Ultrasonographic Evaluation of Vertebral Artery to Detect Vertebobasilar Axis Occlusion

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Background and Purpose We performed the present study to determine whether the site of occlusion in the vertebobasilar circulation could be identified by the measurement of blood flow velocity in the bilateral vertebral arteries.

Methods Using color-coded duplex carotid ultrasonography, we measured the time-averaged mean and end-diastolic flow velocities with incident angle correction in 130 bilateral vertebral arteries between the C3 and C6 segments of the spine in 65 stroke patients with or without occlusive diseases in the vertebobasilar circulation. The site of occlusion was confirmed by cerebral angiography. The subjects included 12 patients with unilateral subclavian artery occlusion (SA group), 11 patients with unilateral occlusion at the origin of the vertebral artery (V1 group), 6 patients with unilateral vertebral artery occlusion before the branching of the posterior inferior cerebellar artery (V2 group), 14 patients with unilateral vertebral artery occlusion after the branching of the posterior inferior cerebellar artery (V3 group), 5 patients with basilar artery occlusion (BA group), 5 patients with unilateral posterior cerebral artery occlusion (PCA group), and 12 patients without any occlusive lesions in the vertebobasilar circulation (control group).

Duplex ultrasonography is widely used to study not only the carotid artery but also the vertebral artery. Touboul et al have reported the application of duplex scanning for investigation of the normal vertebral artery. Recently, color-coded duplex ultrasonography has been used for evaluation of the hemodynamics of the vertebral artery. Many investigators have indicated the usefulness of duplex ultrasonography for evaluating stenotic lesions of the vertebral artery, the subclavian steal phenomenon, and vertebral artery dissection. Dick and Jackson and Davis et al compared duplex ultrasonographic findings in the vertebral artery with angiographic findings and noted a good correlation between the two methods. However, the correlation of these methods with regard to the site of occlusion in the vertebobasilar circulation and the pattern of the vertebral artery flow velocity waveform has not yet been fully evaluated.

Results In the control group the mean and end-diastolic blood flow velocities were 25.5±6.9 cm/s and 16.2±4.3 cm/s, respectively, and the side-to-side differences of these velocities were 4.8±5.2 cm/s and 4.7±4.1 cm/s, respectively. All patients in the SA group demonstrated retrograde flow on the affected side. In the V1 group no flow signals were detected on the occluded side. In the V2 group the mean velocity (7.2±3.1 cm/s) was lower than in the control group, and the end-diastolic velocity was zero on the affected side. In the V3 group the mean and end-diastolic velocities (11.5±3.1 cm/s and 5.9±2.8 cm/s, respectively) on the occluded side were lower than in the control group. Flow velocities on the unaffected side were higher than those on the affected side in the SA, V1, V2, and V3 groups. However, there were no differences in flow velocity between the control, BA, and PCA groups.

Conclusions Measurement of vertebral artery blood flow velocity may help in localizing the site of occlusion in the subclavian and vertebral arteries.

Key Words • duplex scanning • occlusion • vertebral artery • vertebobasilar circulation

Our objective was to determine whether Doppler ultrasound measurement of the mean and end-diastolic flow velocities in the vertebral artery within the vertebral canal could detect occlusion at various sites in the vertebobasilar circulation, including the subclavian, vertebral, basilar, and posterior cerebral arteries.

Subjects and Methods

Duplex carotid ultrasonography was performed in 3134 patients at the Neurosonology Laboratory of the National Cardiovascular Center in Japan between June 1, 1989, and December 31, 1991. We routinely performed B-mode scans and pulsed-Doppler flow velocity measurements for both the carotid and vertebral arteries. Cerebral angiography (arch arteriography and/or three- or four-vessel arteriography) was carried out in 602 of the 3134 patients before or within 1 week after duplex carotid ultrasonography. Of these 602 patients, 53 with occlusive lesions in the vertebobasilar circulation and 12 with a normal verteobasilar system underwent full angiographic evaluation of the intracranial arteries, the bilateral subclavian arteries, the bilateral vertebral arteries, the basilar artery, and the bilateral posterior cerebral arteries. We entered these 65 patients (46 men and 19 women, aged 60.7±9.8 years) into the present study.

Based on their angiographic findings, we divided the 65 patients into the following seven groups: 12 patients with normal angiograms (control group), 12 patients with unilateral occlusion of the subclavian artery proximal to the origin of the vertebral artery (SA group), 11 patients with unilateral occlusion at the origin of the vertebral artery (V1 group), 6 patients
with unilateral vertebral artery occlusion before the branching of the posterior inferior cerebellar artery (PICA) (V2 group). 14 patients with unilateral vertebral artery occlusion after the branching of the PICA (V3 group), 5 patients with occlusion of the middle or distal portion of the basilar artery (BA group), and 5 patients with unilateral perimesencephalic occlusion of the posterior cerebral artery (PCA group). In the V1 group all 11 patients had infarction of the cerebellum and/or medulla oblongata supplied by the PICA on the affected side. In 6 of these 11 patients the proximal vertebral artery was not visualized, but the distal portion was weakly opacified by collateral flow via muscle branches during ipsilateral subclavian arteriography. In the other 5 patients, both ipsilateral subclavian arteriography and contralateral vertebral arteriography failed to visualize not only the proximal portion of the vertebral artery but also the distal portion and the PICA on the affected side. According to these findings, we distinguished the V1 group from subjects with congenital vertebral aplasia.

