Three-Dimensional Transcranial Color-Coded Sonography of Cerebral Aneurysms

Christof Klötzsch, MD; Alessandro Bozzato, MS; Gero Lammers, MD; Michael Mull, MD; Bernhard Lennartz, MD; Johannes Noth, MD

Background and Purpose—The role of 2-dimensional transcranial color-coded sonography (2D-TCCS) as a diagnostic tool in cases of vascular alteration is unquestioned. The skill of the operator, however, may be responsible for some intertrial variability. The clinical value of a new, workstation-based, 3D reconstruction system for TCCS was evaluated in patients with intracranial aneurysms.

Methods—Thirty patients with 30 intracranial aneurysms were investigated (8 men, 22 women; mean ± SD age 54 ± 17 years). The TCCS examinations were performed with a 2-MHz probe using the power mode. The 3D system (3D-Echotech, Germany) consisted of an electromagnet, which induced a low-intensity magnetic field near the head of the patient. A magnetic position sensor was attached to the ultrasound probe and transmitted the spatial orientation of the probe to a workstation, which also received the corresponding 2D-images from the video-port of the duplex machine. The echo contrast enhancer D-galactose (Leovist, Schering, Germany) was used in all patients to improve the signal-to-noise ratio. All patients underwent presurgical digital subtraction angiography (DSA) to demonstrate the aneurysm.

Results—Twenty-nine of 30 angiographically proven intracranial aneurysms (97%) were detected by 3D-TCCS. The aneurysmal diameter estimated by DSA ranged from 3 to 16 mm (mean 7.2 ± 3.6 mm). A comparison of the 3 main diameters of each aneurysm revealed a correlation coefficient of 0.95 between DSA and 3D-TCCS. The 3D determination of the aneurysmal size by 2 experienced sonographers correlated with 0.96.

Conclusions—3D-TCCS is a new, noninvasive method to investigate intracranial aneurysms. The differentiation between artifacts and true changes of the vessel anatomy is much easier in 3D-TCCS than in conventional 2D-TCCS. The new method yields an excellent correlation with the gold standard, DSA. Because the same 3D-TCCS data can be postprocessed by different investigators, it may be possible to improve reproducibility and increase the objectivity of transcranial color-coded duplex sonography. (Stroke. 1999;30:2285-2290.)

Key Words: aneurysm ■ angiography ■ cerebral circulation ■ ultrasonography, Doppler, transcranial

Several investigators1–8 have reported that a detection rate of 75% to 90% for cerebral aneurysms can be achieved using 2-dimensional transcranial color-coded sonography (2D-TCCS). The main criterion for diagnosis of an aneurysm with use of TCCS is a color-coded pulsating appendix connected to a vessel.1,3,5 In larger aneurysms the appendix often reveals a bicolored zone within the aneurysmal lumen as a sequel of bidirectional flow. The diameter of most of the undetected aneurysms is <6 mm.3,5 In particular, small aneurysms near the origin of the ophthalmic artery, where the internal carotid artery (ICA) performs a 180° turn, are not demonstrable, because the C3 and C4 segments of the ICA are too close together. Other regions in which anatomic conditions make the detection difficult are the proximal basilar artery and the intracranial segment of the vertebral artery and its branch, the posterior inferior cerebellar artery. Aneurysms in this region often cannot be reliably differentiated from the widespread tortuosity of these vessels.9 An improvement in the detection of small aneurysms and those of the posterior fossa results from the use of ultrasound contrast-enhancing agents, such as galactose microparticles,7,10 and power TCCS,7,11 which allow the visualization of vessels almost independently of the insonation angle. A promising new approach may be the 3-dimensional reconstruction of serial 2D-TCCS images, because any arbitrary view angle is possible.12,13 This study presents our clinical experiences with a new, workstation-based 3D reconstruction system for TCCS in patients with intracranial aneurysms.

Subjects and Methods
All patients were investigated with a power-based TCCS-system (Acuson XP128/10, 2/2.5-MHz phased-array probe). The patients
were examined with and without an ultrasonic contrast enhancer through the temporal and nuchal bone window. Contrast enhancement was achieved by intravenous injection of a transpulmonary stable agent, which consists of galactose microparticles and a small amount of palmitic acid stabilizing air microbubbles (Levovist, Schering). To reach a stable contrast enhancement of 15 to 20 dB for 8 to 10 minutes without blooming artifacts, the contrast enhancer was applied (2.5 g, concentration 300 mg/mL, rate 1 mL/min) with use of a perfusor (P4000 IVAC). For a precise demonstration of vessel dimensions, it was important to change some parameters of the duplex machine during 3D-TCCS. The color persistence had to be extremely reduced and the color Doppler gain was reduced as well to avoid blooming artifacts. Filter settings were individually adjusted.

