Original Article

Correlation between Brachial-Ankle Pulse Wave Velocity and Arterial Compliance and Cardiovascular Risk Factors in Elderly Patients with Arteriosclerosis

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The objective of this study was to investigate an association between major cardiovascular risk factors and each of brachial-ankle pulse wave velocity (baPWV), ankle-brachial index (ABI), capacitive arterial compliance (C1), and oscillatory arterial compliance (C2) in elderly patients with arteriosclerosis. We analyzed 160 elderly patients with arteriosclerosis. Vessel wall properties were assessed by baPWV and ABI using a VP-1000 Automatic Arteriosclerosis Measurement System, and C1 and C2 were measured using a DO-2020 Cardiovascular Profiling Instrument. In multiple regression analysis, baPWV was significantly correlated with systolic blood pressure (SBP), mean artery pressure, pulse pressure, diastolic blood pressure (DBP), age, and heart rate (r=0.670, 0.627, 0.580, 0.523, 0.490, 0.200; p<0.05), ABI was significantly correlated with pulse pressure, SBP and age (r=−0.250, −0.206, −0.168; p<0.05), C1 was significantly correlated with pulse pressure, SBP, mean artery pressure, age, DBP and heart rate (r=−0.481, −0.469, −0.363, −0.356, −0.239, −0.188; p<0.05), and C2 was significantly correlated with age, SBP, pulse pressure, DBP, fasting blood glucose, mean artery pressure and heart rate (r=−0.411, −0.395, −0.383, −0.277, −0.213, −0.183, −0.173; p<0.05). There were no close correlations between baPWV, ABI, or C1 and fasting blood glucose, total cholesterol, triglycerides, or body mass index. Moreover, there were significant correlations between baPWV and C1 (r=−0.444, p<0.001), and between baPWV and C2 (r=−0.257, p<0.01). In conclusion, these findings underscore the efficacy of baPWV and ABI in identifying the vascular damage of the aged. (*Hypertens Res* 2006; 29: 309–314)

***Key Words*: brachial-ankle pulse wave velocity, ankle-brachial index, capacitive arterial compliance, oscillatory arterial compliance, arteriosclerosis**

Introduction

Arteriosclerosis severely endangers the health of the elderly, mainly because it leads to the degeneration of arterial elasticity. Elasticity is one of the important characteristics of the arteries and is a direct reflection of the condition of these blood vessels in the aged (*1*, *2*). Because it has been reported that brachial-ankle pulse wave velocity (baPWV), capacitive arterial compliance (C1), and oscillatory arterial compliance (C2) can accurately reflect the arterial elasticity (*3*–*5*), the present study was designed to further evaluate the clinical significance of these three parameters. To this end, we investigated the correlation between various cardiovascular risk factors and each of baPWV, C1, and C2 in elderly Chinese patients with arteriosclerosis.

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Methods

Population

The cohort consisted of 160 elderly patients with arteriosclerosis who were registered as outpatients in the Department of Geriatrics of the Qi-Lu Hospital of Shandong University from January 2005 to August 2005, and who had already been diagnosed with cardiovascular disease, cerebrovascular disease, peripheral vascular disease, diabetes mellitus or hyperlipemia, according to the 1999 diagnostic guidelines of the World Health Organization (WHO); and who had been diagnosed no later than 1999 with cardiovascular disease, cerebrovascular disease, peripheral vascular disease, diabetes mellitus or hyperlipemia. All subjects gave their informed consent. The study protocol was approved by the Qi-Lu Hospital of Shandong University Ethics Board. The clinical data for all subjects are shown in Table 1.

Medical History and Examinations

All participants were administered a standardized questionnaire that provided information about their occupation, medical history, drug use, and smoking and personal habits, and their family medical histories. In the quiet room, the blood pressure was measured using a mercury sphygmomanometer on the right arm with subjects in a seated position after a rest of at least 15 min. Arm measurements, *i.e.*, length and circumference, were made during the examination to ensure proper cuff size. Systolic and diastolic blood pressure levels were analyzed as the first and fifth Korotkoff phases (*6*, *7*). None of the subjects had smoked or drunk wine or coffee within 1 h of these examinations. Blood pressure was measured three times with a 5-min interval, and the average of the last two measurements was used in the statistical analysis. Fasting blood glucose, total cholesterol and triglyceride levels were determined by DVI-1650 Automatic Biochemistry and Analysis Instrument (Bayer, Germany). Body mass index (BMI) was calculated as the weight in kg divided by the square of the height in m.

