Imaging of the Intracranial Vertebrobasilar System Using Color-Coded Ultrasound

M. Kaps, MD; G. Seidel, MD; T. Bauer, MD; and B. Behrmann

Background: Anatomic variety and difficult accessibility of the vertebrobasilar arteries pose considerable problems to conventional ultrasound. We evaluated the diagnostic potential of transcranial color-coded sonography in the distal part of this system.

Methods: We insonated the intracranial section of the vertebrobasilar arteries through the foramen magnum window in 24 healthy individuals using a Doppler color flow imaging system in connection with a 2.5-MHz sector transducer. Magnetic resonance images in special inclination planes were performed and compared with the color-coded duplex images in five cases.

Results: The B-mode image of the craniocervical junction and the intracranial parenchymal structures in addition to the color-coded blood flow allowed an unambiguous identification of the vertebrobasilar arteries (vertebral artery, 96%; basilar artery, 79%; and posterior inferior cerebellar artery, 50%). Blood flow velocities were measured considering the insonation angles: vertebral arteries, 50/24 cm/sec (30°); basilar artery, 59/28 cm/sec (4°); and posterior inferior cerebellar artery, 56/30 cm/sec (20°) [peak systolic/end diastolic blood flow velocity (mean angle correction)].

Conclusions: Transcranial color-coded sonography enables accurate identification and differentiation of the intracranial vertebrobasilar arteries and improves accuracy of Doppler measurements. It may prove useful for evaluation of tortuosity and for hemodynamic studies in this vascular territory. (Stroke 1992;23:1577-1582)

KEY WORDS • cerebrovascular disorders • ultrasonics • vertebrobasilar circulation

The wide range of symptoms in vascular disease of the vertebrobasilar territory has prompted considerable interest in noninvasive diagnostic tools. Because of the anatomic variety and topographic characteristics of the vertebrobasilar arteries, ultrasound diagnosis has hitherto been difficult. Conventional Doppler diagnosis enables identification of the exits of the vertebral arteries from the subclavian artery and their atlantal loop. Furthermore, color-coded ultrasound has now also made reliable imaging of the intertransversal course possible. Intracranial sections of the vertebral arteries and the basilar artery are accessible using transcranial Doppler ultrasound. However, because differentiation between left and right vertebral arteries and measurement of the depth of basilar artery origin are difficult, reliability of the Doppler diagnostic technique is unsatisfactory in this area.

Transcranial color-coded sonography (TCCS) has very recently made it possible to demonstrate blood flow in color-coded form in conjunction with B-mode scan. In this study, we concentrated on the question of how the intracranial vertebrobasilar system can be demonstrated using color-coded ultrasound.

Because angiograms of the vertebrobasilar system are routinely produced in projection planes completely different from ultrasonic sections, magnetic resonance images were acquired in adapted planes to ensure correct artery identification.

Subjects and Methods

Intracranial sections of the vertebral arteries and basilar artery were demonstrated with a standard 64-channel, 2.5-MHz, 90°-sector imaging transducer (model HP SONOS 1000, Hewlett-Packard). B-mode real-time sonography was performed with electric focus setting between 4 and 10 cm. In color-coded mode (with a maximal intensity of 207 W/cm² [I spla=86mW/cm²]), blood flow was superimposed on the B-mode image depending on direction (red shades, away from the probe; blue shades, toward the probe) and velocity (range, 39–77 cm/sec in color-coded form [see color bar, Figure 1]). Medium packet size and clutter filter were selected for fast imaging rates and minimizing the high-intensity, low-velocity artificial signals. In Doppler mode the sample volume was adjusted to a 1.2-mm length. During the measurement of blood flow velocity, the B-mode image was refreshed every 3 seconds to confirm the placement of the sample volume. After identification of the artery length of a few millimeters an angle correction was performed by setting a cursor parallel to the blood flow direction (Figure 1). The calculation was based on a 64-point fast Fourier transform.

The ultrasonic waves were transmitted through the occipital foramen magnum after the probe was positioned approximately 4 cm under the occipital protuberance pointing toward the nasion. Patients were...
seated or lying with maximum head flexion. On the cross-sectional image, the foramen magnum was first brought into focus. On the color-coded image, the distal limb of the atlantal loop was identified bilaterally. Because the arteries have a tortuous course, the various sections of the vertebral arteries and the beginning of the basilar artery were brought into focus gradually by tilting and rotating the probe.

