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Changes in the bilateral pulse transit time difference with a moving arm

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Abstract.
BACKGROUND: Changes of pulse transit time (PTT) induced by arm position were studied for unilateral arm. However, consistency of the PTT changes was not validated for both arm sides.
OBJECTIVE: We aimed to quantify the PTT changes between horizontal and non-horizontal positions from right arm and left arm in order to explore the consistency of both arms.
METHODS: Twenty-four normal subjects aged between 21 and 50 (14 male and 10 female) years were enrolled. Left and right radial artery pulses were synchronously recorded from 24 healthy subjects with one arm (left or right) at five angles (90°, 45°, 0°, −45° and −90°) and the other arm at the horizontal level (0°) for reference.
RESULTS: The overall mean PTT changes at the five angles (from 90° to −90°) in the left arm (right as reference) were 16.1, 12.3, −0.5, −2.5 and −2.6 ms, respectively, and in the right arm (left as reference) were 18.0, 12.6, 1.6, −1.6 and −2.0 ms, respectively.
CONCLUSIONS: Obvious differences were not found in the PTT changes between the two arms (left arm moving or right arm moving) under each of the five different positions (all $P > 0.05$).

Keywords: Peripheral arterial volume compliance, pulse transit time (PTT), arm PTT, artery pulse

1. Introduction

The assessment and detection of arterial function is important for cardiovascular physiology and pathophysiology [1,2]. The properties of the peripheral arteries are often used in the assessment of health and disease and are associated with different physiological and clinical conditions, such as aging [2,3], hypertension [4,5], heart failure [6,7], drug injection [8] and arterial disease [9]. Clinically, the *in vivo* characterization and quantification of the arterial properties are difficult to achieve. Arterial compliance is usually used to quantify the arterial characteristics (compliance = blood volume/arterial pressure) [10]. The simultaneous blood volume change and arterial pressure change are needed to calculate the arterial volume compliance [11,12]. However, the direct detection of arterial volume compliance is not easy to accurately achieve since diameter measurements of volume changes are required. As an

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Table 1
Basic characteristics for the 24 subjects studied

Parameters	Value	Range
Number (M/F)	24 (14/10)	–
Age (year)	29 ± 8	21–50
Height (cm)	169 ± 8	151–183
Weight (kg)	63 ± 11	41–87
BMI (kg/m^2)	22 ± 3	15–27
SBP (mmHg)	115 ± 12	93–137
DBP (mmHg)	70 ± 10	57–95
MAP (mmHg)	85 ± 10	69–107

Values are showed as means ± standard deviation (SD) except for numbers (male/female). BMI, SBP, DBP and MAP were abbreviations of body mass index, systolic blood pressure, diastolic blood pressure and mean arterial pressure, respectively.

alternative, pulse transit time (PTT) has been commonly used to assess the arterial volume compliance because of its simplicity [11,13,14].

PTT can change due to blood pressure changes in the arm with arm raising or lowering [15,16]. Raising or lowering arm can easily lead to the changes in blood pressure. Based on this information, Zheng and Murray [17] studied the effects of the arm heights on the PTT by right arm at different positions, demonstrating the PTT increased with the arm raised. However, their study was only performed by moving the right arm at different positions and the PTT changes were calculated from unilateral arm artery pulse waveforms in two separate measurements. It was not studied and was taken for granted that the right arm had consistency with the left arm in PTT induced by arm movement.

This study intended to research the consistency of changes in PTT induced by right arm movement and left arm movement. The hypothesis of the current study is that, in healthy subjects, the bilateral radial artery PTTs should be almost the same if both arms are in the same position. Therefore, one arm be placed in different heights with the other arm placed in the horizontal level as a reference, a PTT changes could be induced and its changes with arm movement could be quantified.

2. Methods

2.1. Subjects

Twenty-four normal subjects aged between 21 and 50 (14 males and 10 females) years were enrolled in this study. Table 1 showed basic clinical information of subjects. Ethical permission was obtained from Shandong University in China and all subjects signed informed protocol.

2.2. Arterial pulse measurement

Testing was carried out in a quiet environment with an ambient temperature of approximately 26°. Each subject was asked to lie down on a bed for a rest. After 5 minutes, each subject's left and right radial arterial pulses were synchronously recorded by piezoelectric sensors manufactured by Hefei-Huake Electronic Technology Research Institute, China, with a sampling rate of 500 Hz.