Brachial-Ankle Pulse Wave Velocity, Ankle-Brachial Index, Capacitive Arterial Compliance and Oscillatory Arterial Compliance

Using the VP-1000 Automatic Arteriosclerosis Measurement System (Colin, Komaki, Japan), the baPWV and ABI could be simultaneously measured by bilateral brachial and tibial arterial pressure waveforms, the lead I electrocardiogram, and the phonocardiogram. Each subject was also subjected to measurements using the DO-2020 Cardiovascular Profiling Instrument (HDI, Eagan, USA). The arterial elastic indices C1 and C2 were measured by right radial arterial pulse wave. In all studies, baPWV, ABI, C1 and C2 were obtained after an at least 15-min rest and were measured twice.

Statistical Methods

All data analysis was performed using the program SPSS 10.0 for Windows. Data were expressed as the mean±SD. Multiple linear regression analysis (Pearson correlation) was used for the relationships between the risk factor variables and each of baPWV, ABI, C1, and C2, and between baPWV and each of C1 and C2. Values of $p<0.05$ were considered statistically significant.

Results

The Correlation between baPWV and ABI and the Risk Factor Variables

In the present cohort of elderly patients with arteriosclerosis, the simple correlation analysis of baPWV and basic variables demonstrated that baPWV was significantly correlated with age, systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean artery pressure, pulse pressure and heart rate, with the relation to SBP being the most significant ($r=0.670$, $p<0.01$). ABI had negative correlations with age, SBP and pulse pressure, with pulse pressure being the most significant variable ($r=-0.250$, $p<0.01$). However, there were no close correlations between fasting blood glucose, total cholesterol, triglyceride levels, or BMI and either baPWV or ABI. These results are summarized in Tables 2 and 3.

The Correlation between C1 and C2 and the Cardiovascular Risk Factors

In multiple regression analysis, C1 and C2 had negative correlations with age (C1: $r=-0.356$; C2: $r=-0.411$; $p<0.05$), pulse pressure (C1: $r=-0.481$; C2: $r=-0.383$; $p<0.05$), SBP (C1: $r=-0.469$; C2: $r=-0.395$; $p<0.05$), mean artery pressure (C1: $r=-0.363$; C2: $r=-0.183$; $p<0.05$), DBP (C1: $r=-0.239$; C2: $r=-0.277$; $p<0.05$) and heart rate (C1: $r=-0.188$; C2: $r=-0.173$; $p<0.05$). Moreover, the only positive correlation was between C2 and fasting blood glucose ($r=-0.213$, $p<0.05$). There were no significant correlations between C1 or C2 and total cholesterol, triglycerides, or BMI. These results are shown in Table 4.

The Correlation between baPWV and C1 or C2

We also analyzed the correlation between baPWV and C1, and between baPWV and C2 in our 160 elderly patients with arteriosclerosis. baPWV, C1 and C2 were simultaneously measured in the same cohort. The data are shown in Figs. 1 and 2. The results showed that there were significant correlations between baPWV and C1 ($r=-0.444$, $p<0.001$), and between baPWV and C2 ($r=-0.257$, $p<0.01$).

Table 1. Clinical Characteristics of Elderly Patients with Arteriosclerosis

	Male (n=106)	Female (n=54)	Total (n=160)
Age (years)	74.02±5.81	69.07±6.62	72.35±6.51
Smoking (%)	32.08	1.85	21.88
BMI (kg/m^2)	25.67±3.16	25.15±3.05	25.49±3.12
SBP (mmHg)	135.92±19.08	135.09±20.18	135.64±19.40
DBP (mmHg)	77.19±9.34	75.28±10.01	76.54±9.58
MAP (mmHg)	103.08±14.18	101.09±14.99	102.41±14.44
PP (mmHg)	58.73±13.68	59.81±14.10	59.09±13.79
HR (bpm)	70.96±12.71	69.26±10.01	70.39±11.86
FBG (mmol/l)	6.13±2.02	5.81±1.29	6.02±1.81
TC (mmol/l)	5.62±1.01	5.49±0.92	5.57±0.98
TG (mmol/l)	1.66±0.72	1.49±0.72	1.60±0.72
R-baPWV (cm/s)	1,830.29±399.84	1,602.39±339.54	1,753.38±394.58
L-baPWV (cm/s)	1,826.58±389.31	1,651.43±370.13	1,767.46±390.71
R-ABI	1.08±0.15	1.08±0.10	1.08±0.13
L-ABI	1.11±0.15	1.11±0.08	1.11±0.13
C1 (ml/mmHg×10)	12.51±5.53	9.48±3.70	11.52±5.19
C2 (ml/mmHg×100)	3.47±2.20	2.46±1.57	3.14±2.07

Data are mean±SD. BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; PP, pulse pressure; HR, heart rate; FBG, fasting blood glucose; TC, total cholesterol; TG, triglyceride; R-baPWV, right limbs brachial-ankle pulse wave velocity; R-ABI, right limbs ankle-brachial index; L-, left limbs; C1, capacitive arterial compliance; C2, oscillatory arterial compliance.

