Original Article

The Relationship between Pulse Wave Velocity and Pulse Pressure in Chinese Patients with Essential Hypertension

Yongbin NI, Hongyu WANG, Dayi HU, and Weizhong ZHANG*

Aortic pulse wave velocity (PWV) is a significant and independent predictor of cardiovascular disease in hypertensive subjects and in patients with end-stage renal disease, but there have been few studies on PWV in Chinese patients with essential hypertension. In this cross-sectional study, we investigated 3,156 consecutive patients (mean age: 53.7 ± 11.58 years) of the Hypertension Division of Ruijin Hospital in Shanghai. Together with sphygmomanometric blood pressure measurements, aortic PWV was measured using a validated automatic device. PWV in patients with pulse pressure (PP) ≥ 60 mmHg was significantly greater than that in patients with PP < 60 mmHg (p < 0.01). PP and PWV were positively related to age (PP: r = 0.396, p = 0.001; PWV: r = 0.531, p = 0.001). After adjustment by age and heart rate, PWV was still closely related to PP (r = 0.249, p = 0.001). At any given systolic blood pressure (SBP), PWV significantly decreased with the increase of diastolic blood pressure (DBP), whereas at any given DBP there was a significant increase of PWV with the increase of SBP. In conclusion, PWV was the major determinant of PP, and was highest in Chinese patients with isolated systolic hypertension, followed by those with systolic and diastolic hypertension, isolated diastolic hypertension, and normal blood pressure. (Hypertens Res 2003; 26: 871–874)

Key Words: carotid-femoral pulse wave velocity, arterial stiffness, essential hypertension

Introduction

A number of epidemiological studies (1, 2) have shown that, in middle age, not only systolic (SBP) and diastolic blood pressure (DBP) but also pulse pressure (PP: the difference between SBP and DBP) is an independent predictor of cardiovascular risk. For a given ventricular ejection, large arterial stiffness is a major determinant of PP, a classical marker of which is pulse wave velocity (PWV). PP generated by intermittent ventricular ejection is propagated throughout the arterial tree at a speed determined by the elastic and geometric properties of the arterial wall and the blood density.

In a cross-sectional study (3), aortic PWV was shown to be associated with cardiovascular risk, as calculated from the Framingham equations. de Simone et al. (4) have reported that in 294 hypertensive patients, the stroke volume/PP ratio, an index of total arterial compliance, was an independent predictor of cardiovascular events but not of cardiovascular deaths after adjustment for classic risk factors. Blacher et al. (5, 6) have observed an independent relationship between arterial stiffness (estimated either from carotid incremental modulus of elasticity or from aortic PWV) and all-cause and cardiovascular mortality in patients with end-stage renal disease. And although the latter studies involved a specific population at high risk of mortality, subsequent studies have shown that PWV is an independent predictor of risk irrespective of whether patients are older or younger than 70 years, or whether or not they have received treatment (3, 7).

There have been several studies (8, 9) on arterial stiffness in the Chinese population. While these works demonstrated that, in the normal Chinese population, there is a progressive increase in wave velocity with ageing, the relationship between arterial stiffness and PP in Chinese hypertensive pa-
Patients remain to be determined. In the present cross-sectional study, we investigated the relationship between PWV and PP in Chinese patients with essential hypertension.

Methods

Patients

From October 1998 to May 2000, 3,156 consecutive patients with essential hypertension entered this cross-sectional study of the Hypertension Division, Ruijin Hospital, Shanghai Second Medical University. In never-treated hypertensive subjects, hypertension was defined as an SBP ≥140 mmHg and/or a DBP ≥90 mmHg, as measured by sphygmomanometry with subjects in a seated position using a minimum of 3 casual measurements in the month preceding the experiment. In establishing a group of treated hypertensive subjects, hypertension was defined as an SBP ≥140 mmHg – DBP, diastolic blood pressure; PWV, pulse wave velocity; PP, pulse pressure; yrs, years.

