Differentiation Between Intracerebral Hemorrhage and Ischemic Stroke by Transcranial Color-Coded Duplex-Sonography

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Background and Purpose—The differential diagnosis of intracerebral hemorrhage versus ischemic stroke has critical implications for stroke management. Transcranial color-coded duplex sonography (TCCS) has been shown to identify intracerebral hemorraghes and intracerebral vessel occlusions. We conducted this study to evaluate the sensitivity and specificity of TCCS in this differential diagnosis and in the detection of stroke complications.

Methods—One hundred fifty-one patients (58 women, 93 men; mean age, 65.6 years [range, 32 to 89 years] ) with acute hemiparesis were enrolled in this prospective study. On admission all patients had a complete neurological examination. A cranial CT scan and a sonographic examination of the brain parenchyma and all extracranial and intracranial cerebral arteries were conducted. The sonographer was blinded for the radiological findings.

Results—According to CT criteria, 60 patients had an intracerebral hemorrhage and 67 patients had an ischemic stroke, and in 24 patients CT findings were inconclusive, showing neither bleeding nor an ischemic stroke. On sonographic examination, 18 patients (12%) had no sufficient acoustic bone window. Of the remaining 133 patients, 126 (95%) were diagnosed correctly by sonography in agreement with CT. Sonography missed 3 atypical bleedings (2 with upper parietal location). In 4 patients without bleeding, an intracerebral hemorrhage was suspected by TCCS because of increased white matter echo density due to microangiopathy. Stroke complications depicted by CT (disturbance of cerebrospinal fluid circulation, hemorrhagic transformation, midline shift, ventricular bleeding) (n=54) were correctly shown by TCCS in 45 patients (83%). No complication was missed that would have required further treatment.

Conclusions—In comparison to the “gold standard” of CT, TCCS identified stroke complications and differentiated between intracerebral hemorrhage and ischemic stroke with reasonable sensitivity. Thus, if CT is not readily available, TCCS may complement clinical examination in patients with acute stroke. In addition, it may also be useful in detecting stroke complications in the follow-up of stroke patients. (Stroke. 1998;29:2563-2567.)

Key Words: cerebral hemorrhage ■ cerebral ischemia ■ stroke, acute ■ tomography, x-ray computed ■ ultrasonography

Stroke is the most common neurological disorder causing death or disability among adults in industrialized nations. Ischemic events account for $\approx 85\%$ of all strokes, and hemorrhages account for $\approx 15\%$.

CT currently also serves to identify important stroke complications.

Depending on local conditions, ready access to CT facilities on admission may not be available everywhere. Large population-based studies revealed that approximately one third of the patients with acute stroke had no CT before treatment was started, and this applied even to centers experienced with stroke management.

Transcranial color-coded duplex sonography (TCCS) is a diagnostic tool that allows a 2-dimensional imaging of brain parenchyma and a color-coded imaging of the intracranial vessels. The method is noninvasive and mobile, and bedside examination is feasible. Previous studies have shown that
TCCS permits the detection of intracerebral hemorrhages and intracerebral vessel occlusions.\textsuperscript{9–11} TCCS is currently being applied only in a few centers, but ultrasound systems suitable for TCCS are widely available even in general hospitals.

The aim of our study was to assess the sensitivity and the specificity of TCCS in the differentiation between intracerebral hemorrhage and ischemic stroke and to examine whether intracerebral complications of cerebrovascular diseases can be detected.

**Subjects and Methods**

Two tertiary care centers, both with 24-hour access to CT, were involved in this prospective study. Compared with general hospitals, more patients with complicated course of stroke or intracerebral hemorrhages are referred to these institutions. This results in a selection of the stroke patients toward cases in which active therapy was considered on referral.

From June 1996 to June 1997, we investigated 151 patients (93 men, 58 women; mean age, 65.6 years [range, 32 to 89 years]) with acute hemiparesis suggestive of stroke. The time from the first onset of symptoms was recorded. On admission all patients had a complete neurological examination. All patients received a complete sonographic examination of the brain parenchyma and all extracranial and intracranial cerebral arteries and a CT examination (CT 9800, CT-Max, General Electric or Somatom DR, Siemens AG). Although we preferred to perform the sonographic examination before CT examination, this was not possible in 85 patients because of ethical or logistic considerations.

In these cases the sonographer was strictly blinded for the CT findings and was not involved in any therapeutic decision. The ultrasound examination was done at least 24 hours after admission.

