Influence of Finger Movement on the Stability of the Oscillometric Pulse Waveform for Blood Pressure Measurement

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Abstract

The importance of accurate blood pressure (BP) measurement is without doubt. In medical clinics the oscillometric automated sphygmomanometer is widely used. However, there are few studies to quantify the influence of the oscillometric pulse waveform stability on the accuracy of BP values. This study addresses this issue.

Cuff pressure signals during the slow deflation phase were measured from 20 healthy normotensive subjects with a deflation rate of 2-3mmHg per second. For each subject, measurements were performed with the normal quiet and still body condition, and also when subjects moved their fingers. Oscillometric pulse waveforms were filtered from the cuff pressure signals. Mean arterial pressure (MAP) was determined from the peak of the second-order Gaussian envelope fitted to the peaks of all heart beats on the oscillometric pulse waveform. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were derived from the cuff pressures at defined ratios to MAP on the oscillometric envelope. The root mean square error (RMSE) between the fitted curve and the pulse amplitudes was used to assess the smoothness of the oscillometric pulse waveform characteristics.

Compared to the quiet condition, finger movement increased the RMSE by 0.28 mmHg [mean ± standard deviation (SD): 0.43±0.21 mmHg vs. 0.15±0.04 mmHg, P<0.01]. Finger movement also resulted in a significant increase of SBP by 7.2 mmHg and DBP by 9.2 mmHg (both P<0.01).

This study quantitatively showed the effect on BP and oscillometric waveform stability of subjects not following the requirement to stay still.

1. Introduction

Blood pressure (BP) is one of the most important physiological parameters of the human body [1]. There are two main methods for non-invasive BP measurement: manual auscultation and automatic technical measurement [2]. Currently, non-invasive blood pressure (NIBP) measurement devices have replaced the manual auscultatory technique and have been widely used in medical institutions and homes [3]. On account of its simple operation, this makes it possible for users to quickly measure their BP without any training.

The majority of NIBP measurement devices are based on the oscillometric technique [4]. Before the BP measurement, the inflatable cuff is wrapped around the limb (usually the upper arm). Then the device analyzes the small pressure pulse changes (oscillometric pulses) caused by the pressure change of the cuff. Usually, the systolic blood pressure (SBP) and diastolic blood pressure (DBP) are determined during cuff deflation [5].

Although most automatic BP devices on the market meet the validation protocols developed by the American Heart Association (AHA) [1] and the British Hypertension Society (BHS) [6], many users do not follow the clinical and devices manufacturer's guidelines. Wrong posture or body movement often leads to inaccurate measurement results [7].

In clinical measurement, movement is one of the main sources of inaccurate BP measurement [8]. However, little information has been obtained on the influence of this condition on the oscillometric waveform.

Therefore, this study aimed to quantify the influence of finger movement on the stability of the oscillometric pulse waveform and the BP values.

2. Methods

2.1. Subjects

Twenty normotensive subjects (10 male and 10 female; age from 28 to 64 years) were studied. The selection criteria of subjects include SBP<140mmHg, DBP<90mmHg, no hypertension, no cardiovascular disease. The detailed subjects information, including gender, age, height, weight, and arm circumference, are summarized in Table 1. The number or mean ± standard deviation (SD) of these parameters is shown in Table 1.

This study received ethical permission from the Independent Ethics Committee (IEC) for Clinical

Research, Zhongda Hospital, Affiliated Southeast University. The investigation conformed with the Declaration of Helsinki, and all subjects gave their written informed consent to participate in the study.

2.2. Blood pressure measurement

All BP measurements were performed with the recommended measurement procedure by BHS in a quiet measurement room. As shown in Figure 1, the cuff pressure was deflated linearly at the recommended deflation rate of 2-3mmHg per second [9]. The data were digitally recorded to the computer at a sampling rate of 200 Hz for offline processing.

Table 1. General data information for the subjects studied.

Parameters	**Values**
Number of subjects	20
Number of males	10
Number of females	10
Age (years)	42.0±12.9
Height (cm)	170.1±7.1
Weight (kg)	66.9±10.6
Arm circumference (cm)	27.6±3.5

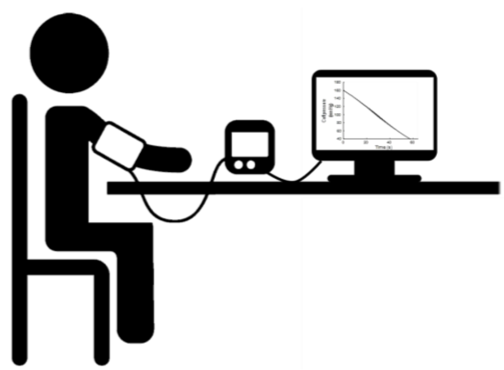

Figure 1. Diagram of BP measurement system for recording cuff pressure.

