Comparison of Transcranial Power Doppler and Contrast-Enhanced Color-Coded Sonography in the Identification of Intracranial Arteries

Thomas Postert, MD, Jens Federlein, MD, Horst Przuntek, MD, Thomas Büttner, MD

Power-based transcranial color-coded sonography and contrast-enhanced transcranial color-coded sonography are ultrasonographic techniques that allow improved visualization of vascular structures. The present study was designed to investigate and compare the diagnostic capacity and applicability of both methods in the assessment of intracranial vessels of the circle of Willis (33 patients) and the vertebrobasilar system (21 patients). Compared to conventional transcranial color-coded sonography, both power-based and contrast-enhanced transcranial color-coded sonography improved the diagnostic sensitivity in identifying peripheral segments and small vessels of the circle of Willis. Contrast-enhanced transcranial color-coded sonography was significantly superior to power-based transcranial color-coded ultrasonography in the depiction of the second segment of the middle cerebral artery (66 of 66 versus 60 of 66, \( P < 0.005 \)), both segments of the anterior cerebral artery (66 of 66 versus 56 of 66 for the A1 segment, \( P < 0.005 \); 61 of 66 versus 44 of 66 for the A2 segment, \( P < 0.005 \)), the first segment of the posterior cerebral artery (66 of 66 versus 55 of 66, \( P < 0.005 \)), and the basilar artery using the transtemporal approach (21 of 21 versus 15 of 21, \( P < 0.05 \)). Using the transforaminal approach contrast-enhanced transcranial color-coded real-time sonography did not increase fine resolution of the vertebrobasilar system compared to power Doppler sonography. In conclusion, contrast-enhanced transcranial color-coded real-time sonography further improves the diagnostic potential of power Doppler sonography in the identification of vascular structures of the circle of Willis. Contrast-enhanced transcranial color-coded sonography and power Doppler sonography are equally effective in visualizing the vertebrobasilar system with branches. KEY WORDS: Power Doppler sonography; Echogenic contrast medium; Transcranial imaging; Color-coded sonography.

Received July 8, 1997, from the Department of Neurology, Ruhr-University Bochum, Bochum, Germany. Revised manuscript accepted for publication October 29, 1997.

Address correspondence and reprint requests to Dr. Th. Postert, Department of Neurology in St. Josef Hospital, Ruhr-University Bochum, Gudrunstr. 56, 44791 Bochum, Germany.

transcranial ultrasonography by allowing detection of peripheral segments and small branches of the intracranial arteries. Recent studies demonstrated that p-TCCS is superior to conventional color-coded Doppler sonography in the noninvasive diagnosis of MCA stenosis and intracranial aneurysms. In extracranial evaluation PDS imaging provided supplemental duplex sonographic information about the identification of the vertebral artery and carotid artery stenosis. Knowledge about the clinical value of CE-TCCS is scant. Small studies demonstrated that CE-TCCS is capable of analyzing intracranial peripheral vascular segments and may improve the diagnosis of low-flow angiomas.

Furthermore, the application of echogenic contrast agents allows visualization of most intracranial vascular structures in patients with inadequate acoustic bone windows. A direct comparison of both techniques to evaluate their diagnostic potential in the assessment of intracranial vessels has not been performed hitherto. We investigated and compared the capacity of p-TCCS and CE-TCCS to improve the fine resolution of arterial segments of the circle of Willis and the intracranial vertebrobasilar system.

SUBJECTS AND METHODS

Fifty-four patients (28 women and 26 men, mean age 48.8 years) without history or physical signs of cerebrovascular disease were enrolled in the study. Ultrasonographic examinations were performed using a phased-array ultrasound system (Ultramark 9 HDI, Advanced Technology Laboratories, Bothell, WA) equipped with a 2.25 MHz 90 sector scan. To provide a standardized comparison between p-TCCS and CE-TCCS all arteries were examined according to the following protocol.

