Intrarenal and Carotid Hemodynamics in Patients With Essential Hypertension

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Background: The pulsatility index (PI) and resistive index (RI) are used as markers of peripheral vascular resistance. Recently intrarenal PI and RI were introduced for the evaluation of the severity of acute and chronic renal failure, as well as for the diagnosis of renal artery stenosis and kidney graft rejection. In the present study, we evaluated intrarenal PI and RI in patients with essential hypertension.

Methods: Fifty-one patients with essential hypertension participated. The intima–media thickness (IMT) and mean diastolic (Vd) and systolic velocity (Vs) in the common carotid artery (CCA) were measured using ultrasound and Doppler flow methods. Relative diastolic flow velocity (Vd/Vs) was calculated as an assessment of CCA hemodynamics. Renal Doppler flow was obtained from the interlobar arteries in each of two kidneys. The mean PI ([peak systolic velocity – end-diastolic velocity]/mean velocity) and mean RI ([peak systolic velocity – end-diastolic velocity]/peak systolic velocity) were calculated.

Results: Intrarenal PI and RI were positively correlated with IMT and negatively correlated with Vd/Vs in CCA, indicating that renal vascular resistance is related to carotid stiffness. A stepwise regression analysis revealed that age and pulse pressure were independently associated with intrarenal PI and RI.

Conclusions: These results suggest that the measurement of PI and RI is useful for the evaluation of arterial stiffness in patients with essential hypertension. Am J Hypertens 2004;17:240–244 © 2004 American Journal of Hypertension, Ltd.

Key Words: Pulsatility index, resistive index, intima–media thickness, Doppler ultrasound, essential hypertension.

The pulsatility index (PI) and the resistive index (RI) are different indices calculated from the blood flow velocities in vessels during the cardiac cycle by a pulsed-wave Doppler ultrasound.1,2 Originally, PI and RI were introduced to detect peripheral vascular disease. The measurement of PI and RI in renal arteries has been reported as a reliable marker of downstream renal resistance.3,4 Furthermore, PI and RI are useful for the diagnosis of renal artery stenosis5 and kidney graft rejection.6 Recently the assessment of PI and RI of intrarenal arteries has been used to assess the severity of target organ damage in patients with hypertension and diabetes mellitus, as well as chronic renal failure.7,9

B-mode ultrasound imaging of the common carotid artery (CCA) has been developed for the in vivo evaluation of early atherosclerotic lesions.10 Hypertensive patients exhibit a greatly increased intima–media thickness (IMT) and a higher prevalence of plaques in the CCA than normotensive individuals.11 We have previously evaluated the hemodynamic changes in the CCA using Doppler ultrasound and demonstrated that the diastolic perfusion rate of the CCA in hypertensive patients with insulin resistance (IR) is lower than that of normotensive subjects and hypertensive patients without IR.12

In the present study, we evaluated pulse-Doppler PI and RI of intrarenal vasculature in hypertensive patients and noted a significant relation between renal hemodynamics and CCA hemodynamics.

Methods

Patients

Patients with essential hypertension participated in the present study. They were recruited from consecutive cases admitted to Ehime University Hospital from July 1999 to January 2003. Hypertension was defined as a systolic
blood pressure (BP) \( \geq 140 \) mm Hg or a diastolic BP \( \geq 90 \) mm Hg measured three times in the sitting position using a brachial sphygmomanometer. Patients with diabetes mellitus and renal failure (creatinine \( >124 \) \( \mu \)g/mL) were excluded from the study. All patients received a diet containing 7 g of NaCl per day and all medications were discontinued at least 1 week before the investigation. Informed consent to the procedures was obtained from each patient.

**Blood Sampling**

Measurement of serum creatinine, total cholesterol, HDL-cholesterol, and triglyceride levels was performed using an automatic analyzer (model TBA-60S, Toshiba Inc., Tokyo, Japan).

**Ultrasound Analysis of the CCA**

Carotid arteries were evaluated using an SSD-2000 (Aloka Co., Tokyo, Japan) and a 7.5-MHz probe as previously described.\(^\text{13}\) After the subject had rested for at least 10 min in the supine position with his or her neck in slight hyperextension, we examined an optimal visualization of the CCA, carotid bulb, and extracranial internal and external carotid arteries bilaterally. The IMT of the far wall was measured in the CCA at both 1 and 2 cm proximal to the bulb from the anterior, lateral, and posterior approaches. The data were then averaged to obtain the mean IMT. Measurements were never taken at the level of discrete plaque. Doppler evaluation was performed by scanning the right CCA in the anterior projection. Under hyperventilation, we examined an optimal visualization of the CCA and evaluated the hemodynamics in the CCA.

