Vertebral Artery Occlusion in Duplex Color-Coded Ultrasonography

Kozue Saito, MD; Kazumi Kimura, MD; Kazuyuki Nagatsuuka, MD; Keiko Nagano, MD; Kazuo Minematsu, MD; Satoshi Ueno, MD; Hiroaki Naritomi, MD

Background and Purpose—To establish the diagnostic criteria for the site of occlusion in the vertebral arteries (VAs) using duplex color-coded ultrasonography.

Methods—In 128 consecutive patients who underwent conventional cerebral angiography, we prospectively measured the diameter, mean flow velocity (MV), peak systolic flow velocity, and end-diastolic flow velocity of both VAs. The diameter-ratio (diameter of contralateral VA divided by that of target VA) and MV-ratio (MV of contralateral VA divided by that of target VA) were determined. Based on the angiographic findings, we classified the VAs into 4 types (5 groups) as follows: (1) the origin of VA occlusion (Origin group: n = 9); (2) VA occlusion before branching into the posterior inferior cerebellar artery (PICA) (Before group: n = 10); (3A) asymptomatic or hypoplastic occlusive VA after branching into the PICA (PICA end group: n = 15); and (4) no significant occlusive lesions in the VA (Control group: n = 194).

Results—No flow signals in the VAs apparently indicated the Origin group. Preserved peak systolic flow velocity but end-diastolic flow velocity of zero cm/s indicated the Before group. MV < 18 cm/s and MV-ratio ≥ 1.4 indicated the PICA end group or After group. Furthermore, these groups could be distinguished as follows: a diameter-ratio < 1.4 indicated the After group. A diameter-ratio ≥ 1.4 indicated the PICA end group. Either MV ≥ 18 cm/s or MV < 18 cm/s in combination with MV-ratio < 1.4 indicated the Control group.

Conclusion—Duplex color-coded ultrasonography can accurately diagnose the site of VA occlusion. (Stroke. 2004;35:1068-1072.)

Key Words: vertebral artery occlusion ultrasonography, Doppler, duplex diagnosis verteobasilar circulation

Duplex color-coded ultrasonography is useful in the evaluation of occlusive lesions in the carotid1-6 and vertebral7-13 arteries (VAs) in acute stroke patients. The diagnostic criteria for occlusive lesions in the carotid arteries have been already established.1,5 Duplex color-coded ultrasonography is also valuable to evaluate pathological VAs, such as VA occlusion,13,14 subclavian steal phenomenon,12,15-17 and vertebral arterial dissection.18-21 The site of VA occlusions is divided into 3 groups: VA origin occlusions, VA occlusions before branching into the posterior inferior cerebellar artery (PICA), and VA occlusions after branching into the PICA. However, the diagnostic criteria in duplex ultrasonography for the site of VA occlusion remain unclear. Furthermore, a few VAs show asymptomatic occlusion or naturally hypoplastic VA ending at the PICA (PICA end).22 The aim of the present study was to establish the criteria for determining the site of occlusion of VAs, including VAs ending at the PICA, using duplex color-coded ultrasonography.

Methods

We prospectively assessed the 256 VAs of 128 consecutive patients (91 men and 37 women, mean ± SD: 63.4 ± 12.2 years) admitted to the National Cardiovascular Center and who underwent intraarterial digital subtraction angiography (IA-DSA) between May 1, 2003 and July 31, 2003. We excluded 16 VAs with 50% to 99% stenosis in diameter on angiography because the flow velocity was also affected by the stenotic lesions. Therefore, 240 VAs were examined in the present study. Eighty-four patients had acute cerebral infarctions (33 in the verteobasilar circulation and 51 in the internal carotid arterial circulation), 12 had transient ischemic attacks, 20 had old infarctions (12 in the verteobasilar circulation, 8 in the internal carotid arterial circulation), 3 had cerebral hemorrhages, and the remaining 9 nonstroke patients had asymptomatic arterial stenotic or occlusive lesions (1 in the basilar artery, 2 in the middle cerebral artery, and 6 in the internal carotid artery). Eighty-four patients with acute stroke underwent IA-DSA within 2.6 ± 3.9 days of stroke onset. Informed consent for IA-DSA was obtained from both the patient and family.

