Visualization of the Basilar Artery By Transcranial Color-Coded Duplex Sonography Comparison With Postmortem Results

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**Background and Purpose**—Transcranial color-coded sonography (TCCS) via the suboccipital approach allows direct and continuous visualization of the basilar artery (BA). In this study, we intended to evaluate the ability of native TCCS in visualizing the length of the BA by means of a comparison with postmortem measurements.

**Methods**—The BA was prospectively studied by TCCS shortly before death (median 3 days) in 46 moribund neurological patients (mean ± SD age 71.1 ± 13.1 years). The length of the BA was determined by measuring the distance between the vertebrobasilar junction and the deepest available flow signal in the top of the BA. During autopsy, photos of the vertebrobasilar system were taken to evaluate the true anatomic length and variations of the course of BA in situ, eg, straight, curved, or S-shaped.

**Results**—Comparison of the in vivo ultrasound measurements of BA length and postmortem data was possible in 44 of 46 cases. In the 2 remaining patients, the BA was occluded. The mean insonation depth of the vertebrobasilar junction was found at 66.9 ± 7.1 mm. The mean BA length was 21.5 ± 6.8 mm by color-coded duplex and 32.9 ± 6 mm anatomically (P < 0.0001). The mean difference between color mode and anatomic findings was 11.3 ± 6.4 mm in the case of a straight BA (35 cases) and 16.3 ± 4.8 mm in an anatomically tortuous course of the BA (9 cases).

**Conclusions**—Color duplex imaging enables correct visualization of the proximal two thirds of the BA, but only exceptionally of its distal one third. A tortuous course of the BA leads to an underestimation of its anatomic length.

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**Key Words:** basilar artery ■ duplex scanning ■ pathology ■ ultrasonography

Even in normal individuals the accurate identification of the intracranial segments of the vertebral arteries and of the basilar artery (BA) and their discrimination from cerebellar arteries by use of transcranial Doppler sonography (TCD) can be difficult.1,2 Compression maneuvers of the vertebral arteries (VAs) may be required to prove the junction of the VAs into the BA, as opposed to a posterior inferior cerebellar artery (PICA)-ending VA. However, compression maneuvers of the VAs are often inconclusive and can be hazardous in patients suffering from vertebrobasilar disease. Moreover, Doppler signal attenuation via the transnuchal pathway hampers reliable identification of distal segments of the BA because of the large insonation depth.

The technique of transcranial color-coded sonography (TCCS) helps to overcome some of the diagnostic insufficiencies of “conventional” TCD. It allows for the simultaneous visualization of intracranial parenchymal structures by B-mode and cerebral artery blood flow by color-coded flow imaging.3 Vertebrobasilar arteries can be depicted directly and continuously. Measurements of vessel length, as well as the hemodynamic assessment, are possible.4-6

In this study, we focused on the ability of transnuchal TCCS to determine the length and the gross morphology of the BA by comparing in vivo ultrasound findings acquired shortly before death with postmortem findings. Furthermore, we wanted to identify the anatomic variations mostly affecting the suboccipital findings at the BA.

**Subjects and Methods**

During a 10-month period, 67 moribund patients from the Neurological Department of our University Hospital were investigated. They were prospectively investigated by a complete Doppler and B-mode sonography of the extracranial and intracranial brain supplying arteries. Fifty of the 67 patients died. In 46 cases (22 men and 24 women; mean age 71.1 ± 13.1 years, range 42 to 95 years)
TABLE 1. Reason for Admission to Hospital

<table>
<thead>
<tr>
<th>Reason for Admission</th>
<th>No. of Patients (n=46)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischemic stroke</td>
<td></td>
</tr>
<tr>
<td>Anterior circulation</td>
<td>19</td>
</tr>
<tr>
<td>Posterior circulation</td>
<td>7</td>
</tr>
<tr>
<td>Intracerebral hemorrhage</td>
<td>16</td>
</tr>
<tr>
<td>Subarachnoidal hemorrhage</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
</tr>
</tbody>
</table>

By means of Doppler mode, blood flow velocity was determined in the presumed midbasilar segment of the depicted BA and was considered to be representative of this patient and his condition. All examinations were performed by the same investigator (G.S.-A.) and were recorded onto videotape. Offline evaluation by videotape was performed in a blinded manner without knowledge of the postmortem findings. The investigator was aware of the clinical diagnoses when the patient was alive.