Before BP measurements were taken, there was a 5–10 minute rest period to stabilize BP. As shown in Figure 1, the subjects were seated on a chair with their feet on the floor. The cuff was wrapped around the upper left arm, and the left arm was supported at the level of the heart [10]. Unless otherwise specified, the subject was asked to avoid any movement of the head or other part of the body during the BP measurement.

Each subject was recorded on three different days. Before the first session, 5-10 minutes was taken to introduce the BP protocol to the subject. Each day-session included 2 sequential BP measurements, with a 3–5 minute rest interval between each measurement. After each BP measurement, the cuff was completely deflated.

For the two recordings in each session, the subjects were asked to keep still and quiet (following the guidelines recommended by the AHA and BHS) and also to open and close their fingers with irregular timing. For each session of all subjects, the order of the two conditions is fixed.

2.3. Data and statistical analysis

The pressure sensor recorded the oscillometric waveform, superimposed on the cuff deflation pressure. The oscillometric pulse is small in comparison with the cuff pressure, and a high-pass filter was used to separate the oscillometric pulse from the cuff pressure. After it was extracted, mean arterial pressure (MAP) was determined from cuff deflation using interactive software developed with Matlab2020a (MathWorks Inc., Natick, Massachusetts, USA). MAP corresponds to the cuff pressure at the peak of the second-order Gaussian model envelope of the oscillometric pulse waveform. SBP and DBP were derived from the cuff pressures at defined ratios to MAP on the oscillometric envelope. The specific process for BP determination is shown in Figure 2.

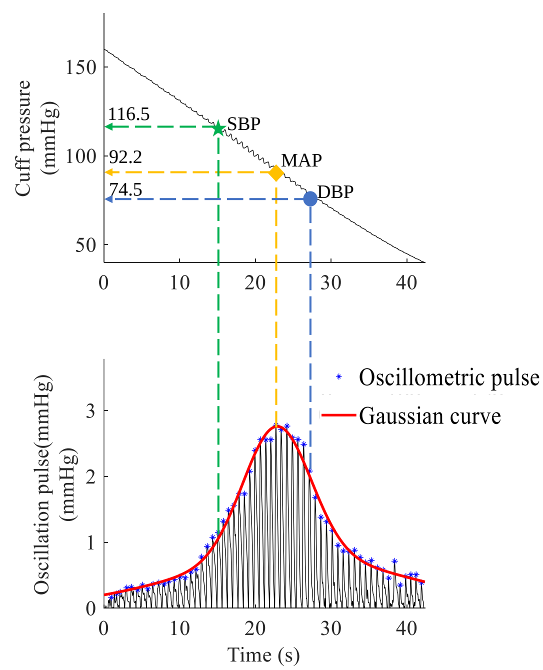

Figure 2. The process of determining the BP from the oscillometric pulse waveform and the cuff pressure. Cuff pressure (top) and oscillometric pulse waveform (bottom), with the oscillometric pulse peaks indicated.

The root mean square error (RMSE) between the fitted curve and the oscillometric pulse amplitudes was used to assess the smoothness of the oscillometric pulse waveform characteristics. For each measurement condition, the mean and standard deviation (SD) of RMSE, SBP, and DBP were calculated for each subject.

The mean and SD of the three repeat measurements were used for statistical analysis. The differences between finger movement and standard quiet conditions were compared by using the paired t test. A value of P<0.05 was considered statistically significant.

3. Results

3.1. The difference between finger movement and standard conditions in oscillometric pulse waveform

Figure 3 illustrates the oscillometric pulse waveform and Gaussian fitting curve for the standard condition in one recording.

