Frontal Bone Windows for Transcranial Color-Coded Duplex Sonography

Erwin Stolz, MD; Manfred Kaps, MD; Andeas Kern, MD; Wolfgang Dorndorf, MD

Background and Purpose—The use of the conventional temporal bone window for transcranial color-coded duplex sonography (TCCS) often results in difficulties in obtaining angle-corrected flow velocity measurements of the A2 segment of the anterior cerebral artery, the posterior communicating artery, and the midline venous vasculature because of the unfavorable insonation angle. The same applies to B-mode imaging of the frontal parenchyma. However, transorbital TCCS raises problems with the insonation of the orbital lens. To overcome these drawbacks, we studied the feasibility of frontal bone windows for TCCS examinations.

Methods—In 75 healthy volunteers (mean age, 45.3 ± 17.0 years; age range, 17 to 77 years), the circle of Willis and the venous midline vasculature were insonated through a lateral and paramedian frontal bone window. Insonation quality of parenchymal structures (B-mode) was graded on a 3-point scale depending on the visibility of typical parenchymal landmarks. In a similar manner, the quality of the color-/Doppler-mode imaging of the arteries of the circle of Willis and the internal cerebral veins was assessed. In 15 patients (mean age, 62.7 ± 13.7 years; age range, 33 to 83 years), the color-/Doppler-mode imaging quality of the intracranial vessels before and after application of an ultrasound contrast-enhancing agent was compared.

Results—B-mode insonation quality was optimal to fair in 73.3% of cases using the lateral and in 52.0% of cases using the paramedian frontal bone window, with defined parenchymal structures used as reference. Insonation quality decreased in those older than 60 years. In those younger than 60 years, angle-corrected flow velocity measurements of the A2 segment of the anterior cerebral artery and the internal cerebral vein were possible in 73.6% and 60.0%, respectively. Contrast enhancement resulted in a highly significant improvement in the imaging quality of the intracranial vessels.

Conclusions—The transfrontal bone windows offer new possibilities for TCCS examinations, although the insonation quality is inferior to the conventional temporal bone window in terms of failure of an acoustic window. This can be compensated for by application of an ultrasound contrast-enhancing agent. (Stroke. 1999;30:814-820.)

Key Words: cerebral arteries • cerebral veins • TCCS • ultrasonography

Transcranial color-coded duplex sonography (TCCS) is an established tool for examination of the basal cerebral arteries. New aspects of TCCS are assessment of the brain parenchyma and intracranial veins and sinuses. The standard approach is insonation through a temporal bone window. With the use of the transfarotinal insonation plane, the vertebralbasilar system can be identified. For examination of the straight sinus, a transcocipital approach has been described. However, the transtemporal approach poses problems in the imaging of the frontal parenchyma and in obtaining angle-corrected flow velocity measurements of the A2 segment of the anterior cerebral artery (ACA) and the posterior communicating artery (PCoA) because of the unfavorable insonation angle. A frontal insonation plane would facilitate the assessment of frontal tumors and aneurysms and could be helpful in solving the question of spasms of the ACA. Furthermore, cross-flow through the PCoA might be identified more easily. The ultrasonographic imaging of the internal cerebral veins (ICVs) that serve as important collateral channels in intracranial venous thrombosis is still only a partially solved problem. Identification rates reported thus far in the literature are <40% in the group aged 20 to 60 years when the transcocipital approach is used.

Although TCCS allows the depiction of flow signals of the circle of Willis through the superior orbital fissure, partly avoiding the limitations of the transtemporal insonation plane, there are as yet no studies that have shown the feasibility of transorbital TCCS using Food and Drug Administration–approved power settings implemented for protection of the orbital lens.

This study was designed to test the abilities of frontal acoustic bone windows for TCCS examination with regard to the aforementioned problems.
Subjects and Methods

Volunteers
Seventy-five healthy volunteers agreed to take part in this study. The age range was 17 to 77 years, with the mean age 45.3 ± 17.0 years. Males (n = 37; mean age, 49.7 ± 16.9 years) and females (n = 38; mean age, 41.1 ± 16.2 years) were nearly equally represented. Thirty-five participants were aged < 40 years, 20 were between 40 and 60 years, and 20 were aged > 60 years. All volunteers were examined without ultrasound contrast enhancement.

