Usefulness of Brachial-Ankle Pulse Wave Velocity Measurement: Correlation with Abdominal Aortic Calcification

Udai NAKAMURA, Masanori IWASE, Sakae NOHARA, Hidetoshi KANAI, Kojiro ICHIKAWA, and Mitsuo IIDA

At present, brachial-ankle pulse wave velocity (baPWV) can be measured easily and noninvasively. We studied the correlation between aortic damage estimated by baPWV and that determined by measuring the length of abdominal aortic calcification (AAC) on X-ray films, which parameter has been significantly associated with cardiovascular morbidity and mortality. baPWV was measured using the form PWV/ankle brachial index (ABI) device in 97 patients free of end-stage renal failure or peripheral arterial disease. baPWV correlated significantly with age ($r^2 = 0.625$, $p < 0.0001$), was significantly higher in hypertensives than in normotensives (2,109 ± 67 vs. 1,623 ± 93 cm/s, $p < 0.0001$), and correlated significantly with systolic blood pressure ($r^2 = 0.64$, $p < 0.0001$) and diastolic blood pressure ($r^2 = 0.397$, $p < 0.0001$). baPWV was significantly higher in diabetic patients than in nondiabetics (2,068 ± 73 vs. 1,813 ± 97 cm/s, $p < 0.05$), but was similar in normolipidemic and hyperlipidemic patients. baPWV did not correlate with body mass index, fasting plasma glucose, total cholesterol, high density lipoprotein (HDL)-cholesterol, low density lipoprotein (LDL)-cholesterol or triglyceride levels, but correlated significantly with AAC length ($r^2 = 0.599$, $p < 0.0001$). Multiple regression analysis indicated that age, systolic blood pressure and AAC length were independent determinants of baPWV. Our results indicate that baPWV is useful for estimating aortic damage and could be a potentially useful predictor of vascular morbidity and mortality. (Hypertens Res 2003; 26: 163–167)

Key Words: pulse wave velocity, aortic calcification, atherosclerosis

Introduction

Pulse wave velocity (PWV) reflects arterial distensibility and aortic PWV is associated with major cardiovascular risk factors (1, 2) and is a strong predictor of prognosis in patients with end-stage renal failure (3) and in those with hypertension (4). Aortic PWV, measured in the distance from the carotid to femoral arteries, has been used for evaluation of aortic stiffness (5). Recently, a simple noninvasive automatic measurement of brachial-ankle PWV (baPWV) was described (6). Although the validity and reproducibility of this new technique have been reported (6), its clinical significance has not been fully investigated. Therefore, the present study was designed to evaluate the efficacy of baPWV in identifying vascular damage. For this purpose, we measured the length of abdominal aortic calcification (AAC) on X-ray films, which has been reported to correlate significantly with cardiovascular morbidity and mortality (7, 8), and correlated this parameter, as well as other clinical and laboratory parameters, with baPWV.

Methods

Ninety-seven patients were recruited from the Second Department of Internal Medicine at Kyushu University Hospi-
### Table 1. Patient Characteristics

<table>
<thead>
<tr>
<th>Number (male/female)</th>
<th>97 (54/43)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>62.3 ± 1.3</td>
</tr>
<tr>
<td>Smoking</td>
<td>40%</td>
</tr>
<tr>
<td>Obesity</td>
<td>21%</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.2 ± 0.4</td>
</tr>
<tr>
<td>Hypertension (on medication)</td>
<td>72% (81%)</td>
</tr>
<tr>
<td>Systolic BP (mmHg)</td>
<td>133 ± 2</td>
</tr>
<tr>
<td>Diastolic BP (mmHg)</td>
<td>77 ± 1</td>
</tr>
<tr>
<td>Diabetes mellitus (on medication)</td>
<td>63% (52%)</td>
</tr>
<tr>
<td>Fasting blood glucose (mg/dl)</td>
<td>120 ± 5</td>
</tr>
<tr>
<td>Hyperlipidemia (on medication)</td>
<td>62% (34%)</td>
</tr>
<tr>
<td>Total cholesterol (mg/dl)</td>
<td>191 ± 5</td>
</tr>
<tr>
<td>HDL cholesterol (mg/dl)</td>
<td>52 ± 2</td>
</tr>
<tr>
<td>LDL cholesterol (mg/dl)</td>
<td>121 ± 4</td>
</tr>
<tr>
<td>Triglyceride (mg/dl)</td>
<td>142 ± 9</td>
</tr>
</tbody>
</table>

Data are given as a proportion of patients or the mean ± SEM. BMI, body mass index; BP, blood pressure; HDL, high density lipoprotein; LDL, low density lipoprotein.