Of the 53 patients with occlusion of the vertebrobasilar circulation, 47 had ischemic stroke and 6 had transient ischemic attacks in the vertebrobasilar artery system. In the control group 3 patients had lacunar infarction, 1 had a transient ischemic attack in the carotid territory, 6 had lacunar stroke, and 2 had transient ischemic attacks in the vertebrobasilar territory. There were no significant differences in age among the seven groups (Table 1).

We used a commercially available color-coded duplex ultrasonicographic device (Toshiba SSA 270 A, Toshiba Inc). The duplex transducer used a 7.5-MHz ultrasound beam for imaging and a 5.0-MHz beam for pulsed Doppler.

Each patient was examined in the supine position, with the neck extended and the head turned away from the side being scanned. The transducer was placed on the neck using the anterior oblique approach. On longitudinal scans the sample volume (2 to 3 mm) was set within the vertebral artery, which was displayed as linearly as possible, between the transverse processes at the C3-4, C4-5, or C5-6 levels of the cervical spine. Particular care was taken to keep the incident angle between the beam and the vertebral artery at 60 degrees or less. The pulse repetition frequency was 3.0 or 3.5 kHz, and the low-pass filter was set at 70 Hz.

Table 1. Blood Flow Velocities In Each Group

<table>
<thead>
<tr>
<th>Group</th>
<th>Age, y</th>
<th>No. of Patients</th>
<th>Sex (M/F)</th>
<th>No. of Arteries</th>
<th>Systolic Velocity Direction</th>
<th>Mean Velocity, cm/s</th>
<th>Mean Velocity SSD, cm/s</th>
<th>End-Diastolic Velocity, cm/s</th>
<th>End-Diastolic Velocity SSD, cm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>60±5.5</td>
<td>12</td>
<td>7/5</td>
<td>24</td>
<td>Antegrade</td>
<td>25.5±6.9</td>
<td>4.8±5.2</td>
<td>16.2±4.3</td>
<td>4.7±4.1</td>
</tr>
<tr>
<td>SA</td>
<td>61.6±10.5</td>
<td>12</td>
<td>8/4</td>
<td>12</td>
<td>Retrograde</td>
<td>[23.0±13.3]</td>
<td>27.9±13.4</td>
<td>[11.0±9.9]</td>
<td>14.8±11.1</td>
</tr>
<tr>
<td>V1</td>
<td>56.6±11.3</td>
<td>11</td>
<td>8/3</td>
<td>11</td>
<td>Antegrade</td>
<td>[50.9±20.99#]</td>
<td>[45.6±20.4]</td>
<td>[22.9±6.9]</td>
<td></td>
</tr>
<tr>
<td>V2</td>
<td>63.7±8.0</td>
<td>6</td>
<td>4/2</td>
<td>6</td>
<td>Antegrade</td>
<td>[7.2±3.1*]</td>
<td>22.5±12.5</td>
<td>[0*]</td>
<td>17.3±8.4</td>
</tr>
<tr>
<td>V3</td>
<td>57.2±12.3</td>
<td>14</td>
<td>12/2</td>
<td>14</td>
<td>Antegrade</td>
<td>[11.5±3.11]</td>
<td>25.2±7.2</td>
<td>[5.9±2.8#]</td>
<td>16.0±5.0*</td>
</tr>
<tr>
<td>BA</td>
<td>69.8±6.1</td>
<td>5</td>
<td>4/1</td>
<td>10</td>
<td>Antegrade</td>
<td>29.0±10.3</td>
<td>5.2±4.6</td>
<td>16.0±6.0</td>
<td>3.6±2.9</td>
</tr>
<tr>
<td>PCA</td>
<td>63.2±6.3</td>
<td>5</td>
<td>3/2</td>
<td>10</td>
<td>Antegrade</td>
<td>25.0±4.5</td>
<td>3.6±3.5</td>
<td>16.1±2.4</td>
<td>1.8±2.0</td>
</tr>
</tbody>
</table>

SSD indicates side-to-side differences; C, patients without any occlusion; SA, patients with subclavian artery occlusion; V1, patients with occlusion at the origin of the vertebral artery; V2, patients with vertebral artery occlusion before branching of the posterior inferior cerebellar artery; V3, patients with vertebral artery occlusion after branching of the posterior inferior cerebellar artery; BA, patients with basilar artery occlusion; PCA, patients with posterior cerebral artery occlusion; [ ], data for the occluded side; and ( ), data for the contralateral side.

We measured the time-averaged mean velocity and the end-diastolic velocity in both vertebral arteries as a mean value obtained from five consecutive cardiac cycles. These velocities were then corrected with incident angle and compared among the various groups. Side-to-side differences of the mean and end-diastolic velocities were also calculated and compared among the groups.

