

The effect of measurement position on brachial–ankle pulse wave velocity

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Arterial stiffness measurements are primarily used for the early detection of arteriosclerosis. Methods and devices that can easily measure arterial stiffness at home are in demand. We propose a simple method for measuring brachial–ankle pulse wave velocity (baPWV) at home using a reclining chair and investigate the effects of positioning on baPWV measurement. We measured baPWV in 50 healthy men (21–70 years) in seven different measurement positions, including the supine position, sitting, sitting with the knees flexed at 45°, sitting with the knees flexed at 0°, reclining at 37°, reclining at 50°, and standing. BaPWV was significantly lower in the supine position ($P < 0.01$) than in the other positions. It was significantly higher in the sitting position ($P < 0.01$) than in the reclining position (37°). No changes in baPWV were seen changing the knee flexion angle alone while sitting. Strong correlations were also observed between baPWV in the supine position and that in other positions. We showed that baPWV in the supine position can be calculated by making corrections to baPWV measured in the sitting position at a reclining angle. Utilizing this corrected value would allow easy measurement at home using a reclining chair.

Key words: posture, pulse wave velocity, vascular stiffness, knee flexion angle

1. Introduction

Decreased arterial flexibility is a risk factor for arteriosclerosis [1] and arterial stiffness is often measured in clinical settings. Several quantitative indices for arterial stiffness exist, but pulse wave velocity (PWV) is the most frequently applied clinically and is considered highly reliable [2], [8]. PWV is the speed at which pulse waves are transmitted within the blood vessels [5]. Pulse waves are measured at two points within the vessels, at the proximal and distal portions. PWV is calculated as $PWV = \Delta d / \Delta T$, where ΔT is the difference between the arrival times of pulse waves and Δd is the distance between the two points. PWV is known to increase when Young's modulus and thickness of the vascular wall increase. It is common for the carotid and femo-

ral arteries to be used as the two intravascular points (carotid–femoral PWV: cfPWV); however, in recent years, brachial–ankle PWV (baPWV), using the brachial and ankle arteries, has been employed as an easier method of measuring PWV ([6], [11], [13]). An excellent correlation is known to exist between cfPWV and baPWV [12].

Arterial stiffness measurements are employed for the early detection of conditions such as arteriosclerosis, in a similar manner to peripheral blood pressure measurements. Therefore, methods and devices that can easily measure arterial stiffness at home are in demand. Usually, baPWV is measured in the supine position, thus requiring more space for measurement and an assistant to fit the cuff. If baPWV could be measured in a sitting position, we anticipate that multiple applications could be possible, as has been the case with peripheral blood pressure meters.

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Received: May 30th, 2014

Accepted for publication: August 4th, 2014

To date, few studies have investigated the effect of measurement position on PWV. Hasegawa et al. [3] measured cuff pressure of the upper arm and ankle when Korotkoff sounds occurred in three positions (head down 30° with the legs up, the supine position, and standing) and compared PWV between these positions. However, the effect of sitting has not been investigated. Nürnberger et al. [7] compared PWV and augmentation indices (AI) estimated from upper arm cuff pressure waveforms in the sitting and supine positions. However, they did not investigate baPWV and only conducted measurements in a normal sitting position (a detailed description is not given, but we assume that the knees and hips were both flexed 90°). We believe that more relaxed measurements could be taken using a reclining chair when testing baPWV alone at home.

We propose a method of easily measuring baPWV at home using a reclining chair. In addition, we investigated how measurement position affected baPWV. Apart from the supine position, measurements were compared between sitting, sitting with the knees flexed at 45°, sitting with the knees flexed at 0°, reclining 37°, reclining 50°, and standing positions.

2. Methods

2.1. Subjects

Fifty Japanese men aged 21–70 years (mean age was 22 years) participated as subjects in this experiment. Table 1 shows the number and physical characteristics of the subjects in each age group. Using an

electronic sphygmomanometer, we measured the systolic and diastolic blood pressure values of the subjects while sitting. Prior to the experiments, the subjects were fully informed regarding the purpose and experiments of this study, and they gave their written consent to participate. The Ethical Review Committee on Research Involving Human Subjects of Utsunomiya University approved this study.