The free-hand system (3D-Echotech) used in this study is adaptable to every commercially available color-coded duplex system. The 3D system consists of an electromagnet, which induces a low-intensity magnetic field near the head of the patient. The composite magnetic field is generated from an array of 3 coils at 90° angles to each other to produce 3 magnetic fields, yielding a 3D orientation. A magnetic position sensor is attached to the ultrasound probe and transmits the spatial orientation (x, y, and z axes) of the probe to a workstation (2x Pentium 400-MHz processors, 256 MB ram), which also receives the corresponding 2D images from the video port of the duplex machine. This approach allows the operator to move the transducer without constraint. To acquire a 3D data block of the circle of Willis, the transducer must be tilted around an axis that is perpendicular to the central axis of the transducer (fanlike rotation) and moved slowly across the temporal bone window or the occipital approach. Over an interval of 30 to 40 seconds, 150 2D images, together with the spatial information, are stored on the hard disk of the workstation. During offline analysis a reconstruction algorithm is able to extract the color-coded information from the 3D data set. The Windows NT 4.0–based software provides a photorealistic surface rendering of the investigated vessels. With use of different threshold values and cutting tools, it is possible to reduce artifact. An experienced ultrasonographer familiar with the equipment can produce an animated 3D image of the circle of Willis in 5 minutes. All patients were additionally investigated with 4-vessel digital subtraction angiography (DSA).

Thirty patients with subarachnoidal hemorrhage due to 30 angiographically proven intracranial aneurysms (8 men, 22 women; mean±SD age 54±17 years) were involved. For the TCCS examination were angiographically confirmed intracranial aneurysms with contrast-enhanced 2D-TCCS and 3D-TCCS.

<table>
<thead>
<tr>
<th>Vessel</th>
<th>2D-TCCS Detected</th>
<th>2D-TCCS Not Detected</th>
<th>3D-TCCS Detected</th>
<th>3D-TCCS Not Detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>AComA</td>
<td>7</td>
<td>1</td>
<td>8</td>
<td>...</td>
</tr>
<tr>
<td>A1CA</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>...</td>
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<tr>
<td>M1CA</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>...</td>
</tr>
<tr>
<td>M2CA</td>
<td>1</td>
<td>...</td>
<td>1</td>
<td>...</td>
</tr>
<tr>
<td>IC1A</td>
<td>2</td>
<td>1</td>
<td>3</td>
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<tr>
<td>IC2A</td>
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<tr>
<td>IC3A</td>
<td>...</td>
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<td>1</td>
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<td>PCOMA</td>
<td>...</td>
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<tr>
<td>PCA</td>
<td>2</td>
<td>...</td>
<td>2</td>
<td>...</td>
</tr>
<tr>
<td>BAS</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>...</td>
</tr>
<tr>
<td>V1A</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Totals</td>
<td>20 (67%)</td>
<td>10 (33%)</td>
<td>29 (97%)</td>
<td>1 (3%)</td>
</tr>
</tbody>
</table>

ICA indicates internal carotid artery; PCA, posterior cerebral artery; ACA, anterior cerebral artery; MCA, middle cerebral artery; VA, vertebral artery; BAS, top of the basilar artery; AcomA, anterior communicating artery; and PCOMA, posterior communicating artery.
nation the investigator was aware of the blood distribution in the CT scans but was blinded to the precise location and dimensions of the aneurysm. In addition, 3D-TCCS data concerning the approximate size (craniocaudal, ventrodorsal, and mediolateral diameter), location, and orientation of the aneurysm were compared with angiographic, intraoperative, and 2D-TCCS data, respectively.

All 2D-TCCS studies with and without contrast were performed by one of the authors (G.L.). The recording of the 3D data and following 3D-TCCS offline analysis was performed by another author (A.B.). With a second offline-analysis by another operator (C.K.), we were able to calculate the interobserver correlation. For this second evaluation the data sets of all 30 patients were analyzed in a random order, without the knowledge of the previously performed 2D-TCCS examinations.