Sonographic examination was performed with a color-flow ultrasound system (Siemens Sonoline Ellegra, Siemens AG or Acuson 128 XP/4). Technical details of TCCS for the evaluation of brain parenchyma and the intracranial vessels have been described previously.\textsuperscript{12,13} The extracranial cerebral arteries of the anterior and posterior circulation were assessed with a 5-MHz linear array, and the intracranial blood vessels of the anterior and posterior circulation were assessed with a 2.0- to 2.5-MHz phased-array transducer. Extracranial and intracranial arteries were examined bilaterally by color flow imaging, and angle-corrected blood flow velocities were determined with integrated pulsed wave (PW) Doppler. In a second step, the depiction of brain parenchyma was performed transtempo-

rally with the use of the 2.0- to 2.5-MHz phased-array transducer. By tilting the duplex probe at the temporal acoustic bone window, the brain stem and the opposite hemisphere were imaged in both axial and coronal planes. At the beginning of the examination, the quality of the temporal acoustic bone window was graduated as follows: good=standard anatomic structures can be visualized; narrow=only midline structures can be identified; no temporal acoustic bone window=patient is not suitable for examination by transcranial ultrasound. With a scanning depth of 16 cm and with progression from the side opposite to the clinically suspected brain pathology, a brightness (B)-mode scan of the affected brain hemisphere was performed. The opposite brain hemisphere was also imaged.

The sonographer was informed of the clinical status of the patient but strictly blinded for any neuroradiological finding or therapeutic procedure. He was asked to comment on the following questions: (1) Is there evidence for intracranial hemorrhage? (2) Is there evidence for vessel occlusion? (3) Are there stroke complications such as hemorrhagic transformation, midline shift, ventricular bleeding, and/or disturbances of cerebrospinal fluid (CSF) circulation?

A homogeneous hyperechoic lesion, sharply delineated from the adjacent brain tissue, served as the sonographic criterion of an intracranial hemorrhage (Figure 1). Its echo density is comparable to that of the falx cerebri or the choroid plexus.\textsuperscript{10} In contrast, the sonographic diagnosis of an acute ischemic stroke is primarily based on vascular occlusion, ie, on the lack of blood flow in an occluded vessel as demonstrated by color Doppler and PW Doppler in the absence of a sonographic hyperechoic lesion (Figure 2). Additional criteria include evidence of collateral flow and reduction of brain pulsation in the distribution of the affected vessel.

If neither an echo dense lesion indicating intracerebral hemorrhage nor a vascular occlusion was identified by TCCS, an acute ischemic stroke was suggested, due to either a lacunar stroke, a branch occlusion not depicted by ultrasound, or an occluded vessel that recanalized spontaneously.

**Visualization of Stroke Complications by TCCS**

An intraventricular hemorrhage is depicted as a hyperechoic structure in an otherwise hypoechoic ventricular system. A hemorrhagic transformation of an ischemic infarction is suspected when the echo density of the white matter changes toward higher values in follow-up examinations. A midline shift was determined by measuring the distance between the midline structures (third ventricle/ mesencephalic raphe) and the skull on both sides, as described by
TABLE 1. Initial CT Findings in Consecutive Patients With Acute Hemiparesis Suggestive of Stroke

<table>
<thead>
<tr>
<th></th>
<th>No. of patients</th>
<th>Male</th>
<th>Female</th>
<th>Mean age, y (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intracerebral hemorrhage</td>
<td>60</td>
<td>52</td>
<td>8</td>
<td>63.0 (32–89)</td>
</tr>
<tr>
<td>Basal ganglia</td>
<td>20</td>
<td>17</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Thalamus</td>
<td>13</td>
<td>12</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Temporal</td>
<td>11</td>
<td>10</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Parietal</td>
<td>8</td>
<td>7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Occipital</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>4*</td>
<td>4</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Cerebral infarction</td>
<td>67</td>
<td>53</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Territory</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle cerebral artery</td>
<td>53</td>
<td>47</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Posterior cerebral artery</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Verteobasilar arteries</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Hemodynamic infarction</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Lacunar infarction</td>
<td>7</td>
<td>7</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>No appropriate diagnosis by CT</td>
<td>24</td>
<td>21</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

*Three subarachnoid hemorrhages with involvement of brain parenchyma, 1 subdural hematoma.

