Intracranial Blood Flow Velocities in Acute Ischemic Stroke

Andrei V. Alexandrov, MD; Christopher F. Bladin, MBBS, FRACP; John W. Norris, MD

Background and Purpose

Transcranial Doppler sonography (TCD) can evaluate noninvasively the blood flow velocities and patency of the main trunk of the middle cerebral artery (MCA). Using TCD we evaluated MCA patency and patterns of flow through the circle of Willis in patients with acute stroke.

Methods

Patients with symptoms of hemispheric stroke were evaluated with serial TCD tests during admission. The Canadian Neurological Scale was used to assess neurological deficits. In all cases computed tomographic scan, 99mTc hexamethylpropyleneamine oxime single-photon emission computed tomography, and carotid duplex were performed, and in some cases cerebral angiography.

Results

Seventy-five consecutive patients with symptoms of acute ischemic stroke (mean time, 8±4 hours) were studied.

The technique of transcranial Doppler (TCD) accurately evaluates blood flow velocities (BFVs) in the intracranial blood vessels. The highest peak systolic BFV detectable at all possible depths in combination with the direction of the flow reflects changes in the intracranial circulation in acute stroke.

TCD is claimed to be comparable to cerebral angiography3,4 and useful as a predictor of clinical improvement in acute stroke if performed early,5,6 particularly in conjunction with single-photon emission computed tomography (SPECT).7 Although different types of middle cerebral artery (MCA) lesions have been documented,8 the circle of Willis patterns of perfusion and the natural history of MCA occlusion in acute stroke remain uncertain.

Subjects and Methods

Consecutive patients presenting in the emergency department with symptoms of acute cerebral ischemia were prospectively evaluated with TCD (EME 2-64) as soon as possible after admission. The ultrasonographer was “blinded” to the diagnosis. The initial TCD was performed in the emergency department, and two subsequent TCD examinations were performed during the hospital stay. Peak systolic BFVs and the direction of the flow were documented at all depths of successful insonation. Carotid duplex ultrasound was performed to detect extracranial carotid artery disease. Scoring of the neurological deficit was performed by a neurologist with knowledge of TCD data using the Canadian Neurological Scale (CNS) on day 1 and day 14. All patients had computed tomography (CT) and 99mTc hexamethylpropyleneamine oxime–SPECT scanning. Cerebral angiography was performed when appropriate. Student’s t test was used to compare the mean CNS scores.

Results

We evaluated 75 consecutive patients: 50 patients with acute ischemic stroke and 25 with transient ischemic attack (TIA). The initial TCD was performed at 8±4 hours.

The following circle of Willis perfusion patterns were seen on TCD: normal, collateral, stenotic, and occlusive.

The normal pattern is associated with symmetry of peak systolic BFVs between both sides of the circle of Willis. A normal difference is less than one third of a smallest peak systolic BFV value; normal BFVs for the MCA are presumed to be ≤140 cm/s.3,8

The collateral pattern is associated with the following collateral pathways found with TCD: anterior and posterior communicating arteries, reversal of ophthalmic artery flow, and MCA flow. Increased BFVs of the contralateral anterior cerebral artery and retrograde ipsilateral anterior cerebral artery flow indicate an anterior communicating collateral pathway.2 Collateral blood flow was also detected in the posterior communicating artery, reflecting a vertebrobasilar contribution to the anterior circulation. Increased BFVs directed toward the transducer at depths of 70 to 85 mm with posterior angulation of the probe may indicate blood flow in posterior communicating arteries. Finally, reversal of the MCA may reflect transcortical collateral flow or meningeal anastomosis.

The main finding of the stenotic pattern is a local increase of peak systolic BFVs (more than one third the...
The patients with stroke were subdivided into two groups: those who had changes of TCD pattern from the initial to the final examination (eg, occlusive to normal) and those who did not. Changes of neurological deficit scores (CNS) from admission to 2 weeks after onset were calculated, and mean scores were compared in these two groups. In the first group (n=26) the mean change of CNS score was 10±14.5; in the second group (n=24) the deficit had worsened, with a mean change of −0.4±18.3 (P=.03).