We measured peak systolic and end-diastolic flow velocity bilaterally in the vertebral artery, the basilar artery, and the posterior inferior cerebellar artery. In addition, the angle between the vascular axis and the ultrasonic beam was measured to calculate an angle-corrected absolute blood flow velocity (Figure 1). This procedure requires careful visualization of the entire course of the artery to exclude tortuosity of the segment under study and ensure reliable angle determination. In individual cases, unfavorable insonation angles up to 70° could be observed (Figure 1). By rotating and tilting the Doppler probe, it was usually possible to adjust an insonation angle below 55° (Table 1); unfavorable an-

<table>
<thead>
<tr>
<th>Artery</th>
<th>With angle correction</th>
<th>Without angle correction</th>
<th>No identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA (right and left)</td>
<td>21/24 (88)</td>
<td>2/24 (8)</td>
<td>1/24 (4)</td>
</tr>
<tr>
<td>BA</td>
<td>13/24 (54)</td>
<td>6/24 (25)</td>
<td>5/24 (21)</td>
</tr>
<tr>
<td>PICA (right or left)</td>
<td>5/12 (42)</td>
<td>1/12 (8)</td>
<td>6/12 (50)</td>
</tr>
</tbody>
</table>

Values in parentheses are percent. VA, vertebral artery; BA, basilar artery; PICA, posterior inferior cerebellar artery.
Figures of more than 55° were excluded for calculation of absolute blood flow velocities. Moreover, correction for insonation angle was not applied when the artery under study had to be examined segment by segment in different insonation planes. In some subjects we were not able to register any flow signal where the artery was expected to be according to anatomic landmarks in B-mode image (Table 1).

Data were obtained from 24 healthy volunteers 12–76 (mean±SD, 36.7±18.2) years of age. We compared the blood flow velocities before and after angle correction. The flow velocity and angle of correction were recorded as mean±SD. In five subjects, magnetic resonance imaging was performed at 1.5 T (Magnetom SP, Siemens) with a two-dimensional flash sequence using the following tomographic parameters: FLASH, 600/12/60° (repetition time/echo time/flip); FOV, 23 cm; 256 × 256 matrix; two acquisitions; 4–5-mm slice thickness. The tomographic inclination was adjusted in line with the clivus after a mediosagittal localizer was brought into focus. Thereafter, color-coded ultrasound of all vertebrobasilar arteries was performed by a second investigator blinded to the results of magnetic resonance imaging. Ultrasound and magnetic resonance images were compared afterward with regard to identification and course of arteries.

Results

The foramen magnum is a readily found orientation point for demonstrating the vertebral arteries. At this landmark, both vertebral arteries bend medially and laterally around the lateral mass of the atlas into the skull at an insonation depth of 5.3±0.3 cm (n=30) (Figure 2). From there, the course of the vertebral arteries can be followed as far as the origin of the basilar artery (Figure 3) by altering the tomographic plane. If the vertebral arteries are color coded red, the posterior inferior cerebellar artery is typically demonstrated in blue because of the opposing direction of blood flow (Figure 4).

Comparison of the magnetic resonance and ultrasound images revealed evident agreement on artery identification (left and right vertebral arteries and basilar artery) in all five volunteers. Concurring results of both methods were also observed concerning individual course and branching of the arteries (Figures 3 and 4).
FIGURE 3. Doppler color flow imaging of the right (R) (large arrow) and the left (L) (small arrow) vertebral artery (VA) and basilar artery (BA) (arrowhead) in two patients (top panels) compared with magnetic resonance images in same subjects in comparable tomographic plane (bottom panels).

TABLE 2. Systolic and Diastolic Blood Flow Velocity Before and After Angle Correction

<table>
<thead>
<tr>
<th>Blood flow velocity</th>
<th>( V_o ) (cm/sec)</th>
<th>( V_c ) (cm/sec)</th>
<th>( V_c-V_o )</th>
<th>( \alpha )</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>40.2±10.5</td>
<td>49.7±12.2</td>
<td>9.5±7.2</td>
<td>30.6±12.2</td>
<td>42</td>
</tr>
<tr>
<td>Diastolic</td>
<td>19.1±5.8</td>
<td>23.7±6.7</td>
<td>4.6±4.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>57.8±8.8</td>
<td>59.4±8.4</td>
<td>1.6±3.0</td>
<td>4.2±7.7</td>
<td>13</td>
</tr>
<tr>
<td>Diastolic</td>
<td>27.1±5.4</td>
<td>28.2±6.3</td>
<td>1.2±2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PICA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>48.2±5.4</td>
<td>55.5±10.5</td>
<td>7.3±10.3</td>
<td>19.5±20.2</td>
<td>6</td>
</tr>
<tr>
<td>Diastolic</td>
<td>25.7±4.3</td>
<td>30.2±8.5</td>
<td>4.5±4.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are mean±SD. \( V_o \), blood flow velocity without angle correction; \( V_c \), blood flow velocity with angle correction; \( \alpha \), insonation angle; \( n \), number of volunteers; VA, both vertebral arteries; BA, basilar artery; PICA, posterior inferior cerebellar artery.
FIGURE 4. Left panel: Doppler color flow images of right (R) (large arrow in right panel) and left (L) (small arrow in right panel) vertebral artery (VA) colored red and right posterior inferior cerebellar artery (PICA) (arrowhead in right panel) colored blue, indicating blood flow directed toward the probe. Right panel: Magnetic resonance image of same subject in corresponding tomographic plane.

