Hemodynamic Evaluation in Patients with Superficial Temporal Artery-Middle Cerebral Artery Anastomosis

—Stable Xenon CT-CBF Study and Acetazolamide—

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Abstract

Sixteen patients with minor completed stroke in the chronic stage underwent superficial temporal artery-middle cerebral artery (STA-MCA) anastomosis. The acetazolamide-activated regional cerebral blood flow (rCBF) was measured 20 minutes after the injection using inhalation of stable xenon and computed tomographic scanning (Xe\textsuperscript{S} CT-CBF study) pre- and postoperatively. Eleven patients (Group 1) showed immediate improvement in neurological state within a few days of the operation, while five (Group 2) showed no improvements. Preoperative rCBF in the ischemic areas without infarction was 30.8 ± 3.0 ml/100 gm/min in Group 1 and 53.0 ± 5.2 ml/100 gm/min in Group 2. Preoperative vasodilatory capacity with acetazolamide in Group 1 was 5.7 ± 8.6 and significantly increased to 19.8 ± 4.9 after surgery. In Group 2, pre- and postoperative vasodilatory capacity was 12.7 ± 3.1 and 14.9 ± 2.9, respectively, and there was no significant change. These results suggested that minor stroke patients with moderate decrease of affected side rCBF (less than 40 ml/100 gm/min) and with hemodynamic impairment may have the surgical indication for STA-MCA anastomosis.

Key words: STA-MCA anastomosis, Xe\textsuperscript{S} CT-CBF study, acetazolamide, hemodynamic compromise

Introduction

Focal cerebral ischemia results from an imbalance between the regional cerebral blood flow (rCBF) and the regional metabolic demands in an area of the brain. A variety of mechanisms contribute to cerebral ischemia, including artery-to-artery embolism, progressive hemodynamic impairment, and small vessel occlusive disease.\textsuperscript{1,16,26} A randomized multicenter cooperative study initiated in 1977 failed to confirm the hypothesis that extra-intracranial (EC-IC) bypass surgery prevents further cerebral ischemia in atherosclerotic internal carotid artery (ICA) or middle cerebral artery (MCA) diseases.\textsuperscript{7}

EC-IC bypass surgery was introduced to treat the hemodynamic causes of cerebral ischemia in 1967.\textsuperscript{32} It was based on the logical assumption that hypoperfusion in a region of the cerebral tissue can be prevented by increasing the CBF in that region, as with other organs in the body such as the heart and kidney. If the conclusions of the cooperative study are to be accepted as correct, it must be concluded that the brain has different activity from other organs and does not benefit even if hypoperfusion improved.

In contrast, many patients showed marked improvement of motor weakness, aphasia, apraxia, agnosia, etc., within a few days of EC-IC bypass surgery.

In this study, we evaluate the rCBF and cerebral vasodilatory capacity (VDC) with stable xenon-enhanced computed tomography (Xe\textsuperscript{S} CT) and acetazolamide in minor stroke patients who may benefit from the bypass surgery.

Materials and Methods

From February 1, 1986 to April 30, 1989, 81 patients with minor completed stroke were treated with
superficial temporal artery (STA)-MCA anastomosis at least 1 month after onset.28) Sixteen of 81 patients underwent resting and acetazolamide (Diamox®)- activated Xe6 CT-CBF study28 before and after surgery. They comprised 11 males and five females with an age distribution of 48–76 years (Table 1).

The Xe6 CT-CBF measurement was performed with short inhalation of 30% Xe and the values were calculated with the curve-fitting method.27 Changes in end-tidal CO2, blood pressure, and electrocardiogram were monitored during the examination. Postoperative rCBF study was performed 14 days after surgery. Diamox-activated (10 mg/kg bolus injection) rCBF was measured 20 minutes after the injection.

CBF functional images in the resting and Diamox-activated state were obtained pre- and postoperatively, and the cortical rCBF in the region of interest, which was thought to be ischemic with normal Hounsfield units on CT scans, was calculated.

