Oscillometric Waveform Difference between Cuff Inflation and Deflation during Blood Pressure Measurement

Chengyu Liu, Dingchang Zheng, Clive Griffiths, Alan Murray

Institute of Cellular Medicine, Newcastle University, Newcastle upon Tyne, UK

Abstract

The majority of automatic blood pressure (BP) measurement devices use the oscillometric method made during cuff inflation or deflation. However, there is currently little information available on the comparison of oscillometric waveform shape between cuff inflation and deflation. This study aimed to provide this information. Oscillometric cuff pressure waveforms were recorded digitally from 10 normotensive subjects during standard BP measurement at slow linear inflation and deflation rates of 2-3 mmHg/s. Three repeat sessions were performed for each subject. Four features were quantified for each oscillometric waveform: the maximum oscillometric pulse peak amplitude (Amax) and three cuff pressure widths corresponding to 70%, 50% and 30% of Amax (denoted as W70, W50 and W30 respectively). For all subjects, these oscillometric waveform features were then compared between cuff inflation and deflation. Analysis of variance showed that there was no significant difference between the three repeat measurements for all four waveform features (all P>0.4). Mean Amax from cuff inflation was 0.7 mmHg higher (mean±SD: 3.7±0.9 vs. 3.0±0.8 mmHg, P<0.001) than that from cuff deflation. For the cuff pressure widths at the three thresholds, W70 was not significantly different between cuff inflation and deflation, but W50 and W30 were both significantly narrower for cuff inflation by 12 mmHg (45±9 vs. 57±11 mmHg) and 22 mmHg narrower (67±10 vs. 89±12 mmHg) respectively; both P<0.001. The oscillometric waveform differences during BP measurement suggest that arteries may behave differently during cuff inflation and deflation.

1. Introduction

Currently, the majority of automatic blood pressure (BP) measurement devices use the oscillometric technique, in which BP values are automatically determined from the small cuff oscillometric pulses detected in the pressurized cuff wrapped around the arm [1, 2]. During BP measurement, an inflatable cuff wrapped around the upper arm is used to restrict blood flow in the brachial artery. Brachial arterial volume decreases with inflation of the cuff and returns with cuff deflation. Usually, BP values are determined during cuff deflation. There are also some devices that automatically determine BP values during cuff inflation to reduce the measurement time [3].

However, the different mechanical behavior of the brachial artery between cuff inflation and deflation may influence the BP values. Zheng *et al* [4] has reported that the measured systolic blood pressure (SBP) from cuff inflation were lower than that from cuff deflation, and the measured diastolic blood pressure (DBP) were significantly higher. Tardy *et al* [5] verified the diameter change of the brachial artery during cuff inflation and deflation using an ultrasound technique. The pressure–diameter hysteresis loop of the carotid artery from animal tests also showed the different arterial mechanical responses between cuff inflation and deflation [6].

In addition, automatically measured BP values are usually determined by analyzing different features extracted from the oscillometric pulse waveform [7]. It has also been reported that the oscillometric pulse waveform will influence the results of BP measurements [8-10]. However, there is currently little information available on the feature analysis and comparison of the oscillometric pulse waveform between cuff inflation and deflation.

Therefore, this study aimed to investigate the shape differences of the oscillometric pulse waveform between standard cuff inflation and deflation, providing a better understanding of the shape of the oscillometric pulse waveform and the different mechanical behavior of the brachial artery between cuff inflation and deflation during BP measurement.

2. Methods

2.1. Subjects

Ten normotensive subjects (6 male and 4 female; age from 25 to 60 years; systolic blood pressure (SBP)<140 mmHg) were studied. The detailed subject demographic information including age, height, weight and BP values 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 number (No.) or means±standard deviations (SDs) are presented.

Parameters	values
No.	10
Age (years)	42±10
Height (cm)	174±8
Weight (kg)	73±9
Systolic blood pressure, SBP (mmHg)	116±11
Diastolic blood pressure, DBP (mmHg)	78±8

2.2. Blood pressure measurement

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

During each auscultatory blood pressure measurement, the cuff pressure was linearly inflated from 20 to 200 mmHg at a rate of 2-3 mmHg/s (standard inflation) and then linearly deflated to 20 mmHg at the same rate (standard deflation) as recommended by British Hypertension Society [2]. Cuff pressure signals were recorded digitally to a computer at a sample rate of 2000 Hz for off-line oscillometric pulse analysis.

2.3. Oscillometric pulse analysis

The originally recorded cuff pressure signals were firstly separated into cuff inflation and deflation segments. Then the oscillometric pulse envelope was extracted from cuff inflation or deflation after identifying the foot of each cardiac cycle pulse and removing the baseline of the cuff pressure. Figure 1 shows examples of the recorded cuff pressure and extracted oscillometric pulse envelope from standard cuff inflation (A) and standard cuff deflation (B).