Examination Technique
TCCS examinations were performed with a phased-array ultrasound system (Hewlett Packard, Sonos 2000) equipped with a 2-MHz transducer. For insonation, a lateral frontal bone window (LFBW) and paramedian frontal bone window (PMFBW) were chosen (Figure 1). The LFBW was located above the lateral aspect of the eyebrow, and the PMFBW was slightly lateral of the midline of the forehead.

B-Mode (Parenchymal) Sonography
For depiction of the parenchymal anatomy, an insonation depth of 16 cm was chosen so that the contralateral skull became visible. The LFBW constantly allowed the imaging of the sylvian fissure in a frontal-transverse insonation plane. In a high percentage of subjects, the middle cerebral artery (MCA) was identified as an anatomic structure from the outline of the vessel lumen as echogenic double reflex (Figure 2). The hypophyseal groove was visible in more than half of the volunteers. Similar to the transtemporal approach, the mesencephalon was depicted as a hypoechogenic structure, although the usual appearance was distorted by the slightly oblique insonation plane.

The most prominent parenchymal structure insonated through the PMFBW was the hyperechogenic choroid plexus of the third ventricle; the ventricle itself was depicted as a hypoechogenic structure, as was the corpus callosum. The orbital roof appeared as a hyperechogenic structure (Figure 3). A frontal-sagittal insonation plane was used for insonation through the PMFBW.

To quantify the parenchymal insonation quality, a 3-point scale was devised on the basis of the visibility of defined parenchymal landmarks. For the LFBW, the sylvian fissure and the mesencephalon were chosen as reference structures; for the PMFBW, the orbital roof, the choroid plexus of the third ventricle, and the corpus callosum were chosen. The following scale was used for both the LFBW and the PMFBW: 2, clearly visible parenchymal landmarks; 1, parenchyma visible but blurred; and 0, no parenchymal structures visible.

Color-/Doppler-Mode Sonography
To insonate the circle of Willis through the LFBW, the insonation depth was lowered to 10 cm, and the pulse repetition frequency (PRF) was adjusted to a medium range (20 cm/s). The most prominent vascular structure when the LFBW was used was the A2 segment of the ACA with a flow direction toward the probe. The ipsilateral A1 segment of the ACA was coded with a flow away from the probe, and the M1 segment of the MCA was coded with a flow toward the probe, although the insonation of the M1 segment was frequently difficult because of the unfavorable insonation angle. The posterior cerebral artery (PCA) was coded with flow away from the transducer in the lateral frontal insonation plane. Frequently the PCoA was depicted (Figure 2). In some volunteers the basilar head was visible.

By further lowering the PRF, the ICVs could be insonated slightly above the choroid plexus of the third ventricle at a depth of 9 to 10 cm with the use of the PMFBW. Reduction of the insonation depth and a low PRF enabled visualization of the pericallosal artery in its course around the knee of the corpus callosum (Figure 4). In some of the volunteers, the basilar head and the PCA could be depicted through the PMFBW.

Figure 1. A, Diaphanoscopy of the human skull showing the location of the LFBW and PMFBW. B, Position of the LFBW (F1) and PMFBW (F2) on the skull surface.

The quality of the color-/Doppler-mode sonography through the frontal bone windows was graded on a 3-point scale depending on the appearance of the frequency-based color-coded signal of a given vessel and the quality of its Doppler spectrum, as follows: 2, vessel
visible to the full extent that can be expected in the given examination plane; Doppler spectrum sufficient for measurement; 1, vessel visible, but fragmented color coding or Doppler spectrum insufficient for measurement; and 0, no vessel visible and/or no Doppler spectrum obtainable.

The frontal bone windows appeared to be generally smaller than the temporal bone window, which allows the insonation in different transverse (mesencephalic, ventricular insonation) and coronal (anterior and posterior) planes. Therefore, generally no differentiation between insonation window and insonation plane was performed. Insonation through the LFBW had a transverse orientation, and that through the PMFBW had a sagittal orientation. From these positions, the vascular and parenchymal structures could be imaged by fanlike tilts of the transducer of approximately $\pm 5^\circ$.

Patients

Fifteen patients (mean age, 62.7 ± 13.7 years; age range, 33 to 83 years) were examined with echo contrast–enhanced TCCS (Leovist; Schering AG; intravenous infusion of 17 mL at a concentration of 300 mg/L by infusion pump, infusion rate 60 mL/h) for the evaluation of the intracranial vasculature. Thirteen patients had acute ischemic stroke, 1 a basilar head aneurysm, and 1 cerebral venous thrombosis. Two of the stroke patients had an occlusion, and 1 had a high-grade stenosis of the extracranial internal carotid artery, diagnosed by duplex sonography.