Patients with end-stage renal failure or peripheral arterial disease (based on an ankle brachial index [ABI, the ratio of ankle pressure to brachial artery pressure] of < 0.9) were excluded from the study. The institutional ethical committee approved the study and all patients gave their informed consent. Obesity was defined as body mass index (BMI) ≥ 26.0 kg/m². Hypertension was defined by systolic blood pressure ≥ 140 mmHg or diastolic blood pressure ≥ 90 mmHg, or use of antihypertensive medication. Diabetes mellitus was defined by World Health Organization (WHO) criteria (9). Hyperlipidemia was defined as fasting serum total cholesterol ≥ 230 mg/dl, low density lipoprotein (LDL)-cholesterol ≥ 140 mg/dl, triglyceride ≥ 150 mg/dl, high density lipoprotein (HDL)-cholesterol < 40 mg/dl or use of lipid-lowering medication. The clinical characteristics of patients are shown in Table 1.

baPWV was measured using a volume-plethysmographic apparatus (form PWV/ABI; Colin Co., Komaki, Japan). This device records the phonocardiogram, electrocardiogram, and volume pulse form and arterial blood pressure at both the left and right brachia and ankles. baPWV was calculated by time-phase analysis between right brachial and volume waveforms at both ankles. The distance between the right brachium and ankle was estimated based on body height. Figure 1 depicts the pulse wave at the right brachium and ankle in an 82-year-old man who showed the highest baPWV value in the present study (3,872 cm/s). Data supplied by the manufacturer indicated that baPWV correlated significantly with aortic PWV (n = 243, r² = 0.71, p < 0.0001). In addition, Yamashina et al. (6) recently reported that baPWV significantly correlated with aortic PWV measured directly by a catheter pressure transducer (n = 41, r = 0.87, p < 0.01) and that the coefficient of variation of interobserver reproducibility was 8.4% and that of intraobserver reproducibility was 10.0%.

Our preliminary investigation showed that baPWV was 1,179 ± 28 cm/s in healthy adult volunteers (n = 15; age, 25 ± 3 years; BMI, 21.6 ± 1.8 kg/m²; systolic blood pressure, 112 ± 10 mmHg).

AAC length was measured in lateral lumbar radiographs. Calcification of the anterior or posterior wall of the abdominal aorta at the level of the first and fifth lumbar vertebrae was traced on tracing paper. The length of the tracing was measured using a precise electronic caliper at 0.01 mm resolution (Calibro Digimatic; Mitutoyo Co., Kawasaki, Japan).

For statistical analysis, Mann-Whitney U-test was used to compare the data of the two groups. Spearman rank test was used for examining the correlation between two variables, and stepwise regression analysis was performed for baPWV and associated variables. Data are expressed as the mean ± SEM.

### Results

baPWV did not differ by sex (males, 2,047 ± 86 cm/s; females, 1,881 ± 78 cm/s) but significantly correlated with age (Fig. 2A, r² = 0.625, p < 0.0001). baPWV was not different between smokers and non-smokers (smokers, 1,911 ± 110 cm/s; nonsmokers, 2,016 cm/s) or between obese and non-obese patients (obese, 1,970 ± 67 cm/s; nonobese, 1,988 ± 124 cm/s), and did not correlate with BMI. baPWV was significantly higher in hypertensives (2,109 ± 67 cm/s) than in normotensives (1,623 ± 93 cm/s, p < 0.0001). baPWV correlated significantly with systolic blood pressure (Fig. 2B; r² = 0.64, p < 0.0001) and diastolic blood pressure (r² = 0.397, p < 0.0001). baPWV was significantly higher in diabetic patients (2,068 ± 73 cm/s) than in nondiabetic patients (1,813 ± 97 cm/s, p < 0.05), but there was no significant correlation between baPWV and fasting plasma glucose levels.

baPWV was not different between patients with and those
without hyperlipidemia (2.014 ± 80 cm/s, 1.908 ± 86 cm/s), and there was no correlation between baPWV and total cholesterol, HDL-cholesterol, LDL-cholesterol or triglyceride levels. AAC length in our patients was 26.4 ± 3.3 mm, and was significantly correlated with age (Fig. 3A; \( r^2 = 0.565, p < 0.0001 \)) and systolic blood pressure (Fig. 3B; \( r^2 = 0.389, p = 0.0001 \)). As shown in Fig. 2C, baPWV correlated significantly with AAC length (Fig. 2C; \( r^2 = 0.599, p < 0.0001 \)). Multiple regression analysis showed that age, systolic blood pressure and AAC length were significant independent determinants of baPWV (Table 2).