Selective IA-DSA was performed using a biplane, high-resolution angiography system (Angio Rex Super-G and DFP-2000A; Toshiba) with a matrix of 1024×1024 pixels. A catheter was inserted into the right brachial artery or femoral artery in accordance with the
Seldinger method, and then guided to the cerebral arteries for diagnostic 4-vessel angiography. Based on the angiographic findings, we classified the VA vessels into 4 types (5 groups) as follows: (1) the origin of VA occlusion (Origin group); (2) VA occlusion before branching into the PICA (Before group); (3) VA occlusion after branching into the PICA, which was divided into 2 groups—(3A) VA symptomatic occlusion after branching into the PICA (After group) and (3B) hypoplastic or asymptomatic occlusive VA after branching into the PICA (PICA end group); and (4) no significant occlusive lesions in the VAs (Control group). The After group was defined as symptomatic VA occlusion associated with acute ischemic stroke presented as a new infarct on MRI including diffusion-weighted imaging (DWI) or transient ischemic attack (TIA) in the vertebrobasilar circulation. The clinical diagnosis of stroke and TIA was made by the attendant physician from the result of MRI (DWI) and neurological findings. When VA occlusion was symptomatic, we identified it as the After group, even if the diameter of the target VA was smaller than that of the contralateral VA.

Using B-mode scans with color imaging and pulsed-Doppler, one investigator with no previous knowledge of the patients' clinical information including angiographic findings (K.S.) measured the Doppler waveforms. We used a Sonos 5500 duplex color-coded ultrasonographic device (Philips) equipped with a 7.5-MHz transducer. First, we measured flow velocities of both VAs within 48 hours before or after IA-DSA.

The VAs were clearly displayed in all patients using angiography and Doppler waveforms (Figure 1). Table 1 shows the VA diameter, diameter-ratio, MV, MV-ratio, EDV, and RI of each VA.

### Results

The VAs were clearly displayed in all patients using B-mode with color imaging, and blood flow velocity was successfully evaluated by pulse Doppler. Conventional MRI T1-weighted (repetition time [TR]/echo time [TE]; 630/14), T2-weighted (TR/TE; 5400/99), and fluid attenuation inversion recovery (FLAIR) (TR/TE; 9000/105) images were obtained. DWI was performed simultaneously using a spin-echo planar imaging sequence. Diffusion gradients were applied in the x, y, and z directions, with a b value of 1000/cm².

Statistical analysis was performed using the Mann-Whitney U test and Kruskal-Wallis test. A value of $P<0.05$ was accepted as indicating statistical significance. Sensitivity and specificity curves were produced to obtain the best cut-off value for each diagnostic criterion.

### Origin Group

Although the VAs were clearly detected using B-mode with color imaging, no blood flow signals, including MV and the time-averaged peak mean flow velocity (MV), corrected using the adequate angle for both VAs. Resistance index (RI) was defined as ($PSV-EDV$)÷$PSV$. The diameter-ratio (diameter of contralateral VA divided by diameter of target VA) and MV-ratio (MV of contralateral VA divided by that of target VA) were also determined. The diameter, diameter-ratio, and flow velocity data for each group were expressed as mean±SD.

Brain computed tomography (CT) and MRI including DWI were performed in all the patients to assess new brain infarctions. DWI was performed simultaneously using a spin-echo planar imaging sequence. Diffusion gradients were applied in the x, y, and z directions, with a b value of 1000/cm².

### Table 1. Parameters in Each Group

<table>
<thead>
<tr>
<th>Group</th>
<th>N of Vessels</th>
<th>VA Diameter (mm)</th>
<th>Diameter-ratio</th>
<th>MV (cm/s)</th>
<th>MV-ratio</th>
<th>EDV (cm/s)</th>
<th>RI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>194</td>
<td>3.76±0.66</td>
<td>0.97±0.27</td>
<td>25.26±7.54</td>
<td>0.94±0.37</td>
<td>15.10±5.39</td>
<td>0.66±0.09</td>
</tr>
<tr>
<td>Origin</td>
<td>9</td>
<td>3.25±1.08</td>
<td>1.39±0.31</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Before</td>
<td>10</td>
<td>3.25±0.72</td>
<td>1.20±0.42</td>
<td>7.24±4.64</td>
<td>2.38±1.55</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>After</td>
<td>12</td>
<td>3.37±0.64</td>
<td>1.10±0.23</td>
<td>12.92±3.29</td>
<td>2.00±0.80</td>
<td>6.69±3.74</td>
<td>0.76±0.14</td>
</tr>
<tr>
<td>PICA end</td>
<td>15</td>
<td>2.62±0.39</td>
<td>1.68±0.31</td>
<td>13.95±3.22</td>
<td>2.31±1.73</td>
<td>7.09±2.46</td>
<td>0.76±0.09</td>
</tr>
<tr>
<td>Total</td>
<td>240</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Diameter-ratio indicates diameter of contralateral VA divided by that of target VA; MV, mean flow velocity; MV-ratio, mean flow velocity of contralateral VA divided by that of target VA; EDV, end-diastolic flow velocity; RI, resistance index = (peak systolic flow velocity − end-diastolic flow velocity) ÷ peak systolic flow velocity.
EDV, in the VAs could be detected using pulse Doppler, allowing the Origin group VAs to be easily identified.