For each oscillometric pulse envelope in cuff inflation or deflation, the maximum oscillometric pulse peak amplitude was defined as Amax, which was the reference amplitude for the subsequent analysis. Three pressure widths corresponding to when the oscillometric pulse peaks were higher than 70%, 50% and 30% of Amax were measured and defined as W70, W50 and W30 respectively. These four features were quantified for each oscillometric waveform. The definition of the four features (Amax, W70, W50 and W30) for the oscillometric pulse envelope from both cuff inflation and deflation are illustrated in Figure 2.

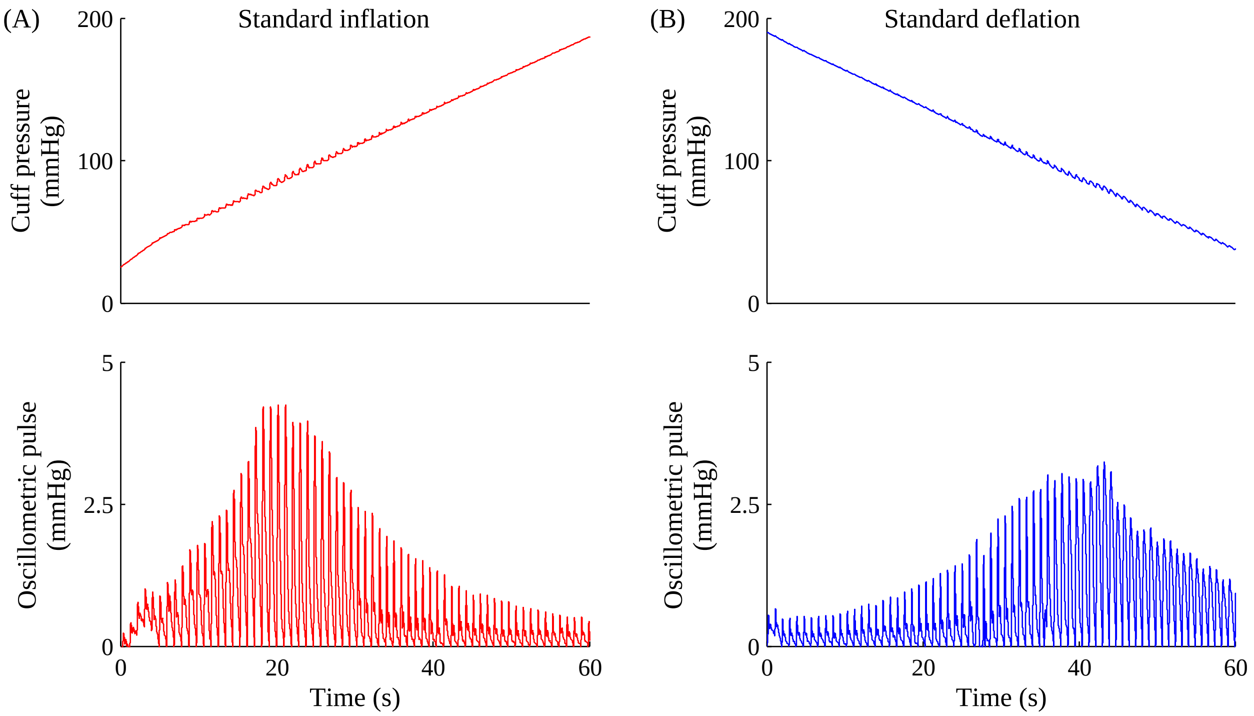

Figure 1. Examples of recorded cuff pressure and extracted oscillometric pulse envelope from standard cuff inflation (A) and standard cuff deflation (B).

