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Original Article

A Comparative Study of Methods of Measurement of Peripheral Pulse Waveform

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Objective: Increased aortic and carotid arterial augmentation index (AI) is associated with the risk of cardiovascular disease. The most widely used approach for determining central arterial AI is by calculating the aortic pressure waveform from radial arterial waveforms using a transfer function. But how the change of waveform by applied pressure and the pattern of the change rely on subject's characteristics has not been recognized. In this study, we use a new method for measuring radial waveform and observe the change of waveform and the deviation of radial AI in the same position by applied pressure.
Method: Forty-six non-patient volunteers (31 men and 15 women, age range 21-58 years) were enrolled for this study. Informed consent in a form approved by the institutional review board was obtained in all subjects. Blood pressure was measured on the left upper arm using an oscillometric method, radial pressure waves were recorded with the use of an improved automated tonometry device. DMP-3000(DAEYOMEDI Co., Ltd. Ansan, Korea) has robotics mechanism to scan and trace automatically. For each subject, we performed the procedure 5 times for each applied pressure level. We could thus obtain 5 different radial pulse waveforms for the same person's same position at different applied pressures. All these processes were repeated twice for test reproducibility.
Result: Aortic AI, peripheral AI and radial AI were higher in women than in men ($P<0.01$), radial AI strongly correlated with aortic AI, and radial AI was consistently approximately 39% higher than aortic AI. Relationship between representative radial AI of DMP-3000 and peripheral AI of SphygmoCor had strongly correlation. And there were three patterns in change of pulse waveform.
Conclusion: In this study, it is revealed the new device was sufficient to measure how radial AI and radial waveform from the same person at the same time change under applied pressure and it had inverse-proportion to applied pressure.

Key Words : augmentation index (AI), radial AI, pulse diagnosis, robotics, pulse detector

Introduction

The augmentation index (AI) derived from central arteries (e.g. aorta and carotid artery) is generally defined as an index of augmentation of central blood pressure in systole derived from the return of pressure waves reflected from the periphery (mainly from the lower body)[1]. Increased aortic and carotid arterial AI are associated with the risk of cardiovascular disease[2,3], mortality and morbidity[4,5]. The most widely used approach for determining central arterial AI is by calculating the aortic pressure

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waveform from radial arterial waveforms using a transfer function, because the measurement of aortic or carotid artery pulse waves by applanation tonometry requires technical expertise and can be uncomfortable for patients. A close relationship between central AI and aging has also been reported[1]. Because AI can also be obtained from radial arterial waveform, radial AI itself could provide information on vascular aging[6].

The central aortic pressure wave is composed of a forward-traveling wave generated by left ventricular ejection and a later-arriving reflected wave from the periphery[7]. As aortic and arterial stiffness increase, transmission velocity of both forward and reflected waves increase, which causes the reflected wave to arrive earlier in the central aorta and augment pressure in late systole. Therefore, augmentation of the central aortic pressure wave is a manifestation of early wave reflection and is the boost of pressure from the first systolic shoulder to the systolic pressure peak[8]. This can be expressed in absolute terms (augmented pressure [AP]) or as a percentage of pulse pressure (augmentation index [AIx])[9]. A noninvasive approach clearly would be of value for the examination of larger populations[3].

Several researchers have indicated that this transfer function (radial artery to aorta) has large between-subject variability[10] and therefore, synthesized ascending aortic AI derived from radial pressure waveforms by the use of a transfer function had no significant correlation with AI derived from invasively measured aortic pressure waves[11]. Recent study has reported that AI has significant variability for the measuring position even in same person's radial artery[12]. Several researchers have also indicated that pulse waveform in the same position is changed by applied pressure[13,14].

We thought this variability might come from measuring method. Now, there are two methods of measurement of radial artery waveform. The first is to use a hand-held pen-type tonometer and self evaluate measured data from operator index. The second is a semiautomatic method that is programmed to determine automatically the pressure against the radial artery to obtain the optimal radial arterial waveform. But neither had recognized change of waveform by applied pressure and the pattern of changes rely on subject's characteristics. In this study, we used a new method for measuring radial waveform and observed the change of waveform and the deviation of radial AI in same position by applied pressure.