Statistical Analysis

DSA and 3D-TCCS findings regarding the aneurysmal diameter were compared by linear regression analysis. The correlation coefficient was calculated for the estimation of aneurysmal size by 2 different investigators through use of 3D-TCCS. The overall accuracy was applied for the angiographic and sonographic estimation of the aneurysmal location.

Results

Correlation of Contrast-Enhanced 3D-TCCS With DSA

Twenty-one aneurysms were located in the anterior circulation, with the most frequent locations being the anterior communicating artery (n=8), the middle cerebral artery (n=5), and the ICA (n=5). Eight aneurysms were found in the posterior circulation (Table). No patient experienced any side effects after application of the echo-contrast enhancer Levovist. Twenty-nine of 30 angiographically proven intracranial aneurysms (97%) were detected by contrast-enhanced 3D-TCCS (Figures 1, 2, and 3). In 1 patient it was not possible to demonstrate an aneurysm of the intracranial segment (V4) of the vertebral artery. The aneurysmal diameter estimated by DSA ranged from 3 to 16 mm (mean 7.2±3.6 mm). A comparison of the 3 main diameters of each aneurysm revealed a satisfactory correlation coefficient of 0.95 between DSA and 3D-TCCS (Figure 4). The overall

Figure 2. A, The sonographic 3D reconstruction in an anterior-posterior view reveals an aneurysm (*) on the top of the T-fork-shaped intracranial carotid bifurcation. B, The angiogram confirmed, in an anterior-posterior view, the detected aneurysm (arrow) on the top of the bifurcation.

Figure 3. A, 3D-TCCS through the foramen magnum revealing the basilar artery (B) and a large, banana-shaped vertebral aneurysm (between brackets) at the confluens of the right (R) and left (L) vertebral artery. B, The angiogram of the right vertebral artery (R) confirmed the vertebral aneurysm (arrow) and the tortuosity of the proximal basilar artery.
agreement between 3D-TCCS and DSA for the description of the spatial orientation of the aneurysms was 68%. The overall accuracy for evaluation of the aneurysmal neck suitable for surgical clipping was 82% for 3D-TCCS compared with DSA and 75% for 3D-TCCS compared with the intraoperative evaluation of the neurosurgeon.

Figure 4. Correlation of the 3 main aneurysmal diameters estimated with use of contrast-enhanced 3D-TCCS and DSA in 29 patients.

The offline 3D reconstruction was performed by 2 experienced sonographers who were familiar with the method. Both investigators were only aware of the infratentorial/supratentorial location of the aneurysm or the affected hemisphere, respectively. The overall agreement was 100% for the location of the aneurysm. The determination of the aneurysmal size correlated with 0.96 between both investigators.

Correlation of Non–Contrast-Enhanced 3D-TCCS With DSA

Only 9 aneurysms (30%) could be detected with non–contrast-enhanced 3D-TCCS. The mean±SD angiographic size of the detected aneurysms was 8.4±3.5 mm. The failure to detect the remaining aneurysms must be attributed to an unfavorable location (n=8), an insufficient bone window (n=4), or a diameter of <6 mm (n=9). Three tubular aneurysms of the anterior communicating artery were not diagnosed, because they could not be differentiated from both distal segments (A2) of the anterior cerebral artery. The non–contrast-enhanced 3D-TCCS examinations frequently revealed vessel discontinuity, and a differentiation from background signals was more difficult.

Correlation of Native 2D-TCCS, Contrast-Enhanced 2D-TCCS, and DSA

In 20 of 30 aneurysms (67%), contrast-enhanced 2D-TCCS was able to demonstrate the intracranial aneurysm. The remaining 10 aneurysms had a diameter of ≤6 mm (n=8) and/or showed an unfavorable location (n=4) (Table). The main aneurysmal diameter estimated with 2D-TCCS revealed a lower correlation coefficient (0.615) for DSA than that obtained with 3D-TCCS. To determinate the third plane (craniocaudal), it was necessary to use a coronal insonation plane for 2D-TCCS. Coronal sections were possible only if the aneurysms were located at the intracranial carotid bifurcation, the middle cerebral artery trunk, or at the top of the basilar artery. Other locations required an extreme inclination of the probe.

Figure 4. Correlation of the 3 main aneurysmal diameters estimated with use of contrast-enhanced 3D-TCCS and DSA in 29 patients.