The whole measurement procedure for each subject included two identical repeat sessions. In each session, five separate measurements were obtained from right arm at 90°, 45°, 0°, −45°, and −90° with left arm at the horizontal level (0°) as the reference arm, and the other five separate measurements were obtained from left arm at five angles with right arm at 0° as the reference arm. The arm side and the

Table 2
Four schemes of the experimental design

Scheme	Session	Reference arm	Moving arm	Position order				
1	1	Left	Right	90°	45°	0°	−45°	−90°
	2	Left	Right	90°	45°	0°	−45°	−90°
2	1	Right	Left	90°	45°	0°	−45°	−90°
	2	Right	Left	90°	45°	0°	−45°	−90°
3	1	Left	Right	−90°	−45°	0°	45°	90°
	2	Left	Right	−90°	−45°	0°	45°	90°
4	1	Right	Left	−90°	−45°	0°	45°	90°
	2	Right	Left	−90°	−45°	0°	45°	90°

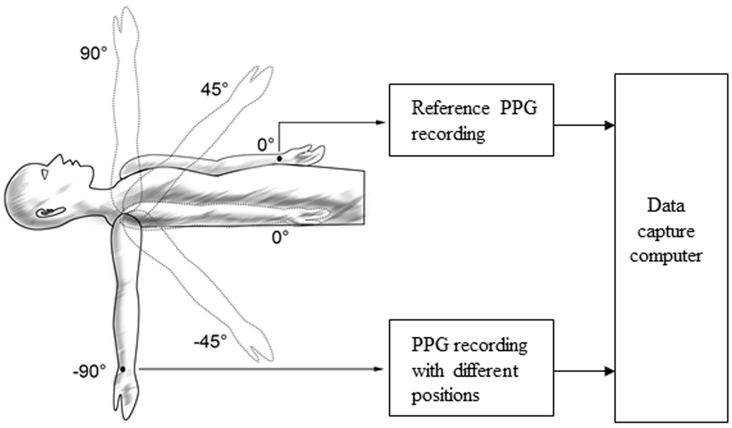

Fig. 1. An example of the measurement process with the right arm at five angles.

positioning order were randomized according to one of four schemes chosen randomly (see Table 2). Figure 1 shows an example of the measurement process with the right arm moving.

During each measurement, the moving arm was placed on a mechanical support to avoid movement. Subjects were instructed to breathe regularly and gently during the measurement. When the signal presented is stable, radial artery pulses from the left and right sides were simultaneously recorded for 40 s. All measurements were performed by the same operator. At the beginning and end of each whole measurement procedure, blood pressures (SBP and DBP) were measured with the subject supine using a validated BP monitor (102, Dongyue healthcare, Shandong, China).

2.3. Radial arterial pulse analysis

The foot points of each recorded radial artery pulse were first detected by an open-source algorithm, 'wabp' from PhysioNet [18,19] and were then verified manually. As shown in Fig. 2, the beat-by-beat PTT changes between the arm at five angles and the reference arm at the horizontal level were calculated from the pulse foot points within the same heartbeat. For each subject, the PTT change was calculated by the average for 10 consecutive heart beats in each arm angle. In total, 20 PTT changes for each subject were evaluated (from 2 repeats, with the left or right arm as the moving arm, and 5 arm positions).

2.4. Data and statistical analysis

The means and standard deviations (SDs) of the PTT changes between one arm at five angles (90°,