The patients were divided into five groups by age (≤40 years, 41–50 years, 51–60 years, 61–70 years, and > 70 years). Because Franklin et al. (1) showed that PP was higher in subjects who developed new coronary heart disease (CHD) events (about 60 mmHg) than in those free of such events (less than 60 mmHg), patients of the present study were also divided into two groups (PP ≥60 mmHg and PP < 60 mmHg) according to PP. Finally, the patients were divided into 16 groups according to the BP classifications of the 1999 WHO/ISH guidelines for management of hypertension (which belonged to the four following classes: normotensives, isolated diastolic hypertensives, isolated systolic hypertensives, and diastolic and systolic hypertensives) (Fig. 1).

PWV Measurement

After BP determination, the PWV measurement was performed in a controlled environment at 23 ± 3°C using an automated Complior device (Colson, Pantin, France). PWV was determined along the descending thoracoabdominal aorta using the foot-to-foot velocity method, which has been described and validated previously (10). Briefly, two pressure waves were recorded transcutaneously at two sites (at the base of the neck for the common carotid artery and over the
femoral artery). Pulse transmit time was determined as the average of 10 consecutive beats. The distance traveled by the pulse wave was measured over the body surface as the distance between the two recording sites (the vertical distances were measured between the two sites to eliminate overestimation of vessel length because of abdominal swelling or heavy fat). Aortic PWV was calculated as the ratio of distance to transmit time.

In addition, information compiled from the questionnaire completed at the beginning of the study included gender, age, heart rate, weight and height, body mass index (BMI), and waist and hip circumferences. BMI and waist-hip ratio (WHR) were calculated as BMI = weight/height² (kg/m²) and WHR = waist circumference/hip circumference.

Statistical Analysis

Data were expressed as the means ± SD. Analysis of variance and F test were used to evaluate whether PWV and PP means differed according to the categorical variable. Pearson correlation was applied to determine whether PWV or PP was correlated with age. Multiple linear stepwise regression was used to identify which of the following played roles in the PP variations: age, sex, heart rate (HR), height, weight, waist circumference, hip circumference, WHR, BMI and PWV. SBP and DBP were not included in this model. The inclusive and exclusive criteria were 0.05 and 0.10, respectively. A value of \( p < 0.05 \) was considered to indicate statistical significance.

Results

Clinical Characteristics

This study population \( (n = 3,156) \) was middle-aged (53.7 ± 11.58 years), predominantly male (64.9%), and slightly overweight (BMI: 25.6 ± 3.18 kg/m²). Although only approximately 20% of the patients had well-controlled BP (SBP: < 140 mmHg and DBP < 90 mmHg), its mean was not very high (SBP: 145.0 ± 19.00 mmHg, DBP: 92.1 ± 12.17 mmHg). The mean values of PP and PWV were 52.8 ± 16.20 mmHg and 11.47 ± 2.17 m/s, respectively.

In comparison with patients with PP < 60 mmHg, age, waist circumference, WHR, heart rate, SBP, and PWV in patients with PP ≥ 60 mmHg were significantly greater, where-as height, weight, and DBP were significantly less (Table 1). PP and PWV significantly increased with age (by decade) (PP: \( r = 0.396, \ p = 0.000; \ PWV: \ r = 0.531, \ p = 0.000 \)) (Table 2). After adjusting for age and heart rate, PWV was still closely related to PP (\( r = 0.249, \ p = 0.000 \)).

Figure 1 showed that, at any given SBP, PWV significantly decreased with the increase of DBP, whereas at any given DBP there was a significant increase of PWV with the increase of SBP.

Stepwise Linear Regression of PP

As shown in Table 3, the factors significantly influencing PP were PWV and age (\( p = 0.001 \), respectively). The regressive equation was: PP(mmHg) = 12.455 + 2.113 \( \cdot \) PWV(m/s) + 0.301 \( \cdot \) Age(years).

Discussion

In this study involving 3,156 Chinese patients with essential hypertension, we showed that PWV was the major determinant of PP, that patients with higher PP had greater PWV, and that PWV was closely related to PP after adjustment for age and HR. Thus PWV was highest in patients with isolated systolic hypertension, followed in order by those with systolic and diastolic hypertension, isolated diastolic hypertension, and normal BP.