2.2. Measurement device and baPWV

We created our own baPWV measurement device. A cuff for adults and a cuff for children were each used at the right upper arm and the right ankle. Each cuff was inflated with an air pump (DP140; MEDO Industries Co., Ltd., Tokyo, Japan), and the cuff pressure was measured with a pressure sensor (FP101; Yokogawa Electric Corporation, Tokyo, Japan; measurement range: 0–20 kPa). The solenoid valve located between the cuff and pump was closed to maintain a constant cuff pressure once the cuff pressure reached 50 mmHg. After the pulse waveform measurement period had elapsed, the solenoid valve for deflation was opened, and the cuff pressure was released. The output voltage of the pressure sensor was recorded on a computer at a sampling frequency of 1,000 Hz using a compact recorder (EDS-400A; Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan).

After canceling noise with 10 Hz low-pass and 0.1 Hz high-pass digital filters, the obtained output voltage was converted to pulse waveforms. The difference between the minimum times of both waveforms in one heartbeat was measured from the upper

Table 1. Physical characteristic of the subjects

Age group	<i>n</i>	Age, years	Body weight, kg	Height, cm	Body fat, %	SBP, mm Hg	DBP, mm Hg
20	16	23.3 (1.4)	61.9 (8.3)	170.9 (5.8)	17.6 (3.2)	124.1 (9.6)	74.4 (10.9)
30	10	34.8 (2.9)	70.4 (11.0)	171.6 (7.2)	22.4 (4.2)	137.8 (9.6)	88.8 (10.8)
40	10	43.0 (2.7)	68.0 (5.2)	170.4 (6.0)	23.3 (3.4)	132.8 (13.8)	84.3 (10.3)
Over 50	14	58.7 (6.5)	65.0 (8.3)	169.1 (5.2)	25.2 (3.2)	138.5 (15.1)	89.0 (10.3)
Total	50	39.4 (14.6)	68.0 (9.9)	170.4 (5.9)	21.9 (4.5)	132.6 (13.4)	83.4 (12.1)

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure. Values are expressed as mean (SD).

arm and ankle pulse waveforms and the pulse wave propagation time difference was calculated by averaging the time difference for 10 heartbeats. With reference to the literature [16], on the basis of the height of the subjects, we calculated the difference in distance from the aortic valve opening to the upper arm and ankle and calculated PWV using this value divided by the pulse wave propagation time difference.

2.3. Measurement position

There were seven different measurement positions. The supine position, which is the usual baPWV measurement position, was set as a reference. Sitting in a reclining chair was considered the sitting position (Fig. 1). While sitting, the subjects looked ahead in the horizontal direction with their back in contact with the back of the reclining chair. In this position, the subject's hips were flexed 65° , their knees flexed 90° , and their upper body was tilted backwards 25° from the vertical plane. While sitting, the subjects moved just their knees to the 45° and 0° (extended position) flexion positions. When the reclining angle of the reclining chair was set at the maximum range of motion, the upper body was tilted 50° backwards from the vertical plane (reclining 50°). In this position, the hips were flexed 50° and the knees 40° . In addition, when the reclining angle was set at half the range of motion, the upper body was tilted 37° backwards from the vertical plane (reclining 37°). In this position, the hips were flexed 65° and the knees 70° . The subjects rested in the reclining chair with the upper arms parallel to the upper body, the forearms placed on the

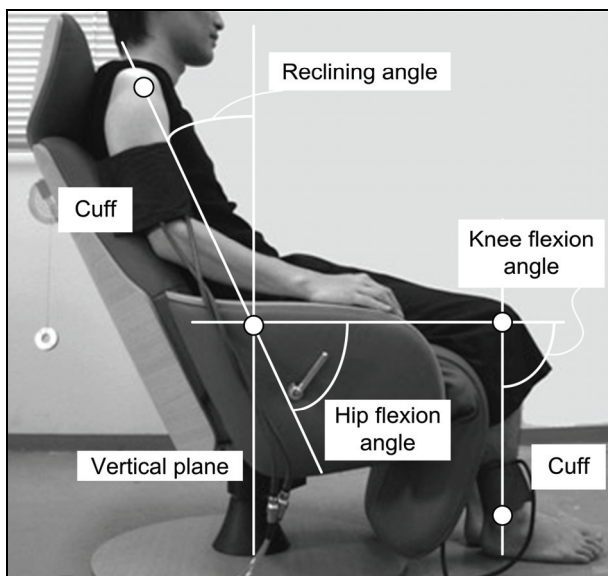


Fig. 1. Sitting position using a reclining chair

elbow rests, and the elbows flexed to 90° . Furthermore, their feet only came into contact with the floor in the sitting position. We included standing as a position to compare our results with those of Hasegawa et al. [3].

