Novel Doppler Technique to Assess Systemic Vascular Resistance
— The Snuffbox Technique —

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Background To explore an alternative to the systemic vascular resistance index (SVRI) for monitoring peripheral circulation in patients in the intensive care unit (ICU), the resistive index (RI) in the upper extremity arteries was measured by using surface Doppler ultrasound.

Methods and Results The correlation between RI and vascular resistance was assessed in vitro using a vessel phantom in a Donovan-type mock circulation system. In addition, 15 ICU patients who had undergone open-heart surgery were studied. Mean arterial pressure, central venous pressure and cardiac output were measured 30 times at 10 min intervals after patients returned to the ICU following surgery, and the SVRI was calculated from these parameters. At the same time points, 3 parts of the upper extremity arteries (brachial artery in the cubital fossa (BA), radial artery at the wrist (RA), and radial artery at the anatomical snuffbox (SB)) were scanned by Doppler ultrasound, and the resistance index (RI) for each artery region was calculated. In vitro, RI increased with higher vascular resistance, exhibiting a significant correlation (r=0.982, p<0.0001). In vivo, the average incidence angles at the BA and RA were larger than 60°, while that at the SB was only 11.5±10.8°. The overall correlation between SVRI and RI for all patients was not significant for the BA or RA, but was significant for the SB (p<0.0001). In individual patients, the correlation of SVRI with RI at the BA or RA was significant in 3 patients only, whereas significant correlation for the SB was observed in all patients. Doppler waveform analysis at the SB revealed diastolic flow reversal with increased SVRI.

Conclusions Measurement at the SB provides an ideal ultrasound incidence angle for the measurement of blood flow velocity. Hence, RI measured in this way may serve as an indicator of peripheral vascular resistance, and may be effective for the evaluation of peripheral circulatory disturbance. (Circ J 2005; 69: 688–694)

Key Words: Hemodynamic; Postoperative care; Resistive index; Systemic vascular resistance

Circulation following renal transplantation and progressive nephropathy. However, RI has mainly been used for evaluating blood flow to a target organ, but not for hemodynamics. In patients with extreme hemodynamics, including those who have had open-heart surgery and following an emergency, it is very important to know the impairment of the peripheral circulation; therefore, if RI could be used simply to quantify systemic blood vessel resistance, it could be an important parameter for circulation control, based on a different perspective from that of cardiac output and oxygen saturation of mixed-venous blood. Here, we measured RI in the upper extremity arteries, examined the most effective point of measurement, and determined whether this technique allows for the quantitative evaluation of peripheral circulatory disturbance.

Methods

Measurements of RI
At each measurement point, a 7.5 MHz probe was positioned on the measurement surface and a target artery (simulated peripheral artery in vitro) was imaged in B mode. A site with the minimum ultrasonic incidence angle was selected in the artery on display and pulsed Doppler ultrasonography was conducted. The systolic maximum velocity ($V_{max}$) and diastolic minimum velocity ($V_{min}$) of the pulsed Doppler waveforms were determined and...
recorded, and RI was calculated using the following formula (Fig 1).

\[
\text{Resistive Index} = \frac{(V_{\text{max}} - V_{\text{min}})}{V_{\text{max}}}
\]

The ultrasonography system used in the present study allowed the automatic calculation of RI from the pulsed Doppler waveforms.

**In Vitro Experiment**

In collaboration with Shimadzu Corporation and Kyoto Kagaku, a vessel phantom was constructed from soft urethane resin, with internal diameters of 20 and 6 mm to mimic the aorta and peripheral artery, respectively. Stainless steel connecting tubes were attached to allow connection with an artificial heart. The echo probe was aligned with an inclination angle of 64° so that the ultrasonic incidence angle was fixed at 26°.

Mock peripheral artery was calculated and assessed for correlation with SVR (dyne·s⁻¹·cm⁻⁵) in vitro. Water was used as the operating fluid. SVR was calculated by using mean arterial pressure (MAP; mmHg), CVP and CO as follows:

\[
\text{SVR (dyne·s}^{-1} \cdot \text{cm}^{-5}) = \frac{(\text{MAP} - \text{CVP})}{\text{CO}} \times 80
\]

**In Vivo Study**

**Patients** The study included 15 patients who were fully monitored in the ICU after having had open-heart surgery in our department between August 2003 and December 2003 (Table 1). Patients were excluded from the present study if: (1) they had any impairment of the upper extremity circulation, such as those who underwent radial artery harvesting for coronary artery bypass grafting or had suspected occlusion of the radial artery prior to surgery; and (2) if they had undergone an operation that involved large arteries of the aortic arch. Informed consent was obtained from all patients.