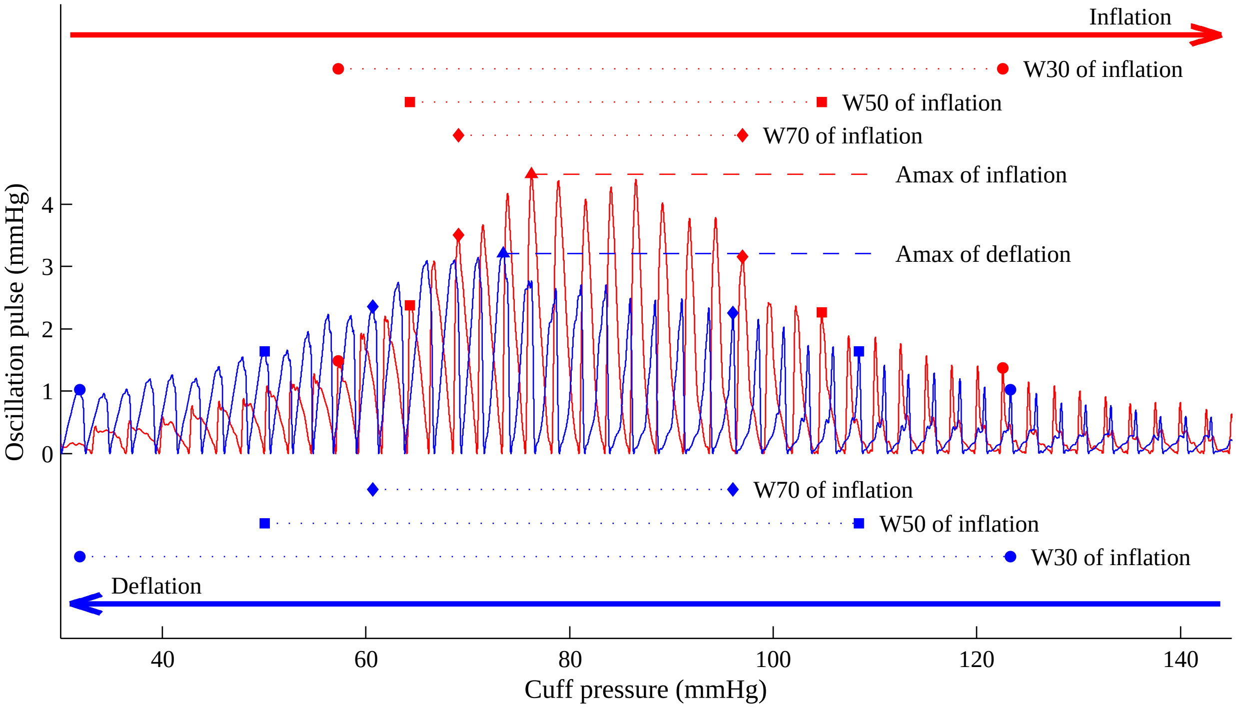

Figure 2. Definition of the four features (Amax, W70, W50 and W30) for the oscillometric pulse envelope from both cuff inflation and deflation. Differences in oscillometric pulse envelope shape can be noted between cuff inflation and deflation.

2.4. Statistical method

The means and SDs of the four features (Amax, W70, W50 and W30) were calculated separately for cuff inflation and deflation segments. The overall mean values from the three repeat measurements were used for the statistical analysis. The differences in four features between cuff inflation and deflation were compared by using the paired *t* test. A value of $P<0.05$ was considered statistically significant.

3. Results

3.1. Measurement repeatability

Analysis of variance showed that there was no significant difference between the three repeat measurements for all four features (all $P>0.4$). This indicates that measurements were not influenced by the time between measurements, and confirms the stability of arterial mechanical behavior with repeat measurements.

3.2. Feature differences between cuff inflation and deflation

Table 2 gives the overall results for all four features for both cuff inflation and deflation. The maximum oscillometric pulse peak amplitude Amax from cuff inflation was 0.7 mmHg higher than that from cuff deflation ($P<0.001$). Cuff pressure width features W50 and W30 were significantly narrower for cuff inflation by 12 mmHg and 22 mmHg respectively; both $P<0.001$. However, W70 had no significantly difference between cuff inflation and deflation ($P=0.3$). The oscillometric waveform feature differences during BP measurement suggest that arteries may behave differently during cuff inflation and deflation.

Table 2. Maximum oscillometric pulse peak amplitude (Amax) and cuff pressure widths corresponding to 70%, 50% and 30% of the Amax for both cuff inflation and deflation measurements.

indices	Inflation	Deflation	*P*-values
Amax (mmHg)	3.7±0.9	3.0±0.8	<0.001
W70 (mmHg)	29±6	31±8	0.3
W50 (mmHg)	45±9	57±11	<0.001
W30 (mmHg)	67±10	89±12	<0.001

4. Discussion and conclusion

In this study, we have confirmed the different oscillometric waveform envelope features for standard cuff inflation and deflation measurements.

It has been reported that the pressure-volume (P-V) relation is nonlinear and is an asymmetric bell-shaped curve [11]. The asymmetrical feature of the oscillometric waveform envelope between the high and low pressure regions from cuff deflation was also found in both healthy normotensive and hypertensive subjects, showing nonlinearity of the P-V relation [12].

Our finding of the change of the oscillometric pulse waveform shape from cuff inflation and deflation agreed with this nonlinear P-C relationship. We have found the maximum oscillometric pulse peak amplitude from cuff inflation was significantly higher than that from cuff deflation. We have also found that the overall shape of the oscillometric waveform envelope from cuff inflation is significantly narrower than that from cuff deflation. Furthermore, because the oscillometric pulse amplitude and shape are related to the arterial compliance, any factors, including ageing and cardiovascular diseases, associated with the changes of arterial compliance can also influence the amplitude and shape of the oscillometric waveform envelope.

To further understand the oscillometric waveform shape features between cuff inflation and deflation, a large number of physiological and pathological oscillometric waveforms need to be investigated. This may eventually improve the oscillometric technique for automatical BP measurement.

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Address for correspondence.

Chengyu Liu
Institute of Cellular Medicine
Newcastle University
Newcastle upon Tyne
NE1 4LP, UK
Tel: +44-7455592002
chengyu.liu@ncl.ac.uk