The frequency of identification of the vertebrobasilar arteries and angle correction are shown in Table 1, and the results of the flow velocity measurements are presented in Table 2. It was possible to measure the angle-corrected blood flow velocity in the vertebral arteries in 88% of the subjects. The peak systolic and end-diastolic blood flow velocities with mean angle correction of 30° were 50 and 24 cm/sec, respectively. Comparing both sides, there was no statistical difference of mean blood flow velocity ($p>0.27$) or angle correction ($p>0.34$). In 54% of the subjects, flow velocity in the basilar artery was 59 cm/sec for systolic and 28 cm/sec for diastolic flow, measured after angle correction of 4°. In 42% the posterior inferior cerebellar artery could be measured as 56 and 30 cm/sec after angle correction of 20°. Blood flow velocities of all studied arteries were within the "normal" range of 2 SDs, irrespective of angle correction. The confluence of the vertebral arteries into the basilar artery was seen at an average depth of 7.1±0.4 cm ($n=10$).

FIGURE 5. Left panel: Transtemporal imaging of PI section of posterior cerebral arteries (PCA) (red, right PCA; blue, left PCA). Right panel: Scheme of topography: 1, right PCA; 2, left PCA; 3, pedunculus cerebri; and 4, aqueductus cerebri.
Discussion

Color-coded ultrasound imaging of the intracranial vertebrobasilar system requires probes using low frequency to enable deeper penetration. Color coding of the blood flow is a prerequisite for transcranial diagnosis. Detailed analyses of five volunteers, undergoing magnetic resonance images as well as color-coded ultrasound, proved excellent correlation of both methods concerning vessel identification, course and branching of the arteries, and demarcation of ultrasonic "landmarks" (i.e., foramen magnum). We did not attempt to compare angle measurements determined by color-coded duplex to those in magnetic resonance images because in our experience it is impossible to establish reliable standardized insonation planes with a handheld transducer. Nevertheless, color-coded duplex for the first time provides accurate imaging of the intracranial vertebrobasilar arteries. The procedure is noninvasive and time saving (less than 15 minutes). The results can be documented in picture form, allowing interpretation by others.

The differences between corrected and uncorrected blood flow velocities were minor (see Table 2), as tortuous segments of the vertebrobasilar system with unfavorable insonation angles could be identified and subsequently excluded from quantification of flow velocity. Under favorable conditions, proximal sections of the cerebellar arteries can be differentiated. Moreover, knowledge of the precise course of the arteries improves the reproducibility of Doppler data.

Substantial sources of error with conventional (blind) transcranial Doppler sonography are the highly variable thickness of tissue at the craniocervical junction, the lack of orientation points for the distal section of the vertebral arteries, and possible confusion with cerebellar arteries (bidirectional flow signals).3-5 For this reason, no reliable reference values for the flow velocity in the vertebral arteries have hitherto been available. These problems do not arise with TCCS. The intracranial course of the vertebral arteries could be identified in most subjects (96%) in an insonation depth between 5.3±0.3 and 7.1±0.4 cm. The vertebrobasilar junction was clearly depicted in 10 of 24 subjects, and the further course distally could be identified in 79% (19 of 24). The depth of confluence, determined in our collective by TCCS, concurs with previous transcranial Doppler5 and magnetic resonance imaging studies.6

However, the signal attenuation caused by the considerable depth of the basilar artery (7-10 cm) limits the color Doppler. For this reason the distal sections of the basilar artery cannot as yet be demonstrated transnuchally. The transtemporal approach, however, has now made it possible to study the posterior cerebral arteries7 (section P1 and P2; Figure 5) and in some cases even the basilar head.8

Prediction of hypoplastic or aplastic vertebral arteries should be based primarily on the examination of the extracranial segments because of the better resolution with a higher (i.e., 7.5 MHz) ultrasound frequency transducer. Through the development of special low-frequency probes designed primarily for transcranial use and color-capturing techniques,9 further important technical refinements can be expected. Increased spatial resolution might facilitate the delineation of smaller cerebellar arteries.

References

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