Anatomic Length and Course of the BA

During autopsy, special care was taken not to damage the basal cerebral arteries, including the vertebrobasilar system. The vessels remained attached to the basis of the brain to avoid artificial changes such as stretching or distortion of the BA. Photos of the vertebrobasilar system were taken immediately after the brain was removed from the skull. A reference divided in millimeters was placed next to the BA. Several photos were made of the entire BA, including the vertebrobasilar junction and the top of the BA, with a CE-50 camera (Chinon) with a zoom objective 52 mm in diameter (Soligor C/D) and a focus of 95 to 210 mm focus and a Sensia Il Fujichrome 100 color slide film (Fuji; Figure); thereafter, the brain was placed in formalin for fixation. One to 2 weeks later, photos of the basal aspect of the fixed brain were made again. The length of the BA was measured on the photos (ie, color slides) of the fresh and fixed specimen at 12- to 20-fold magnification; the measurements were carried out along the entire course of the BA.

To describe the variations in the course of the BA, a subdivision was made into the following 4 configuration types: (1) straight (curve of <20°), (2) slightly single-curved (ie, 20° to 45°), (3) severely single-curved (ie, >45°), and (4) S-shaped. This subdivision considered only lateral deviations of the BA from the midline in an anterior-posterior view, not sagittal deviations.

Comparison Between TCCS and Anatomic Findings

The distance between the depth of the vertebrobasilar junction and the deepest reliably identified segment of the BA was compared with the corresponding anatomic length measurement at the fresh specimen. “Reliably identified” refers to the deepest available color signal and spectral waveform that could be clearly distinguished from an artifact and/or from a signal of a different vessel.

The difference between the anatomic and the TCCS-based length of the BA was evaluated in millimeters. Mean values, standard deviations, medians, and ranges were calculated. The nonparametric Wilcoxon signed rank test for matched pairs was performed to check the difference between anatomic and TCCS measurements for statistical significance. The same procedure was applied to the difference between color mode and Doppler mode. Statistical significance was declared at the 0.05 level.

In 11 cases, only photos of the fixed specimens were available. This is why measurements of the fresh and the fixed specimens were compared in advance to estimate the influence of the fixation procedure. The mean difference in BA length of 1.3 mm yielded a negligible effect of fixation in this gross pathological analysis.

The study was performed according to the Hungarian laws, and patients were studied in compliance with a protocol previously approved by the local ethics committee of the University Medical School.

Results

Anatomic analysis of the course of the BA revealed that the straight type was the most common configuration (n=37; 80%); the slightly curved and the severely curved types were present in 5 (11%) and 3 cases (7%), respectively. The S-shaped type was seen in only 1 case.

Comparison of in vivo and postmortem measurements of BA length was possible in 44 of the 46 cases. In these patients, an occlusion or a hemodynamically relevant stenosis

sufficient TCCS and corresponding postmortem findings were available.

Reasons for admission to hospital of these patients are given in Table 1: there were 16 cases of intracerebral bleeding detected by initial CT scan. Supratentorial parenchymal hemorrhage was found in 12 cases, and infratentorial hemorrhage was observed in 2. In another 2 cases, a supratentorial and infratentorial hemorrhage occurred at the same time. The intracerebral hemorrhage was accompanied by intraventricular bleeding in 8 cases. An additional subarachnoid hemorrhage occurred in 2 of 16 cases.

In every case, the cause of death was determined by an experienced pathologist during autopsy. Seventeen patients died of pneumonia. In 15 cases the cause of death was increased intracranial pressure; 7 patients died of pulmonary embolism. In 5 cases the cause of death was cardiopulmonary arrest, in 1 case the patient died of sepsis, and in 1 case the cause of death remained unknown, despite necropsy. The median interval between the ultrasound examination and death was 3 days (range 2 hours to 135 days).

TCCS

The intracranial segments of the VAs and the BA were assessed by TCCS via the foramen magnum (suboccipital approach) with a dual frequency 2.0/2.5-MHz 90° sector imaging transducer (HP SONOS 2000, Hewlett-Packard). An emission frequency of 2 MHz was used for all studies. The ultrasound beam was placed approximately 4 cm beneath the occipital protuberance, while the patients were lying in a lateral position with the neck semi-inclined. The majority of patients were examined at the bedside in the intensive care unit. In these cases, the examiner’s position was at the patient’s side. Patients with raised intracranial pressure were investigated in supine position; the examiner elevated the patient’s head by means of a pillow to place the ultrasound beam at the nuchal region. The position of the head was never changed to the same level as the body during ultrasound. The ultrasound studies of patients with intracranial bleeding were included only if an adequate flow signal could be detected. To optimize the quality of the Doppler signal and consider a tortuous course of the insonated arteries, the probe was moved slightly to the right or left of the midnuchal position. The examination was started at an insonation depth of 10 cm. By superimposing the color-coded image with the B-mode gray scale image at this site, the typical Y-shaped vertebrobasilar junction could easily be visualized. The axial sample volume of 0.29 cm was kept constant during the measurements. At the beginning of each examination, the color scale was set at 42 cm/s; during the course of the examination, color scale and color gain settings were chosen individually to provide optimal imaging conditions. Visualization of a color signal at a distal site without a corresponding pulsed Doppler signal was judged to be an artifact (so-called color bleeding). The length of the BA was evaluated in millimeters. Mean values, standard deviations, medians, and ranges were calculated. The nonparametric Wilcoxon signed rank test for matched pairs was performed to check the difference between anatomic and TCCS measurements for statistical significance. The same procedure was applied to the difference between color mode and Doppler mode. Statistical significance was declared at the 0.05 level.

