Asymmetrical Oscillometric Pulse Waveform Envelopes in Normotensive and Hypertensive Subjects

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Abstract

This study investigated the symmetry of the oscillometric waveform shape obtained during non-invasive auscultatory blood pressure measurement.

The oscillometric cuff pressures were recorded from ten normotensive and ten hypertensive subjects. The cuff pressure corresponding to the maximum oscillometric pulse was taken as the automated mean arterial pressure (MAP). The cuff pressures corresponding to 30%, 50% and 70% of the maximum oscillometric pulse peak amplitude were measured for both the high and low pressure regions. At the three different thresholds, the cuff pressure widths (absolute difference to the MAP) in the high and low pressure regions were compared.

For both the normotensive and hypertensive groups, the cuff pressure widths in the high pressure region were significantly larger than in the low pressure region at the normalised amplitude levels of 50% and 70% (all P<0.01), which confirmed an asymmetrical feature of the oscillometric waveform envelope.

1. Introduction

The importance of blood pressure measurement is without doubt. There are currently two different non-invasive ways of measuring blood pressures: manual auscultatory technique and automatic technique. Because automatic blood pressure measurement devices are very simple to operate, they are used frequently by the general public as well as many health care institutions [1]. They have successfully encouraged patients to take control of their health and reduce their blood pressures.

The vast majority of automatic blood pressure measurement devices use the oscillometric technique, in which blood pressure pulses radiating down the arm are transmitted to the blood pressure cuff and detected electronically with a pressure sensor. As the cuff pressure is deflated (or inflated in some devices), the small pulses extracted from the recorded cuff pressure signal can be analysed as an oscillometric pulse waveform.

Automated blood pressures are usually determined by analysing different features extracted from the oscillometric pulse waveform [2-4]. Manufacturers derive their own algorithms to estimate automated blood pressures after referencing to manual measurements obtained during the device development by each manufacturer. But there is currently no way of absolutely calibrating this oscillometric pulse waveform because there is little information available on the features of the oscillometric pulse waveform. It has also been reported that the oscillometric pulse waveform is a potential contributor to the differences between oscillometric and auscultatory pressure measurements [5, 6].

Therefore, for a better understanding of the shape of the oscillometric pulse waveform, this study investigated the symmetry of the oscillometric pulse waveform in healthy normotensive and hypertensive subjects.

2. Methods

2.1. Subjects

Ten normotensive subjects (5 male and 5 female; age from 25 to 62 years; systolic blood pressure (SBP)<140 mmHg) and ten hypertensive subjects (5 male and 5 female; age from 40 to 80 years; SBP≥140 mmHg) were studied. The detailed subject demographic information including age, height and weight are summarized in Table 1. This study received ethical permission, and all subjects gave their written informed consent.

Subject group	Normotensive	Hypertensive
No. subject	10	10
Average age (years)	46±15	57±14
Height (cm)	170±9	170±14
Weight (kg)	69±9	80±18
SBP (mmHg)	110±9	149±6
DBP (mmHg)	74±5	93±8

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

ISSN 0276−6574

Computing in Cardiology 2010;37:377−380.

2.2. Blood pressure measurement

Three repeat auscultatory blood pressure measurements were performed with the British Hypertension Society recommended measurement procedure in a quiet clinical measurement room. They were measured under resting condition with a clinically validated electronic sphygmomanometer (Accoson *Greenlight 300* from AC Cossor & Son (Surgical) Ltd) [7] by the same trained and experienced observer. The overall mean and standard deviation (SD) values of the SBP and diastolic blood pressure (DBP) are included in Table 1.

During each auscultatory blood pressure measurement, the oscillometric cuff pressure was electronically and linearly deflated from approximately 200 mmHg at a rate of 2-3 mmHg/s and was recorded digitally to a computer at a sample rate of 2000 Hz for off-line oscillometric waveform analysis.