Table 1 Clinical Profiles of the 15 Patients in the Study

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Age (years)</th>
<th>Sex</th>
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<th>Operation</th>
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<td>AR</td>
<td>AVR</td>
</tr>
<tr>
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<td>59</td>
<td>M</td>
<td>MR, TR</td>
<td>MVR, TAP</td>
</tr>
<tr>
<td>3</td>
<td>62</td>
<td>F</td>
<td>AR</td>
<td>AVR</td>
</tr>
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<td>4</td>
<td>54</td>
<td>M</td>
<td>MR, TR</td>
<td>MVR, TAP</td>
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<td>M</td>
<td>AP</td>
<td>CABG</td>
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<td>59</td>
<td>F</td>
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<td>MVR</td>
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</table>

AR, aortic regurgitation; AVR, aortic valve replacement; MR, mitral regurgitation; TR, tricuspid regurgitation; MVR, mitral valve replacement; TAP, tricuspid annuloplasty; AP, angina pectoris; CABG, coronary artery bypass grafting; MS, mitral stenosis; AS, aortic stenosis.
Data Collection

The MAP, CVP, and CO values were measured 30 times per patient at approximate intervals of 10 min, starting when the patient returned to the ICU after having had surgery. A pulmonary artery catheter (oximetry CCO thermodilution catheter 744HF75, Edwards Lifesciences Corporation) was used for continuous monitoring of CO. SVRI was calculated as follows:

\[ \text{SVRI (dynes·s}^{-1} \cdot \text{cm}^{-5} \cdot \text{m}^{-2}) = \frac{\text{MAP} - \text{CVP}}{\text{CO} \times 80 / \text{body surface area (m}^2)} \]

At the same time points, blood flow in the upper extremity arteries was measured at 3 artery points (brachial artery in the cubital fossa (BA), radial artery at the wrist (RA), and radial artery at the anatomical snuffbox (SB)) by pulsed Doppler ultrasound. The RI for each artery point was calculated by using waveform analysis, and the correlation with the SVRI was assessed (Fig.3).

Ultrasonography was conducted by using an ultrasound system (SSD-5500, UST-5539; ALOKA, Tokyo, Japan), equipped with a 7.5 MHz linear probe.

Statistical Analysis

Results are expressed as means±standard deviation. Linear correlation analysis was performed by using statistical software (Stat View-5.0J; Abacus Concepts, CA, USA). Statistical significance was evaluated at p<0.05.

Results

In Vitro Experiment

In the in vitro circulation system, the maximal SVR was 1,528. Therefore, RI was measured at 35 different SVR levels within the range 992–1,528. RI increased with
higher SVR, exhibiting a significant positive correlation (r=0.982, p<0.0001; Fig 4).

In Vivo Study

Incidence Angle of the Ultrasound Beam at Each Measurement Point The average incidence angles of the ultrasound beam at the BA and RA were 65.6±10.6° (range, 36–90°) and 69.7±9.8° (range, 42–88°), respectively. The average incidence angle at the SB was 11.5±10.8° (range, 0–30°).

Correlation of SVRI With RI The correlation between SVRI and RI was first evaluated based on the overall data collected from 15 patients. Although RI tended to increase with higher SVRI values for the BA and RA, the correlations were not significant (BA: r=0.074, p=0.1204; RA: r=0.081, p=0.0887). In contrast, a significant positive correlation was observed between SVRI and RI for the SB (r=0.582, p<0.0001; Fig 5).

In each patient, the correlation between SVRI and RI was evaluated. At the BA or RA, only 3 patients showed significant correlation between SVRI and RI, however, the other 12 patients had no significant correlations between the 2 data sets. At the SB, all 15 patients showed a significant correlation between SVRI and RI, and correlation coefficients were higher than 0.7 in 12 patients (Table 2).

An analysis of Doppler waveforms at the SB revealed that higher SVRI values were associated with sharper waveforms, and diastolic flow reversal occurred when
SVRI was particularly high (Fig 6). An SVRI value over 2,000 was frequently associated with diastolic flow reversal (82%), and thus RI values exceeded 1. In contrast, an SVRI value less than 2,000 was rarely associated with diastolic flow reversal (7%).