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Comparison of in vivo and postmortem measurements of BA length was possible in 44 of the 46 cases. In these patients, an occlusion or a hemodynamically relevant stenosis...
of the BA had been excluded in advance by ultrasound. In the 2 remaining cases, the diagnosis of a BA occlusion had been made based on the absence of the Doppler signal in the BA and on a reduced flow velocity and increased pulsatility index of the Doppler signal in the VAs. In both patients, this diagnosis could be confirmed after death by sectioning the BA into 3-mm slices. Both occluded BAs had a straight course.

The mean values of the in situ findings and of the TCCS measurements are shown in Table 2.

The overall mean difference in the length of the BA between the color-coded mode and the anatomic measurement was 12.4±6.4 mm (median 12.5 mm, range –6 to 25 [negative values indicate that the length detected by TCCS was greater than that detected anatomically]) (P<0.0001). Furthermore, the overall mean difference in the length of the

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**TABLE 2. Ultrasound Findings and Anatomic Analysis**

<table>
<thead>
<tr>
<th>TCCS findings</th>
<th>Mean Value</th>
<th>SD</th>
<th>Median</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>BA length (mm), color visualization</td>
<td>21.5</td>
<td>±6.8</td>
<td>20.5</td>
<td>9–37</td>
</tr>
<tr>
<td>Depth of vertebrobasilar junction</td>
<td>66.9</td>
<td>±7.1</td>
<td>66.5</td>
<td>52–83</td>
</tr>
<tr>
<td>(mm), color signal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deepest color signal, mm</td>
<td>88.1</td>
<td>±9.6</td>
<td>87.5</td>
<td>66–118</td>
</tr>
<tr>
<td>Deepest Doppler spectrum, mm</td>
<td>91.3</td>
<td>±9.1</td>
<td>91.5</td>
<td>71–118</td>
</tr>
<tr>
<td>BA length (mm), spectral detection</td>
<td>24.5</td>
<td>±6.7</td>
<td>24.5</td>
<td>11–37</td>
</tr>
<tr>
<td>Peak-systolic velocity, cm/s</td>
<td>47.6</td>
<td>±14.8</td>
<td>45</td>
<td>23.1–80.7</td>
</tr>
<tr>
<td>End-diastolic velocity, cm/s</td>
<td>15.4</td>
<td>±7.9</td>
<td>12.3</td>
<td>5.8–37.3</td>
</tr>
</tbody>
</table>

| Anatomic findings                    |            |      |        |       |
| Length of BA, mm                     | 32.9       | ±6   | 31     | 25–57 |
BA between the Doppler mode and the postmortem measurement was 9.8±6.1 mm (median 9.5 mm, range −10 to 23; P<0.0001). Length measurements determined by Doppler mode were always greater than or equal to those obtained on color mode: The mean difference between measurements evaluated by color-coded mode and Doppler mode was 3.0±2.6 mm (median 2 mm, range 0 to 11; P<0.0001).

In 35 cases with a straight BA course, the mean difference between color mode–based measurements and anatomic measurements was 11.3±6.4 mm (median 11 mm, range −8 to 25). In the 9 patients with a tortuous BA configuration, the anatomic measurement revealed a greater length of the BA than could be evaluated during color mode imaging. The mean difference was 16.3±4.8 mm (median 16 mm, range 7 to 22).

In 5 cases, the BA length evaluated by ultrasound was greater than in the anatomic reality. In 5 patients, the investigator visualized the distal basilar bifurcation by TCCS; in these cases, the difference between postmortem analysis and visualization by color mode were −6 mm, −4 mm, −1 mm, +5 mm, and +6 mm, respectively.

