Evaluation of Pulse Wave Velocity Reproducibility for Two Different Methods of Determining Pulse Wave Transit Time

Nak B. Lee\textsuperscript{1}, Young K. Yoon\textsuperscript{1}, Young J. Jeon\textsuperscript{1}, Jae J. Im\textsuperscript{2}
Dept. of Mechatronics Eng., Graduate School, Chonbuk National University, Korea\textsuperscript{1}
Division of Electronics & Information Engineering, Chonbuk National University, Korea\textsuperscript{2}

For the detection of blood flow velocity in human, PWV(pulse wave velocity) has been studied and proposed as one way to diagnose and evaluate distensibility of vessels. Measurement of PWV, which is inversely related to arterial wall distensibility offers a simple and potentially useful approach. Objective of this study was to compare the PWV values calculated based on the two different methods of extracting pulse wave transit time, foot-to-foot method and heart sound-to-dicrotic notch method. PWV values obtained by two operators using two different equipments were analyzed for the comparison of reproducibility.

Mean differences for equipment A laid almost at zero for both radial and femoral PWV values, which implies high reproducibility. Also, 2SD values of PWV are low, 0.34 for radial and 0.33 for femoral. On the other hand, mean differences for equipment B are appeared to be far from zero, -0.17 for carotid-radial and –0.30 for carotid-femoral PWV values. Standard deviations of PWV are 0.49 for radial and 0.81 for femoral, which implies low reproducibility. Direct comparison of absolute values for two PWV values does not have important meaning, but the results of this study with equipment A, which uses the method of 2\textsuperscript{nd} heart sound to dicrotic notch transit time, imply the better reproducibility for the PWV measurement. Since the reproducibility of the measurement is critical for the diagnosis in clinical use, it is necessary to provide the accurate algorithm for the detection of more stable features from the pulse waveform.

Introduction

For the detection of blood flow velocity in human, PWV(pulse wave velocity) has been studied and proposed as one way to diagnose and evaluate distensibility of vessels. Measurement of PWV, which is inversely related to arterial wall distensibility offers a simple and potentially useful approach. Measurements of PWV are classified into two methods, ultrasonic imaging using doppler sensors and pulse wave analysis using pressure sensors. The latter method, which is more comfortable and economical was presented as a useful method which provides the parameter, PWV, for the evaluation of vascular abnormalities.

PWV is a velocity of pulse wave between two measuring sites, and simply determined by dividing distance between two sites by time taken for the pulse wave to travel between those two points. If the distance is known, determination of pulse wave transit time is the most important requirement for accurate calculation of PWV values. Moreover, reproducibility of the PWV values also depends on the calculation methods of pulse wave transit time. That is, detection of certain points from a pulse wave is critical for the improvement of the accurate extraction of PWV value.

Widespread method for the calculation of PWV is based on the extraction of foot-to-foot transit time, which is determined by the time difference between upstroke points of two pulse waves. The other method for the determination of pulse wave transit time is based on the heart sounds characteristics and the dicrotic notch of a pulse wave. First heart sound occurs with the closure of the AV(atrio-ventricular) valves and the 2\textsuperscript{nd} heart sound occurs...
with the closure of the aortic valve. Since the dicrotic notch of a pulse wave occur when the aortic valve closes, time difference between the starting point of the 2nd heart sound and the dicrotic notch of a pulse wave at a certain pulse site represents the pulse wave transit time from the heart to a specific point of a body.

Objective of this study was to compare the PWV values calculated based on the two different methods of extracting pulse wave transit time, foot-to-foot method and heart sound-to-dicrotic notch method. PWV values obtained by two operators using two different equipments were analyzed for the comparison of reproducibility. Results of the study will be used for the development of a more stable and accurate PWV measurement system.

Methods

Data collection was performed at the Wales Heart Research Institute, University of Wales, Cardiff, UK. Twenty healthy male subjects (mean age of 33 years) without any cardiovascular disease were participated for the study. Two different equipments, equipment A (PP-1000, Hanbyul Meditech, Korea) which uses the heart sound-to-dicrotic notch method and equipment B (SphygmoCor, AtCor Medical, Australia) which uses the foot-to-foot method, were operated by two observers. Each observer made two consecutive measurements using two equipments in a random order from the same subject. Surface distances were measured and used for the PWV calculation for both methods.

Using equipment A, five signals, ECG, heart sound, and pressure waveforms at the carotid, radial, and femoral arteries, were recorded simultaneously for the duration of 10 seconds. On the other hand, using equipment B, 10 seconds of recordings for ECG and pressure waveforms were performed sequentially in the order of pulse wave measurements at the carotid, radial, and femoral arteries. Representative waveforms obtained from two equipments are shown in figure 1.

