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Stroke. 1999;30:1604-1609
doi: 10.1161/01.STR.30.8.1604

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Yield of Transcranial Doppler in Acute Cerebral Ischemia

Andrei V. Alexandrov, MD, RVT; Andrew M. Demchuk, MD, FRCPC; Theodore H. Wein, MD, FRCPC; James C. Grotta, MD

Background and Purpose—The objective of this study was to evaluate the yield of emergent transcranial Doppler (TCD) for the evaluation of acute cerebral ischemia.

Methods—We performed urgent bedside non–contrast-enhanced TCD in patients with acute cerebral ischemia before or immediately after baseline CT scanning. A fast-track scanning protocol (≤15 minutes) and detailed diagnostic criteria were developed for portable single-channel TCD testing. TCD results were compared with angiography.

Results—Of 130 consecutive patients studied, 36 were eligible for thrombolytic therapy; 46 with ischemic strokes and 48 with transient ischemic attacks were not eligible for thrombolysis. TCD identified occlusions in 69% of thrombolysis-eligible patients, compared with 24% and 0% of patients with strokes and transient ischemic attacks, respectively, not eligible for thrombolysis ($P<0.01$). Stenosis was present in 17%, 33%, and 35%, and normal vessels were found in 14%, 43%, and 65% in the respective patient subgroups. TCD also identified abnormal pulsatility of flow (12 patients), abnormal flow velocities (12), microembolic signals (5), or early recanalization (5) (34 of 130; 26%). In 65% of all patients, TCD was compared with angiography (digital subtraction angiography, MR angiography, or CT angiography). Despite a 15% rate of absent temporal windows, TCD had 88% accuracy for abnormal (occlusion and stenosis) versus normal vessels: sensitivity 87.5%, specificity 88.6%, positive predictive value 87.5%, and negative predictive value 88.6%.

Conclusions—A proximal occlusion on TCD was found in 69% of thrombolysis-eligible patients. In 26% of all patients, TCD provided further relevant information that, in addition to angiography, helped to refine the severity of a stenosis and determine stroke pathogenesis. Emergent TCD is both sensitive and specific in determining arterial occlusion and stenosis in acute cerebral ischemia. (Stroke. 1999;30:1604-1609.)

Key Words: occlusion ■ stroke, acute ■ thrombolysis ■ ultrasonography, Doppler, transcranial

Neurovascular imaging is essential to the development of acute stroke therapies,1 because there is tremendous heterogeneity in the pathophysiology of ischemic stroke. Rapid identification of the location and severity of arterial obstruction provides information that aids in the triage of acute stroke patients. Several studies have evaluated digital subtraction angiography (DSA), contrast-enhanced CT angiography (CTA), magnetic resonance angiography (MRA), and ultrasound in the acute stroke setting.2–5 DSA documented complete arterial occlusion in 76% of acute stroke patients within 6 hours of symptom onset, of which 66% were intracranial.2 Non–contrast-enhanced transcranial Doppler (TCD) has been reported to have a sensitivity of 80% and a specificity of 90% compared with DSA in patients presenting within 5 hours of middle cerebral artery (MCA) stroke.6

TCD may be used as a screening test to determine the need for further angiographic studies. The bedside availability, convenience to the patient, and continuous monitoring option make TCD particularly suitable and practical for emergency evaluations. TCD also allows real-time assessment of the flow velocity, pulsatility, and microembolization, information that is not available with angiography. Most studies report a good correlation between intracranial ultrasound and angiography2–6; however, details on insonation protocols and diagnostic criteria for arteries other than the MCA are lacking. On the basis of previous publications,2–17 we developed a fast-track insonation protocol for an experienced sonographer to urgently evaluate acute stroke patients as well as the detailed diagnostic criteria for normal, stenosed, and occluded extracranial and intracranial vessels. The goal of this study was to evaluate the yield of emergent TCD to rapidly triage acute stroke patients and to confirm its accuracy in the emergency setting.

