Comparison of Transcranial and Cervical Continuous-Wave Doppler in the Evaluation of Intracranial Collateral Circulation

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Adequate intracranial collateral circulation reduces risk of stroke in carotid artery surgery. To evaluate their relative accuracies in assessing intracranial collateral blood flow, we prospectively compared transcranial Doppler and continuous-wave Doppler of the cervical carotid arteries combined with compression of the common carotid artery in 28 consecutive patients before carotid endarterectomy. Ten healthy volunteers served as controls. Three patients (11%) were excluded from compression of arteries because of diffuse disease in the common carotid artery. A total of 199 compressions were performed without complications. Lack of a suitable transtemporal window precluded the performance of transcranial Doppler in three patients (12%). The anterior communicating artery was identified in all the normal volunteers and 80% of patients by both methods. The posterior communicating artery was identified by both methods in 16 of 20 attempts in controls. Continuous-wave Doppler identified the posterior communicating artery in 30 of 50 attempts in patients; transcranial Doppler identified the posterior communicating artery in 20 of 44 attempts in patients ($p > 0.5$). Detection of intracranial collaterals correlated with intraoperative carotid artery back pressure measurements in 23 of 25 patients (92%). We conclude that continuous-wave Doppler of the extracranial arteries combined with common carotid artery compression is a safe and easy way to detect intracranial collaterals, with an accuracy equivalent to transcranial Doppler. (Stroke 1990;21:1584–1588)

The risk of cerebral ischemia after various therapeutic interventions can be predicted by the adequacy of collateral circulation.1–4 For example, intracranial collateral blood flow correlates with untoward hemodynamic consequences of common carotid artery cross-clamping.5,6 Transcranial Doppler, which directly insonates the intracerebral arteries,7,8 is a useful noninvasive technique for diagnosing and monitoring patients at risk for cerebral ischemia and hemorrhage.9–12 Compression maneuvers of the common carotid arteries are required to evaluate the presence of the three communicating arteries in the circle of Willis using transcranial Doppler.9,13 In 1981, Franceschi14 described an alternative technique to detect and evaluate intracranial collaterals; compression of the common carotid artery is performed during insonation of the extracranial internal carotid artery and vertebral artery with a continuous-wave Doppler probe. Determination of communicating artery patency with this method correlated well with angiographic studies.5,15 We compared the cerebral collateral patterns identified by both transcranial Doppler and continuous-wave Doppler (combined with compression maneuvers) and evaluated the relative accuracy and utility of these techniques.

Subjects and Methods

Ten normal healthy volunteers (five men and five women) with a mean age of 32 years (range 26–41) and with no history of arterial or cerebrovascular disease served as controls. Twenty-eight consecutive patients (18 men and 10 women) selected for carotid artery thrombendarterectomy comprised the study group. Mean age was 69 years (range 56–74). All patients had duplex scans of the extracranial arteries (ATL-400, Advanced Technology Laboratories, Seattle, Wash.), conventional transcranial Doppler studies (TC II-64, Carolina Medical Electronics, Inc., Wixom, Mich.), and intracranial Doppler velocimetry. Transcranial Doppler was performed using a transcranial Doppler probe (TC-1164, Carolina Medical Electronics, Inc.) and a 4.0-MHz transducer fitted to a 60-000-MHz pulsed Doppler.
and complete angiograms of the aortic arch and both carotid and vertebral arteries. Common carotid artery compression combined with transcranial Doppler and continuous-wave Doppler examinations were attempted in all individuals.

Compressions of the common carotid artery were performed at the base of the neck just above the clavicle directly over the common carotid artery at a point demonstrated by the duplex scanning to be normal. Finger compression was maintained for two to three cardiac cycles. To ensure the efficacy of compression, a pulse detector ear clip (Medasonic, Mt. View, Calif.), which generated pulse tracings on a separate monitor, was attached to the ipsilateral ear lobe. Flattening of this pulse wave during compression indicated cessation of blood flow through the compressed carotid artery. Six compressions were performed in each study. One compression was used to detect the anterior communicating artery and two to detect the posterior communicating arteries with each noninvasive technique. Three patients (10.7%) were excluded from the compression maneuvers because duplex study demonstrated diffuse atherosclerosis in the common carotid artery associated with contralateral internal carotid artery occlusion. Thus, complete evaluation of intracranial collaterals by both methods was possible in 25 patients.