2.3. Oscillometric waveform analysis

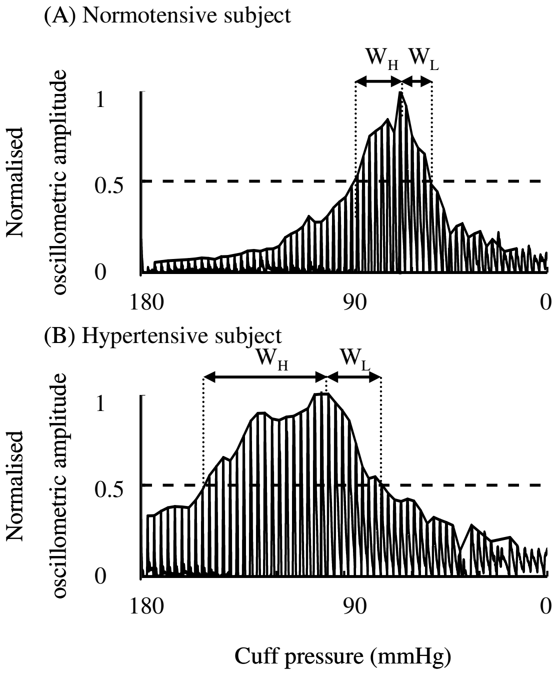
Interactive software was developed using Matlab 7.0 to extract the oscillometric pulses from the recorded cuff pressure. Each oscillometric pulse was normalised to the maximum oscillometric pulse peak amplitude. The oscillometric waveform envelope was related to cuff pressure and formed by connecting the sequential peaks of the normalised oscillometric pulses. Figure 1 gives two typical examples of the oscillometric waveforms from a normotensive subject and a hypertensive subject.

The cuff pressure corresponding to the maximum oscillometric pulse peak amplitude was taken as the automated mean arterial pressure (MAP), which was the reference pressure for subsequent calculations. The cuff pressures corresponding to 30%, 50% and 70% of the maximum oscillometric pulse peak amplitude in each waveform envelope were then measured for both the high and low pressure regions. At each of the three thresholds, the cuff pressure widths (absolute pressure difference referenced to the automated MAP) were calculated for both the high and low pressure regions. The calculation methods of the cuff pressure widths are also illustrated in Figure 1. The average cuff pressure widths from the three repeat measurements in each subject were used for statistical analysis.

2.4. Data and statistical analysis

The means and SDs of the cuff pressure and cuff pressure widths in the high and low pressure regions were calculated separately for the healthy normotensive group and the hypertensive group.

The cuff pressure widths from the normotensive and hypertensive groups were compared by using Student's t-test. A paired t-test was then used to compare the cuff pressure widths between the high and low pressure regions. A value of P<0.05 was considered statistically significant.


(A) Normotensive subject

(B) Hypertensive subject

Figure 1. Typical oscillometric waveforms from a healthy normotensive subject (A) and a hypertensive subject (B). The calculation method for the cuff pressure widths in the high and low pressure regions (W_H and W_L) with the threshold of 0.5 is also given.

3. Results

3.1. Cuff pressure width

Table 2 gives the overall cuff pressures and cuff pressure widths corresponding to 30%, 50% and 70% of the maximum oscillometric pulse amplitude for the two subject groups studied.

For the healthy normotensive group, the overall means and SDs of the cuff pressure widths in the high and low pressure regions for the normalised oscillometric pulse amplitude levels of 30%, 50% and 70% were 43±6 vs 36±9 mmHg, 29±6 vs 17±7 mmHg, and 22±5 vs 10±4 mmHg, respectively.

For the hypertensive group, the corresponding values were 52±10 vs 47±10 mmHg, 40±9 vs 28±10 mmHg, and 28±8 vs 19±8 mmHg.

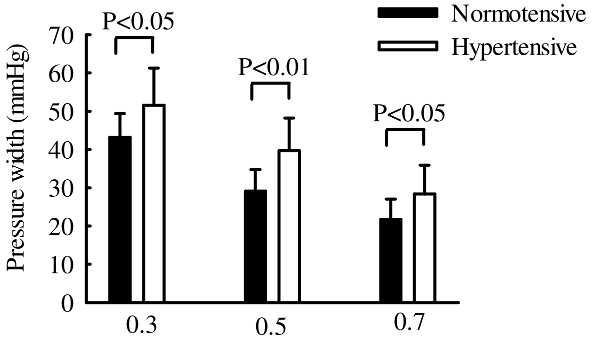
Threshold	30%		50%		70%		100%
Pressure region	H	L	H	L	H	L	
Cuff pressures (mmHg)							
Normotensive	124±10	45±11	110±8	64±9	103±9	71±7	81±6
Hypertensive	160±9	61±11	148±7	80±12	137±5	90±9	108±7
Cuff pressure widths (mmHg)							
Normotensive	43±6	36±9	29±6	17±7	22±5	10±4	
Hypertensive	52±10	47±10	40±9	28±10	28±8	19±8	

Table 2. Cuff pressures and cuff pressure widths corresponding to 30%, 50% and 70% of the maximum oscillometric pulse amplitude in the high and low pressure regions for both the healthy normotensive and hypertensive groups. H represents high pressure region; L represents low pressure region.

