Validation of Transcranial Doppler With Computed Tomography Angiography in Acute Cerebral Ischemia

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Background and Purpose—Both transcranial Doppler (TCD) and spiral computed tomography angiography (CTA) are used for noninvasive vascular assessment tools in acute stroke. We aimed to evaluate the diagnostic accuracy of TCD against CTA in patients with acute cerebral ischemia.

Methods—Consecutive patients presenting to the Emergency Department with symptoms of acute (<24 hours) cerebral ischemia underwent emergent high-resolution brain CTA with a multidetector helical scanner. TCD was performed at bedside with a standardized, fast-track insonation protocol before or shortly (<2 hours) after completion of the CTA. Previously published diagnostic criteria were prospectively applied for TCD interpretation independent of angiographic findings.

Results—A total of 132 patients (74 men, mean ± SD age 63 ± 15 years) underwent emergent neurovascular assessment with brain CTA and TCD. Compared with CTA, TCD showed 34 true-positive, 9 false-negative, 5 false-positive, and 84 true-negative studies (sensitivity 79.1%, specificity 94.3%, positive predictive value 87.2%, negative predictive value 90.3%, and accuracy 89.4%). In 9 cases (7%), TCD showed findings complementary to the CTA (real-time embolization, collateralization of flow with extracranial internal carotid artery disease, alternating flow signals indicative of steal phenomenon).

Conclusions—Bedside TCD examination yields satisfactory agreement with urgent brain CTA in the evaluation of patients with acute cerebral ischemia. TCD can provide real-time flow findings that are complementary to information provided by CTA. (Stroke. 2007;38:1245-1249.)

Key Words: acute ischemic stroke ■ CT angiography ■ transcranial Doppler

Bedside transcranial Doppler (TCD) can detect, localize, and grade the severity of intracranial arterial obstruction.1,2 Spiral computed tomography angiography (CTA) is a valuable imaging tool with a high potential for application in acute cerebral ischemia.3,4 Data are limited on the correlation of TCD and CTA in acute stroke.5-7 We aimed to evaluate the diagnostic accuracy of TCD against CTA in patients with acute cerebral ischemia.

Patients and Methods

Our stroke treatment team routinely uses portable, 2-MHz, power-motion or single-channel TCD (PMD 100, Spencer Technologies; Ez-Dop, Compumedics) as a noninvasive screening test in the Emergency Department for the evaluation of acute stroke patients. Bedside TCD is carried out simultaneously with clinical assessment and blood draws by experienced sonographers using a standardized, fast-track (<15 minutes) insonation protocol to identify suspected arterial obstruction.2 Ultrasound results are interpreted at bedside according to previously published diagnostic criteria.1,2,6-8 All sonographers were blinded to the angiographic results.

An insonation depth of 45 mm or more was used for the identification of proximal (ie, M1) middle cerebral artery (MCA) flow signals and depths of 30 to 45 mm for presumed distal MCA flow signals (ie, M2). After the identification of both proximal M1 MCA and proximal A1 anterior cerebral artery (ACA) signals at a depth of ~65 mm (range 58 to 70 mm), the probe was aimed inferiorly and slightly posteriorly, and flow signals of the terminal internal carotid artery (TICA) were obtained at a depth of 60 to 70 mm. Proximal (M1) MCA occlusion was defined as the absence of flow or the presence of minimal, blended, or damped flow signals throughout the MCA at an insonation depth of 45 to 65 mm, accompanied by flow diversion in the ipsilateral ACA or posterior cerebral artery. Distal (M2) MCA occlusion was defined as minimal, blended, or damped flow signals at an insonation depth of 30 to 45 mm and the presence of flow diversion signals in ipsilateral neighboring arteries (ie, other M2 branches), TICA occlusion was diagnosed as the absence of flow or the presence of minimal, blended, or damped flow signals at an insonation depth of 60 to 70 mm accompanied by anterior cross-filling with flow reversal at the ipsilateral ACA or collateral flow with increased velocities in the ipsilateral posterior communicating artery. Primary TCD findings in ACA stenosis included a focal and significant mean flow velocity (MFV) increase (MFV ≥ 80 cm/s and ≥ 30% difference compared with the contralateral ACA segment) at a depth of 62 to 75 mm. ACA occlusion was diagnosed as the absence of flow or the presence of minimal, blended, or damped flow signals at an insonation depth of 62 to 75 mm. The contralateral...
ACA (if available) or ipsilateral MCA was used as a comparison vessel in case of ACA occlusion. Decreased and high-resistance flow velocities with normal systolic flow acceleration indicated hypoplastic or tortuous A1 ACA segments.