Subjects and Methods

The Stroke Treatment Team, University of Texas–Houston, routinely uses a single-channel, portable, non–contrast-enhanced TCD (Multigon 500M) as a noninvasive screening test in the emergency department (ER) for evaluating acute stroke patients. An experienced sonographer on call (STAT Neurosonology Service) arrived in the ER at the same time as the stroke neurologist and performed urgent bedside TCD before or immediately after baseline CT scanning. No delays in routine patient evaluation and delivery of thrombolytic...
therapy were experienced as a result of TCD testing. To avoid delays, the sonographer used a fast-track insonation protocol (see the Appendix, which may be found on the World Wide Web at http://www.strokeaha.org) to identify the location of arterial obstruction in ≤15 minutes after TCD equipment was set up in the ER. The sequence of vessels targeted by TCD examination in the ER was guided by the neurological evaluation. TCD was interpreted immediately on completion by a neurologist without knowledge of angiographic results using detailed diagnostic criteria (Appendix; Figures 1 and 2). If a patient had no temporal windows, a non–contrast-enhanced examination of the orbital and posterior vessels was performed. These limited studies were also entered into the analysis. In addition, any abnormal flow signals detected were included in the TCD report after completion of the test.

Patients received recombinant tissue plasminogen activator intravenously according to the FDA-approved protocol within 3 hours in a dose of 0.9 mg/kg. Intra-arterial thrombolysis was administered in patients presenting between 3 and 6 hours after stroke onset. Patients presenting with sustained neurological deficits beyond 6 hours or resolving deficits at any time after onset (transient ischemic attacks, TIAs) did not receive thrombolysis.

Angiographic tests including DSA, MRA, or CTA were performed when feasible. Patients with presumed proximal arterial occlusions were more likely to receive DSA, whereas others had either CTA at the time of admission CT or MRA within the first 48 hours. Patients with TIAs or lacunar presentation and normal TCD were least likely to undergo angiography during their hospital stay. Most patients routinely underwent MRI/MRA scanning within 48 hours irrespec-

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**Figure 1.** Distal left M1 MCA stenosis. A 70-year-old woman presented with multiple left MCA TIAs and a history of hypertension. Left M1 MCA recording shows a “double-waveform” sign because of a wide (11.8-mm) gate of insonation. Maximum MFV in stenotic segment is 124 cm/s, with PI 0.5. Second waveform displays slower poststenotic flow, with MFV of 32 cm/s and a low PI of 0.4, probably because of compensatory vasodilation. Right M1 MCA has uniform low-resistance flow along its stem (MFV 72 cm/s; PI 0.9). MRA shows attenuated flow signal in distal left M1 and proximal M2 MCA distribution.

**Figure 2.** M1 MCA subtotal stenosis. TCD findings include a blunted or minimal right M1 MCA signal, a 2:1 left (L) to right (R) MCA MFV ratio, right ACA compensatory velocity increase (R ACA > L MCA), and a normal left MCA systolic flow acceleration. MRA shows a flow signal void due to a slow and minimal flow in the mid-M1 segment with some flow reconstitution in distal branches. Bif indicates bifurcation.
tive of TCD results. After a written report was provided by a neuroradiologist, both reports were compared to determine true-positive, true-negative, false-positive, and false-negative TCD results for normal versus abnormal (stenosed or occluded) vessels. The accuracy parameters were calculated, including sensitivity, specificity, and positive and negative predictive values. A $\chi^2$ analysis was used to compare TCD findings in patient subgroups.

**Results**

Among 130 patients evaluated with TCD, 36 patients were eligible for intravenous or intra-arterial thrombolytic therapy because they had persisting neurological deficit within 3 hours (intravenous) and 3 to 6 hours (intra-arterial) after stroke onset. Other patients were not eligible for thrombolysis: 46 stroke patients presented beyond the 6-hour window, and 48 patients had resolving deficits (TIAs). On TCD, 69% of thrombolysis-eligible patients had occlusions, compared with 24% and 0% of patients with strokes and TIAs, respectively, not eligible for thrombolysis, $P<0.01$. A stenosis was present in 17%, 33%, and 35%, and normal vessels were found in 14%, 43%, and 65% of patients in the respective subgroups (Figure 3).