Seidel et al: a difference of 0.4 cm between the measured distances was considered to represent a significant midline shift. CSF circulation disturbance was determined by width measurement of the third and lateral ventricles, as previously described. A width >0.9 cm of the third ventricle and >2 cm of the frontal horn of the lateral ventricle was considered a ventricular enlargement.

The results of the sonographic examination were compared with the results of the corresponding CT images by an independent neuroradiologist (E.H.). Sensitivity, specificity, and predictive value of the test were calculated.

Results

The average time interval between the first onset of symptoms and admission was 7 hours (range, 1 to 24 hours). The CT examinations of the 151 patients (Table 1) showed an intracerebral hemorrhage in 60 cases; 67 patients had an ischemic cerebral infarction. In 24 patients, an intracranial hemorrhage could be excluded by admission CT, but no focal lesion responsible for the acute neurological deficit could be identified on the admission and follow-up CT.

An appropriate sonographic evaluation through the intact skull was achieved in 133 of 151 patients (88%). In the remaining 18 patients (12%), a sufficient delineation of brain structures was not feasible because of an inadequate bone window. These patients were excluded from further analysis of sonographic data. Of the 133 patients in whom TCCS findings permitted evaluation, the bone window was graded as good in 91 patients (68%) and narrow in 42 patients (32%).

In this group of 133 patients, 53 had an intracranial hemorrhage on CT. Transcranial ultrasound detected 50 and missed 3 intracranial hemorrhages. In 2 patients with a narrow acoustic bone window, 1 case each of parietal and frontopolar bleeding were missed (diameter ≤1 cm). In another patient, TCCS failed to detect a basal ganglia bleeding even though the patient had an adequate acoustic bone window. In this patient CT showed a large basal ganglia bleeding with an extensive midline shift. We suggest that the enormous rise of intracranial pressure resulted in a decrease of echogenicity of the intracerebral hematoma. In patients with sonographically identified hematomas, no pathological color Doppler or PW Doppler findings of the basal cerebral arteries were observed except for slightly elevated ratios of systolic and diastolic velocities in some patients, indicating increased intracranial pressure.

CT could exclude an intracranial hemorrhage in 80 of those 133 patients, whereas ultrasound gave no evidence for an intracranial hemorrhage in 76 patients. In 4 patients with clinical evidence of ischemic stroke and marked microangiopathy on CT scan, TCCS showed a diffuse increase of the echo density of the white matter, which was misinterpreted as an intracerebral bleeding. Color Doppler and PW Doppler recordings of the 76 patients with normal B-mode image of the brain parenchyma showed a vessel stenosis or occlusion in 36 patients (47%) (middle cerebral artery in 20 patients, internal carotid artery in 15 patients, vertebral artery in 1 patient) and a normal flow in the extracranial and intracranial cerebral arteries in 37 patients (49%). In 3 cases (4%) we could obtain an adequate B-mode image but no sufficient Doppler recording of the basal cerebral arteries (Table 2).

In summary, a correct sonographic diagnosis was made in 126 (95%) of the 133 evaluable patients. The sensitivity of ultrasound in the detection of intracranial hemorrhage was 94%, and specificity was 95% (Table 3). The positive predictive value of TCCS was 91%, and the negative predictive value of TCCS was 95%. If we included the patients with insufficient bone window, TCCS would diagnose strokes correctly in 83%. However, with an insufficient bone window neither a false-positive nor a false-negative result can emerge.

CT scans depicted 54 stroke complications, eg, midline shift, ventricular enlargement, hemorrhagic transformation, and ventricular bleeding in the 133 patients who could be examined by ultrasound (Table 4). In comparison, TCCS showed 45 (83%) of these complications. No complication that required further treatment was missed. In particular, small ventricular bleedings restricted to the occipital horns were not identified in 7 patients. A midline shift was not identified by TCCS in 2 cases of the 23 midline shifts recorded by the neuroradiologist. In both cases the midline shift was <0.5 cm. Ventricular enlargement and hemorrhagic transformation were precisely determined by ultrasound.

Discussion

This study shows that TCCS allows a differentiation between intracranial hemorrhage and ischemic stroke in the vast majority of patients. In 95% of our cases, stroke subtypes were identified correctly when 18 patients not suitable for sonography were excluded. These findings confirm data of previous studies.