Methods

1. Study Subjects

Forty six subjects were enrolled for this study. There were 31 men and 15 women with a mean

Table 1. Subject characteristics and Aortic and Radial Pressures at Baseline

	Male(N=31)	Female(N=15)	P-value
Age (years)	25.80±7.04†	25.06±3.68	
Body Mass Index	22.84±2.94	19.45±1.21	<0.001
Heart rate (beat min-1)	68.10±12.04	74.40±8.74	<0.05
Systolic BP (mmHg)	119.47±10.92	101.17±9.62	<0.001
Diastolic BP (mmHg)	69.45±8.06	66.60±7.04	NS
Aortic AI* (%)	6.131±2.31	15.53±7.90	<0.001
Peripheral AI (%)	45.77±15.99	55.60±12.24	<0.01
Radial AI (%)	45.69±16.16	54.86±12.89	<0.01

* AI = augmentation index, †Data are meanSD. versus male.

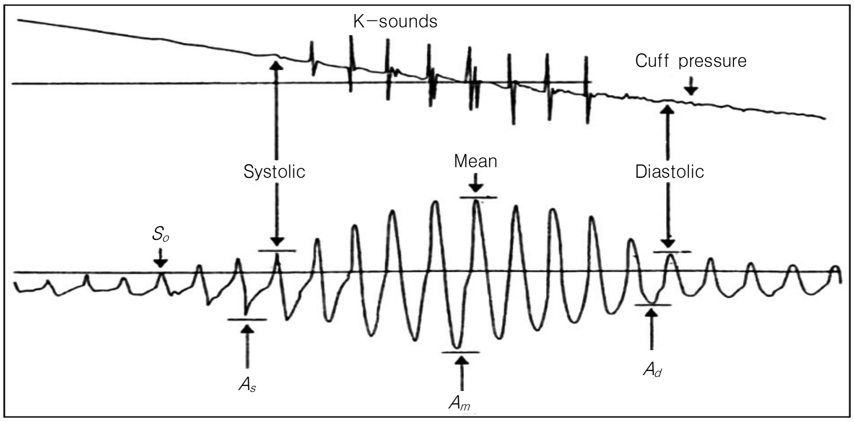

Fig. 1. Diagram of general oscillometric blood pressure detecting method.

age of 59 years (range, 21 to 58 years). They were non-patient volunteers who have no history of cardiovascular disease, diabetes, or hyperlipidemia. Informed consent in a form approved by the institutional review board was obtained from all subjects. Table 1 provides a summary of clinical characteristics, and aortic and radial blood pressures at baseline.

2. Measurements

Blood pressure was measured on the left upper arm using an oscillometric method (HEM-780; Omron Healthcare Co., Ltd., Kyoto, Japan) after 5 min of rest in the sitting position. (Fig. 1)

Radial pressure waves were recorded with the use of an improved automated tonometry device (DMP-3000; DAEYOMEDI Co., Ltd. Ansan, Korea), after measuring BP via the left upper arm (Fig. 2).

DMP-3000 has robotics mechanism to scan and trace automatically the blood vessel's exact position and to apply pressure to take stable multi-step waveforms (Fig. 3).

We used an arterial tonometry sensor with an array of 5 piezoresistive semiconductor transducers. It was designed to find the exact position on the blood vessel. The sensor was put on the left radial artery and pressure applied at multiple levels (50g, 90g, 140g, 190g, 240g).

For each subject, radial arterial pressure waveforms

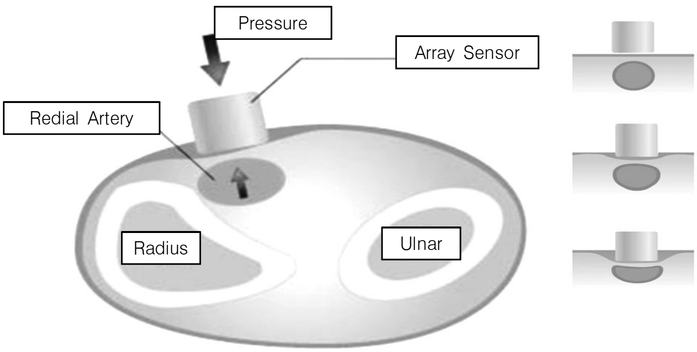

Fig. 2. Diagram of deformation of blood vessel by applying pressure.