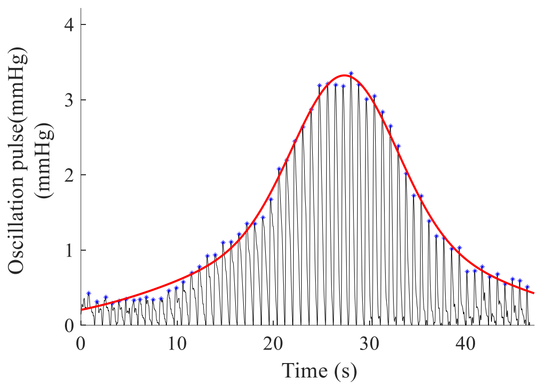

Figure 3. The Gaussian fitting curve under standard conditions.

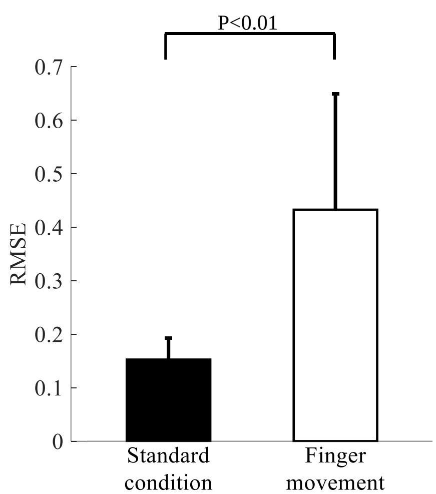

Figure 4. Mean ± SD of variability from all subjects under different conditions.

Figure 4 shows the effect of finger movement on RMSE. Compared to the standard condition, finger movement increased the RMSE by 0.28 mmHg [mean ± SD: 0.43±0.21 mmHg vs. 0.15±0.04 mmHg, P<0.01]. It can be seen that finger movement affected the smoothness of the fitted curve in the BP measurement.

3.2. The effect of finger movement on BP values

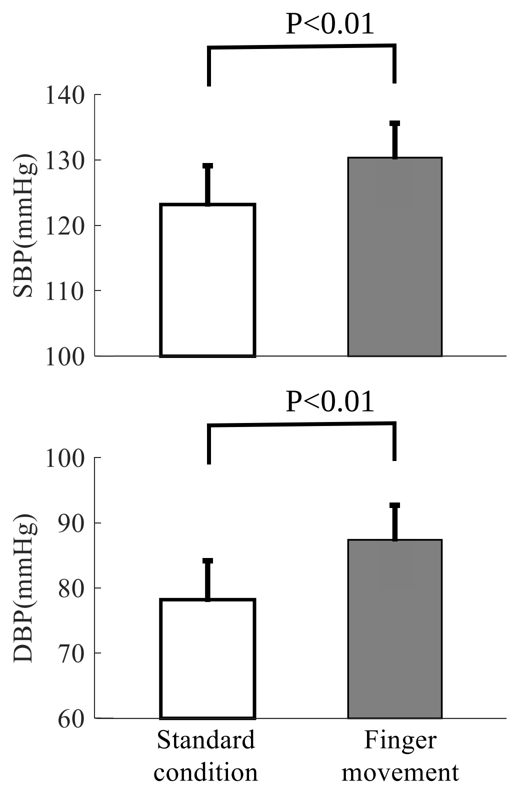

Figure 5. BP errors caused by finger movement.

In addition to the influence of finger movement on the oscillometric waveform, it also caused measurement errors in BP. As shown in Figure 5, finger movement resulted in a significant increase of SBP by 7.2 mmHg [mean ± SD: 130.4±5.2 mmHg vs. 123.2±6.0 mmHg] and DBP by 9.2 mmHg [87.4±5.3 mmHg vs. 78.2±4.4 mmHg] (both P<0.01).

4. Discussion and conclusion

In this study, we have shown that finger movement affected the smoothness of the oscillometric pulse waveform. Compared with the standard condition, this condition also caused a significant increase in the BP values (SBP and DBP).

In medical institutions or at home, some users move their fingers during BP measurement. This situation is a source of BP errors. Since the arterial pulse is a weak physiological signal, the stability of the signal is disturbed when the finger moves. In addition to finger movement, there are many sources of inaccuracy in BP measurements, such as deep breathing [11], arm position [12], and cuff size [13,14]. However, current NIBP devices display only the BP values, and the reliability of the data is unknown. There has been little information on the quality of BP data. We show that for stable and accurate results, the patient should follow the instructions of the doctor and devices manufacturer to avoid unwanted conditions.

In summary, this study provides quantitative evidence for the influence of finger movement on the stability of the oscillometric pulse waveform.

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