Although TCCS is remarkably sensitive, it cannot match the sensitivity of CT in the detection of intracerebral hemorrhages. At present CT is unequivocally the method of choice in examining patients with acute stroke. However, a signifi-
certain number of physicians in Europe have no 24-hour access to CT or MRI, and in approximately one third of stroke patients specific treatment was started without having a definite diagnosis.\(^1,7\) Therefore, sonographic examination could be considered when CT is not readily available to complement clinical examination\(^17\) provided that technical development of ultrasound (harmonic imaging, tissue harmonic imaging, 2.5 D-array-sector probes) will further improve its reliability and the quality of images so that its diagnostic yield will become generally acceptable. In comparison to CT, ultrasound is noninvasive and more widely available; 2- to 2.5-MHz phased-array transducers needed for transcranial sonography are also used for echocardiography and are part of the standard equipment of modern ultrasound systems.

At present, \(\approx 15\%\) of the patients cannot be examined by TCCS because of narrow temporal acoustic bone windows, and frontal and parasagittal regions of the brain are difficult to assess when the bone window is narrow. For this reason 2 intracerebral hemorrhages were missed in the present study. Another problem is cerebral microangiopathy, which leads to a slight and diffuse increase in echo density of the white matter resembling the sonographic pattern of intracerebral hemorrhage. It is therefore necessary to investigate both hemispheres: If the examiner finds an identical pattern of increased echo density in both hemispheres, microangiopathy is more likely than bleeding. In addition, as Seidel and coworkers\(^11\) have observed, a hemorrhagic transformation of an ischemic stroke may be misinterpreted as a primary intracerebral bleeding. The fact that the sonographic diagnosis of an acute ischemic stroke is exclusively based on the (color-) Doppler-sonographic identification of a vascular occlusion constitutes a further limitation. If an occluded vessel is recanalized in the acute stage of ischemic infarction,\(^18\) brain echo density is not altered, and therefore no sonographic clue points toward a cerebral infarction.\(^9,10\)

While an occlusion of smaller branches of the basal cerebral arteries cannot be detected by TCCS, a comparison of MR angiography and TCCS demonstrated equal sensitivity of both methods in the identification of vascular occlusions of the major basal cerebral arteries.\(^19\)

TCCS provides a real-time display of the affected brain and of intracerebral complications in the course of the disease, such as a disturbance of CSF circulation and space-occupying effects. Ventricular bleeding can also be recognized by means of TCCS. Therefore, the method is suitable for the follow-up of stroke patients.\(^20\)

In conclusion, TCCS is a mobile, noninvasive, and cost-effective method that allows a distinction between intracerebral hemorrhage and ischemic stroke in the majority of patients and provides insights into the dynamic evolution of cerebrovascular diseases and resulting complications. Although the accuracy of TCCS is at present inferior to that of CT, technical improvements in the future will make TCCS more reliable and suitable for the differentiation of stroke subtypes.

**Acknowledgments**

We thank M. Schließer for her technical assistance and Professor K. Reiners for a critical revision of the manuscript.

**TABLE 3. Comparison of CT and TCCS in the Differentiation Between Intracerebral Hemorrhage and Ischemic Stroke**

<table>
<thead>
<tr>
<th>CT diagnosis</th>
<th>TCCS Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemorrhage</td>
<td>No Hemorrhage</td>
</tr>
<tr>
<td>Intracerebral hemorrhage</td>
<td>50       3</td>
</tr>
<tr>
<td>No hemorrhage</td>
<td>4          76</td>
</tr>
</tbody>
</table>

Sensitivity and specificity for TCCS calculated from these data were 94% and 95%, respectively.

**TABLE 4. Visualization of Stroke Complications by CT and TCCS (TCCS =100%)**

<table>
<thead>
<tr>
<th>Complication</th>
<th>CT</th>
<th>TCCS (% of CT Findings)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midline shift</td>
<td>23</td>
<td>21 (91%)</td>
</tr>
<tr>
<td>Ventricular enlargement</td>
<td>6</td>
<td>6 (100%)</td>
</tr>
<tr>
<td>Hemorrhagic transformation</td>
<td>3</td>
<td>3 (100%)</td>
</tr>
<tr>
<td>Ventricular bleeding</td>
<td>22</td>
<td>15 (68%)</td>
</tr>
<tr>
<td>All complications</td>
<td>54</td>
<td>45 (83%)</td>
</tr>
</tbody>
</table>
References


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