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# Waveform Analysis of the Brachial-ankle Pulse Wave Velocity in Hemiplegic Stroke Patients and Healthy Volunteers: A Pilot Study

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**Abstract.** [Purpose] Brachial-ankle pulse wave velocity (BaPWV), which has been reported as an index of arterial stiffness, is very closely related to cardiovascular risk factors. A high BaPWV indicates high cardiovascular risk. However, BaPWV and pressure waveforms after stroke are not fully understood. [Methods] BaPWV was measured in thirty-two subjects (twenty-two healthy volunteers and ten stroke patients) while they were in the supine position. It was measured in their bilateral upper and lower extremities. [Results] BaPWV was significantly increased in the stroke group compared with the healthy volunteers. It was also significantly increased on both the affected and non-affected sides of stroke patients in the stroke group. Furthermore, analysis of the pressure waveforms showed that the peak pressure was significantly increased in the stroke group compared with the control group. The peak pressure on both the affected and non-affected sides was also significantly greater than in the control group. However, the rise and decay times were significantly decreased in the stroke group compared with the control group. The rise and decay time on both the affected and non-affected sides were also significantly more decreased than in the control group. [Conclusion] The results demonstrated that increased BaPWV and changed pulse waves are closely associated with the pathologic states of hemiplegic stroke patients.

**Key words:** Brachial-ankle pulse wave velocity, Pressure waveform, Stroke

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## INTRODUCTION

Stroke patients generally suffer from significant impairments, including muscle weakness, loss of motor control, and spasticity[1–4)]. In rehabilitation, it is important to understand nerve and cardiovascular system impairment because this type of subtle disorder might be closely related to functional outcomes in patients who have suffered stroke[1, 5, 6)]. Physical therapy for hemiplegic stroke patients primarily concerns the rehabilitation of motor function to perform activities of daily living, such as walking, grasping, reaching, and other physically demanding movements[1, 7, 8)]. Risk of stroke is highly dependent on blood pressure, age, and other factors[6, 9, 10)]. The development of blood pressure is associated with changed vascular reactivity and increased transmural pressure producing atrial stretch, which directly affects the vascular smooth muscles[9–11)]. The pulse wave velocity of blood, which reflects arterial stiffness, is an independent predictor of the prognosis of cardiovascular risk factors[12)]. In particular, the brachial-ankle pulse wave velocity (BaPWV) in the assessment of cardiovascular risk factors is often used to predict early cardiovascular disease, and it is used as a clinical indicator[12, 13)]. Higher BaPWV correlates with a stiffer arterial wall and greater cardiovascular risk factors[14)]. In contrast, decreased BaPWV can be related to a decrease in vessel stiffness[15)]. Despite the importance of this for hemiplegic stroke patients, the changes in the BaPWV waveform are not fully understood in terms

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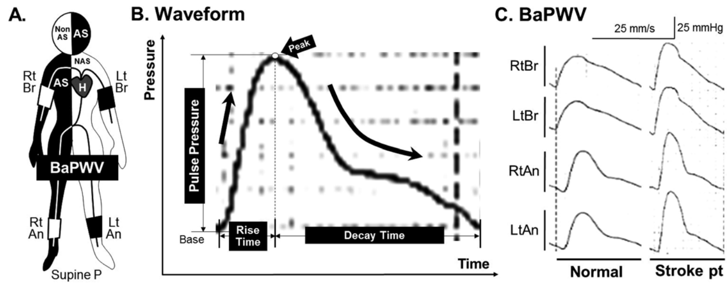


**Fig. 1.** Schematic representation of the measurements of BaPWV for the stroke patients and normal healthy volunteers
BaPWV was determined as described in the Methods section. BaPWV, brachial-ankle pulse wave velocity; H, heart; RtBr and LtBr, right and left brachium; RtAn and LtAn, right and left ankle; Supine P, supine position; NonAS and NAS, non-affected side; AS, affected side; Stroke pt, hemiplegic stroke patients.

of peak pressure, rise time, and decay time, which are used to confirm the pressure characteristics of the circulation. Thus, in this study, we analyzed the pressure waveforms of BaPWV on the affected side in stroke patients and compared them with their respective values on the non-affected side.

## SUBJECTS AND METHODS

Thirty-two subjects (normal group, 22; stroke group, 10) were examined from November 2009 to the end of November 2011. The stroke group consisted of stroke patients who visited GO hospital in Korea. The subjects received written and verbal explanations of the purposes and procedures of the study. The stroke group was treated with physical therapy six days a week for four weeks. BaPWV was measured in their bilateral upper and lower extremities using a plethysmography (form PWV; Colin Co., Ltd., Komaki, Japan), which simultaneously recorded pulse wave velocity, blood pressure, an electrocardiogram, and heart sounds (Fig. 1A). The subjects were examined while resting in the supine position. Electrocardiographic electrodes were placed on both wrists, and cuffs were wrapped around the bilateral brachium and ankles (Fig. 1A). Pulse waveforms at the brachium and ankle were recorded using a semiconductor pressure sensor after a rest of at least five minutes. This method was previously reported[16, 17]. This device provides accurate automatic measurement of BaPWV[18] (Fig. 1A). In waveform analysis, the basal levels of waveforms, such as those of the peak pressure, rise time, and decay time, on the non-affected side were considered 100%, respectively[19] (Fig. 1B). The statistical analysis was performed using the SPSS 12.0 software. The data were expressed as the mean ± standard error (SE) of the measurements. Differences between the control and experimental groups were analyzed with the Student's t-test and one-way ANOVA for multiple comparisons. A p value of $< 0.05$ was considered statistically significant. The protocol for the study was approved by the Committee of Ethics in Research of the University of Yongin, in accordance with the terms of Resolution 5-1-20, December 2006.