2.4. Measurement conditions [15]

All experiments were conducted after 3 pm, 2–3 h after a meal. The subjects were asked to refrain from smoking or vigorous exercise prior to experiments. The temperature within the laboratory was set to 20°C – 28°C and they were asked to enter the laboratory at least 10 min before beginning the experiments. After explaining the content of the experiments to the subjects and obtaining their written consent, they were asked to rest for at least 5 min in a sitting position before baPWV measurements. They were also asked to rest for 5 min or more in a sitting position between each measurement position. After 5 min of rest following completion of all experiments, they responded to a questionnaire regarding personal information and underwent physical measurements. They were also instructed to avoid talking or sleeping during measurements.

3. Results

3.1. Typical cuff pressure waveforms

Figure 2 shows typical upper arm and ankle cuff pressure waveforms in the supine, sitting, and standing positions. The minimum value per heartbeat of cuff pressure waveforms in both sites in the supine position can be clearly identified in Fig. 2(a). With regard to the upper arm cuff pressure waveforms in the sitting and standing positions, Fig. 2(b) and 2(c) show that the amplitude is decreased by approximately 40% compared with those in the supine position. In addition, we can clearly identify the minimum values per heartbeat, as with the supine position. However, the amplitude decreased by approximately 70% in the ankle cuff pressure waveform. These results suggest that ankle cuff pressure is affected by measurement position to a greater extent than upper arm cuff pressure. Although it was somewhat difficult to identify the minimum value from the ankle cuff pressure waveform, we determined this using the minimum value of the upper arm cuff pressure waveform as an indicator.

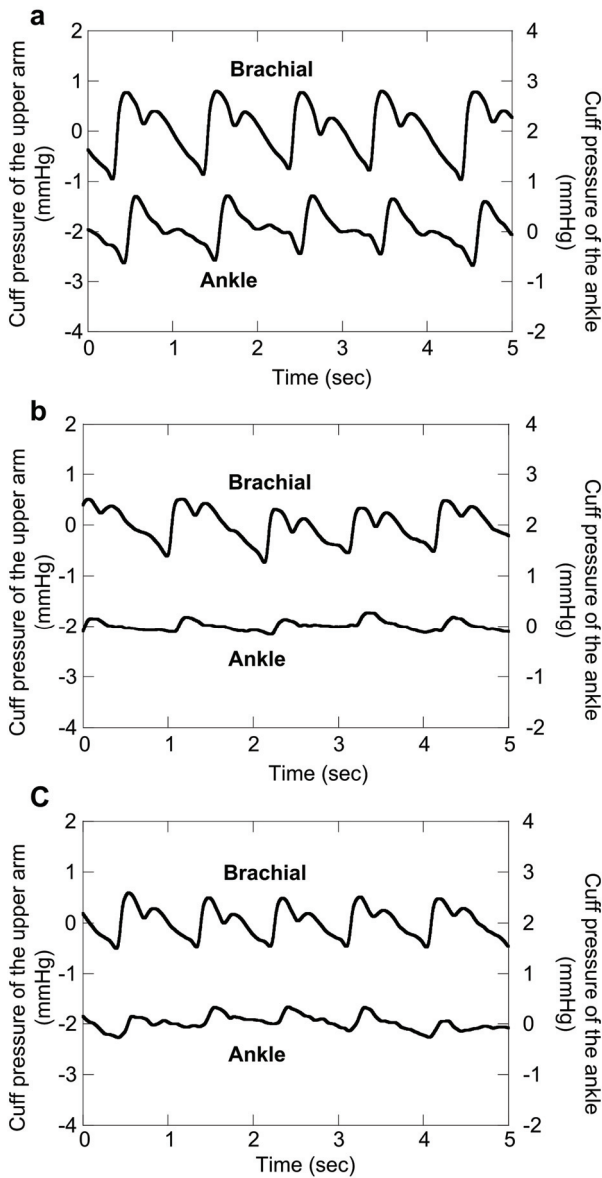


Fig. 2. Typical data of the pressure pulse waveforms in the cuffs at the brachial and ankle (22 years old male, SBP: 128 mm Hg, DBP: 67 mm Hg) in (a) spine position, (b) sitting position, and (c) standing position

