Increased cerebral blood flow after external carotid artery revascularization

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Ten patients with symptoms of cerebral ischemia were found to have totally occluded internal carotid arteries with significant external carotid artery stenosis or occlusion. Eight patients underwent external carotid endarterectomy, and two patients underwent saphenous vein bypass to the external carotid artery from the subclavian artery. Cerebral blood flow was measured with $^{133}$Xe in six patients preoperatively and in five postoperatively. Four of the six patients had diminished mean flow on the affected side, and three had diminished flow on the contralateral side. All patients had abnormalities in regional cerebral blood flow. Postoperatively, all patients had significant improvement in mean blood flow on the side treated with operation (15% to 39%), and four had improvement of blood flow on the contralateral side (12% to 52%). All had improvement in regional cerebral blood flow. Nine of the 10 patients were relieved of their symptoms. One patient, despite improvement in cerebral blood flow, continued to have diminished cerebral flow and symptoms postoperatively. Subsequent extracranial-intracranial bypass relieved his symptoms and his cerebral blood flow returned to normal. Thus external carotid artery revascularization is effective in increasing total and regional cerebral blood flow and in relieving symptoms of internal carotid artery occlusion and external carotid stenosis. Cerebral blood flow measurement with $^{133}$Xe is useful in preoperative patient selection and objective assessment of operative results.

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The importance of the extracranial internal carotid artery and intracranial collateral pathways in maintaining cerebral blood flow is well recognized. However, a role for the external carotid artery in cerebral circulation has not been firmly established. Numerous external carotid to internal carotid artery collateral vessels have been demonstrated anatomic ally, angiographically, and by Doppler flow techniques, but the extent of their contribution to intracranial circulation in the presence of internal carotid artery obstruction is unclear. The functional significance of these collateral vessels has been suggested by the relief of symptoms of cerebral ischemia in patients with total internal carotid artery occlusion after external carotid artery revascularization; however, documentation of improved cerebral blood flow has been lacking. We studied patients with internal carotid artery occlusion and external carotid stenosis before and after external carotid artery revascularization by measuring regional cerebral blood flow (rCBF) with $^{133}$Xe. The results support the concept that the external carotid artery is an important source of collateral flow to the brain in the face of internal carotid artery occlusion.

METHODS

In the past 2 years we treated 10 symptomatic patients with total occlusion of the internal carotid artery and external carotid stenosis or occlusion. The patients ranged in age from 42 to 77 years; four were men and six were women. Four patients presented with lateralizing transient hemispheric ischemic symptoms, and three had recurrent amaurosis fugax involving one eye. Five patients had a past history of stroke, and two had a recent completed stroke with good recovery. One patient had a past history of stroke and had disabling syncopal attacks without lateralizing neurologic symptoms. Cerebral angiography demonstrated complete occlusion of the inter-
nal carotid artery with more than 50% stenosis of the external carotid artery on the symptomatic side in each patient (Fig. 1). In addition, four patients had complete occlusion of the contralateral internal carotid artery.

The rCBF was measured preoperatively in six patients with a xenon inhalation technique (Novo inhalation cerebrograph) developed by Obert et al. The patient breathes $^{133}$Xe gas mixed with room air (5 to 7 mCi/L) for 1 minute through a tight-fitting mask. The arterial concentration of $^{133}$Xe is estimated from the end-tidal $^{133}$Xe activity in the expired air. After a 1-minute saturation, the patient breathes room air for a washout period of 10 minutes. Sixteen sodium iodide crystal scintillation detectors, positioned symmetrically over both hemispheres, record the 10-minute desaturation curve.

The output data are processed through an HP 9845S computer with a two-compartment analysis. The first compartment provides the estimate of gray matter flow. This analysis permits the separation of flow in the gray matter from flow in the white matter and extracranial noncerebral tissues. Both rCBF measurements at each probe, as well as mean hemispheric blood flow data, are generated with a complete data printout within 15 minutes (Fig. 2).

Six patients underwent measurement of rCBF before operation, and five underwent both preoperative and postoperative rCBF measurement. All patients underwent revascularization of the external carotid artery.