**Discussion**

Previous studies on imaging of the vertebrobasilar system with TCCS were carried out in healthy subjects and not in patients with a much wider anatomic variety due to vascular disease. In only in a few studies was a “gold standard” used as a reference for ultrasound findings.²⁻⁸ Kaps et al⁹ compared visualization of vertebrobasilar arteries by TCCS with axial MR images in volunteers. Droste et al⁹ evaluated the diagnostic benefit of echocontrast agent in patients with insufficient precontrast TCCS investigations of the vertebrobasilar system; in some cases, the authors validated their ultrasound findings with conventional angiography or MR angiography. In our study, we compared the in vivo ultrasound assessment performed a few days before death with the corresponding postmortem findings in 46 patients. To the best of our knowledge, ours is the first study of this kind with vertebrobasilar vasculature.

In concordance with previous TCCS studies, we found a wide range for the insonation depth of the vertebrobasilar junction (52 to 83 mm); Martin et al⁷ and Droste et al⁹ identified the origin of the BA at an insonation depth of 54 to 88 mm and 62 to 84 mm, respectively. Schöning and Walter⁶ detected the junction site at a distance of 55 to 76 mm in women and 65 to 80 mm in men. The large variation of the thickness of the nuchal soft-tissue layer and the variable adaptation pressure of the probe used by the investigator to place the transducer in its optimal position are reasons for this broad range. In a pathoanatomic validation study, Ringelstein et al⁹ measured the distances of various vertebrobasilar landmarks from the nuchal skin surface in sagittal MRI images of the skull; they found that the distance from the suboccipital skin surface to the vertebrobasilar junction ranged between 70 and 110 mm.

Besides our study and that of Droste et al⁹ no other studies have evaluated the diagnostic accuracy of TCCS for measurement of BA length. Similarly to our results, the authors of the latter series could image the vertebrobasilar junction and the proximal 2 cm of the BA completely or partially after the application of echocontrast agent in most patients with insufficient precontrast TCCS examination.

The postmortem length of the BA was as large as 32.9±6.6 mm; this value exactly agrees with previous anatomic studies, which reported an average BA length of 32 to 33 mm.⁹,¹⁰ Comparing ultrasonic (21.5±6.8 mm) and anatomic (32.9±6.6 mm) measurements, we evaluated a shorter BA by color imaging with a mean difference of 12.4±6.4 mm. Surprisingly, in 11% (5/44) of the cases, the BA was shorter in anatomically measured length compared with values determined by TCCS. We assume that the investigator erroneously insonated the proximal segment of one PCA in cases of overestimation by ultrasound and consequently could not depict the real superior bifurcation.

Our data demonstrate that an anatomically tortuous (curved or S-shaped) configuration of the BA leads to a systematic underestimation of TCCS in measuring vessel length. The mean difference between color mode and anatomic measurement was larger in case of tortuous course than it was in the remaining patients (16.3±5 mm versus 11.3±6 mm). We attribute this to 2 facts: First, a tortuous configuration of the BA introduces per se a higher possibility to lose the Doppler signal distally to the site of change in direction. Second, we did not trace a serpentine shape of the BA segment by segment by means of extremely different positions of the transducer, because the summation of such segmental measurements would have yielded an incorrect overall-length measurement.

The results of our postmortem validation study confirmed those of Brandt et al¹¹: In a clinical prospective study, the authors could show in 19 patients with clinically suspected acute BA occlusion that native extracranial and intracranial Doppler sonography is able to exclude proximal BA occlusion verified by CT angiography; however, in 2 cases of distal BA occlusion, Doppler sonography findings were false-negative.

In summary, we could show by means of a comparison between in vivo and postmortem findings that native transtemporal TCCS enabled us to visualize the proximal two thirds of the BA length. A tortuous BA might confound an accurate measurement, and variations of the superior bifurcation of BA may make it harder to identify distal segments of the BA transtemporally. This confirms a rule of sonography that the transtemporal insonation of the origin of both posterior

### TABLE 3. Difference Between TCCS (Color Mode) and Anatomic Analysis (n=44) in Measurement of BA Length

<table>
<thead>
<tr>
<th>Difference Between TCCS and Anatomical Measurements</th>
<th>No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postmortem measurement of BA &lt; ultrasonic finding</td>
<td>5</td>
</tr>
<tr>
<td>Postmortem measurement of BA &gt; ultrasonic finding</td>
<td>39</td>
</tr>
<tr>
<td>1–5 mm</td>
<td>4</td>
</tr>
<tr>
<td>6–10 mm</td>
<td>8</td>
</tr>
<tr>
<td>11–15 mm</td>
<td>12</td>
</tr>
<tr>
<td>&gt;15 mm</td>
<td>15</td>
</tr>
</tbody>
</table>

³
cerebral arteries is an unavoidable step for a reliable judgment of the vertebrobasilar system.

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References
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