**Discussion**

Recent advances in ultrasound technology have enabled both morphological analysis and functional assessment of various diseases, based on blood-flow monitoring by Doppler ultrasonography. Hence, Orihashi et al reported that cerebral complications associated with selective cerebral perfusion in aortic surgeries can be predicted and evaluated by blood flow monitoring in the central retinal artery. After Sampson performed arterial flow monitoring in a transplanted kidney using continuous wave Doppler monitoring in 1969, this technique has been performed widely to identify transplant rejection and has also been used to assess acute renal failure or renal transplants. A recently developed Doppler guidewire enables Doppler measurements in the coronary arteries to be taken. By using this device, Shimada et al determined the coronary flow reserve in acute myocardial infarction patients in the convalescent stage, and investigated the relationship between coronary flow reserve and late myocardial morphologic outcomes. RI was first proposed for use in this context by Franceschi. Norris and Barnes suggested an association of RI with renal vascular resistance. RI has since been reported to increase with elevated vascular resistance in the renal parenchyma or with the increased severity of renal dysfunction. Furthermore, RI has been found to be useful in ophthalmology, and Rankin et al reported higher RI in glaucoma patients compared to normal subjects after analyzing the blood flow in orbital arteries. Harris et al also evaluated the effects of medication in glaucoma patients using RI in retrobulbar arteries. Hence, RI is usually measured in the inflow arteries of local organs, and is mainly used for the functional assessment of target organs. Regarding the blood vessel itself, Barutcu et al compared hemodynamic changes in the common carotid artery that were associated with smoking, by using various parameters, including RI. However, the association of RI with more standard parameters of vascular resistance, such as SVRI, remains to be studied.

The significant correlation demonstrated between SVR and RI may provide new insights into the pathophysiology of various diseases. Further studies are needed to confirm the clinical utility of RI in the assessment of vascular resistance in different conditions.
Novel Technique to Assess SVR

A significant correlation between SVRI and RI at the SB was obtained in 15 patients, but an even stronger correlation was observed when data were analyzed for each patient separately. The difference in vascular resistance between individuals is large, and patients with hypertension and RI in in vitro studies suggests a clear association between SVRI and RI. However, we note that the operating fluid used, water, has different properties, including different viscosity, compared to those of blood. As blood flow is affected by factors such as elasticity, frictional resistance of the vascular walls and blood viscosity, the correlation in vivo is expected to be weaker than that observed in vitro.

The waveforms obtained by the Doppler method are influenced by the angle between the ultrasound beam and blood flow direction. The incidence angle is critical in the Doppler analysis of blood flow, and an angle smaller than 60° is required to reduce the error to less than 20%. More accurate signals can be obtained with an angle closer to 0°. In the present study, waveforms of diastolic flow reversal were commonly detected in many patients with an incidence angle of 60° and greater, and most RI values for these patients exceeded 1.0, even under extremely low SVRI conditions; this resulted in variable RI values. As the average incidence angles at the BA and RA were greater than 60°, these measurement points were considered unsuitable for analysis of blood flow. In contrast, measurement at the SB showed an average incidence angle of 11.5±10.8°. The SB denotes the site of depression located at the base of the thumb. The artery crossing this region connects the dorsal branch of the radial artery and deep palmar arch, and runs perpendicularly to the body surface. Therefore, a very small incidence angle of the Doppler beam is obtained, showing the SB to be ideal for Doppler analysis of blood flow. Koichi et al suggested that SB blood flow monitoring is useful to examine the patency of both radial and ulnar arteries before harvesting for coronary artery bypass grafting, and it can be applied clinically as a reliable alternative to Allen’s test. Compared to the above study, the mean incidence angle at the SB was smaller in the present study, suggesting that measurement techniques, including detection of the target vessel and measurement stability, were markedly improved and led to more stable values.

In the present study, Doppler waveform analysis at the SB showed a sharper waveform as SVRI levels increased, and diastolic flow reversal was frequently associated with a SVRI value higher than 2,000. This suggests that the qualitative evaluation of peripheral vascular resistance by using the Doppler method may be possible. With an increase in peripheral vascular resistance, systolic blood flow velocity also increases. However, diastolic blood flow velocity decreases more conspicuously, and even reaches zero or turns to diastolic reverse flow as SVRI increases. These findings are consistent with previous studies in which Norris et al demonstrated a decrease in diastolic blood flow and an increase in RI in the renal arteries associated with an increase in renovascular resistance, using a canine model of sephadex microsphere embolization of the renal arteries. Arima et al also observed marked changes in diastolic renal blood flow, but not systolic blood flow during acute rejection of renal transplantation. Therefore, it is assumed that diastolic blood flow is more significantly affected by peripheral vascular resistance than systolic blood flow. In particular, diastolic flow reversal suggests severely impaired peripheral circulation.

Lespold et al reported that increased resistance of intra-renal arteries or impaired blood flow secondary to renal microangiopathy contributes significantly to the progression of diabetic nephropathy, which suggests the involvement of severe arteriosclerotic lesions in diabetic patients. Hosojima et al examined patients with diabetic nephropathy by using renal Doppler ultrasonography, and reported that RI in the interlobar arteries was higher in these patients and increased with disease progression. In addition, by using an in vitro phantom model, Bude and Rubin suggested that RI is correlated not only with vascular resistance but also with vascular compliance. These reports, together with our findings, suggest that the monitoring of arterial compliance or endothelial functions using RI at the SB may allow future quantitative evaluation of the severity of arterial sclerosis.

References

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