Transcranial Doppler studies were performed through the temporal window with a 2-MHz pulsed-wave, range-gated probe, as described previously. Middle cerebral artery velocity and posterior cerebral artery velocities were obtained bilaterally in patients with a suitable window. The spectral analysis of each intracranial signal was performed with online 64 fast Fourier transformation. Results were displayed as velocities (centimeters per second). Criteria for identification of the various intracranial arteries included depth of signal, angulation and direction of the probe, and direction of blood flow. The anterior communicating artery was demonstrated by insonating the middle cerebral artery while the contralateral common carotid artery was compressed (Table 1). Temporary cerebral ischemia produced by the compression would recruit blood flow from the opposite side, that is, the side of the middle cerebral artery insonation. If the anterior communicating artery was patent, peak middle cerebral artery velocity increased by 30% or more because of increased blood flow. If the anterior communicating artery was absent, there was minimal or no change in peak middle cerebral artery velocity because blood flow did not increase in response to contralateral carotid compression. The posterior communicating artery was demonstrated by insonating the posterior cerebral artery while the ipsilateral common carotid artery was compressed (Table 1). Temporary cerebral ischemia recruited blood from the ipsilateral posterior circulation. A 30% or more increase of posterior cerebral artery velocity at the time of compression indicated an open ipsilateral posterior communicating artery. Minimal or no change in posterior cerebral artery velocity indicated an absent posterior communicating artery. Both posterior communicating arteries were examined using this technique.

A 4-MHz probe (Medasonic) was used for continuous-wave Doppler studies. The internal carotid artery and vertebral artery were insonated. Spectral analysis was performed and displayed in an identical manner to the method described for transcranial Doppler. Vessels were identified by their anatomic locations and characteristic waveforms. The anterior communicating artery was evaluated by insonating the internal carotid artery while the contralateral common carotid artery was compressed (Table 1). A 30% or greater increase in peak internal carotid artery velocity indicated anterior communicating artery patency. Minimal or no change in the internal carotid artery velocity during compression indicated an absent anterior communicating artery. The posterior communicating artery was demonstrated by insonating the vertebral artery while the ipsilateral common carotid artery was compressed (Table 1). The same criteria of changes in the peak velocity as described for transcranial Doppler were used. Bilateral examinations were performed to evaluate both posterior communicating arteries.

All patients underwent carotid thromboendarterectomy under general anesthesia. Carotid artery back pressure was measured in standard fashion after cross-clamping the common carotid artery and external carotid artery. A temporary intraluminal shunt was inserted when 1) back pressure was less than 50 mm Hg, 2) the contralateral internal carotid artery was occluded, or 3) the patient had suffered a prior stroke.

Data were analyzed using the CLINFO PLUS computer program provided through the Division of

| TABLE 1. Identification of Intracranial Collaterals With Common Carotid Compression |
|---------------------------------|---------|----------|-------------------------------|
| Test modality                  | Artery to insonate | Artery to compress | Basis for interpretation          |
| Anterior circulation          | TCD     | MCA      | Contralateral                  | >30% in peak velocity=patent ACoA |
|                               | CWD     | ICA      | CCA                           |                         |
| Posterior circulation         | TCD     | PCA      | Ipsilateral                    | >30% in peak velocity=patent PCoA |
|                               | CWD     | VA       | CCA                           |                         |

TCD, transcranial Doppler; MCA, middle cerebral artery; CCA, common carotid artery; ACoA, anterior communicating artery; CWD, continuous wave Doppler; ICA, internal carotid artery; PCA, posterior cerebral artery; PCoA, posterior communicating artery; VA, vertebral artery.
Research Resources of the Heart, Lung, and Blood Institute, National Institutes of Health. Pearson’s and Yates’ χ² analyses were used to compare the two testing modalities. Nonparametric data were analyzed with Spearman’s rank test.