RESULTS

All 10 patients had internal carotid artery occlusion on the symptomatic side, and four patients had contralateral internal carotid occlusion. Eight patients had external carotid stenosis of 50% to 95% on the symptomatic side and underwent external carotid endarterectomy. No attempt was made to reopen the occluded internal carotid artery. Two patients had total occlusion of the external and common carotid arteries in addition to internal carotid artery occlusion. Revascularization was achieved by saphenous vein bypass to the external carotid artery from the subclavian artery.
Table I. rCBF* in six patients with internal carotid occlusion and external carotid stenosis

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Symptomatic side</th>
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<th></th>
<th>Contralateral side</th>
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<tr>
<td></td>
<td>Mean</td>
<td>Abnormal regions (of 8)</td>
<td>Mean</td>
<td>Abnormal regions (of 8)</td>
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<tr>
<td>4†</td>
<td>50.9</td>
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<td>49.3</td>
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<tr>
<td>5†</td>
<td>28.5</td>
<td>7</td>
<td>28.5</td>
<td>7</td>
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<tr>
<td>6†</td>
<td>43.3</td>
<td>8</td>
<td>51.5</td>
<td>6</td>
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<td></td>
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</table>

*Expressed as ml/100 gm/min; normal range = 56 to 91 ml/100 gm/min
†Indicates bilateral internal carotid artery occlusion.

Table II. Mean hemispheric blood flow* before and after external carotid artery revascularization in five patients with internal carotid artery occlusion

<table>
<thead>
<tr>
<th>Patient No.</th>
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<th>Contralateral side</th>
<th></th>
<th></th>
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<tbody>
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<td>Postop</td>
<td>% change</td>
<td>Preop</td>
<td>Postop</td>
<td>% change</td>
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*Expressed as ml/100 gm/min.

Preoperative mean hemispheric blood flow on the symptomatic side ranged from 57.6 to 28.5 ml/100 gm/min (Table I). In four of the six patients, mean blood flow was below normal, and in two patients flow was at the lowest limit of normal (57.1 and 57.6 ml/100 gm/min—normal range, 56 to 91). Mean hemispheric flow was also decreased in the contralateral hemisphere in four of the six patients. Patients with bilateral internal carotid artery occlusion did not necessarily have the lowest flows. All patients had focal decreases in rCBF in both hemispheres. As the hemispheric flow decreased, there was an increase in the number of regions with decreased flow.

Postoperatively, the mean hemispheric blood flow on the side treated with operation increased in all patients by 15% to 39%. In four of the five patients, mean hemispheric flow returned to the normal range (Table II). On the contralateral side, there also was an increase in mean hemispheric flow of 12% to 52% in four of the five patients. The degree of improvement in mean flow was similar in both hemispheres. In one patient (No. 5), rCBF improved after revascularization, but remained in the abnormal range bilaterally. This patient continued to have disabling syncope postoperatively.

The rCBF improved in four of the five patients with a decrease in the number of hypoperfused regions postoperatively (Table III). Patient No. 5 continued to be symptomatic and continued to have abnormal flow in most measured regions.

Nine of the 10 patients were relieved of their symptoms after external carotid artery revascularization. Follow-up to 2 years revealed no recurrence of symptoms in eight of these patients. One patient developed a new stroke on the side treated with operation concomitant with an episode of hypotension. Arteriography demonstrated continued wide patency of the subclavian to external carotid artery bypass, and follow-up rCBF studies remained normal. The patient neurologically recovered. One patient with continued abnormal rCBF, despite improvement after revascularization, remained symptomatic postoperatively. He subsequently underwent extracranial-intracranial bypass with an increase in rCBF to the normal range and relief of his symptoms of syncope.

DISCUSSION

Numerous anastomotic channels exist between the external and internal carotid arteries,7, 8, 15, 24 and it has been suggested that these anastomoses may
account for up to 30% of intracerebral circulation in patients with bilateral internal carotid artery occlusion.7

Uncommonly, the external carotid artery may be a source of cerebrovascular symptoms, both with a patent internal carotid artery8,9 or an occluded internal carotid artery.5,10 Symptoms may be the same for the internal carotid artery with amaurosis fugax12,11 or lateralizing hemispheric symptoms.4 Clinical reports have documented relief of cerebral ischemic symptoms5,5 and amaurosis fugax,5,11 as well as improvement in cognitive function10 after external carotid artery revascularization.