Table 2. Pearson Correlation Coefficients between baPWV and Risk Factor Variables in Elderly Patients with Arteriosclerosis (n=160)

	R-baPWV		L-baPWV	
	Pearson correlation coefficient	p value	Pearson correlation coefficient	p value
Age	0.467**	0.000	0.490**	0.000
SBP	0.670**	0.000	0.581**	0.000
DBP	0.523**	0.000	0.477**	0.000
MAP	0.627**	0.000	0.552**	0.000
PP	0.580**	0.000	0.472**	0.000
HR	0.182*	0.022	0.200*	0.011
FBG	0.153	0.053	0.145	0.067
TC	0.071	0.371	0.040	0.616
TG	0.110	0.166	0.075	0.348
BMI	0.060	0.448	0.060	0.451

*$p<0.05$, **$p<0.01$. SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; PP, pulse pressure; HR, heart rate; FBG, fasting blood glucose; TC, total cholesterol; TG, triglyceride; BMI, body mass index; R-baPWV, right limbs brachial-ankle pulse wave velocity; L-baPWV, left limbs brachial-ankle pulse wave velocity.

Discussion

Numerous instruments can be used to assess arterial stiffness noninvasively. The VP-1000 Automatic Arteriosclerosis Measurement System and DO-2020 Cardiovascular Profiling Instrument have already been utilized in many hospitals throughout the world, and have been shown to effectively detect the arterial stiffness. baPWV mainly reflects the large arterial stiffness, while ABI is more useful for revealing occlusions of the lower body (*3*, *8*). C1 mainly reflects the elasticity of large arteries, while C2 is an index for the elasticity of small arteries (*9*). In the present study, using multiple correlation analysis, we found that baPWV, C1 and C2 were significantly correlated with age, blood pressure and heart rate. Moreover, baPWV was closely correlated with C1 ($r=-0.444$, $p<0.001$) and C2 ($r=-0.257$, $p<0.01$).

Tomiyama *et al*. (*10*) reported that arterial stiffness

Table 3. Pearson Correlation Coefficients between ABI and Risk Factor Variables in Elderly Patients with Arteriosclerosis (n=160)

	R-ABI		L-ABI	
	Pearson correlation coefficient	p value	Pearson correlation coefficient	p value
Age	−0.168*	0.034	−0.136	0.088
SBP	−0.137	0.085	−0.206**	0.009
DBP	−0.046	0.566	−0.050	0.527
MAP	−0.105	0.188	−0.125	0.116
PP	−0.161*	0.042	−0.250**	0.001
HR	−0.137	0.084	−0.082	0.302
FBG	−0.078	0.325	−0.137	0.085
TC	−0.141	0.075	−0.078	0.326
TG	−0.052	0.511	−0.011	0.887
BMI	−0.030	0.711	−0.029	0.712

*p<0.05, **p<0.01. SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; PP, pulse pressure; HR, heart rate; FBG, fasting blood glucose; TC, total cholesterol; TG, triglyceride; BMI, body mass index; R-ABI, right limbs ankle-brachial index; L-ABI, left limbs ankle-brachial index.

Table 4. Pearson Correlation Coefficients between C1, C2 and Risk Factor Variables in Elderly Patients with Arteriosclerosis (n=160)

	C1		C2	
	Pearson correlation coefficient	p value	Pearson correlation coefficient	p value
Age	−0.356**	0.000	−0.411**	0.000
SBP	−0.469**	0.000	−0.395**	0.000
DBP	−0.239**	0.002	−0.277**	0.000
MAP	−0.363**	0.000	−0.183*	0.021
PP	−0.481**	0.000	−0.383**	0.000
HR	−0.188*	0.017	−0.173*	0.029
FBG	−0.030	0.723	−0.213**	0.007
TC	−0.075	0.380	−0.143	0.092
TG	−0.077	0.365	−0.057	0.505
BMI	−0.061	0.440	−0.128	0.106

*p<0.05, **p<0.01. SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; PP, pulse pressure; HR, heart rate; FBG, fasting blood glucose; TC, total cholesterol; TG, triglyceride; BMI, body mass index; C1, capacitive arterial compliance; C2, oscillatory arterial compliance.