Subgroup A: Circle of Willis

This subgroup consisted of 33 patients (18 women, mean age 46 years; 15 men, mean age 50.3 years). The transcranial sonographic examination employed the standard technique described in previously published studies. Color Doppler sonography was first used to visualize a vascular segment and was followed by PDS. This process was repeated twice. In 33 patients CE-TCCS examinations of the circle of Willis employing the same steps as in the unenhanced investigation were performed. We tried to identify the identical plane of section in the TCCS and p-TCCS examinations with great accuracy, before 400 mg/ml echogenic contrast medium (Levovist, Schering AG, Berlin, Germany) was injected. A contraindication to Levovist application was galactosemia. We tried to identify the following arteries: ACA (A1 and A2 segments), MCA (M1 and M2 segments), posterior communicating artery, and PCA (P1 and P2 segments). Identification rates of single segments of the circle of Willis with CE-TCCS and p-TDS were evaluated and compared. The whole examination was recorded on videotape. Two independent investigators reviewed the videotapes. A vessel was considered to be visualized if both investigators confirmed it.

Subgroup B: Vertebrobasilar System

This subgroup consisted of 21 patients (10 women, mean age 43.6 years; 11 men, mean age 49.6 years). In this subgroup the scanning plane was shifted to a coronal prepontine plane to detect distal parts of the basilar artery. The vertebral arteries and infratentorial parts of the basilar artery were investigated using an occipital transforaminal approach after the probe was positioned under the occipital protuberance pointing toward the nasion. The foramen magnum was identified for orientation. At this landmark the vertebral arteries (V3 segment in red = tortuous segment within the transverse process of the atlas) were visualized and followed by altering the tomographic plane toward the vertebrobasilar junction (V4 segment in blue = segment between vertebral loop and vertebral artery junction). Finally, infratentorial parts of the basilar artery were examined by further tilting the transducer. The examination through the transforaminal approach was performed in color-coded, power-based, and contrast-enhanced images. Identification criteria for a vascular segment were identical to those for the investigation through the temporal bone.

Optimal visualization of all vascular segments was possible with pulsed repetition frequencies between 1000 and 4500 Hz. In all examinations the color ultrasound gain level was set just below the level of the appearance of background noise. Statistical analysis was performed by the chi-square test for independence.

RESULTS

The results of TCCS, p-TCCS, and CE-TCCS examinations of the circle of Willis are summarized in Table 1. Table 2 gives the identification rates of the vertebrobasilar system using the three different ultrasonographic methods. No adverse events were
observed during or after the injection of the echogenic contrast agent. The mean time to contrast appearance was 45 s, and average persistence time of 450 s.

### CE-TCCS and p-TCCS of the Circle of Willis

In most patients the first segment of the ACA, the PCA, and both segments of the MCA could be visualized successfully using TCCS, p-TCCS, and CE-TCCS. CE-TCCS and p-TCCS were equally sensitive and clearly superior to TCCS in the depiction of the second segment of the PCA. Compared to p-TCCS, CE-TCCS allowed a significantly better identification of the M2, A1, A2, and P1 segments (Figs. 1, 2). The interobserver agreement for p-TCCS and CE-TCCS examinations of the vascular segments of the circle of Willis ranged between 87% and 100%.

### CE-TCCS and p-TCCS of the Vertebrobasilar System

In nearly all patients identification of the basilar artery and the V3 and V4 segments of the vertebral artery through the transforaminal approach was already possible with conventional TCCS examinations. Nevertheless, it is noteworthy that CE-TCCS was superior to p-TCCS in the identification of the basilar artery in coronal transtemporal sections. The interobserver agreement in p-TCCS and CE-TCCS investigations was high for the assessment of the basilar artery and vertebral arteries (94% to 100%).