In these patients, the imaging quality of the intracranial vasculature was assessed with the use of the frontal bone windows in terms
of the number of the vessels imaged and the quality of insonation according to the 3-point scale for grading the color-/Doppler-mode imaging described above.

Data Evaluation

The software package Turbo Statistik 3.0 was used for statistical data evaluation. A nonparametric ANOVA (Mann-Whitney U test) was used for comparison of flow velocities between different age and sex groups, and Fisher’s exact test was used for comparison of absolute frequencies of identification rates of intracranial vessels. For comparison of precontrast and postcontrast color-/Doppler-mode scores, Fisher’s exact test was also used. In this case, the number of insonated vessels rated with a score of 2 on the color-/Doppler-mode scale (i.e., those vessels with clinically useful insonation conditions) before and after contrast enhancement were compared.

Results

B-Mode (Parenchymal) Sonography

Scores of 2 and 1 for parenchymal insonation quality through the LFBW were reached in 73.3% of volunteers; 26.7% showed lack of a sufficient acoustic bone window. The PMFBW allowed a fair insonation quality (scores of 2 and 1) in 52.0% of cases; no acoustic window was found in 48.0% of volunteers. A clear age dependence for both the LFBW and the PMFBW was observed. Insonation quality scores of 2 and 1 were found in 81.8% of cases for the LFBW and in 60.0% for the PMFBW for those aged ≤60 years; for those aged >60 years, insonation quality declined to 50.0% (P<0.001) and 30.0% (P<0.05), respectively. Best insonation conditions were found in the volunteers aged <40 years. In this age group, scores of 2 and 1 were reached in 91.4% through the LFBW and in 68.6% through the PMFBW. Men tended to have a better acoustic bone window than women for both the LFBW and the PMFBW.

Color-/Doppler-Mode Sonography

The rates of sufficient vascular insonation conditions, corresponding to a score of 2 on the scale grading the quality of color-mode imaging and the Doppler spectrum, are summarized in Table 1. The LFBW allowed angle-corrected flow velocity measurements of the different segments of the circle of Willis at insonation rates between 73.6% and 40.0% in those volunteers aged ≤60 years. In the same age group, the PMFBW allowed a sufficient insonation of the ICV in 60.0% (Table 1). In those aged >60 years, insonation conditions declined markedly for both the LFBW and the PMFBW. This finding was statistically significant for the A2 ACA (P<0.0001), the A1 ACA (P<0.0001), the M1 MCA (P<0.0001), the PCA (P=0.0003), the PCoA (P=0.0027), and the ICV (P=0.02).

The angle-corrected flow velocity measurements for the A2 segment of the ACA and the ICV are summarized in Table 2. Systolic and diastolic flow velocities of the A2 ACA decreased with increasing age (P<0.05). This effect did not reach the level of significance for the ICV. Women tended to have higher systolic and diastolic flow velocities than men for both the A2 ACA and the ICV, although this was without statistical significance.

Patients

Echo contrast enhancement resulted in a marked improvement of the imaging quality of the intracranial vessels, whereas contrast enhancement had no effect on B-mode (parenchymal) sonography. The precontrast and postcontrast enhancement results are summarized in Table 3. Concerning the quality of the acoustic window assessed on the B-mode (parenchymal) scale, the patient and normal collective groups were not distributed equally when similar age groups were compared; in the patient group, only 6 of 15 (40%) had a good to fair LFBW, and only 2 of 15 (13%) had a good to fair PMFBW. Three patients had a total lack of any acoustic
penetration. Even contralateral and ipsilateral skull structures were not visible in those patients.

With the use of the LFBW, native TCCS was able to delineate sufficiently (ie, score of 2 on the color-/Doppler-mode scale) the different segments of the circle of Willis at success rates ranging between 0% and 27%. Echo contrast enhancement resulted in a significant improvement of vascular imaging conditions, with success rates for the different segments of the circle of Willis ranging between 53% for the M1 MCA and 70% to 80% for the remaining arterial segments (Table 3). A diagnostically sufficient color and Doppler signal of the basilar head was found in 7% with native TCCS; echo contrast enhancement increased the success rate to 40%. Contrast enhancement resulted in a diagnostically useful color and Doppler signal in up to 40% of cases with the use of the PMFBW. Those patients without any acoustic penetration of the ultrasound beam did not show any contrast-enhancing effect.