3.2. Comparison of cuff pressure width between normotensive and hypertensive groups

As shown in Figure 2, for both the high and low pressure regions, the cuff pressure widths from the hypertensive group were significantly larger than those from the normotensive group at the three different thresholds, suggesting a wider oscillometric waveform envelope in the hypertensive group.

(A) High pressure region



(B) Low pressure region

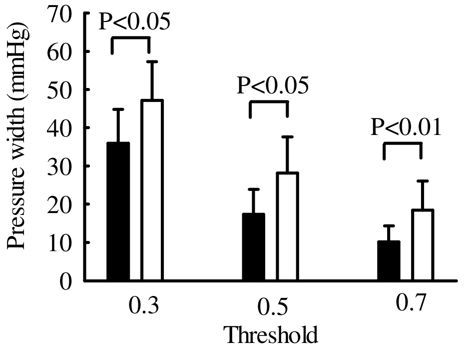
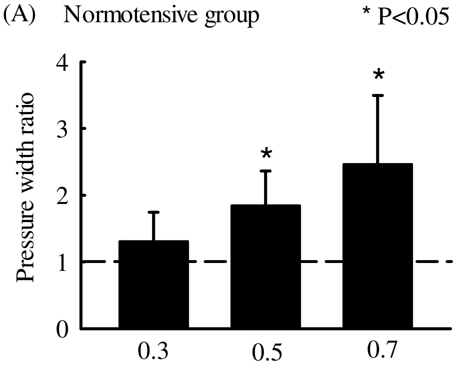


Figure 2. Cuff pressure width at the three different normalised amplitude levels for both the high pressure region (A) and low pressure region (B). The black bars are from the healthy normotensive group, the white bars are from the hypertensive group.

3.3. Comparison of cuff pressure width between high and low pressure regions

For both groups, the cuff pressure widths in the high pressure region were significantly larger than in the low pressure region at the normalized amplitude levels of 50% and 70%, but not at 30%. As shown in Figure 3, the cuff pressure width ratios between the high and low pressure regions were significantly larger than 1 at the normalized amplitude levels of 50% and 70%, confirming an asymmetrical feature of the oscillometric waveform envelope.

(A) Normotensive group



(B) Hypertensive group

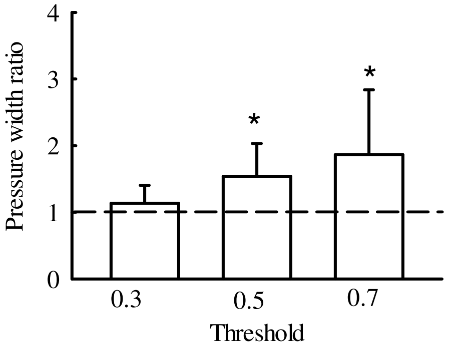


Figure 3. The ratio of cuff pressure width between the high and low pressure regions at the three different normalised amplitude levels. (A) is for the healthy normotensive group and (B) is for the hypertensive group.

4. Discussion and conclusion

We have confirmed the asymmetrical feature of the oscillometric waveform envelope in both healthy normotensive and hypertensive groups.

It has been reported that changes in the amplitude of the blood volume pulsation (or the recorded oscillometric pulse amplitude) in response to the transmural pressure (the difference between internal arterial pressure and external cuff pressure) changes are associated with the nonlinearity of the pressure-volume (P-V) relation of the artery [8, 9]. It has also been reported that the artery is maximally compliant when the external cuff pressure equals the MAP, and the pressure-compliance (P-C) relationship is an asymmetric bell-shaped curve [10, 11]. Our finding of the asymmetry of the oscillometric pulse waveform shape agreed with this asymmetry of the P-C relationship.

Furthermore, because the oscillometric pulse amplitude is related to the arterial compliance, any factors, including ageing and cardiovascular diseases, associated with the changes of arterial compliance can also influence the shape of the oscillometric waveform envelope. We have also found that the overall shape of the oscillometric waveform envelope from the hypertensive group is significantly wider than that from the healthy normotensive group.

To fully understand the oscillometric waveform shape, a large number of physiological and pathological oscillometric waveforms including oscillometric waveforms from special clinical groups need to be investigated, and the different patterns of the oscillometric waveform need to be classified and quantified. This may eventually improve the oscillometric technique for blood pressure determination.

Acknowledgements

Dingchang Zheng and Roberto Giovannini are funded by the Engineering and Physical Sciences Research Council (EPSRC).

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