**Renal Doppler Analysis**

The renal Doppler analysis was performed by placing the sample at three different positions (superior, mid, and inferior) in each of two kidneys, guiding with color flow mapping similar to the CCA. The mean PI ([peak systolic velocity – end-diastolic velocity]/mean velocity) and mean RI ([peak systolic velocity – end-diastolic velocity]/peak systolic velocity) were calculated.\(^\text{1,2}\)

**Determination of Left Ventricular Mass Index**

Echocardiographic studies were carried out using an SSD-6500 echocardiograph with a 3.5-MHz transducer (Aloka) according to the recommendations of the American Society of Echocardiography.\(^\text{14}\) Left ventricular mass (LVM) was estimated using the formula of Devereux and Reichek (Penn convention)\(^\text{15}\) and was adjusted for the body surface area to obtain the LVM index (LVMI).

**Twenty-four-hour BP Determination**

Twenty-four-hour systolic and diastolic BP (24h systolic BP and diastolic BP) was measured by a cuff-oscillometric method using an FB-250 oscillometer (Fukuda Denshi Co., Ltd., Tokyo, Japan). Blood pressure was measured every 30 min from 6:00 AM to 10:00 PM and every 60 min from 10:00 PM to 6:00 AM of the following day.\(^\text{16}\) Pulse pressure was calculated (mean 24h systolic BP – mean 24h diastolic BP).

**Statistical Analysis**

All values are expressed as mean ± SD. Pearson’s correlation coefficient was used to determine the significance of associations. A stepwise regression analysis was applied to evaluate the determinant factor of PI and RI. A \( P \) value < .05 was considered statistically significant.

**Results**

Fifty-one patients with essential hypertension were enrolled in this study. Clinical characteristics of the subjects are shown in Table 1. Intrarenal hemodynamic data were positively correlated with morphologic and hemodynamic alteration of the CCA. Both PI and RI were positively correlated with the IMT of the CCA (\( r = 0.532, P < .0001 \) and \( r = 0.564, P < .0001 \), respectively; Fig. 1) and negatively correlated with the relative diastolic flow velocity \( Vd/Vs \) (\( r = -0.559, P < .0001 \) and \( r = -0.571, P < .0001 \), respectively; Fig. 2). Furthermore, PI and RI were positively correlated with age (\( r = 0.682, P < .0001 \) and \( r = 0.682, P < .0001 \), respectively) and pulse pressure (\( r = 0.628, P < .0001 \) and \( r = 0.679, P < .0001 \), respectively).

**Table 1.** Clinical characteristics of the participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Number (M/F)</td>
<td>51 (29/22)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>59 ± 14</td>
</tr>
<tr>
<td>Body mass index</td>
<td>25.2 ± 3.9</td>
</tr>
<tr>
<td>24-h systolic blood pressure (mm Hg)</td>
<td>155 ± 18</td>
</tr>
<tr>
<td>24-h diastolic blood pressure (mm Hg)</td>
<td>91 ± 12</td>
</tr>
<tr>
<td>Mean blood pressure (mm Hg)</td>
<td>112 ± 11</td>
</tr>
<tr>
<td>Pulse pressure (mm Hg)</td>
<td>64 ± 19</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>73 ± 13</td>
</tr>
<tr>
<td>Total cholesterol (mg/dL)</td>
<td>207 ± 35</td>
</tr>
<tr>
<td>HDL-cholesterol (mg/dL)</td>
<td>54 ± 21</td>
</tr>
<tr>
<td>Triglyceride (mg/dL)</td>
<td>143 ± 67</td>
</tr>
<tr>
<td>Creatinine (mg/dL)</td>
<td>0.8 ± 0.2</td>
</tr>
<tr>
<td>Intima–media thickness (mm)</td>
<td>0.81 ± 0.16</td>
</tr>
<tr>
<td>Left ventricular mass index</td>
<td>123 ± 32</td>
</tr>
<tr>
<td>Pulsatility index</td>
<td>1.30 ± 0.29</td>
</tr>
<tr>
<td>Resistivity index</td>
<td>0.65 ± 0.08</td>
</tr>
</tbody>
</table>
respectively; Fig. 3). However, there was no relationship between intrarenal hemodynamic data and LVMI. Both PI and RI were not associated with total cholesterol, HDL cholesterol, and triglyceride levels. The RI was significantly correlated with body mass index ($r = 0.312$, $P = .0257$) but not PI ($r = 0.246$, $P = .0817$). A stepwise regression analysis for PI or RI was performed with age, body mass index, pulse pressure, and total cholesterol as independent variables. Age and pulse pressure were independently associated with PI and RI (Table 2).