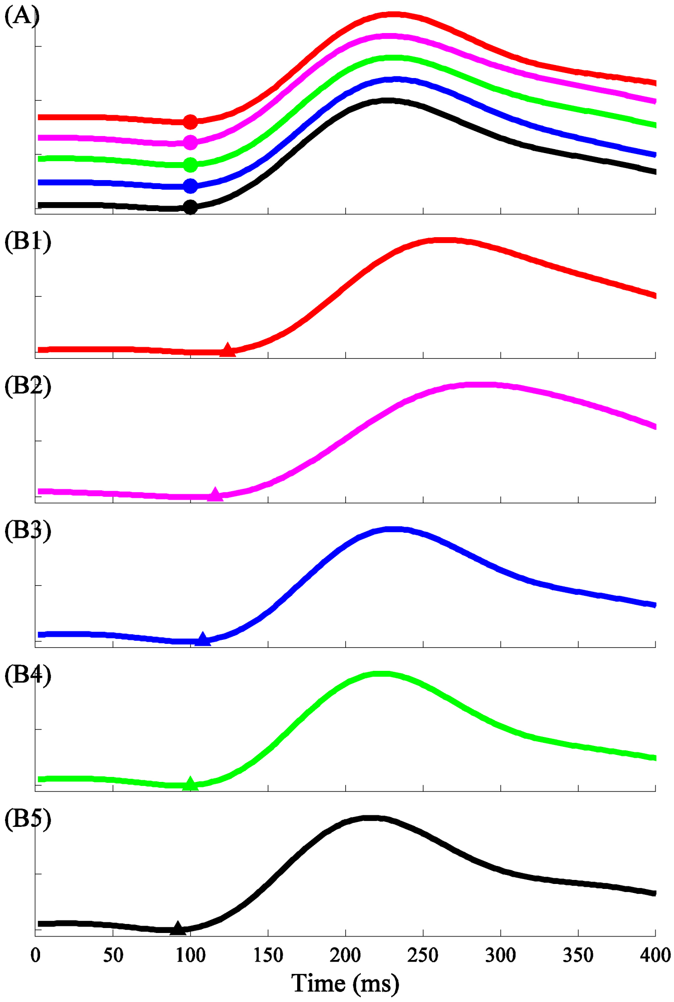

Fig. 2. Examples of recorded pulse waveforms and the corresponding pulse feet to show the PTT changes between the reference arm at the horizontal level (A) and the arm at various positions (B1–B5, 90°, 45°, 0°, −45°, and −90°, respectively).

45°, 0°, −45°, and −90°) and the other arm at the horizontal level were calculated first, separately for each position and for the first and repeat sessions. The between-sessions repeatability was analyzed using Variances analysis (ANOVA). Post-hoc multiple comparisons were then used to determine the statistically significant changes in the PTT change between any two positions of the five different arm positions with the arm moving. It was considered statistically significant as $P < 0.05$.

3. Results

The overall means and SDs of paired differences in the PTT changes between the two repeat measurement sessions are detailed in Fig. 3. There were no significant differences between the two repeat sessions for both arms (all $P > 0.05$). Therefore, the averages of the PTT changes from the two repeat sessions were used for further analysis, as shown in Table 3. As expected, positioning the arm at different levels caused significant effects on the PTT change. With the moving arm position changes from 90°,

Table 3
The overall means and SDs of PTT changes from the two repeat sessions

Position	Overall PTT changes (ms)	
	With the left arm moving	With the right arm moving
90°	16.1 ± 6.6	18.0 ± 7.0
45°	12.3 ± 6.6	12.6 ± 6.8
0°	−0.5 ± 3.8	1.6 ± 4.8
−45°	−2.5 ± 4.0	−1.6 ± 5.2
−90°	−2.6 ± 4.4	−2.0 ± 5.3