Results

One hundred ninety-nine compression maneuvers were performed. No neurologic or cardiac complications occurred during or after the compressions. No subjects experienced discomfort due to the tests.

Both transcranial Doppler and continuous-wave Doppler demonstrated the anterior communicating artery in each of the 10 control subjects. In four instances (20%), both tests indicated an absent posterior communicating artery. In two individuals, the posterior communicating artery was demonstrated with continuous-wave Doppler insonation of the vertebral artery, whereas it was not found by transcranial Doppler. There was no statistical difference in the accuracy of transcranial Doppler versus continuous-wave Doppler in defining collateral pattern in controls (Table 2).

Absence of a satisfactory temporal window precluded the performance of transcranial Doppler in three patients (12%). Thus, 22 patients underwent complete studies with both methods (Table 3). The anterior communicating artery was demonstrated in 16 of 22 patients with transcranial Doppler and 20 of 25 patients with continuous-wave Doppler. The two modalities agreed in 18 patients. In four patients, demonstration of the anterior communicating artery was successful with one method but unsuccessful with the other.

The posterior communicating artery was shown in 20 of 44 attempts with transcranial Doppler and in 30 of 50 attempts with continuous-wave Doppler. These results were not significantly different. Continuous-wave Doppler detected a posterior communicating artery in six patients when transcranial Doppler did not. Transcranial Doppler identified one posterior communicating artery that was not detected by continuous-wave Doppler.

Seventeen patients (68%) had internal carotid artery back pressure measurements of 50 mm Hg or higher. In all 17, at least one patent communicating artery (anterior or posterior) was demonstrated by the compression studies preoperatively (Table 4). Two patients with satisfactory back pressures had a temporary intraluminal shunt placed because of contralateral carotid occlusion (Table 4).

Eight patients had a carotid artery back pressure of less than 50 mm Hg and had temporary intraluminal shunts. In six of these (75%), the preoperative evaluation correctly predicted inadequate collateral circulation. Complete absence of communicating arteries or a single low-flow collateral was independently demonstrated by both techniques. In two patients, the noninvasive evaluation overestimated the collateral circulation compared with carotid back pressure. Overall, the preoperative noninvasive evaluation of the collateral circulation accurately predicted the internal carotid artery back pressure in 23 of 25 studies and the temporary shunting requirement in 21 of 23, or 91% of the patients.

Discussion

The importance of the intracranial collateral circulation in responding to cerebral ischemia has been well documented.1-4,6 Direct correlation between middle cerebral artery velocity and intraoperative carotid artery back pressure has been reported.6 Likewise, good collateral circulation has been associated with favorable outcomes of carotid operations.5,15 Thus, knowledge of the collateral circulation obtained by noninvasive tests preoperatively may be important in evaluating operative risk and planning operative strategy. For example, as early as 1914, Hunt16 suggested that the severity of symptoms after carotid artery occlusion depended in part on the adequacy of collateral channels, especially the communicating arteries of the circle of Willis. In 1964, Wiener et al17 confirmed this hypothesis in 72 cases of complete carotid occlusion examined by autopsy or arteriography. More recent studies of internal carotid occlusion have substantiated an approximately

### Table 2. Demonstration of Intracranial Collaterals With Compression Maneuvers in Normal Volunteers

<table>
<thead>
<tr>
<th></th>
<th>Transcranial Doppler</th>
<th>Extracranial CW Doppler</th>
<th>Agreement of methods (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACoA</td>
<td>10</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>PCoA</td>
<td>14</td>
<td>6</td>
<td>90</td>
</tr>
</tbody>
</table>

*p*=NS. CW, continuous wave; ACoA, anterior communicating artery; PCoA, posterior communicating artery.

### Table 3. Demonstration of Intracranial Collaterals on Preoperative Evaluation of Patients With Carotid Disease

<table>
<thead>
<tr>
<th></th>
<th>Transcranial Doppler</th>
<th>Extracranial CW Doppler</th>
<th>Agreement of methods No. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACoA</td>
<td>16</td>
<td>6</td>
<td>73</td>
</tr>
<tr>
<td>PCoA</td>
<td>20</td>
<td>24</td>
<td>45.5</td>
</tr>
</tbody>
</table>

*p*=NS. CW, continuous wave; ACoA, anterior communicating artery; PCoA, posterior communicating artery.
pression should be performed low in the neck to avoid the carotid sinus; 2) duplex imaging of the arterial wall should be obtained before compression to avoid manipulation of stenosed, ulcerated, or calcified arteries; and 3) compression should be of short duration to avoid ischemic complications.