The age and flow velocity data for each group were expressed as mean±SD. For the analysis of velocity data, we used the unpaired t test and ANOVA followed by Scheffe’s multiple comparison test. A value of P<.05 was accepted as indicating a statistically significant difference.

Results

The vertebral arteries were clearly visualized on B-mode images in all patients. The mean and end-diastolic flow velocities and the side-to-side differences for each group are shown in Table 1.

Fig 1. Angiogram and Doppler waveforms of a patient in the control group. BA indicates basilar artery; PCA, posterior cerebral artery; PICA, posterior inferior cerebellar artery; and VA, vertebral artery.
In the control group blood flow was antegrade, and the mean and end-diastolic flow velocities were 25.5±6.9 cm/s and 16.2±4.3 cm/s, respectively; the side-to-side differences of the mean and end-diastolic velocities were 4.8±5.2 cm/s and 4.7±4.1 cm/s, respectively (Fig 1). In the SA group all patients demonstrated retrograde flow on the affected side in the systolic phase or during the entire cardiac cycle (Fig 2). In all patients of the V1 group the vertebral artery was identified by B-mode imaging on the occluded side, but no signals were obtained throughout the cardiac cycle. In the V2 group a flow signal on the affected side was identified only during the systolic phase but not in the diastolic phase (Fig 3), and the mean flow velocity (7.2±3.1 cm/s) was significantly lower than that in the control, SA, BA, and PCA groups (P<.01). In the V3 group (Fig 4), the mean and end-diastolic velocities (11.5±3.1 cm/s and 5.9±2.8 cm/s, respectively) on the occluded side were significantly lower than those in the control, SA, BA, and PCA groups (mean velocity, P<.01 versus the control, BA, and PCA groups, P<.05 versus the SA group; end-diastolic velocity, P<.01 versus the control, BA, and PCA groups).

Flow velocities on the unaffected side were higher than those on the affected side in the SA, V1, V2, and V3 groups (mean velocity, P<.01 in the SA, V2, and V3 groups; end-diastolic velocity, P<.01 in the V2 and V3 groups, P<.05 in the SA group) and were higher than those in the control, BA, and PCA groups (the difference was statistically significant for mean velocity in the SA and V1 groups [P<.05]) (Table 1).

The side-to-side differences of the mean and end-diastolic velocities were greater in the SA, V1, V2, and V3 groups than in the control, BA, and PCA groups (the difference was significant in the V1 group [Z'<.01] and the V3 group [P<.05]).

We found no significant differences in the mean or end-diastolic flow velocities among the control, SA, BA, and PCA groups.

Therefore, the SA and V1 groups were easily distinguished from the other groups by the demonstration of retrograde flow and no flow signals, respectively, with an accuracy of 100%. The V2 group was also easily identified with 100% accuracy by the detection of a positive
mean velocity and no end-diastolic flow. In addition, the presence of positive mean and end-diastolic velocities and mean velocity less than 18 cm/s (mean ± 2SD of the time-averaged mean velocities in the V3 group) identified the V3 group with an accuracy of 94.3%. However, the BA and PCA groups could not be distinguished from the control group.

Discussion
In patients with occlusion of the subclavian artery proximal to the branching of the vertebral artery, several investigators have demonstrated retrograde flow in the vertebral artery on the affected side using ultrasonography.13 Our results are compatible with their findings in that the diagnosis of subclavian artery occlusion proximal to the vertebral artery origin was easy using duplex sonography (Table 2).

In the present study vertebral artery flow velocity patterns were categorized into three types depending on the site of occlusion, ie, at the origin, before the branching of the PICA, and after the branching of this vessel (Table 2).

The difference in end-diastolic flow velocity between the V2 and V3 groups is thought to be based on differences in collateral vascular resistance. In the V3 group with vertebral artery occlusion after the branching of the PICA, blood could flow through the vertebral artery as far as the PICA. Therefore, peripheral vascular resistance in the V3 group was lower than that in the V2 group with vertebral artery occlusion before the branching of the PICA, resulting in higher end-diastolic flow velocities in the V3 group than in the V2 group.

A previous study showed that a patient with basilar artery occlusion (the site of occlusion not specified) demonstrated damped flow signals in the bilateral vertebral arteries.13 However, we could not distinguish the BA or PCA groups from the control group. If the basilar artery were occluded proximally and the collateral flow poor, we might have detected damped flow in the bilateral vertebral arteries as well as in the vertebral artery of the affected side in the V3 group. The site of basilar artery occlusion is so variable that additional diagnostic techniques such as transcranial Doppler ultrasonography or cerebral angiography should be used for the evaluation of the basilar or posterior cerebral artery.

In the SA, V1, V2, and V3 groups, flow velocities on the unaffected side were not only higher than those on the affected side but were also higher than those in the control, BA, and PCA groups. These results may be caused by compensatory acceleration of blood flow velocity on the nonoccluded side to increase the collateral circulation. It seems that marked side-to-side difference is a characteristic ultrasonographic finding in patients with unilateral subclavian or vertebral artery occlusion.

We conclude that measurement of blood flow velocity in the vertebral artery and Doppler waveform analysis may help to identify the site of occlusion in the subclavian and vertebral arteries.

References
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