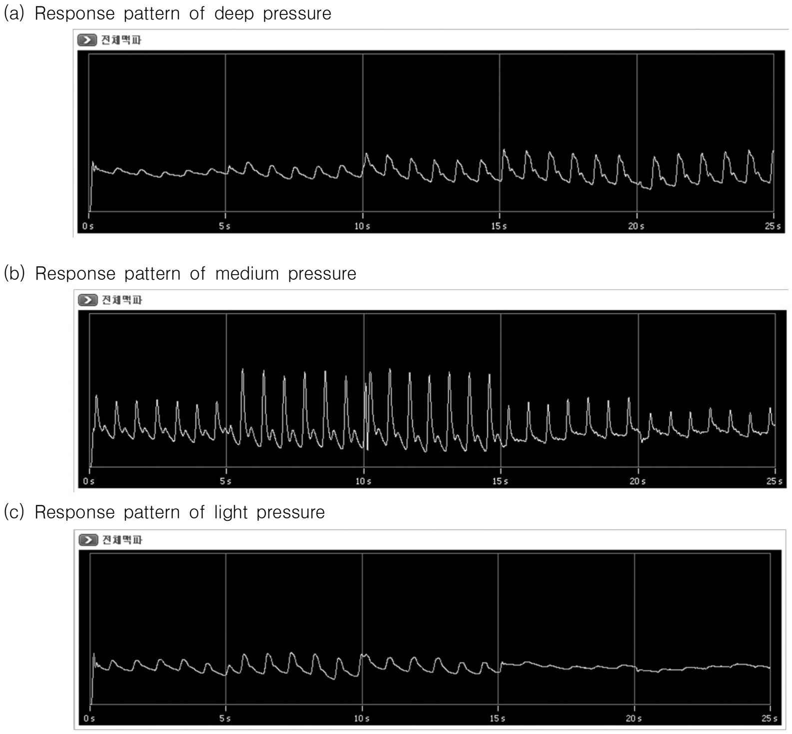

Fig. 3. Obtained pulse waveforms of multiple levels.

Each pressure stage records the pulse wave for 5 seconds. (a) Response pattern of deep pressure, (b) Response pattern of medium pressure, (c) Response pattern of light pressure. Each pattern has relation to the subject's individual characteristics.

were recorded for 5 seconds for each level. Radial AI was calculated as follows:

[(second peak radial systolic pressure - diastolic pressure) / (first peak radial systolic pressure - diastolic pressure) ´100(%)] (Fig. 4)[6].

The first and second peaks of systolic pressure and diastolic pressure were automatically detected using fourth derivatives for each radial arterial wav-

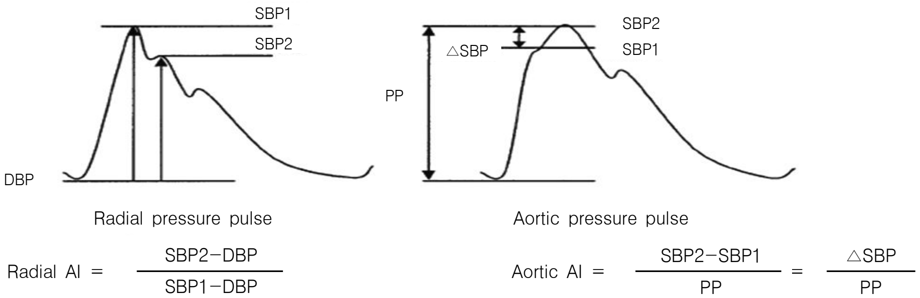

Fig. 4. An actual tracing of a radial arterial waveform. Radial augmentation index (AI) = (SBP2 − DBP)/(SBP1 − DBP) (%). DBP =diastolic pressure; PP = pulse pressure; SBP1 = first systolic blood pressure component; SBP2 = second systolic blood pressure component. Aortic AI is defined as (SBP2 − SBP1)/PP (%), D SBP = SBP2 − SBP1.

Table 2. Subject characteristics and Aortic & Radial AI Parameters.

	Male (N=31)	Female (N=15)	P-value
Aortic AI* (%)	6.13 ± 12.31†	15.53 ± 7.90	<0.001
Aortic AI at 75 (%)	2.58 ± 10.93	13.83 ± 8.90	<0.001
Peripheral AI (%)	45.77 ± 15.99	55.60 ± 12.24	<0.01
Radial AI (%)	45.69 ± 16.16	54.86 ± 12.89	<0.01
Applied pressure (g)	184.77 ± 40.31	163.93 ± 33.96	<0.05
Aortic AI - Radial RI (%)	39.56 ± 9.09	39.32 ± 9.33	NS
Height (cm)	173.45 ± 5.74	160.80 ± 4.19	<0.001
Weight (kg)	68.90 ± 10.71	50.33 ± 4.34	<0.001
Age (years)	25.80 ± 7.04	25.06 ± 3.68	
Body Mass Index	22.84 ± 2.94	19.45 ± 1.21	<0.001
Heart rate (beat min-1)	68.10 ± 12.04	74.40 ± 8.74	<0.05
Systolic BP (mmHg)	119.47 ± 10.92	101.17 ± 9.62	<0.001
Diastolic BP (mmHg)	69.45 ± 8.06	66.60 ± 7.04	NS
Mean arterial BP (mmHg)	86.12 ± 7.68	78.12 ± 7.64	<0.001