## RESULTS

Table 1 summarizes the clinical characteristics of the hemiplegic stroke patients that participated in this study. BaPWV was significantly increased in the stroke group compared with the healthy volunteers (Table 2). BaPWV on both the affected and non-affected sides in stroke patients was also significantly greater than in the control group (Fig. 1C and Table 2). Furthermore, analysis of the waveforms showed that peak pressure was significantly increased in the stroke group compared with the normal group. Peak pressure on both the affected and non-affected sides was also significantly greater than in the normal group (Table 2). However, the rise and decay times were significantly decreased in the stroke group compared with the normal group. The rise and decay times on both the affected and non-affected sides were also significantly less than those in the normal group, respectively (Table 2).

## DISCUSSION

Stroke is a common neurological disease that causes poor blood circulation among senior citizens and often leads to functional deficits in motor control[1, 3, 4, 11]. Stroke patients will have resulting motor deficits, including decreases in muscle activity and changes in motion patterns[1, 3, 4, 7]. In the present study, we partially found in plethysmographic analysis that BaPWV is upregulated in stroke patients compared with normal subjects. The peak pressure was also significantly increased in the stroke patients compared with the normal subjects. However, the rise and decay times were significantly decreased in the stroke patients compared with the normal groups. It has been reported that BaPWV is used to predict cardiovascular disease and is used as a clinical indicator[12, 13, 20]. In particular, Nakano and colleagues showed a strong relationship between stroke and pulse wave velocity[21]. The development of pulse wave velocity-related hypertension is directly associated with altered vascular

**Table 1.** Clinical characteristics of the hemiplegic stroke patients

| No | Age (yr) | Gender | BMI ($kg/m^2$) | Time post-stroke (mo) | AS | Lesion site |
|---|---|---|---|---|---|---|
| 1 | 40 | Male | 28.1 | 24 | L | Middle cerebral artery |
| 2 | 53 | Male | 27.8 | 13 | L | Basal ganglia |
| 3 | 31 | Male | 27.9 | 53 | L | Thalamic ICH |
| 4 | 55 | Female | 23.5 | 15 | R | Middle cerebral artery |
| 5 | 67 | Female | 18.5 | 42 | L | Thalamic ICH |
| 6 | 64 | Female | 27.2 | 46 | R | Thalamic ICH |
| 7 | 87 | Male | 27.1 | 33 | L | Middle cerebral artery |
| 8 | 86 | Female | 19.2 | 6 | L | Middle cerebral artery |
| 9 | 54 | Female | 25.7 | 53 | L | Thalamic ICH |
| 10 | 54 | Male | 28.9 | 29 | R | Middle cerebral artery |

BMI, body mass index; AS, affected side; L, left side; R, right side; ICH, intracerebral hemorrhage

**Table 2.** Differences in BaPWV and pressure waveform between the affected and non-affected sides of hemiplegic stroke patients compared with normal subjects

| Variables | Normal | Stroke patients | | |
|---|---|---|---|---|
| | | Total | Non-affected | Affected |
| BaPWV (cm/s) | 1436.7 ± 32.9 | 1670.8 ± 41.7* | 1635.0 ± 62.6* | 1706.7 ± 56.1* |
| Peak Pressure (%) | 100.0 ± 0.0 | 160.4 ± 3.8* | 149.9 ± 3.9* | 170.8 ± 4.1* |
| Rise Time (%) | 100.0 ± 0.0 | 78.3 ± 2.1* | 75.3 ± 1.8* | 81.4 ± 3.6* |
| Decay Time (%) | 100.0 ± 0.0 | 91.0 ± 3.5* | 92.1 ± 5.1* | 89.9 ± 5.1* |

Mean ± SE. BaPWV, brachial-ankle pulse wave velocity. *Significantly different from normal groups with $p < 0.05$.

reactivity and increased transmural pressure or stretch, which directly affects vascular smooth muscles[9, 22, 23]. In addition to their effects on vascular smooth muscle tone, mineralocorticoids have an important influence on the central control of blood pressure[9, 24]. Furthermore, previous studies showed the influences of age and sex on the results of noninvasive BaPWV measurement[20, 25]. In other words, BaPWV was higher in males and older patients than in females and younger groups, respectively[20, 25]. These results were associated with an increase in pulse wave velocity, implying a decrease in aortic compliance[26]. Our study showed similar results; that is, it showed that BaPWV was significantly increased in the stroke group compared with the control group, which indicated that the blood vessels were unstable[26]. The results obtained in our study suggest that the effects of exercise therapy approaches and other stimulations on the changes in BaPWV require further study in patients after stroke.

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