### Discussion

The recently developed “form PWV/ABI” can measure baPWV noninvasively and quickly, and thus has been used in clinical practice. baPWV is dependent on stiffness of the brachial artery as well as stiffness of the arterial tree extending from the aorta to the tibial artery. Previous studies speculated that the increase in PWV from the femoral to the tibial artery was greater than that from the aortic arch to the femoral artery (6). Suzuki et al. (10) used baPWV as an index of arterial stiffness in the lower extremities and demonstrated that diabetic patients with high baPWV had decreased flow volume in calf and foot arteries by magnetic resonance angiograms. However, they excluded patients with peripheral arterial disease in their study. Our preliminary studies showed that patients with peripheral arterial disease had rather lower baPWV when ABI was less than 0.8.

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**Table 2. Multiple Regression Analysis of baPWV and Significantly Associated Variables**

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>( \beta ) coefficient</th>
<th>( t ) value</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>15.13</td>
<td>4.85</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Systolic BP (mmHg)</td>
<td>10.88</td>
<td>6.76</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>AAC length (mm)</td>
<td>5.89</td>
<td>4.57</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

\( F \) ratio = 60.3 \( r^2 = 0.66 \) \( (p < 0.0001) \)

baPWV, brachial-ankle pulse wave velocity; BP, blood pressure; AAC, abdominal aortic calcification.
calcification in patients with end-stage renal failure, who are known to have abnormal systemic calcium metabolism and deposition (18, 19). The present study showed that baPWV correlated with abdominal aortic calcification in patients without end-stage renal failure, confirming that calcification of the aorta increases the rigidity of the arterial wall. Although it has been reported that aortic PWV does not correlate with coronary calcification determined by CT and might not predict the presence of coronary atheroma (20), a recent longitudinal study demonstrated that aortic PWV was an independent predictor of primary coronary events (21).

In conclusion, we have demonstrated in the present study that baPWV was positively and independently correlated with age, blood pressure and AAC length. baPWV is a useful index of aortic damage and might have potential as a predictor of vascular morbidity and mortality.

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References


(n = 11; baPWV, 1,528 ± 303 cm/s), suggesting that occlusive arterial lesions may erroneously lower baPWV. We investigated whether baPWV reflects vascular damage in a manner similar to aortic PWV, which measures stiffness from the carotid to the femoral artery. Yamashina et al. found that patients with coronary artery disease or coronary risk factors had higher baPWV than age-matched healthy controls. The present study extended the clinical significance of baPWV by demonstrating its correlation with age, blood pressure and abdominal aortic calcification. However, baPWV was not related to risk factors such as sex, glycemia, or the presence of hyperlipidemia, whereas aortic PWV has been correlated with these parameters in several studies (2, 11, 12). This disagreement may be partly explained by the effects of medication on the risk factors or by the smaller number of subjects in the present study (2, 11, 13).

Although PWV reflects functional changes in arterial wall compliance, the relationship between PWV and structural changes, especially between arterial stiffness and atherosclerosis, is not fully understood. Farrar et al. (14) demonstrated in monkeys that an atherogenic diet increased PWV and aortic intimal area, while an atherosclerosis regression diet decreased both parameters. The presence of atherosclerosis may lead to arterial stiffening. On the other hand, stiffening of the arterial wall increases shear stress and leads to vessel wall damage and atherosclerosis. Taniwaki et al. (15) reported a positive correlation between aortic PWV and carotid intima-media thickness in patients with type 2 diabetes mellitus. In the population-based Rotterdam Study (16), aortic PWV significantly correlated with common carotid intima-media thickness, severity of plaques in the carotid artery, and severity of plaques in the aorta in elderly individuals. Arterial lesions commence as fatty streaks, progress to raised lesions, and are then complicated by ulceration, calcification, or hemorrhage. Radiographically detected calcification of the aorta correlates well with atherosclerotic plaques at autopsy, and in most cases visible calcification represents advanced atherosclerosis (17). In addition, the aortic wall undergoes progressive accumulation of calcium in the elastin-rich layer of the media during aging, especially in diabetic patients, and results in medial arterial calcification. Aortic calcification is a predictor of subsequent cardiovascular morbidity and mortality independent of major cardiovascular risk factors (7). Recently, the Framingham Heart Study reported that the severity of abdominal aortic calcification correlated with subsequent cardiovascular disease and death in a prospective study of more than 20 years (8). Although modern technologies such as CT have been used for the detection of vascular calcification, the method used to measure AAC length in our study was relatively simple and was able to measure both calcified atheroma and medial calcification. The measured AAC length in our study correlated with baPWV independent of age and blood pressure, which are major determinants of aortic PWV. Previous studies have demonstrated a close association between aortic PWV and abdominal aortic...