**Before Group**

Peak systolic flow velocity was preserved, but EDV was zero cm/s in all patients in the Before group. In addition, the MV (7.2±4.6 cm/s) was the lowest among all the groups, excluding the Origin group (P<0.0001). Excluding the Origin group, an EDV of zero cm/s allowed the Before group VAs to be easily distinguished from the other groups.

**Distinguishing After and PICA End Groups From the Control Group**

Of the 3 groups other than the Origin and Before groups, the MV, EDV, and RI of the After and PICA-end groups (After group: 12.9±3.3 cm/s, 0.78±0.14, respectively; PICA end group: 14.0±3.2 cm/s, 7.1±2.5 cm/s, 0.76±0.09, respectively) were lower than those of the Control group (25.3±7.5 cm/s, 13.4±8.6 cm/s, 0.42±0.09, respectively) (P<0.0001). Using sensitivity–specificity curve analysis for discriminating the Control group from the After and PICA end group, the cut-off point of the RI and MV were 0.7 (sensitivity 74.0% and specificity 72.6%) and 18 cm/s (sensitivity 92.6% and specificity 90.2%; Figure 2A), respectively. Therefore, MV was a better parameter than RI for discriminating the After and PICA end groups from the Control group. However, 18 of 43 patients with MV<18 cm/s belonged to the Control group and the positive predictive value was low (58.1%). Of these 43 VAs with MV<18 cm/s, the sensitivity–specificity curve for MV-ratio to distinguish the After and PICA end groups from the Control group showed a cut-off value of 1.4 and gave a sensitivity of 84.0% and specificity of 82.3%. If we used the combined criteria of both MV<18 cm/s and MV-ratio ≥1.4 to distinguish the After and PICA end groups from the Control group, then sensitivity, specificity, accuracy, and positive predictive value were 85.2%, 97.4%, 95.9%, and 82.1%, respectively.

**Distinguishing the PICA End Group From the After Group**

No significant difference in MV, EDV, and RI between the After and PICA end group was observed. However, the diameter (2.62±0.39 mm) in the PICA end group was the smallest among all the groups (Before group: 3.25±0.72 mm; After group: 3.37±0.64 mm; Control group: 3.76±0.66 mm) (P<0.0001). The diameter-ratio (1.68±0.31) in the PICA end group was also the largest among all the groups (Before group: 1.20±0.42; After group: 1.10±0.23; Control group: 0.97±0.27, respectively) (P<0.0001). Using sensitivity–specificity curve analysis for discriminating the PICA end group from the After group, the cut-off point of VA diameter and diameter-ratio were 2.8 mm (sensitivity 73.3% and specificity 83.3%) and 1.4 (sensitivity 93.3% and specificity 91.7%), respectively (Figure 2B). Therefore, the diameter-ratio was a better parameter than VA diameter for discriminating the PICA end group from the After group.

**Ultrasoundographic Diagnostic Criteria**

Figure 3 shows the criteria for the site of VA occlusion, including PICA end with duplex color-coded ultrasonography based on the present results. Table 2 shows the relationship between the cerebral angiographic findings and our ultrasonographic diagnosis. One VA vessel of the After group had the diameter-ratio ≥1.4. Therefore, we classified it as the PICA end, based on ultrasonographic criteria. The accuracy for conformity between them was 95.0%.

**Discussion**

The present study has established the ultrasonographic diagnostic criteria for determining the site of VA occlusion. Kimura et al demonstrated the usefulness of measurement of VA flow velocity using duplex ultrasonography for the localization of the site of VA occlusion. They reported EDV of zero cm/s in a VA occlusion site before branching into the PICA, which is consistent with the present findings. Furthermore, they described that the MV was significantly lower in a VA occlusion after branching into the PICA than in the nonocclusive VA group. However, accurate diagnostic criteria for differentiating these types were not established in their study.
TABLE 2. Comparison of Angiographic and Ultrasonographic Diagnoses