Transcranial Doppler has been shown to be an accurate and reproducible method for the evaluation of the intracranial collateral circulation.\(^3\)\(^,\)\(^6\)\(^,\)\(^8\)\(^,\)\(^9\) However, it requires highly trained technicians, special equipment, and the presence of a suitable sonoluent transtemporal window. Most patients undergoing carotid surgery do not undergo a preoperative evaluation of their collateral vessels by transcranial Doppler. Conversely, continuous-wave Doppler insonation of the extracranial arteries is performed routinely in most noninvasive vascular laboratories as part of the standard evaluation of the carotid and vertebral arteries. Our results suggest that addition of common carotid artery compression to this examination can supply accurate information regarding the collateral circulation, which is comparable to the information obtained with transcranial Doppler. Moreover, continuous-wave Doppler combined with common carotid artery compression is an alternative simple and safe method to evaluate intracranial collaterals when transcranial Doppler information is unavailable.

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### References


### Table 4. Correlation Between Internal Carotid Artery Back Pressure and Intracranial Collaterals

<table>
<thead>
<tr>
<th>No. patients</th>
<th>Back pressure ≥50 mm Hg</th>
<th>Back pressure &lt;50 mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of collaterals demonstrated preoperatively</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Shunt used</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

25% resultant stroke rate, but did not identify features that would differentiate patients likely to suffer strokes from those likely to remain asymptomatic after carotid thrombosis.\(^18\)\(^,\)\(^19\) Information about intracranial collaterals provided by our study potentially may generate algorithms to guide recommendations for carotid endarterectomy, particularly in patients with asymptomatic carotid stenosis.

The normal anatomy of the intracranial collateral vessels is extremely variable.\(^3\) Only 50% of the population have a complete circle of Willis.\(^1\)\(^,\)\(^20\) The anterior communicating artery is either hypoplastic or missing in 5–10% of people, and one of the posterior communicating arteries is effectively absent in 30%.\(^21\)\(^,\)\(^22\) Because the collateral arteries are not in constant use, their presence is not easily demonstrated. Only 20% of selective angiographic studies show collateral vessels unless a carotid occlusion exists.\(^23\)\(^,\)\(^24\) Thus, a true in vivo “gold standard” for confirmation of collateral artery patency does not exist. Nevertheless, we are conducting an ongoing study using angiography to help explain the lack of concordance in some of our results.

When the common carotid artery is compressed, blood flow to the ipsilateral cerebral hemisphere momentarily decreases, leading to local vasodilation in the peripheral vascular bed. Blood from the contralateral circulation (via the anterior communicating artery) or the posterior circulation (via the ipsilateral posterior communicating artery) will flow into the low-resistance area, so that normal cerebral perfusion is maintained. Thus, common carotid artery compression induces flow in the dormant communicating arteries, which is stimulated by the temporary hemispheric ischemia.

Common carotid artery compression for the detection of intracranial collateral circulation has been used successfully in angiographic studies\(^23\) with high accuracy and low complication rates.\(^25\)\(^,\)\(^26\) Nevertheless, theoretical considerations of discomfort, bradycardia, hypotension, and even stroke and death exist.\(^27\) No complications occurred from digital carotid compression in our series, and similar safety has been repeated by others.\(^5\)\(^,\)\(^9\)\(^,\)\(^13\)\(^,\)\(^23\)\(^,\)\(^25\)\(^,\)\(^26\) To avoid untoward events, we recommend the following tenets: 1) compression should be performed low in the neck to avoid the carotid sinus; 2) duplex imaging of the arterial wall should be obtained before compression to avoid manipulation of stenosed, ulcerated, or calcified arteries; and 3) compression should be of short duration to avoid ischemic complications.

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