increases with aging. The reason is that the thickness of the artery walls and interstitial collagen markedly increase with aging. Furthermore, several studies have shown that the structure of vessels changes when an increase in blood pressure causes an augmentation of vascular tension (*11–13*). That is to say, with vascular smooth muscle cell hyperplasia and vessel wall thickening, diffuse fibrosclerosis and the local scleratheroma will occur in the vessel wall over the long term. These effects, in turn, will lead to an increase in arterial stiffness, a quickening of PWV, and a decrease of C1 and C2 (*12*, *14–17*). The chief characteristic of blood pressure in the aged is that SBP and pulse pressure increase, and DBP decreases with aging. The widened pulse pressure mainly results from the elevation of SBP. Therefore, the correlations between baPWV, C1, C2 and SBP, between baPWV, C1, C2 and pulse pressure are higher than those between baPWV, C1, C2 and DBP. baPWV, C1, and C2 were each correlated with DBP. This discrepancy in results may have been related to the effects of age, SBP, or medication on the risk factors. Moreover, baPWV was correlated with C1 and C2, but the correlation between baPWV and C1 was significantly higher than that between baPWV and C2. On one hand, because baPWV and C1 mainly reflect the large arterial stiffness, C2 chiefly reflects small arterial elasticity. There are marked differences between the structure of the large and small arteries. The large artery wall has numerous elastic membranes and fibers, while the small artery wall has slight elastic tissue. On the other hand, C1 mainly reflects the elastic properties of large arteries, while baPWV also includes peripheral arterial components that contain more muscle tissue (*9*, *18*, *19*). There were

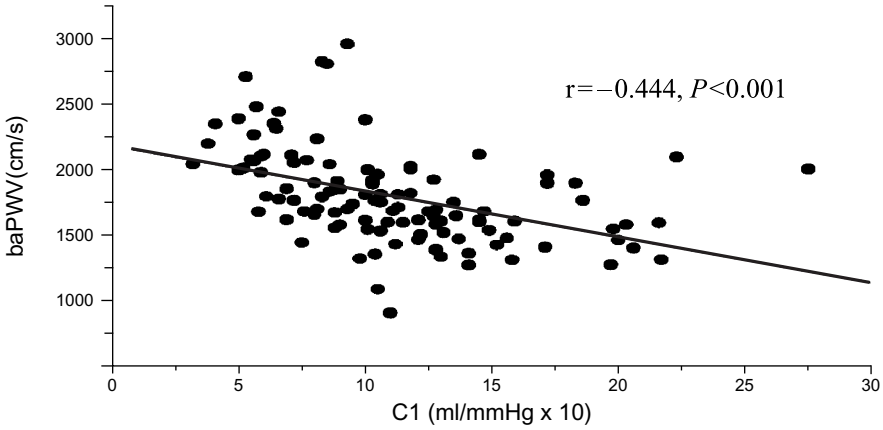

Fig. 1. *The correlation analysis of baPWV and C1 (*n*=160).*

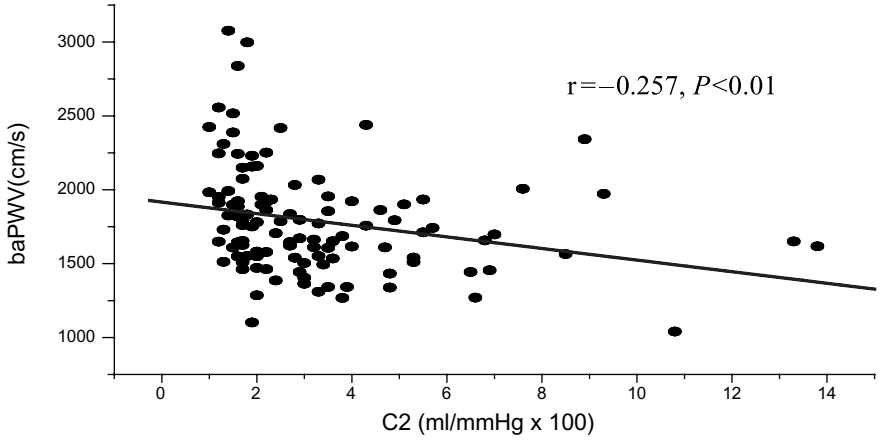

Fig. 2. *The correlation analysis of baPWV and C2 (*n*=160).*

no significant correlations between baPWV, C1, or C2 and total cholesterol, triglycerides, or fasting blood glucose in the present study, although several previous studies have reported that baPWV, C1, and C2 were correlated with these risk factors (*5*, *20–22)*. The discrepancy can be partly explained by the effects of mediation on these risk factors.

baPWV and ABI are two independent indexes that can be used to appraise the functional status of the arteries from different points of view. When measured simultaneously, they can sensitively and precisely reflect the degree of arteriosclerosis or arterial obstruction in elderly patients. Therefore, there is clinical significance to diagnosing arteriosclerosis early. Early diagnosis will contribute to the choice of an effective therapy for potential and high-risk patients in the sub-clinical phase, and to the effective administration of medicines to patients in the clinic. In the future, baPWV and ABI may play an important role in controlling the morbidity and mortality of cardiovascular or cerebrovascular diseases.

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