<table>
<thead>
<tr>
<th>Angiographic Diagnosis</th>
<th>Total</th>
<th>PICA End</th>
<th>After</th>
<th>Before</th>
<th>Origin</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonographic Diagnosis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>189</td>
<td>2</td>
<td>11</td>
<td>13</td>
<td>0</td>
<td>194</td>
</tr>
<tr>
<td>Origin</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Before</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>After</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>PICA end</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>193</td>
<td>9</td>
<td>11</td>
<td>13</td>
<td>14</td>
<td>240</td>
</tr>
</tbody>
</table>

In the present study, except for patients in the Origin and Before groups, 98.9% of patients with MV ≥18 cm/s had nonocclusive VAs, whereas 41.9% of patients with MV <18 cm/s also had nonocclusive VAs. Therefore, the criteria of threshold of MV <18 cm/s alone were insufficient to accurately distinguish the After group from the Control group. Using the combination of both MV-ratio ≥1.4 and MV <18 cm/s, sensitivity, specificity, accuracy, and positive predictive value to distinguish the After and PICA end groups from the Control group were much better at 85.2%, 97.4%, 95.9%, and 82.1%, respectively.

The VA blood flow wave and velocity between the After and PICA end groups were similar. Thus, we were unable to distinguish these groups by blood flow alone. Most hypoplastic VAs end in the PICA, and hypoplastic VA has been defined as a VA diameter of <2 mm.13,23–25 In the present study, the mean and range of VA diameter in the PICA end group were certainly small, at 2.62±0.39 mm and 1.70 to 3.14 mm, respectively, and the PICA end group diameter was the smallest among the 5 groups. Therefore, the hypoplastic VA criteria of <2 mm may be high in specificity but low in sensitivity. When we used a cut-off value of 2.8 mm obtained from sensitivity and specificity curve analysis to distinguish the PICA end group from the After group, the accuracy was 77.8%, which was not overly useful. However, when we used a diameter-ratio ≥1.4 for the analysis, the sensitivity, specificity, and accuracy increased to 93.3%, 91.7%, and 92.6%, respectively, which was superior to that obtained using a cut-off VA diameter value of 2.8 mm. Therefore, a diameter-ratio ≥1.4 was identified as the criterion with which to differentiate between the After and PICA end groups. Diameter-ratio of symptomatic VAs occlusion was usually <1.4. In this study, we had 1 symptomatic VA occlusion with the diameter-ratio ≥1.4, which was diagnosed as PICA end by ultrasonography. This point may be one of the limitations in the present study.

Nicolau et al13 examined RI in VA occlusion but did not discriminate the site of VA occlusion between before and after branching into the PICA. They reported that the RI in VA occlusion was higher than in non-VA occlusion. In the present study, although RI was higher in the After group than in the other groups, MV was superior to RI as a parameter to determine VA occlusion.

In the present study, the MV in 15 (18 vessels) of 117 patients in the Control group was <18 cm/s. Of these 15, 3 had an occlusion at the top of the basilar artery (BA), and 3 had bilateral fetal type of the posterior cerebral arteries (PCA). The blood flow of the VAs may be decreased under such conditions. This finding represents a limitation to the use of our criteria for identification of VA occlusion site.

We did not have any stenotic VAs in our present study. When the origin of VAs had stenosis, the blood flow velocity sometime reduces. Bray et al26 reported that the velocity curve of severe stenotic VAs with their origin showed isolated ascending and lengthened systolic time and a systolic notch. Therefore, we should be able to distinguish it from the distal VA occlusion.

Another limitation is that asymptomatic acquired VA occlusion cannot always be distinguished from naturally hypoplastic VA ending in the PICA, as differentiating them is difficult in some patients, even with the findings of IA-DSA, MRI, and clinical symptoms. Therefore, the PICA end group may include asymptomatic acquired VA occlusion. In addition, in the present study, there were no patients with bilateral VA occlusion after branching into the PICA. Such patients may have been erroneously assigned into the Control group, because the MV-ratio in patients with bilateral VA occlusion would have been <1.4. Therefore, if a patient’s neurological findings suggest occlusive lesions of the BA or VA after branching into the PICA, and the MV of both VAs is <18 cm/s and the MV-ratio is <1.4, those vessels would need to be assessed by transcranial Doppler or transcranial color-coded sonography.

In conclusion, measurement of the blood flow velocity and diameter of the VAs using duplex color-coded ultrasonography can help diagnose the site of VA occlusion. Ultrasonography is a noninvasive tool and can be performed bedside immediately after stroke patient admission. The present VA occlusion criteria may be used to evaluate VA occlusive lesions in acute stroke patients, in particular, those with medullary and brain stem infarction.

References


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