Results

Eleven of 16 patients showed marked neurological improvement within a few days after surgery (Group 1), while the neurological state of five patients was unchanged (Group 2). Disturbed higher cortical functions such as aphasia, agnosia, and apraxia

Table 1 Clinical summary of 16 patients with STA-MCA anastomosis

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age, Sex</th>
<th>Signs and symptoms</th>
<th>CT</th>
<th>Angiography (collateral circulation)</th>
<th>Postoperative improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>71, F</td>
<td>rt hemiparesis, motor aphasia</td>
<td>sLDA</td>
<td>lt IC occl. (ophth.)</td>
<td>+*</td>
</tr>
<tr>
<td>2</td>
<td>64, M</td>
<td>rt hemiparesis, motor aphasia</td>
<td>sLDA</td>
<td>lt M1 occl. (LMA)</td>
<td>+</td>
</tr>
<tr>
<td>3</td>
<td>58, M</td>
<td>rt hemiparesis, motor aphasia</td>
<td>sLDA</td>
<td>lt M2 occl. (LMA)</td>
<td>+*</td>
</tr>
<tr>
<td>4</td>
<td>60, M</td>
<td>lt hemiparesis, visual spatial agnosia</td>
<td>sLDA</td>
<td>rt IC occl. (ophth.)</td>
<td>+</td>
</tr>
<tr>
<td>5</td>
<td>62, M</td>
<td>lt hemiparesis, hemiasomatognosia</td>
<td>sLDA</td>
<td>atrophy (LMA)</td>
<td>+*</td>
</tr>
<tr>
<td>6</td>
<td>63, M</td>
<td>lt hemiparesis, dysarthria</td>
<td>sLDA</td>
<td>rt M1 occl. (LMA)</td>
<td>+</td>
</tr>
<tr>
<td>7</td>
<td>72, M</td>
<td>rt hemiparesis, motor aphasia</td>
<td>sLDA</td>
<td>lt IC occl. (ACom + LMA)</td>
<td>+</td>
</tr>
<tr>
<td>8</td>
<td>48, M</td>
<td>Gerstmann's syndrome</td>
<td>sLDA</td>
<td>lt M2 occl. (LMA)</td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>64, F</td>
<td>rt hemiparesis, motor aphasia</td>
<td>sLDA</td>
<td>lt IC occl. (ophth.)</td>
<td>+*</td>
</tr>
<tr>
<td>10</td>
<td>76, F</td>
<td>rt hemiparesis, total aphasia</td>
<td>sLDA</td>
<td>lt M1 occl. (LMA)</td>
<td>+*</td>
</tr>
<tr>
<td>11</td>
<td>47, M</td>
<td>lt hemiparesis, depressive state</td>
<td>sLDA</td>
<td>rt IC occl. (ACom + LMA)</td>
<td>+</td>
</tr>
<tr>
<td>12</td>
<td>52, F</td>
<td>rt hemiparesis</td>
<td>normal</td>
<td>lt IC occl. (ACom)</td>
<td>−</td>
</tr>
<tr>
<td>13</td>
<td>62, F</td>
<td>rt hemiparesis, motor aphasia</td>
<td>sLDA</td>
<td>lt IC occl. (ACom)</td>
<td>−</td>
</tr>
<tr>
<td>14</td>
<td>60, F</td>
<td>rt hemiparesis</td>
<td>sLDA</td>
<td>lt IC occl. (PCom)</td>
<td>−</td>
</tr>
<tr>
<td>15</td>
<td>56, M</td>
<td>lt hemiparesis, dysarthria</td>
<td>sLDA</td>
<td>rt M2 occl. (LMA)</td>
<td>−</td>
</tr>
<tr>
<td>16</td>
<td>58, M</td>
<td>lt hemiparesis</td>
<td>sLDA</td>
<td>rt M2 occl. (LMA)</td>
<td>−</td>
</tr>
</tbody>
</table>

All the patients were treated with single superficial temporal artery-middle cerebral artery (STA-MCA) anastomosis. *Neurological state was improved but hemiparesis still remained postoperatively. sLDA: small low-density area, occl.: occlusion, IC: internal carotid artery, M1,M2: first or second segment of middle cerebral artery, ophth.: ophthalmic artery, LMA: leptomeningeal anastomosis, ACom,PCom: anterior or posterior communicating artery.

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were more improved than motor weakness in Group 1. In Group 2, three patients showed ICA occlusion with good collateral circulation through the anterior (AComA) or posterior communicating artery (PComA). The other two patients showed the occlusion of the MCA branch with collaterals through leptomeningeal anastomoses from the anterior cerebral artery (ACA) and their neurological deficits were hemiparesis and dysarthria.

Preoperative rCBF in the ischemic areas without infarction in 16 patients was 37.8 ± 10.7 ml/100 gm/min (mean ± SD) and it increased to 43.6 ± 9.4 ml/100 gm/min postoperatively. The postoperative rCBF increased significantly in Group 1 (p < 0.001) while there were no significant changes in Group 2 (Fig. 1).