* AI = augmentation index, †Data are mean ± SD. versus male.

eform and averaged.

For each subject, we took the measurement 5 times for each applied pressure level. We obtained 5 different radial pulse waveforms for the same person's same position at different applied pressures. The representative pulse waveform was selected by the highest frequency of the measuring pulse waves. All these processes were repeated twice for test reproducibility.

3. Statistical Analysis

All values are expressed as mean ± SD, if not specified. The difference between men and women was evaluated by analysis of variance. Correlation

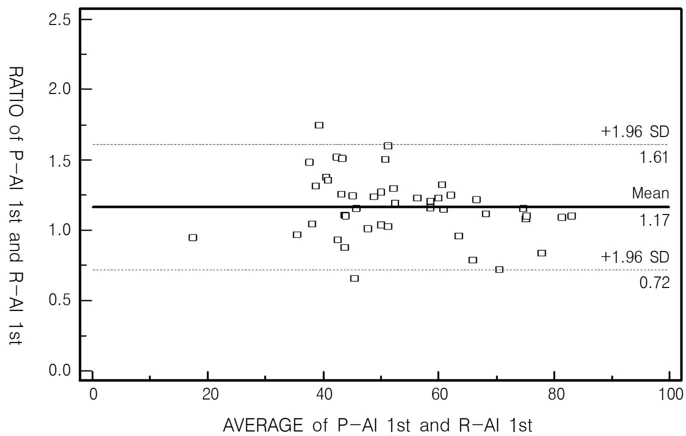

Fig. 5. Bland & Altman Graph of P-AI and R-AI 1st-measuremnt

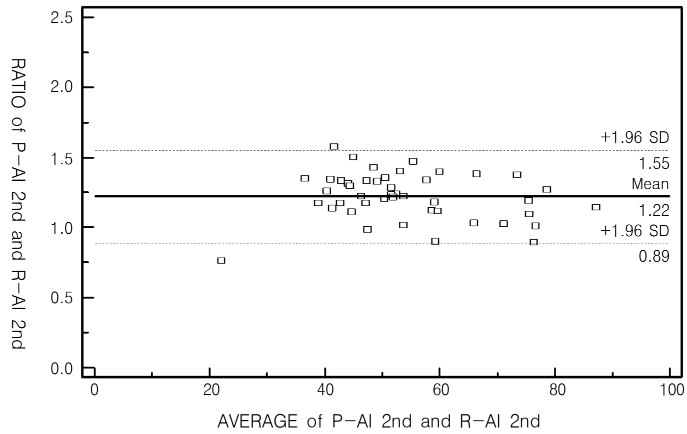

Fig. 6. Bland &Altman Graph of P−AI and R−AI 2nd−measuremnt.

analysis was performed to assess relation between peripheral AI, Aortic AI of SphygmoCor and representative radial AI of DMP-3000. Agreement between the peripheral AI of SphygmoCor and the representative radial AI of DMP-3000 was evaluated by Bland & Altman plots for each measurement. The reproducibility of heart rate, brachial blood pressure, radial first and second and systolic peak pressures were evaluated by the within-subject standard deviation (SD) for the two trials, respectively. The Kruskal-Wallis test was performed to find change of AI by applied pressure. All statistical analyses were performed using the Minitab statistical software package (MINITAB Corp., Pennsylvania, USA). A probability value of $P<.05$ was considered to be statistically significant.

4. Results

The study subjects were 46 non patient volunteers (31 men and 15 women). They were aged 21-58, mean height was 169.33 ± 7.95 cm, and mean weight was 62.85 ± 12.63 kg. As shown in Table 2., height, body weight, systolic, diastolic, and mean arterial blood pressures were lower in women than in men ($P<0.001$), whereas aortic AI, peripheral AI and radial AI were higher in women than in men ($P<0.01$). Radial AI strongly correlated with aortic AI although radial AI was consistently approximately 39% higher than aortic AI. Heart rate was higher in women while applied pressure was lower ($p<0.05$).