Conclusions

The usefulness of 2D-TCCS as a diagnostic tool for vascular alterations is unquestioned, but its dependence on operator skill was contributed to conflicting results in some trials. Compared with DSA, the demonstration of vessel disease through use of screenshots or video clips of 2D-TCCS examinations is often not clear for those who are unfamiliar with the method. Multiple 2D-TCCS images must be integrated in the sonographer’s mind to develop a 3D impression of the intracranial vessel anatomy. Various 2D-TCCS studies report that the minimal detectable diameter of an intracranial aneurysm ranges between 3 to 6 mm, but the detection of aneurysms may be possible if 2 vascular segments are close together. The restriction to only a few insonation windows (temporal, macial, transorbital) with variable insonation conditions sometimes makes it impossible to obtain optimal image planes for diagnosis of vascular changes.

In the past few years computer technology has advanced sufficiently to allow the development of visualization techniques suitable for 3D-TCCS. Power-based TCCS is better suited than mean frequency–based TCCS for 3D reconstruction, because it is more sensitive in detecting low flow near the vessel wall and is less degraded by noise and clutter. Together with advances in acquisition, reconstruction techniques and the use of echo-contrast enhancer, this means that 3D images of high quality can be produced.

Using a power-based 3D-TCCS system, Delcker et al have reported a detection rate of 60% to 90% through the temporal bone in ipsilateral vessels (A1, M1, M2, P1 and P2, and posterior communicating artery) in 10 patients. The identification rate was increased to 100% with use of a transpulmonary stable contrast agent. The contralateral vessels were visualized in just 10% to 60% of cases, whereas after application of an echo-contrast enhancer identification rates of 80% to 100% could be obtained. Bauer et al compared frequency-based 3D-TCCS with power-based 3D-TCCS, using the echo contrast enhancer Levovist. They found significantly better vessel continuity as well as smoother vessel surfaces when using power mode.

To our knowledge, the present study is the first investigation of intracranial vessel disease on a large number of patients with use of 3D-TCCS. Compared with conventional 2D-TCCS, the differentiation between artifact and real
changes of the vessel anatomy is much easier and yields an excellent correlation with the gold standard, DSA. The echo-contrast enhancer enables the 3D reconstruction of small vascular alterations, avoids vessel discontinuity, and significantly improves the differentiation from disturbing background signals. The low rate of detected aneurysms (30%) using nonenhanced 3D-TCCS underlines the necessity of applying contrast enhancers for sonographic 3D reconstruction.

3D-TCCS significantly improved the detection of intracranial aneurysms compared with 2D-TCCS (97% versus 67%) and revealed a better correlation of the estimated aneurysmal diameters with the angiographic data (0.95 versus 0.615). The relatively low detection rate of aneurysms with use of contrast-enhanced 2D-TCCS in the presented study was mainly caused by the large number of small aneurysms. 3D-TCCS enables the investigator to reconstruct virtually any arbitrary view angle and may allow the comparison with 3D techniques such as CT or MR angiography. Unfavorably located vessel segments, such as the carotid siphon, can be insolated in transversal planes and may be assessed after 3D-reconstruction. Because the same 3D-TCCS data can be postprocessed by different investigators, it may be possible to improve reproducibility and increase the objectivity in transcranial color-coded duplex sonography. Remote consultations of the sonographic examinations are possible because the complete data of the 3D examination are digitally stored and can be transferred by usual methods of digital data transfer.

Other techniques compete with 3D-TCCS in the noninvasive detection of intracranial vessel disease. MR angiography enables the detection of intracranial aneurysms with a sensitivity of up to 90% and a specificity of 75%, but in aneurysms with a diameter of <5 mm or a location in the carotid siphon, the sensitivity decreases to 60%. With CT angiography it is possible to detect aneurysms >5 mm with a sensitivity of 90%. Due to its vicinity to the skull, the sensitivity decreases if the aneurysms are located in the carotid siphon. Further disadvantages may be the interference of venous flow signals and allergic reactions against the contrast agent. The radiation exposure excludes repeated investigations with CT-angiography.

In summary, 3D-TCCS is not suitable as a screening method, because of its limited sensitivity in detecting small aneurysms and aneurysms in particular locations. The major limitation is an absent temporal bone window, which is found in only 5% of the population but in up to 30% of women aged >70 years.

However, routine 3D-TCCS examinations for other reasons will increase the incidental detection of asymptomatic intracranial aneurysms and offer the chance to treat them before rupture. Its advantages lie in the possibility to perform the examination in a stroke unit or intensive care unit within a few minutes and to obtain a day-by-day follow-up.

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References


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