TCD showed other signs of abnormal circulatory conditions in 34 of 130 patients, or 26%. TCD showed abnormal pulsatility of flow (pulsatility index, PI, $\geq 1.2$) in 12 patients. When present in all intracranial vessels, these findings were consistent with a history of hypertension or a systolic blood pressure $\geq 200$ mm Hg on admission. In 3 patients, a unilateral increased pulsatility of flow correlated with distal MCA occlusion or the presence of early mass effect on CT and increased intracranial pressure (Figure 4).
TCD showed abnormal flow velocities in 12 patients, including 2 with abnormally low (≤20 cm/s MCA mean flow velocity [MFV]) velocities due to decreased cardiac output (congestive heart failure, myocardial infarction). In others, a general increase in flow velocities above normal values was attributed to the presence of hypertension, anemia, or decreased blood viscosity.

Real-time detection of cerebral microembolization was possible during a short TCD examination in 5 patients because the frequency of microembolic signals (MESs) was >10/min. MESs were heard without decreasing the gain. When present, MESs indicated an active cardioembolic source in 1 patient (Figure 5), proximal carotid stenosis or occlusion in 2 patients, and intracranial clot dissolution in 2 patients. MESs were detected distal to the clot formation in the terminal internal carotid artery (ICA) and MCA.

Early recanalization during emergent evaluation was found by TCD in 5 patients with distal M1 or M2 obstruction (Figure 6). The TCD findings included the appearance or improvement of the proximal M1 flow signals (2 patients) and distal M1 flow signals (3 patients). Microembolization distal to the site of obstruction was noted in 2 of these patients. Other signs of recanalization included the reduction of flow pulsatility in the proximal arterial segments.

TCD failed to insonate via transtemporal window in 20 of 130 patients, or 15%. Of 130 patients, 84, or 65%, subsequently had either DSA, MRA, or CTA.

Figure 5. Atrial fibrillation, microembolic signals, and subclavian steal. A 70-year-old woman with previously known subclavian steal was admitted with a new-onset visual field defect. CT showed a new occipital lobe infarct. TCD demonstrated variable flow velocities and irregular heart rate due to paroxysmal atrial fibrillation, microembolic signals (arrows), and a steal-like high-resistance flow in the reversed vertebral artery (below baseline). Transesophageal echocardiography was performed next and showed previously unrecognized endocarditis with intracardiac thrombus.

Figure 6. MCA reperfusion. At 2 hours: distal M1 MFV 17 cm/s, PI 0.7; proximal M1 MFV 15 cm/s, PI 0.8. At 2.5 hours: distal M1 MFV 25 cm/s, PI 1.0; proximal M1 MFV 40 cm/s, PI 1.1. At 24 hours: distal M1 MFV 40 cm/s, PI 1.2; proximal M1 MFV 40 cm/s, PI 1.1.

TCD showed subtotal M1 stenosis in a patient with MCA syndrome and NIHSS score 15. After 30 min of iv TPA infusion TCD showed a proximal M1 reperfusion with persisting distal obstruction and no clinical improvement. Intrarrenal urokinase was given.

Note flow diversion to perforators.

At 24 hours TCD and MRA showed patent MCA and the patient had minimal motor deficit with NIHSS 5.
versus normal vessels compared with angiography was 88%. Accuracy parameters were as follows: sensitivity 87.5%, specificity 88.6%, positive predictive value 87.5%, and negative predictive value 88.6%.

There were 5 false-negative and 5 false-positive TCD studies (Table 1). The absence of temporal windows led to a false-negative TCD study in only 1 patient. TCD showed only 1 false-positive result for the anterior circulation vessels. The remaining 8 of 10 errors were made in assessment of the posterior circulation vessels regarding distal basilar artery (BA) and extracranial vertebral artery (VA) patency.

### Discussion

Our study demonstrated that emergent TCD has the highest yield in thrombolysis-eligible patients. In this study, 69% of these patients had rates of extracranial and/or proximal intracranial occlusions on TCD similar to or higher than previously reported detection rates, including angiographic findings during acute cerebral ischemia. Our diagnostic criteria account for a “blunted” waveform sign, pulsatility of flow changes, and other signs of branch occlusions. These subtle flow abnormalities are not commonly reported in the literature.