VDC and asymmetry index were defined as follows:

\[
\text{VDC} = \frac{A_{\text{after D}} - A_{\text{before D}}}{A_{\text{before D}}} \times 100
\]

\[
\text{Asymmetry index} = \frac{B - A}{(A + B)/2} \times 100
\]

where A: rCBF on the affected side, B: rCBF on the unaffected side, D: injection of Diamox.

VDC in Group 1 increased postoperatively (p < 0.01). In Group 2, pre- and postoperative VDC had no significant change (Fig. 2). In the preoperative period, the asymmetry index in Group 1 increased significantly after the Diamox injection (p < 0.01). However, there were no significant changes between pre- and post-Diamox injection in the postoperative period. The asymmetry index in the postoperative period improved significantly (p < 0.001). On the other hand, the asymmetry index in Group 2 was much lower than that in Group 1, and there were no significant changes before and after the Diamox injection or surgery (Fig. 3).

**Representative Case Reports**

**Case 8** (Fig. 4): A 48-year-old male was admitted to our institute with acalculia, agraphia, and finger agnosia. He had had a right hemiparesis and aphasia due to cerebral infarction 2 years prior to admission. He was diagnosed as having Gerstmann’s syndrome.
On admission, CT scans demonstrated a low-density area in the left temporal region. Cerebral angiography demonstrated an occlusion of the posterior trunk of the left MCA. Preoperative Xe133 CBF study disclosed an extensive low-CBF area in those regions. rCBF in the left parietal cortex was 28 ml/100 gm/min although CT scans demonstrated no infarcted region. Unaffected side rCBF was 62 ml/100 gm/min. After the Diamox injection, rCBF increased slightly to 31 ml/100 gm/min on the affected side and increased to 70 ml/100 gm/min on the unaffected side.

Postoperatively, rCBF in the left parietal cortex was 31 ml/100 gm/min in the resting state, and
Diamox increased it to 36 ml/100 gm/min. Neurological condition improved within a few days of the operation.

Case 9 (Fig. 5): A 64-year-old male was admitted with right hemiparesis and motor aphasia. He had had a right hemiparesis and total aphasia due to cerebral infarction 2 months before admission.

He could walk unaided and could understand simple sentences on admission. CT scans demonstrated a small low-density area in the left paraventricular region. Cerebral angiography showed left ICA occlusion with collaterals through the ipsilateral ophthalmic artery. Preoperative Xe\textsuperscript{1} CT-CBF study showed an extensive low-CBF area in the left hemisphere. Cortical rCBF in the lesion which was not infarcted on CT scans was 38 ml/100 gm/min. After the Diamox injection rCBF decreased slightly to 34 ml/100 gm/min.

Postoperatively, rCBF in left hemisphere increased to 54 ml/100 gm/min in the resting state. Diamox increased it to 62 ml/100 gm/min. Motor aphasia improved within a few days of the operation. He could give appropriate names to some objects around him.

Case 12 (Fig. 6): A 52-year-old female was admitted with 1-year history of right hemiparesis.

On admission, she could walk unaided and CT scans demonstrated no abnormalities. Cerebral angiography showed left ICA occlusion with good collaterals through AComA. An unruptured AComA aneurysm was incidentally detected. She underwent an aneurysmal neck clipping.

Xe\textsuperscript{1} CT-CBF study before STA-MCA anastomosis disclosed that cortical rCBF in the left hemisphere was 60 ml/100 gm/min and it increased to 68 ml/100 gm/min with Diamox activation. STA-MCA anastomosis was performed on the left side.

Postoperative cortical rCBF in the left side was 62 ml/100 gm/min and it increased to 69 ml/100 gm/min after the Diamox injection. Her neurological condition remained unchanged.

Case 15 (Fig. 7): A 56-year-old male was admitted with left hemiparesis and dysarthria. He had had a cerebral infarction 6 months prior to admission.

CT scans demonstrated a small low-density area in the right frontal lobe on admission. Cerebral angiography demonstrated occlusion of the posterior branch of the right MCA with leptomeningeal anastomosis via the ipsilateral ACA and posterior cerebral artery. Preoperative Xe\textsuperscript{1} CT-CBF study disclosed a slightly low-CBF area (52 ml/100 gm/min) but the rCBF increased slightly to 56 ml/100 gm/min with Diamox activation.

Postoperatively, rCBF was 57 ml/100 gm/min in the resting state, and Diamox induced a large increase to 68 ml/100 gm/min. However, he had no neurological changes.