As shown in Fig. 5 and Fig. 6, relationship between representative radial AI of DMP-3000 and Peripheral AI of SphygmoCor showed strong

Table 3. Results of Kruskal-Wallis test for all 5 pressure levels

	Median	Average rank	Z
Level 1 (50g)	64.50	306.3	6.42
Level 2 (90g)	56.95	277.9	4.28
Level 3 (140g)	50.20	228.8	0.23
Level 4 (190g)	45.50	182.9	-3.55
Level 5 (240g)	38.40	134.2	-7.36
H = 101.55 DF = 4 P = 0.000			

correlation.

The within-subject SD of the twice trials was 2.3 ± 2.4 bpm, 3.9 ± 3.0mmHg, 2.7 ± 2.3mmHg, 3.3 ± 3.1%, 2.8 ± 3.0% and 5.2 ± 5.2%, for heart rate, brachial systolic and diastolic blood pressure, peripheral AI, aortic AI and representative radial AI, respectively.

Results of the Kruskal-Wallis test are shown in Table 3., and we can find AI is inverse-proportional to applied pressure that has purpose to measure the AI value.

We see that there are three patterns in change of pulse waveform. Some people had the same pattern of pulse waveform shape for each of the 5 levels, others had a second pattern of pulse waveform shapes and a few others had a third pattern of pulse waveform shapes. (Fig. 7)

Conclusions

In the present study, we evaluated the association between representative radial AI obtained by DMP-3000 and aortic AI obtained by SphygmoCor. There was a highly significant and close association between AI obtained by two methods. This finding indicates the validity of radial AI automatically obtained with DMP-3000, which scans and traces the radial artery's blood vessel position and takes the pulse waveform at multiple levels of applied pressure.

We found measured waveform could be changed by applied pressure and radial AI is in inverse proportion to applied pressure in a non-patient population.

There are three patterns in changes of pulse waveforms. Some have the same pattern of pulse waveform shapes for all 5 levels, others have a second pattern of pulse waveform shapes over 5

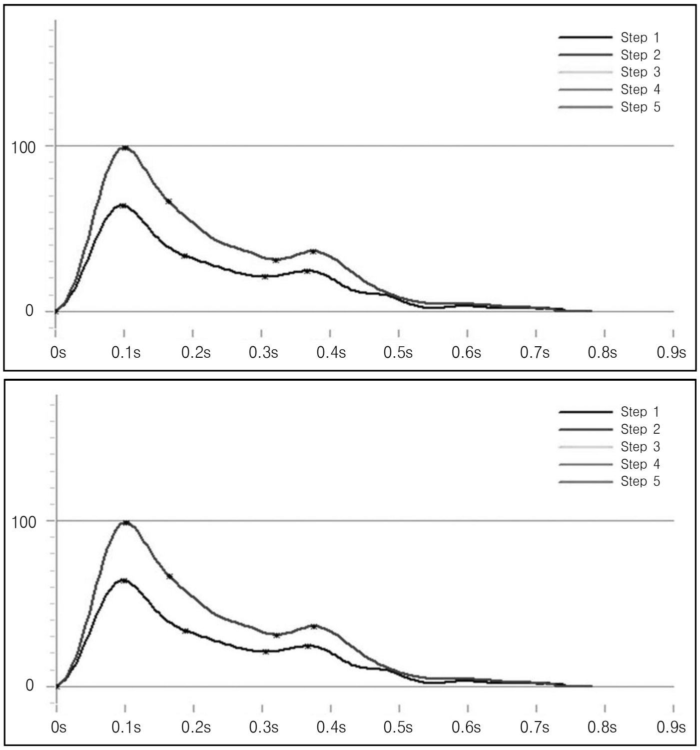

Fig. 7. Two different pulse shape patterns in the same person. 1st and 2nd level have the same pattern and 3rd, 4th and 5th level have the same pattern.

levels, but a few have a third pattern of pulse waveform shapes at the 5 levels.

So we need further study to determine optimal applied pressure to use for cardiac disease such as hypertension. Observation of the many different types of disease and age groups in view of hemodynamics and mechanics, to find the reason for pulse waveform deformation at the same measuring point, is also needed.

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