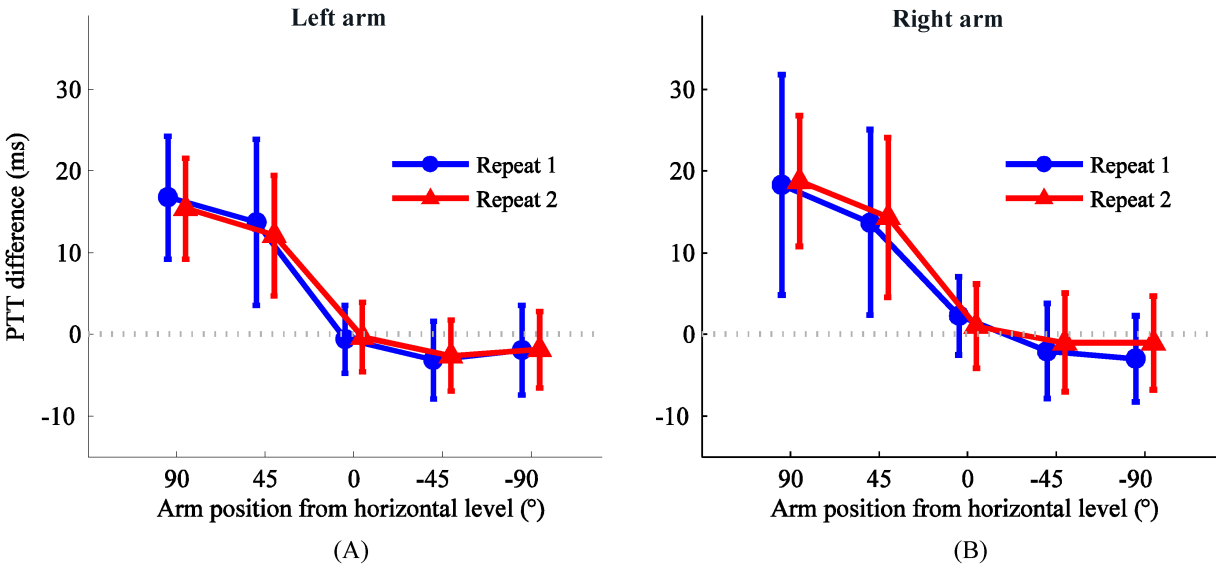

Fig. 3. Means and SDs of the PTT change between one arm at different positions (90°, 45°, 0°, −45°, and −90° to the horizontal level) and the other arm at the horizontal level as the reference. (A) PTT change for left arm (right arm at the horizontal level as reference) and (B) PTT change for right arm (left arm at the horizontal level as reference).

45°, 0°, −45° to −90°, the mean PTT changes for the left arm were 16.1, 12.3, −0.5, −2.5 and −2.6 ms and the corresponding values for the right arm were 18.0, 12.6, 1.6, −1.6 and −2.0 ms, respectively. After post-hoc multiple comparisons of the changes in the PTT change between any two positions, statistically significant differences were found between 90° and 0° positions, between 45° and 0° positions, but not between −90° and 0° positions or between −45° and 0° positions. In addition, there were no significant differences in the PTT change between the two arms (left arm moving or right arm moving) under each of the five different positions (all $P > 0.05$).

4. Discussion and conclusion

As an indirect and non-invasive technique, the measurement of PTT changes with the arm moving has been reported to quantify the changes of peripheral arterial property. This study quantified and compared the PTT changes induced by right arm movement with the PTT changes induced by left arm movement in order to research the consistency of changes in PTT induced by both arm movement.

Blood pressure changes in the arm with the arm at different heights [15,16] and PTT can change due to blood pressure changes. Arm position affects PTT was reported by Zheng and Murray [17]. However, Liu reported the relationship between PTT changes and peripheral arterial BP changes induced by lifting right arm above heart level. Zheng et al. mentioned the PTT changes with the arm above and below heart level, but they also obtained the unilateral PTT changes induced by the right arm movement. Moreover Liu and Zheng et al. obtained the PTT changes asynchronously. Since the two separate measurements were performed at different times, the physiological factors of heart rate, blood pressure and emotional status could be different. Pulse morphological changes due to heart rate and blood pressure factors have been widely studied and verified [4,5,20,21]. The effect of emotional status on the tiny morphological changes in the pulse was also confirmed in a recent study [22]. Foo researched the PTT changes observed with different limb positions synchronously [14]. In his study, the PTT changes obtained with the arm raising or leg declining and a random selection of arm (the left or right arm) and a random selection of leg (the left or right leg) were adopted.

It was ignored and was taken for granted that the right arm had consistency with the left arm in PTT induced by arm movement. In this study, we collected arterial pulses simultaneously in both arms, making the comparison between the horizontal and the non-horizontal positions more accurate.

With either the left arm raising or the right arm raising, the trend in PTT changes due to the arm moving is fairly consistent with the results reported by Zheng and Murray [17]. With either the left arm declining or the right arm declining, the trend in PTT changes due to the arm moving is fairly consistent with the results reported by Zheng and Murray [17]. The right arm had consistency with the left arm in PTT induced by arm raising or declining.

Although both arm are consistent with PTT changes, there are little difference between them at each position. PTT changes with right arm raising were little big than that with left arm raising, while absolute value of PTT changes with right arm declining were little small than that with left arm declining. The reason of this may be the difference of physiological structure between both arm, may be the sensor error partly. The limitations of this study should be mentioned. First, the bilateral PTTs are not necessarily the same all the time. It is possible that the brachial arteries in the two arms have different stiffness in cardiovascular disease patients, which would cause different PTTs measurements in the two arms. However, in the current study, our cohort included healthy and relatively young subjects. Therefore, the prerequisite could be hold. The quantification of the potential effect of vascular disease on the PTT changes with the arm moving will take place in our future work.

In conclusion, this work has provided scientific evidence for the changes in the bilateral peripheral arterial property difference with the arm moving, which is an important step in using the bilateral arterial property difference as a simple non-invasive procedure for vascular health screening.

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Conflict of interest

None to report.

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