To illustrate the different TCD patterns and their potential value if thrombolytic therapy is being considered, we present four patients studied within the first 4 hours after onset of symptoms.

**Patient 1**
A 46-year-old woman was seen 4 hours after the onset of mild left-sided resolving hemiparesis. At the initial TCD examination blood flow in both ophthalmic arteries was reversed in direction, and there were increased BFVs in both posterior communicating arteries (Fig 2, left panel). BFVs in both MCAs were normal. Bilateral internal carotid artery occlusions were found on carotid duplex ultrasound. Bilateral internal carotid artery occlusions and collateral blood flow via posterior communicating arteries and ophthalmic arteries were also seen on intra-arterial digital subtraction angiography performed the same day (Fig 2, right panel). The neurological deficit completely resolved at 10 hours; a CT scan performed 1 week later was normal.

**Patient 2**
A 59-year-old man presented with mild left arm and facial weakness while driving near the hospital. TCD was performed in the emergency department 50 minutes after the onset of symptoms, and a right MCA stenosis was found (Fig 3, left panel). CT demonstrated a "hyperdense" MCA at 70 minutes after the onset, indicating a thrombus (Fig 3, right panel). SPECT showed hypoperfusion in the right MCA territory at 95 minutes. Cerebral angiography at 2 hours after the onset of symptoms showed a 99% stenosis of the right internal carotid artery starting at the bulb and extending to the MCA main trunk. Serial TCD tests performed during the first 24 hours showed increasing BFVs in the right MCA. The neurological deficit worsened over the next 12 hours, and the CNS score changed from 95 on admission to 50 by the first 24 hours and 2 weeks after onset. The patient was left with a dense left-sided hemiparesis. Cerebral infarction was seen on day 3 CT scan; right MCA BFVs returned to a normal value of 120 cm/s 2 weeks after onset.

**Patient 3**
A 46-year-old man with atrial fibrillation was admitted 4 hours after the onset of dense right-sided hemiparesis with motor aphasia. Admission CT was negative. The initial TCD showed increased MCA BFVs (Fig 4, top panel) with a diversion of the flow toward the left anterior cerebral artery, indicating a stenotic lesion of the left MCA trunk distal portion (Fig 4, bottom left panel). Within the next hour the patient developed complete right-sided hemiplegia. A CT scan at 6 hours

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### Patterns of Perfusion of the Circle of Willis in Acute Stroke

<table>
<thead>
<tr>
<th>TCD Patterns</th>
<th>Admission</th>
<th>Day 2</th>
<th>Day 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>15</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Collateral</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Stenotic</td>
<td>5</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>Occlusive</td>
<td>0</td>
<td>22</td>
<td>10</td>
</tr>
</tbody>
</table>

TCD indicates transcranial Doppler sonography; TIA, transient ischemic attack. Admission at 8±4 hours after stroke onset.

*In patients with TIA only an initial study was performed.

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### Natural History of MCA Occlusion

![Line graph shows spontaneous recanalization of middle cerebral artery (MCA) assessed by serial transcranial Doppler sonography at 4 hours, 8 hours, 2 days, and 2 weeks after ischemic stroke (n=50). Vertical axis represents percentage of arteries that remained occluded.](image)

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showed hemorrhagic infarction in the corresponding vascular distribution. Carotid duplex findings were normal. Cerebral angiography at 10 hours showed an embolus in the distal trunk of the left MCA, presumably of cardiac origin (Fig 4, bottom right panel).

**Patient 4**

A 62-year-old man was admitted 4 hours after the sudden onset of right-sided hemiplegia and aphasia. The admission CT was normal. TCD showed an asonic left MCA with diversion of the flow toward the left anterior cerebral artery with clear ultrasound "windows" (occlusive TCD pattern) (Fig 5, top left). SPECT at 6 hours showed an absent perfusion in the left MCA distribution (Fig 5, top right). Serial TCD tests indicated a spontaneous MCA recanalization by day 7 (Fig 5, bottom left). SPECT at that time demonstrated considerable reperfusion of the involved area (Fig 5, bottom right). A CT scan at day 10 demonstrated an infarction in the left MCA distribution in the same location as the initial perfusion deficit on SPECT. The patient had a very poor recovery (CNS score of 30 on admission had changed to 55 at 2 weeks).