However, despite good clinical results, objective documentation of improved rCBF has been lacking. Machleder and Barker13 have demonstrated that the external carotid artery provides a significant component to the internal carotid back pressure at the time of operation, suggesting an important functional connection between the external and internal carotid systems. We have sought further objective evidence for benefit from external carotid artery revascularization by measuring 133Xe cerebral blood flow.

The 133Xe inhalation technique for measuring rCBF was first introduced by Mallett and Veall11 and developed by Obrist et al.21 Its main advantage over previous techniques is that it eliminated the need for the intraarterial injection of tracer. This provided a clinically useful technique for the measurement of rCBF. Measurements can be made repeatedly on the same patient with minimal discomfort and risk. In addition, flow values for both cerebral hemispheres, as well as the brain stem and cerebellum, can be measured simultaneously16 and the effects of arterial PCO2, activity and sensory stimulation can be determined.17

A major disadvantage of the inhalation technique has been contamination of the clearance curves by radioactivity from the scalp, air sinuses, and other extracerebral sources.21,22 Differences in the clearances rate for gray matter, white matter, and extracerebral tissue may be utilized to separate noncerebral components of flow.17 Obrist et al.23 proposed a two-compartment analysis of a 10-minute desaturation curve after a 1-minute period of inhalation. This minimizes the contribution of the extracerebral component of flow because of the long time required for saturation and desaturation of extracerebral tissues. Numerous investigators have found this technique to be a reliable and reproducible measure of gray matter rCBF.16,17,29-31 There is good agreement between the xenon inhalation technique with a

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>No. of abnormal regions (8 each hemisphere)</th>
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<td></td>
<td>Symptomatic side</td>
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Table III. The rCBF before and after external carotid artery revascularization in five patients with internal carotid artery occlusion

The reproducibility of serial rCBF measurements is 2.5%.17 However, numerous physiologic variables influence rCBF including arterial PCO2 and alterations in normal physiologic functions. The coefficient of variability from day to day has been found to be 7% to 14%.2,16 Thus differences in flow must exceed 14% to be considered significant at the 0.05 level.21 All of our patients had a 15% or greater increase in mean hemispheric blood flow on the side treated with operation after external carotid artery revascularization, indicating a true increase in rCBF as a result of the operative procedure. In addition, three of the five patients had increased rCBF in the opposite hemisphere, indicating extensive crossover of the collateral network from one side of the scalp and brain to the other.

Regional variations exist in rCBF under normal conditions.16 Two of our six patients had normal mean hemispheric blood flow preoperatively, but had decreased flow in several cerebral regions. The number of abnormally perfused regions decreased in all patients after external carotid artery revascularization. Abnormalities in rCBF have also been noted with occlusive disease of the internal carotid arteries,17 with an increase toward normal after internal carotid artery endarterectomy.19

The improvement in rCBF after external carotid artery revascularization in our patients confirms the importance of external carotid collateral vessels in maintaining cerebral circulation when the internal carotid artery is occluded. These collateral vessels enlarge and become more prominent with gradual occlusion of the internal carotid artery.6,23 This probably accounts for the lack of neurologic symptoms in some patients with total occlusion of the
internal carotid artery. Sudden internal carotid artery occlusion without fully developed collateral vessels may result in extensive neurologic deficit. Similarly, obstruction of the external carotid artery with diminished flow into the network of collateral vessels will result in symptoms of cerebral ischemia. Restoration of flow to the external carotid artery may be accomplished with either endarterectomy or bypass procedures.

We have found the measurement of xenon rCBF with the inhalation technique to be a safe, reliable, and useful measure in the evaluation of patients with cerebral occlusive disease. It is useful in evaluating the extent of cerebral ischemia preoperatively and can demonstrate the effectiveness of revascularization procedures postoperatively. In patients with continued symptoms postoperatively, cerebral blood flow measurements are useful in planning further therapy. Thus in one patient, although the rCBF improved after external carotid artery revascularization, it remained abnormal. Subsequent intracranial revascularization resulted in an increase in rCBF to the normal range and relief of the patient’s symptoms.

REFERENCES