This study confirms that TCD is both sensitive and specific in determining arterial occlusion or stenosis in acute cerebral ischemia, as previously reported. With a 15% rate of absent temporal windows, our accuracy was 88%. Although MCA lesions can be missed in these patients, a combination of transorbital and transforaminal examinations can identify ICA and BA lesions. The tradeoff between sensitivity and specificity in our study is minimal, indicating that the fast-track insonation protocol and diagnostic criteria may serve as a good bedside screening tool for triaging acute stroke patients.

Previous reports showed that TCD accuracy for MCA lesions decreases when patients with absent temporal windows are included. In our study, patients with anterior and posterior circulation strokes were included, and failure to insonate via temporal window was higher than previously reported (15% versus 6%). Our data show that a limited TCD study may still provide accurate results for proximal ICA and vertebrobasilar lesions. The major single source of error in our study was poor assessment of the distal basilar artery. Potential ways to improve the accuracy of intracranial ultrasound studies include color-coded imaging and contrast-enhanced sonography. Emergency situations preclude the use of bulky and expensive bedside equipment. The advantages of contrast-enhanced imaging should be combined with portability of ultrasound devices.

TCD shows the level of hemodynamically significant arterial obstruction, including extracranial, proximal, or distal intracranial segments. This information can help select patients for angiography and possible intra-arterial thrombolysis. In the PROACT, 105 thrombolysis-eligible patients with clinically suspected MCA occlusion underwent cerebral angiography, which showed no M1-M2 occlusion in 59 patients, or 56%. Normal arterial patency was found in 14% of thrombolysis-eligible patients and 65% of patients with minor strokes and TIAs. If urgent TCD is normal, there is almost an 89% chance that subsequent angiography will not discover an arterial occlusion. Although a normal TCD cannot completely rule out arterial pathological lesions, our data and previous observations suggest that its accuracy parameters are sufficient to avoid immediate angiography in many patients. In addition, a normal TCD examination is a good prognostic sign, as previously demonstrated.

CTA is capable of identifying patent or occluded vessels with poor leptomeningeal collaterals with rates similar to those by TCD in 22 patients with acute cerebral ischemia. Our recent analysis of 190 correlative neuroimaging studies showed that TCD determines the level of arterial occlusion with a sensitivity of 81% to 94%. In our opinion, TCD is complimentary to CTA because it points to the level of arterial obstruction and may help select the CTA target (ie, the circle of Willis or extracranial arteries).

Also, TCD helps to refine the severity of stenosis and provides clues to stroke pathogenesis. In 26% of all patients, TCD provided additional information to angiography, including flow velocities at the site of obstruction (ie, blunted signals), abnormal flow pulsatility, abnormal flow velocities, and microembolic signals. TCD helps to decide whether flow gaps on MRA were produced by an artifact, subtotal stenosis, complete occlusion, or reversed flow direction (ie, retrograde filling of the distal basilar artery in the presence of a proximal lesion). TCD offers a convenient, noninvasive, and repeatable way to monitor reperfusion without delays in administration of treatment.

TCD is a valuable tool in the evaluation of stroke patients at centers with trained technologists and expert interpreters. Current limitations include operator dependency and ultrasound attenuation through the skull and soft tissues. At present, TCD relies largely on the skill of a sonographer. In our opinion, the skill of a sonographer could be substituted only by changing the technology into a high-power, low-frequency, nonhandheld, reproducible flow-imaging examination. Improvement in ultrasound signals can be achieved by use of tight-fixation devices and contrast enhancement.

In conclusion, 69% of thrombolysis-eligible patients had a proximal occlusion on TCD. In 26% of all patients, TCD offered information additional to angiography to refine the severity of a stenosis and stroke pathogenesis. This study confirms that TCD is both sensitive and specific in determining arterial occlusion and stenosis in acute cerebral ischemia.

### Table 1. TCD Accuracy Compared with Angiography to Differentiate Normal Versus Abnormal (Stenosis or Occlusion) Vessels (n=84)

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+ indicates abnormal vessels (stenosis or occlusion); −, normal vessels. Angiographic studies were used as the gold standard.

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References