### DISCUSSION

In TCCS examinations the low signal intensity is a major limitation that may complicate adequate identification of intracranial vascular structures. The purpose of our study was to evaluate and compare the diagnostic value of CE-TCCS and p-TCCS, two recently introduced ultrasonographic techniques with improved diagnostic potential compared with conventional color-coded sonography. In agreement with previous TCCS studies using galactose microbubble suspension or spherosome suspensions containing phospholipids, we found that by appropriate enhancement of the signal intensity, distal brain arteries can be identified, even when they escape visualization by noncontrast examination. In a phase I study Kaps and associates described a distinct enhancement of the color signal in eight patients after the injection of BY 963 (phospholipid suspension). Otis and coworkers found an increase in the diagnostic utility of transcranial ultrasonography in 77% of the patients studied. In none of the studies was a precise differentiation according to different vessels or vascular segments performed. In the CE-TCCS study (SH U 508 A [galactose-based microbubbles]) of Bogdahn and colleagues, which included 10 patients, the authors reported on a strong enhancement of the color signal in all examinations. In one fifth of the examinations the second segment of the MCA and the ACA were depictable only when contrast agents were used. The M3 segment of the MCA could be visualized only with CE-TCCS in 80% of examinations, and the posterior

### Table 1: Identification of Basal Cerebral Circulation with CE-TCCS in 33 Patients (Percentages in Parentheses) Versus TCCS and p-TCCS

<table>
<thead>
<tr>
<th></th>
<th>TCCS</th>
<th>p-TCCS</th>
<th>CE-TCCS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Middle cerebral artery</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>66 (100)</td>
<td>66 (100)</td>
<td>66 (100)</td>
</tr>
<tr>
<td>M2</td>
<td>56 (76)</td>
<td>60 (83)</td>
<td>66 (100)*</td>
</tr>
<tr>
<td><strong>Anterior cerebral artery</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>50 (76)</td>
<td>56 (84)</td>
<td>66 (100)†</td>
</tr>
<tr>
<td>A2</td>
<td>32 (48)</td>
<td>44 (67)</td>
<td>61 (92)‡</td>
</tr>
<tr>
<td><strong>Posterior cerebral artery</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>49 (74)</td>
<td>55 (83)</td>
<td>66 (100)†</td>
</tr>
<tr>
<td>P2</td>
<td>27 (41)</td>
<td>46 (70)</td>
<td>48 (73)</td>
</tr>
<tr>
<td><strong>Posterior communicating artery</strong></td>
<td>10 (15)</td>
<td>23 (35)</td>
<td>34 (51)</td>
</tr>
</tbody>
</table>

Insonation from the right and left side.

*Significantly better identification rate in CE-TCCS examination than in p-TCCS investigation (P < 0.05), chi-square test for independence.

†Significantly better identification rate in CE-TCCS examination than in p-TCCS investigation (P < 0.005), chi-square test for independence.
communicating artery in 60% of examinations. In coronal sections the basilar artery was detectable exclusively using CE-TCCS in four of six patients. Using the transforaminal approach in four patients, the use of contrast agent improved the identification rates for all vertebrobasilar arteries. Our results in a larger group of patients confirm the finding of an increased diagnostic sensitivity for peripheral segments of the intracranial arteries and small caliber vessels after the application of echogenic contrast agent. The identification rates are comparable for all major vascular structures.

The second ultrasonographic technique with a better signal-to-noise ratio than conventional color-coded sonography is PDS. In contrast to color-coded sonography PDS generates intravascular color signals from the amplitude of the echo signal, which depends of the density of red blood cells within the vessel. Our p-TCCS findings are in agreement with two PDS studies of the circle of Willis7,19 reporting on an increased diagnostic value for small and low-flow arteries. One of the main disadvantages of p-TCCS is the lack of information about flow direction. p-TCCS is unable to demonstrate cross-flow through the circle of Willis, as has been described in recently published TCCS study in patients with unilateral obstructive carotid artery disease. It provides no important advantages in comparison to TCCS in the examination of peak arterial systolic and end diastolic velocities of intracranial vessels. In kidney examinations, flash artifacts caused by transducer or patient motion are known to be a further possible disadvantage. In contrast, p-TCCS examinations of the brain were less often susceptible to flash artifacts.