All patients with extracranial internal carotid artery occlusion or stenosis unambiguously displayed a flow direction of the PCoA directed from the PCA to the intracranial internal carotid artery on the affected side and from the internal carotid artery to the PCoA on the unaffected side, demonstrating a cross-flow condition. Furthermore, a retrograde flow direction in the A1 segment of the ACA was observed in these patients ipsilateral to the extracranial occlusion or stenosis, indicating a cross-flow from the contralateral ACA through the anterior communicating artery. Using a sagittal insonation plane through the PMFBW and a transverse temporal insonation plane, we observed a partial thrombosis of a basilar head aneurysm, and its size could be confirmed correctly in 1 patient compared with MR angiography. The status of the ICVs could be assessed correctly compared with the results of MR angiography in 1 patient with cerebral venous thrombosis. Normal venous flow velocity and direction indicated that the ICV did not serve as a collateral venous pathway in this patient.

Discussion
As a standard approach for TCCS, the temporal bone window has been widely used for identification of the main segments of the circle of Willis and, as a new development, of intracranial veins and sinuses.1,2,6–8 Furthermore, the temporal bone window allows the identification of parenchymal abnormalities such as intracerebral hemorrhage, tumors, and pathology of the ventricular system.1,3–5 However, because of the unfavorable insonation angle, measurements of flow velocities of the A2 segment of the ACA, the PCoA, and the venous midline vasculature are often unreliable. The same difficulties apply to imaging of the frontal parenchyma.

Although the depiction of flow signals of the circle of Willis through the orbit by TCCS is possible,14 thus far no studies have shown the feasibility of this approach when Food and Drug Administration–approved ultrasound intensity settings implemented for the protection of the orbital lens are used. This study was designed to test the abilities of front acoustic bone windows for TCCS examination with regard to the aforementioned problems.

B-Mode (Parenchymal) Sonography
For transcranial duplex sonography, the current technological standard is the use of sector transducers. The best spatial resolution is reached in the center beams of the sector. This technical fact and the anatomic location of the temporal bone window often result in difficulties in imaging the frontal regions of the brain parenchyma. The frontal bone windows provide additional transverse and sagittal frontal insonation windows with the use of the LFBW and the PMFBW. With LFBW insonation, quality is sufficient in >80% of cases aged ≤60 years with defined parenchymal structures used as reference points. The most interesting feature of the LFBW is the ability to insonate the MCA main stem as an anatomic structure, visible as a hyperechogenic double reflex.

Although the imaging quality of the PMFBW is inferior to the insonation through the LFBW, it offers adequate imaging conditions in 60% of cases in those aged ≤60 years. In addition to the transverse and coronal insonation planes through the temporal bone window, the PMFBW enables the imaging of intracranial structures in a sagittal plane, depicting the choroid plexus of the third ventricle, the corpus callosum, and the hypophyseal groove. The frontal bone windows in conjunction with the conventional temporal acoustic window allow a more accurate size measurement of intracranial structures, as could be demonstrated in our patient with a basilar head aneurysm. In this study we observed a marked drop in imaging conditions with increasing age. This effect was more pronounced in women than in men. The most probable reason for this fact is increasing frontal hyperostosis with increasing age. Overall, lack of a sufficient acoustic window occurred more frequently compared with the con-

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**TABLE 1. Age Dependence of the Insonation Rate of Vascular Structures**

<table>
<thead>
<tr>
<th>Age, y</th>
<th>A2 ACA</th>
<th>A1 ACA</th>
<th>M1 MCA</th>
<th>PCA</th>
<th>PCoA</th>
<th>ICV</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;40</td>
<td>60/70 (85.7)</td>
<td>51/70 (72.8)</td>
<td>44/70 (62.9)</td>
<td>42/70 (60.0)</td>
<td>34/70 (48.6)</td>
<td>26/35 (74.3)</td>
</tr>
<tr>
<td>40–60</td>
<td>21/40 (52.5)</td>
<td>15/40 (37.5)</td>
<td>14/40 (35.0)</td>
<td>12/40 (30.0)</td>
<td>10/40 (25.0)</td>
<td>7/20 (35.0)</td>
</tr>
<tr>
<td>&gt;60</td>
<td>9/40 (22.5)</td>
<td>7/40 (17.5)</td>
<td>6/40 (15.0)</td>
<td>7/40 (17.5)</td>
<td>6/40 (15.0)</td>
<td>6/20 (30.0)</td>
</tr>
<tr>
<td>≥60</td>
<td>81/110 (73.6)</td>
<td>66/110 (60.0)</td>
<td>58/110 (52.7)</td>
<td>54/110 (49.1)</td>
<td>44/110 (40.0)</td>
<td>33/55 (60.0)</td>
</tr>
</tbody>
</table>