In patients with no temporal windows, a noncontrast-enhanced TCD examination of the orbital and posterior circulation vessels is routinely performed. These limited studies are also included in the present analysis. All patients eligible for thrombolytic therapy according to standard criteria receive recombinant tissue plasminogen activator intravenously. Patients with resolved neurologic deficits at the time of examination were considered having transient ischemic attacks.

Emergent high-resolution brain CTA with a multidetector (4I) helical scanner (Lightspeed, GE Medical Systems) is routinely performed in all patients with no evidence of intracranial bleeding and no contraindication for CTA (contrast medium allergy or serum creatinine levels >1.2 mg/dL). CT scans were obtained at a 1.3-mm slice thickness, with a 1-mm interval during a bolus injection (50 mL) of contrast material. Multiplanar reformats were created in the axial, coronal, and sagittal planes. The degree of stenosis was defined as the narrowest vessel diameter divided by a normal diameter of the vessel. The choice of a normal diameter was made according to a standard algorithm of selection of a nonaffected denominator (choice 1 =prestenotic segment, choice 2=poststenotic segment, choice 3=feeding vessel). Significant intracranial artery stenosis was considered when the narrowest diameter of the residual lumen was <50%. Intracranial artery occlusion was diagnosed when no reconstitution of distal flow was detected. Neuroradiologists dictated CTA reports independent of TCD findings.

### Statistical Analysis

Continuous variables are presented as mean and SD or as median (range). Noncontinuous variables are presented as percentages. The accuracy parameters (sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV] and overall accuracy) of the screening test (TCD) against the “gold standard” of CTA were calculated after computation of true-positive, false-positive, true-negative, and false-negative values. SPSS Inc, version 11.5 for Windows, was used for statistical analyses.

### Results

A total of 132 patients (74 men, mean age 63 ± 15 years) underwent emergent neurovascular assessment with brain CTA and TCD within 24 hours from symptom onset (Table 1). Twenty-three (17%) patients received intravenous or intra-arterial thrombolysis (median National Institutes of Health Stroke Scale score = 12, range 4 to 25 points). No delay in treatment resulted from ultrasound testing. Seventy-five (57%) patients were found ineligible for thrombolysis. Twenty-four cases (26%) had transient ischemic attacks. The time delay between TCD and CTA ranged from 10 to 130 minutes (median 35 minutes). A total of 46 cases were evaluated with TCD before CTA (35%), whereas in 86 patients, CTA was performed before TCD (65%). When TCD was performed after CTA, sonographers were blinded to the dictated or even preliminary CTA reports because of the short time period that elapsed between the 2 studies.

Bedside TCD revealed intracranial artery stenosis or occlusion in 39 cases (Figure 1): proximal (M1) MCA (n = 19), distal (M2) MCA (n = 11), ACA (n = 1), TICA (n = 3), posterior cerebral artery (n = 1), basilar artery (BA, n = 2), and vertebral artery (VA, n = 2). Temporal windows were absent in 15 cases (11%). CTA findings were unremarkable in 67% of the study population and revealed intracranial artery stenosis or occlusion in 33% of the remaining cases. Intracranial thrombolytic treatment was administered in 5 patients. The results of digital subtraction angiography (DSA) performed during the intra-arterial thrombolysis confirmed the findings of the baseline CTA in all cases.

Compared with CTA, TCD showed 34 true-positive, 9 false-negative, 5 false-positive, and 84 true-negative studies (sensitivity 79.1%, specificity 94.3%, PPV 87.2%, NPV 90.3%, and accuracy 89.4%). The accuracy parameters of TCD for detecting arterial stenosis or occlusion in the MCA, TICA, and BA are presented in Table 2. The overall TCD accuracy for stenosis or occlusion in the proximal MCA was nearly 100% (sensitivity 94%, specificity 98%, PPV 89%, and NPV 99%). Absent temporal windows led to 2 false-negative TCD studies. The remaining 7 false-negative studies were made in posterior (distal BA and VA, n = 5) and anterior circulation (distal M2-MCA branches, n = 2) vessels. The 5 false-positive TCD cases were attributed to minimal flow signals due to suboptimal angle of insonation in the distal BA (n = 1) and ACA (n = 1), misinterpretation of a collateral flow signal (n = 1), and stenotic velocities that were not confirmed by CTA after thrombolysis (n = 2). These patients had a 4-point reduction in the National Institute of Health Stroke Scale score during thrombolysis, with complete recanalization and time delays (90 to 105 minutes) between TCD and CTA causing this discrepancy. In patients with absent temporal windows (n = 15), there were 2 false-negative (proximal MCA, distal MCA) and 1 true-positive (VA) cases. CTA was normal in the remaining 12 cases.