Comparisons of our p-TCCS and CE-TCCS findings show that the use of echogenic contrast agents may further improve the diagnostic sensitivity in the assessment of intracranial vascular structures of the circle of Willis. In particular, peripheral segments of the ACA and the MCA can easily be depicted in the

<table>
<thead>
<tr>
<th></th>
<th>TCCS</th>
<th>p-TCCS</th>
<th>CE-TCCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basilar artery (coronal*)</td>
<td>9 (43)</td>
<td>15 (71)</td>
<td>21 (100)†</td>
</tr>
<tr>
<td>Basilar artery (transforaminal)</td>
<td>21 (100)</td>
<td>21 (100)</td>
<td>21 (100)</td>
</tr>
<tr>
<td>Vertebral artery (V3 segment)</td>
<td>41 (98)</td>
<td>41 (98)</td>
<td>41 (98)</td>
</tr>
<tr>
<td>Vertebral artery (V4 segment)</td>
<td>41 (98)</td>
<td>41 (98)</td>
<td>41 (98)</td>
</tr>
</tbody>
</table>

*Coronal sections through transtemporal approach.
†Significantly better visualization using CE-TCCS than compared to p-TCCS ($P < 0.05$), chi-square test for independence.

Figure 1 Transtemporal axial sections. A, In the color-coded image only parts of the M1 segment can be delineated (1). B, p-TCCS depicts the M1 (1), M2 (2), and A1(3) segments. Note that a precise differentiation of the vascular segment of the MCA bifurcation (arrow) is possible. C, Additionally, in CE-TCCS scans the ipsilateral A2 (4) segment is visible. The bifurcation of the MCA mainstem into the M2 segments appears blurred, and a precise differentiation of vascular structures is not possible (arrow).
The majority of patients after application of echogenic contrast agents, whereas PDS often failed to visualize these structures. With respect to vascular structures of the vertebrobasilar system through the transtemporal approach, CE-TCCS was superior to p-TCCS in the visualization of the basilar artery in coronal sections. Nevertheless, using the transforaminal approach neither method could substantially increase the diagnostic value of conventional color-coded sonography. However, in addition to high costs are other limitations of CE-TCCS. Despite slow injection rate artifacts due to excessive signal enhancement appeared in 14 CE-TCCS examinations. In these cases intracranial arteries appeared swollen and blurred on ultrasonograms. Furthermore, during the phase of optimal contrast enhancement vascular segments in close proximity were not distinguishable. In particular, the second segment of the ACA and branches of the second segment of the MCA could not be delineated as single vessels, whereas p-TCCS allowed accurate differentiation of the vessel wall and perivascular parenchymal structures in all cases. Neither in transtemporal nor in transforaminal p-TCCS examinations did flash artifacts occur. Because of the limited duration of the diagnostically relevant time window, the contrast-enhanced examination has to be performed rapidly, which may be impossible in uncooperative patients or those with inadequate venous access. Multiple injections of echogenic contrast agents or newer agents that provide increasing enhancement time may lengthen the relatively short diagnostic time period.

This is the largest study on the diagnostic sensitivity of CE-TCCS, and we also compare CE-TCCS and PDS in the identification of intracranial vessels. It was not our aim to compare ultrasonographic findings with angiographic studies, which represent the gold standard in vascular diagnosis. We cannot rule out the possibility that segments of intracranial arteries or small vessels were hypoplastic or aplastic in some patients. In conclusion, our study demonstrates that PDS and CE-TCCS allow accurate and reproducible identification of the most vascular structures of the circle of Willis and the vertebrobasilar system and are clearly superior to conventional TCCS examinations. Furthermore, in comparison to PDS, CE-TCCS further improves the diagnostic sensitivity for most vascular segments of the circle of Willis. The rapid and easy visualization of the broad color-coded signals of the main intracranial arteries in CE-TCCS examinations may be useful in the diagnosis of intracranial occlusive diseases, since a lack of detection of these signals may be highly suggestive of an occlusion. Both hypotheses need to be confirmed in further studies.

REFERENCES