3.2. The effect of measurement position on baPWV

Figure 3 shows the effect of measurement position on baPWV in all 50 subjects. BaPWV measured in the supine position was significantly lower than that measured in the other positions. Moreover, baPWV measured in the 37° reclining position was significantly lower ($P < 0.01$) than that measured in other positions, except those in the supine and 50° reclining positions. Lastly, baPWV measured in the 50° reclining position was significantly lower ($P < 0.01$) than that measured in the standing posi-

tion. We found that baPWV increased when the measurement position changed from the supine position to the sitting and standing positions. However, no change in baPWV was seen by changing the knee flexion angle alone in the sitting position, and although baPWV decreased by changing the measurement position from the sitting position to the 37° reclining position, baPWV did not decrease further by increasing the reclining angle.

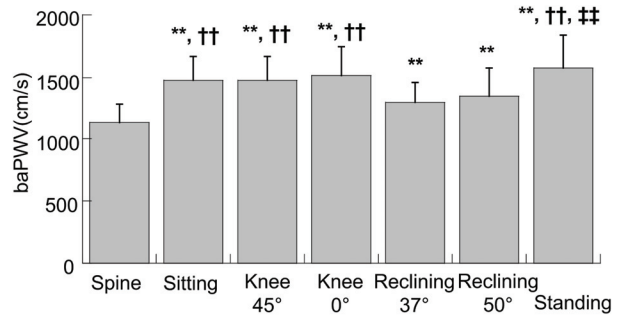


Fig. 3. Effect of measurement position on baPWV. ** $P < 0.01$, vs. Spine position; †† $P < 0.01$, vs. Reclining 37°; ††† $P < 0.01$, vs. Reclining 50°

3.3. Correlation with baPWV in the supine position

Figure 4 shows the correlation between baPWV in the sitting with the knees flexed at 0° and supine positions for all the subjects. Both are expressed with a linear correlation in the figure with a Pearson product-moment correlation coefficient of $r = 0.81$ ($P < 0.001$, SPSS ver.17.0). Thus, both can be said to have a positive correlation. Table 2 shows the correlation equations and coefficients of baPWV between the supine position and the other positions. All correlations showed P values of < 0.001 , revealing a good linear correlation.

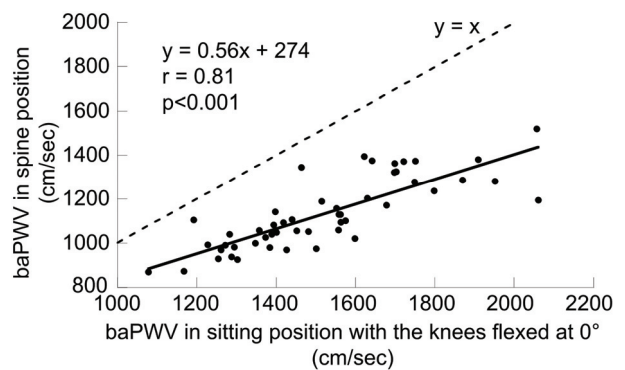


Fig. 4. Correlation between baPWV in sitting position with the knees flexed at 0° and that in spine position

Table 2. Correlation equations and coefficients of baPWV between the supine position and the other positions

x	y	$y = ax + b$	r
Standing	Spine	$y = 0.44x + 443$	0.72
Sitting	Spine	$y = 0.46x + 456$	0.54
Knee 45°	Spine	$y = 0.55x + 310$	0.65
Reclining 37°	Spine	$y = 0.67x + 258$	0.67
Reclining 50°	Spine	$y = 0.56x + 376$	0.79

4. Discussion

We measured baPWV in the supine position and compared it with six other measurement positions (standing, sitting, knees flexed 45°, knees extended, reclining 37°, and reclining 50°) in 50 subjects of different ages. We used the results to investigate the effect of measurement position on baPWV and to find correlations between the values measured in the supine position and in the other positions. We found that baPWV measured in the supine position was significantly lower ($P < 0.01$) than that measured in the other positions. Nonetheless, we also noted a good correlation between the supine position and the other measurement position for all the subjects.