In 9 cases (7%), TCD showed findings complementary to CTA (Figure 2): collateralization of flow with extracranial ICA disease, real-time embolization, and alternating flow signals indicative of steal phenomenon. In 5 patients with collateral flow signals (reversed ophthalmic artery, anterior cross-filling, posterior communicating flow), proximal ICA occlusion was confirmed by subsequent neck CTA or DSA.

### Table 1. Baseline Characteristics, and TCD and CTA Findings of the Study Population (N = 132)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline characteristics</td>
<td></td>
</tr>
<tr>
<td>Mean age (SD), y</td>
<td>63 (15)</td>
</tr>
<tr>
<td>Male sex</td>
<td>56</td>
</tr>
<tr>
<td>Hypertension</td>
<td>74</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>36</td>
</tr>
<tr>
<td>Ischemic heart disease</td>
<td>30</td>
</tr>
<tr>
<td>Hypercholesterolemia</td>
<td>55</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>17</td>
</tr>
<tr>
<td>Median National Institutes of Health Stroke Scale score (range)*</td>
<td>12 (4–25)</td>
</tr>
<tr>
<td>TCD findings</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>70</td>
</tr>
<tr>
<td>Stenosis/occlusion</td>
<td>30</td>
</tr>
<tr>
<td>CTA findings</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>67</td>
</tr>
<tr>
<td>Stenosis/occlusion</td>
<td>33</td>
</tr>
</tbody>
</table>

*Continuous variables are presented as mean (SD) or as median (range). Noncontinuous variables are presented as percentages. *tPA-treated patients.
Discussion

Our study showed that bedside TCD examination yields satisfactory agreement with urgent brain CTA in patients with acute cerebral ischemia. CTA is a sensitive and specific tool for emergent vascular assessment, because it depicts the normal anatomy of the circle of Willis more reliably than does magnetic resonance angiography and has an excellent yield for the detection of intracranial steno-occlusive disease (sensitivity 100%, PPV 93.4%) when compared with DSA.5 With the current inability of CTA to measure flow velocities or detect transient emboli, TCD can also provide real-time flow information that is complementary to CTA. Additionally, TCD can study hemodynamic changes in response to various stimuli, including breath-holding index and hyperemia testing to induce or augment steal.13

Our findings are discrepant from those of Suwanwela et al,5 who reported poor correlation of TCD with CTA in patients with distal M1/M2 disease. In the former study, TCD and CTA were performed within 2 and 7 days after stroke onset. In contrast, our acute stroke patients underwent emergent vascular imaging with a time difference of <2 hours between TCD and CTA. A long time delay between ultrasound and CTA may provide ample time for thrombus propagation, dissolution, or reocclusion to occur, accounting for discrepancies between the studies. Nevertheless, individual accuracy parameters for TCD in the present report were comparable to other smaller studies.6,7

Our study has limitations, including the need for considerable sonographer expertise to complete and interpret testing promptly and efficiently. Our study also identified clinical situations when TCD could not be reliably interpreted, including limited visualization of the distal BA or M2-MCA and absent temporal windows. Moreover, it needs to be acknowledged that TCD cannot reliably differentiate a hypoplastic A1 ACA with low-velocity, high-resistance flow signals from an occluded ACA with damped residual flow signals. However, it should be noted that both TCD and CTA were performed in the emergency setting with a relatively narrow time window. We also attempted

TABLE 2. Accuracy Parameters for Detecting Intracranial Occlusion by TCD Findings

<table>
<thead>
<tr>
<th>Site of Arterial Occlusion</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCA</td>
<td>90%</td>
<td>97%</td>
<td>90%</td>
<td>97%</td>
</tr>
<tr>
<td>TICA</td>
<td>75%</td>
<td>100%</td>
<td>100%</td>
<td>99%</td>
</tr>
<tr>
<td>BA</td>
<td>33%</td>
<td>99%</td>
<td>50%</td>
<td>98%</td>
</tr>
</tbody>
</table>

Figure 1. A, Power-motion TCD showing left M1-MCA occlusion with blunted signals at 54 mm and normal contralateral MCA below; B, left M1-MCA stenosis with elevated velocities and systolic bruit at 48 mm; C, right terminal VA stenosis with MFV of 113 cm/s at 70 mm. TCD findings (A through C) were confirmed by CTA (D through F, respectively). Insert represents urgent DSA image in the patient with M1-MCA stenosis.
to minimize selection bias by including consecutive patients who had CTA, irrespective of their TCD findings.

In conclusion, emergent TCD yields a substantial proportion of steno-occlusive arterial lesions, in good agreement with CTA in patients with acute cerebral ischemia. TCD and CTA, if performed together within a narrow time window, may compensate for each other’s shortcomings and can provide a rapid and informative emergency vascular assessment tool for stroke patients.

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Disclosures
None.

References
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