparison.

We also found that automated MAP based on the maximum oscillometric pulse was smaller than manual MAP calculated from the empirical function. This finding agreed with the results published by Kiers et al. [15].

Another interesting finding is, although the high cuff pressure associated with the oscillometric pulses having half maximum amplitude was close to SBP, they were significantly different. It suggests that the empirical blood pressure determination algorithms based on a fixed oscillometric pulse waveform feature would not provide accurate measurement

In conclusion, there are large variations in the pulse characteristics at SBP, DBP and MAP. This complicates a reliable automatic estimation of these values.

Acknowledgements

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