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**TABLE 2. Angle-Corrected Flow Velocities of the A2 Segment of the ACA and the ICV**

<table>
<thead>
<tr>
<th></th>
<th>PSV, cm/s</th>
<th>EDV, cm/s</th>
<th>Depth, cm</th>
<th>Angle, °</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2 ACA</td>
<td>97.7 ± 20.6</td>
<td>44.2 ± 12.1</td>
<td>5.5 ± 0.5</td>
<td>20.6 ± 13.1</td>
</tr>
<tr>
<td>ICV</td>
<td>13.6 ± 4.1</td>
<td>9.9 ± 2.9</td>
<td>8.9 ± 1.1</td>
<td>5.8 ± 8.9</td>
</tr>
</tbody>
</table>

PSV indicates peak systolic velocity; EDV, end-diastolic velocity.
Cranial window approach, with an expected rate of up to 20% of cases. The use of frontal bone windows for parenchymal diagnostics in the group aged >60 years is limited by this fact.

**Color-/Doppler-Mode Sonography**

The rate of depiction of the A2 segment of the ACA with the use of the temporal bone window and frequency-coded TCCS is rather low, with insonation rates between 40% and 65%. With the use of the frontal bone windows, in 70% of cases flow velocity measurements of the A2 segment of the ACA were possible in the group aged >60 years. Our normal values of flow velocities are similar to those found for the A1 segment of the ACA. However, the identification rate of the PCoA is low at 40% without echo contrast enhancement and is not routinely possible. On the other hand, the LFBW enables an angle-corrected flow velocity measurement of the PCoA that is not possible in the temporal insonation plane. The drop in the identification rates for the A1 ACA, M1 MCA, and PCA may be explained by the unfavorable insonation angle in the frontal examination plane.

In the frontal sagittal insonation plane, imaging of the A2 segment of the ACA, the pericallosal artery, and the ICVs is possible. The identification rate of the ICVs by the paramedian frontal approach is far higher than the results obtained by insonation through the occipital bone when similar age groups are compared (60% versus 34% in those aged ≤60 years). Our reference values of flow velocities in the ICV are in agreement with the results published in the literature. Vascular imaging conditions deteriorated with increasing age.

**Effect of Echo Contrast Enhancement and Findings in Patients**

As expected by consideration of previous studies, contrast enhancement resulted in a marked improvement in the number and insonation length of the intracranial vessels imaged. Contrast enhancement can compensate for the deteriorating imaging conditions offered by the frontal bone windows in the age group of the typical stroke patient. However, in those cases without any acoustic penetration, no contrast-enhancing effect can be expected.

Contrast-enhanced frontal TCCS enabled a more accurate determination of cross-flow conditions in those stroke patients with stenotic or occlusive disease of brain-supplying arteries because of an unambiguous assessment of the flow velocity and direction of the PCoA. In >40% of patients, the assessment of the basilar head region was possible through the frontal acoustic windows.

In summary, we have demonstrated the feasibility of frontal bone windows for TCCS examination. The frontal bone windows allow the insonation of vasculature and parenchyma in additional insonation planes not offered by the conventional temporal approach.

**Acknowledgment**

The authors are indebted to Dr. H.R. Duncker, Institute for Anatomy and Cellbiology, Justus-Liebig University, for his help in preparing the diaphanoscopy of the human skull.

**References**


**TABLE 3. Effect of Echo Contrast Enhancement on Imaging Quality of Vascular Structures in the Patient Group**

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Precontrast Score</th>
<th>Postcontrast Score</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>LFBW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1 ACA</td>
<td>20</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>A2 ACA</td>
<td>18</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>M1 MCA</td>
<td>12</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>PCA</td>
<td>16</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>PCoA</td>
<td>22</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Basilar head</td>
<td>13</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>PMFBW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pericallosal artery</td>
<td>24</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>ICV</td>
<td>24</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Great cerebral vein of Galen</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Straight sinus</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>


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