Few studies to date have investigated the effect of measurement position on PWV. Hasegawa et al. [3] measured upper arm and ankle cuff pressure with the head down 30° (and legs up), in the supine position, and in the standing position in subjects aged 15–75 years and compared items such as PWV. They found that PWV increased from 10.9 to 17.6 m/s, when the measurement position changed from the supine to the standing position. In the present study, the same trend was seen, with the baPWV increasing from 11.3 to 15.8 m/s. Hasegawa et al. measured blood pressure in the upper arm and ankle in each position and found no significant differences between the values at the two sites in the supine position; however, blood pressure increased significantly by about 70 mm Hg in the ankle compared with that in the upper arm in the standing position. According to Hasegawa et al. [3], standing causes the arteries of the lower extremities to expand because of the increase in ankle blood pressure and compliance. This, in turn, is associated with the decrease in elastic modulus of the arteries, which results in increased PWV in arteries with stiff walls.

Nürnberg et al. [7] compared PWV and AI estimated from upper arm cuff pressure waveforms in the sitting and supine positions in healthy individuals and patients with cardiovascular disease. Although they

did not observe a significant difference in PWV and AI as a result of measurement posture, an increasing trend was observed. They also observed a significant correlation between the sitting and supine positions. Jaccoud et al. [4] estimated central pressure waveforms from radial artery pulse pressure measurements in the sitting and supine positions in pregnant women in their third trimester and women who were not pregnant. They compared AIs obtained from these central pressure waveforms and the time until the start of the reflected wave. Their results showed that systolic AI (sAI@75) that had undergone heart rate correction increased significantly and the time until the start of the reflected wave (sT1r, dT1r) decreased significantly in the sitting position compared with that in the supine position. Sitting is known to increase systolic blood pressure and heart rate, thereby causing a reduction in cardiac output. The increase in systolic blood pressure causes blood vessel dilation and is assumed to accelerate PWV and reflected waves. The increase in heart rate and the speed of reflected waves act to increase AI and cardiac output acts to decrease AI. Similar results were observed in a study by Reesink et al. [9]. In the present study, pulse waveforms of the upper arm were not particularly affected by measurement position, as shown in Fig. 2. In contrast, ankle pulse waves greatly varied according to the measurement position. This suggests that elevated systolic blood pressure brought about by sitting causes PWV throughout the entire body to increase; however, the cause of increased baPWV is thought to be increased ankle PWV associated with increased hydrostatic pressure in the arteries of the lower extremities.

It is known that baPWV may not be a good indicator of vessel stiffness in patients with hypertension [17]. The reason for this is that increased vascular stiffness caused by elevated blood pressure expanding the arteries results in increased baPWV. Moreover, it has been pointed out that wall stiffness of the central aorta, which most strongly reflects arteriosclerosis, is not taken into consideration. To overcome these disadvantages, the cardio-ankle vascular index (CAVI) was developed [10]. However, CAVI requires heart sounds to be recorded; therefore, it not a simple method that would be useful for taking measurements at home, which was the objective of the present study. Because baPWV uncorrected for blood pressure has been shown to be useful for predicting the risk of arteriosclerosis [14], we believe that baPWV measurements alone are sufficient. However, the effects of measurement position on CAVI are of great interest.

The findings of this study revealed good correlation between baPWV in the supine and sitting posi-

tions. Furthermore, our results showed that the reclining angle of the upper body while sitting affected baPWV measurement. By making corrections for the reclining angle, baPWV can be calculated in the supine position when performing easy measurements at home using a reclining chair.

Acknowledgement

This work was supported by Adaptable and Seamless Technology transfer Program through target driven R & D (A-STEP, AS242Z00975P) from Japan Science and Technology Agency (JST).

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