**Discussion**

Our TCD results show that intracranial arterial obstruction occurred in 70% of patients in the immediate phase of stroke, concordant with findings from angiographic studies. Most (86%) initial MCA occlusions had spontaneously recanalized by 2 weeks. However, in our study only the initial TCD findings had a predictive value for short-term recovery.

The four cases reported represent the various flow patterns of an MCA thromboembolic event within the first hours of cerebral ischemia. The patients presented with similar severity of hemiplegia, but the severity of perfusion deficit and recovery were dramatically different.
Patients 1 and 2 had occlusions of the extracranial portions of the internal carotid arteries. In the first patient collaterals developed and MCA BFVs were normal, whereas in the second patient an internal carotid artery thrombus extended into the MCA, producing stenotic high BFVs. In patient 1, normal MCA BFVs indicate a favorable prognosis, unlike the second patient. If the first patient was considered a candidate for thrombolysis, the risk of intracerebral hemorrhage might outweigh the benefit. The second patient might also be considered for thrombolysis. However, extracranial internal carotid artery thrombosis decreases the effectiveness of thrombolysis for stroke. Color-coded carotid duplex scanning may be valuable in urgent screening of acute stroke patients for extracranial internal carotid artery obstruction if any immediate therapy is planned.

Patient 3 seems an ideal candidate for a thrombolytic trial. He had a stenotic MCA lesion at the time of the initial examination both on TCD and cerebral angiography, whereas the admission CT was negative. However, he then became completely hemiplegic. The second CT scan 6 hours after onset showed hemorrhagic transformation of the infarct, while the MCA remained severely stenosed. It may be useful to monitor MCA BFVs after admission when the patient is waiting for administration of the thrombolytic agent, because spontaneous recanalization may occur at any time. Also, serial TCD tests may provide valuable information on possible reocclusion of the MCA after thrombolytic treatment.

Patient 4 had an asonic segment in the MCA main stem. Although angiography was not performed, there was indirect confirmation of the TCD findings by SPECT, which showed complete focal absence of perfusion, as described previously. This combination of TCD and SPECT findings indicates a poor prognosis. This patient might have been an ideal candidate for thrombolysis because the MCA was occluded. It recanalized spontaneously by day 7. There was no hemorrhagic transformation detected on later CT scanning. However, patients presenting with severe hemiplegia and deteriorating strokes with an altered level of consciousness are not eligible for current thrombolytic trials.

Three types of MCA patency were assessed using the peak systolic velocity criteria: normal, stenotic,
and occlusive. Normal MCA BFV within the first 4 to 24 hours was associated with good recovery. Although 40% of patients with acutely normal MCA BFV may still have minor or moderate stroke, early normal MCA BFV is a window for clinical optimism regarding recoverability. Serial TCD measurements will help to decide if the MCA stenosis is acute or chronic. Stenotic MCA BFVs indicate medium short-term recovery. MCA occlusion is the most unfavorable prognostic TCD finding in the acute phase of stroke and was not seen in patients with TIAs. In 10% of patients the intracerebral arteries could not be insonated through the temporal window; the accuracy of TCD diagnosis may improve with contrast agents that allow better penetration of the cranial bones by enhancing the Doppler signal.18

Color-coded carotid duplex ultrasonography should be used in the immediate phase of stroke to detect significant extracranial carotid obstruction, and TCD provides information on the patency of intracranial vessels. Although data on the prognostic value of SPECT are controversial,19-21 its combination with TCD may be more valuable.7 SPECT and TCD may be used to differentiate TIAs and minor strokes from severe strokes, and serial TCD can be used for monitoring the patency of intracranial arteries.6,22

In conclusion, our TCD data show that 67% of patients with acute ischemic stroke had an occluded MCA within 4 hours after onset; by 2 weeks 86% of these had recanalized. TCD performed within 24 hours predicts short-term recovery.

Acknowledgments

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References

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