### Discussion

The echo-Doppler technique in renal arteries is highly effective in the diagnosis of several pathologic renal conditions such as arterial stenosis, urinary tract obstruction, and acute renal transplant rejection. The PI and RI were introduced by Gosling et al in 1971 and Pourcelot in 1974, respectively, to detect peripheral vascular disease. A high index of PI and RI is associated with a high difference in velocity between the systolic and the diastolic phase. This difference in flow velocities reflects downstream resistance, which could at least in part depend on the degree of peripheral arterial stiffness. Recently, PI and RI in intrarenal arteries have been evaluated in patients with hypertension. Petersen et al reported that both PI and RI were significantly higher in hypertensive patients than normotensive subjects and both PI and RI were correlated with renal plasma flow, renal vascular resistance, and creatinine clearance. The increased PI and RI measured at the level of the intrarenal arteries are also associated with end organ damage of patients with hypertension or diabetes mellitus. Pontremoli et al reported that RI was positively correlated with the albumin-to-creatinine ratio and IMT in hypertensive patients. In patients with non–insulin-dependent diabetes, Boeri et al reported that patients with macroangiopathy exhibited a significantly higher RI. In the present study, we have
demonstrated that intrarenal PI and RI were associated with carotid arteriosclerosis and hemodynamic alteration.

Hypertensive patients have an increased IMT of the CCA and this pathologic change is related to cardiovascular complications and future cerebrovascular events.\(^\text{11}\) In this study, we have demonstrated that the PI and RI of intrarenal arteries are positively correlated with the IMT of CCA in hypertensive patients thereby, indicating that measurement of PI and RI is useful for the evaluation of atherosclerosis. Previously, we evaluated the hemodynamic changes in the CCA using Doppler ultrasound and demonstrated that the diastolic perfusion rate (Vd/Vs) of the CCA in hypertensive patients with insulin resistance was significant lower than that of both normotensive subjects and hypertensive patients without insulin resistance.\(^\text{12}\) This previous report showed that hypertensive patients, especially those with insulin resistance, exhibit an increased arterial stiffness of the CCA by hemodynamic criteria. In the present study, we showed that Vd/Vs was also associated with the PI and RI of intrarenal arteries, indicating that abnormal hemodynamic alterations occurred in different organs to a comparable degree in hypertensive patients.

We were unable to demonstrate the positive relationship between LVH and intrarenal PI or RI. Pontremoli et al\(^\text{8}\) reported that hypertensive patients with an elevated RI showed a significantly higher prevalence of LVH, but they were also unable to demonstrate a positive correlation between RI and LVMI. These results suggest that the mechanism of hypertension-mediated progressive damage and injury differ between vessels and the myocardium.

In stepwise regression analysis, both PI and RI were independently associated with age and pulse pressure. Increased pulse pressure and increased stiffness and thickness of the CCA wall were shown to be significant and independent predictors of cardiovascular complications,\(^\text{18–21}\) mainly for myocardial infarction but also for stroke.\(^\text{22}\) Our results in the present study suggest that the PI and RI of intrarenal arteries could be a useful marker of end organ damage and might be a predictor of future cardiovascular complications in hypertensive patients.

In conclusion, we have demonstrated that intrarenal PI and RI are positively correlated with both morphologic and hemodynamic alteration of the CCA, indicating that renal vascular resistance is related to carotid stiffness. Both PI and RI were independently associated with age and pulse pressure. Measurement of PI and RI may well be useful for the evaluation of arterial stiffness in patients with essential hypertension.

**Table 2.** Stepwise regression analysis for intrarenal pulsatility index and resistive index

<table>
<thead>
<tr>
<th></th>
<th>Partial Correlation Coefficient</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsatility index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>0.544</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Pulse pressure</td>
<td>0.420</td>
<td>&lt;.001</td>
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<tr>
<td>Resistive index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>0.517</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Pulse pressure</td>
<td>0.503</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Stepwise regression analysis for pulsatility index and resistive index were performed with the following parameters: age, body mass index, pulse pressure, and total cholesterol.

**References**