Equipment A extracts carotid pulse wave transit time between the 2nd heart sound and the dicrotic notch of the carotid pulse wave. The same methods are applied to obtain radial and femoral pulse wave transit times. That is, transit time is actually a time difference between closing of aortic valve and its resulting pulse wave at a certain point of a body. Then, carotid, radial, femoral PWVs are calculated based on the surface distances between the two recording sites. Equipment B extracts pulse wave transit time using the R-peak of a recorded ECG as a reference frame. Upstroke points of pulse waves at the carotid, radial, and femoral arteries are detected using intersecting tangent methods, and the time difference of upstroke points between carotid pulse and radial pulse are obtained for carotid-radial pulse transit time. The time difference of upstroke points between carotid pulse and femoral pulse are also obtained for carotid-femoral pulse transit time. Then, carotid-femoral PWV and carotid-radial PWV are calculated based on the surface distances between the two recording sites.

Fig. 1. Representative waveforms recorded from two equipments, A(left) and B(right).
Results and Discussion

Radial and femoral PWV values obtained from two different equipments were compared to evaluate the reproducibility of the measurements. Two analyses, within-operator and between-operator, for each equipment were performed. The results for the reproducibility of within-operator are summarized in table 1. The values in the table are the averaged differences of the measured PWV values and their standard deviations for 17 subjects. As can be seen from the table, PWV values from equipment A provides much lower differences than those from equipment B, 50-70% lower, which implies higher reproducibility. It appeared same for both operators, operator A and B.

Table 1. Reproducibility of PWV values expressed in the mean differences and standard deviations on consecutive readings within each operator

<table>
<thead>
<tr>
<th>sites for PWV</th>
<th>within-operator (A)</th>
<th>within-operator (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>radial</td>
<td>0.15±0.20</td>
<td>0.13±0.16</td>
</tr>
<tr>
<td>femoral</td>
<td>0.08±0.05</td>
<td>0.09±0.08</td>
</tr>
<tr>
<td>Equipment B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>carotid-radial</td>
<td>0.30±0.27</td>
<td>0.48±0.39</td>
</tr>
<tr>
<td>carotid-femoral</td>
<td>0.29±0.30</td>
<td>0.37±0.32</td>
</tr>
</tbody>
</table>

Figure 2. Scatter plots showing reproducibility of the averaged differences between PWV values obtained by two operators, A and B, with each equipment.
Reproducibility of PWV values for each equipment was evaluated by comparing PWV values obtained from two operators, A and B, between-operator. Data were analyzed using Bland-Altman plots and reproducibility was expressed in terms of the mean difference and standard deviation between the measurements obtained from two operators. The results are shown in figure 2 as scatter plots. Mean differences for equipment A laid almost at zero for both radial and femoral PWV values, which implies high reproducibility. Also, 2SD values of PWV are low, 0.34 for radial and 0.33 for femoral. On the other hand, mean differences for equipment B are appeared to be far from zero, -0.17 for carotid-radial and –0.30 for carotid-femoral PWV values. Standard deviations of PWV are 0.49 for radial and 0.81 for femoral, which implies low reproducibility.

Since the study was performed using two different equipments, absolute values obtained from two equipments could not be directly compared. Also, the PWV values from two equipments have different origins of pulse wave starting points, equipment A from the aortic valve and equipment B from the carotid artery. However, those two different values could represent the same meaning of pulse wave from the heart to the radial and femoral arteries, and the purpose of this study was to compare the reproducibility of the calculated PWV values based on different techniques of extracting pulse wave transit times.

Conclusions

Since equipment B do not measure the heart sound, it was not possible to compare transit time using starting point of 2\textsuperscript{nd} heart sound and dicrotic notch pulse wave. It only provided the PWV values based on the transit time between upstroke points of pulse waves at two sites. Direct comparison of absolute values for two PWV values does not have important meaning, but the results of this study with equipment A, which uses the method of 2\textsuperscript{nd} heart sound to dicrotic notch transit time, imply the better reproducibility for the PWV measurement.

Since the reproducibility of the measurement is critical for the diagnosis in clinical use, it is necessary to provide the accurate algorithm for the detection of more stable features from the pulse waveform. This study will be extended for the comparison of PWV values for the patients with various vascular risks for clinical application.

References

2. Christopher C., Patricia W., Sanjeev G., Shroff, Ted F., John D. Carroll, Determination of pulse wave velocities with computerized algorithms, American Heart Journal, 121(5); 1460-1469, 1991