In the present investigation, we used PWV as a marker of aortic stiffness, since it is related to the square root of the elasticity modulus and to the thickness/radius ratio (10). The PWV, as determined from the foot-to-foot transit time in the aorta, serves as a simple, reproducible, and non-invasive index of regional aortic stiffness.

Arterial stiffening may be attributable to the fracture of load-bearing elastic lamellae and degeneration of the arterial wall as a result of cyclic stress. In a study by O’Rourke et al. (11), calculations based on the rubber method indicated that if elastin was repeatedly stretched by 10% of its length, it would fracture after 800 \( \cdot \) 10⁶ cyclic stretches, while it would fracture after 3,000 \( \cdot \) 10⁶ cycles if stretched by 5% of its length per cycle. The increase of PP contributed to hypertrophy and/or hyperplasia of smooth muscle in the arterial wall, and intraarterial pulsatile flow was the major stimulant of the structure and function of vessel smooth muscle cells (12). On the other hand, with the increase of PWV, wave re-

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized coefficients</th>
<th>Standardized coefficients</th>
<th>( t )</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>12.455 ± 1.507</td>
<td>8.263 ± 0.396</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>PWV (m/s)</td>
<td>2.113 ± 0.141</td>
<td>0.282 ± 0.249</td>
<td>14.936</td>
<td>0.001</td>
</tr>
<tr>
<td>Age (years)</td>
<td>0.301 ± 0.026</td>
<td>0.215 ± 0.121</td>
<td>11.362</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 3. Stepwise Linear Regression of PP
flections would return to the root of the aorta in systole in advance, leading to an increase of SBP and PP and a decrease of DBP. In this way, PWV and PP would mutually affect each other, forming a vicious cycle.

Large-scale epidemiological studies and clinical trials have repeatedly demonstrated that PP has prognostic value as a cardiovascular risk factor. But brachial PP is only an indirect estimate of arterial stiffness. Many factors other than arterial stiffness can influence the value of PP, such as heart rate, cardiac contractility, and venous pressure. We showed that PWV was closely related to PP after adjustment by age and heart rate. And because PWV was more reproducible, we speculate that PWV is more predictive of cardiovascular events than PP.

Increased arterial rigidity can be improved by antihypertensive drugs, especially nitrates, calcium antagonists, and angiotensin converting enzyme (ACE) inhibitors (13). Our recent study demonstrated that long-acting nitrates, i.e., isosorbide-5-mononitrates, have potential value in improving large arterial distensibility in Chinese patients with essential hypertension independent of BP alteration. This agent might be used as an effectively additive drug in hypertension control (14).

In this study, PP was calculated from SBP and DBP, both measured with a sphygmomanometer at the site of the brachial artery. Because of the physiological PP amplification between central and peripheral arteries, brachial PP may not reflect aortic PP, which influences left ventricular afterload and coronary perfusion. There may have been a selection bias resulting from the inclusion of patients receiving antihypertensive therapy, because antihypertensive drugs can decrease PWV.

However, our previous studies showed that antihypertensive drugs changed BP in parallel with PWV, so that the relationship between the two was not changed. In addition, there has been no report of an antihypertensive drug substantially altering arterial stiffness. When treated and untreated subjects were combined, we found that PWV was still closely correlated with PP. In addition, Liu et al. (15) showed that BP was significantly different among the different ethnic Chinese populations. Because most of the subjects in our study were from the Han population, and there were very few subjects from other ethnic populations, we could not address the question of whether or not the PWVs vary among different ethnic populations, although we presume that such ethnic differences exist.

In summary, our results showed that large arterial stiffening was the major determinant leading to an increase of PP in the present cohort, and that the increased PP, in turn, accelerated the stiffening of the large artery. Thus arterial stiffness and PP mutually influenced each other in a vicious cycle. At any given SBP, PWV decreases with the increase of DBP, and at any given DBP, PWV increases with the increase of SBP.

References