Discussion

EC-IC bypass surgery has been widely performed on patients with cerebrovascular occlusive diseases since its introduction.\textsuperscript{20} It is intended to improve the cerebral hemodynamics and consequently to reduce the incidence of further strokes.\textsuperscript{10,21,24,30} However, in 1985, the EC-IC Bypass Study Group reported negative results concerning its clinical effectiveness on patients with ICA or MCA atherosclerotic diseases.\textsuperscript{17} In a subgroup of patients, however, there may be serious hemodynamic compromises in cerebral circulation and hemodynamic ischemic events.\textsuperscript{20}

The majority of patients with cerebral ischemia have symptoms due to thromboembolism. However, patients with transient ischemic attacks or stroke due to hemodynamic insufficiency nonetheless represent a significant minority. Following ICA occlusion, ipsilateral episodic ischemic events may occur, but even in these patients, distal cerebral embolism has been shown to be a common pathogenetic mechanism.\textsuperscript{2,3,18,31} In a smaller group, however, the collaterals are less efficient and hemodynamic ischemic events may develop; such patients should be sought among those with severely stenotic or occlusive vascular lesions.\textsuperscript{2,3,5,23}

A reduced capacity for collateral flow cannot be
recognized by evaluating rCBF in the resting state. The flow reserve may be estimated from cerebral VDC. Using 5% CO₂ inhalation, the CBF and cerebral vasoactivity were measured in patients with cerebrovascular diseases. Dyken⁶ described the ICA occlusion group as having a significantly smaller increase in CBF than the ICA stenosis group. Norrving et al.⁷ reported impaired CO₂ response in patients with poor collateral blood flow via the circle of Willis. Identification of patients with hemodynamic compromise, however, is not possible by clinical criteria and remains difficult on the basis of conventional diagnostic studies such as cerebral angiography and CT scanning of the brain. Positron emission tomography, which has been applied clinically and undoubtedly provides superior information on CBF and metabolism, is not readily available.⁸ Therefore we measured rCBF in the resting state and under activation with acetazolamide loading in order to investigate the regulatory and VDC of the cerebral circulation.¹¹,¹¹,²¹ The study was performed before and after the EC-IC bypass surgery to determine whether there was any improvement in hemodynamic capacity that could be regarded as evidence supportive of a beneficial effect from surgery. Moreover, it serves to identify candidates for the operation who would show immediate postoperative improvement.

Acetazolamide rapidly inhibits of carbonic anhydrase in erythrocytes. Acetazolamide administration of at least 10 mg/kg body weight is sufficient to achieve full physiological inhibition.¹⁷ However, the high increase in CBF with the slight change in arterial carbon dioxide pressure (PaCO₂) and the marked increase in CBF cannot be explained by this event.²⁰ It has been speculated that the effect might occur via direct inhibition of carbonic anhydrase located in the cerebral tissue. A large amount of this enzyme has been detected in the glial cells and the choroid plexus as well as in the endothelium of capillaries in the cerebral tissue.²⁰ The decrease in tissue pH seems to be explained by cerebral carbonic acidosis, which corresponds to an increase in PaCO₂ of about 15–18 mmHg. Thus the CBF increase can be explained by the decrease in the tissue pH.²⁰

In our study, it was possible to measure the rCBF with Xe¹ CT and loading of acetazolamide in 16 patients in the pre- and postoperative periods. Eleven of 16 patients showed marked improvement in their neurological abnormalities, while the other five showed no immediate postoperative change. Postoperative rCBF on the affected side in the improved group increased significantly but in the unchanged group did not show any significant change. Preoperative VDC with acetazolamide was low in the improved cases but it increased significantly postoperatively. However, the unchanged patients did not show any significant difference before and after surgery. The asymmetry index in the improved group was much higher than that in the unchanged group in the preoperative period, and acetazolamide induced much
greater increase in the improved group. While the surgical procedure decreased the asymmetry index in the improved group, loading of acetazolamide did not induce any significant change. In contrast, in the unchanged group, no significant change was observed throughout the study, and the index was much lower than that in the improved group. Preoperative angiography showed the occlusions of the main arterial trunk and leptomeningeal anastomosis and/or EC-IC bypass through the ophthalmic artery as collaterals in the improved group, whereas in the unchanged group, the AComA or PComA served as good collaterals. In Cases 15 and 16, leptomeningeal anastomosis was revealed as collaterals on angiograms, but rCBF on the affected side was relatively high. In the improved group, disturbed higher cortical functions showed a much greater amelioration than did hemiparesis.

Our study indicated that patients with minor ischemic stroke whose CBF on the affected side is less than 40 ml/100 gm/min, and who demonstrate hemodynamic impairment will benefit from STA-MCA bypass surgery. In particular, patients with disturbed higher cortical functions and small low-density areas on CT scans are likely to show marked improvement of their neurological deficits with the surgical procedure early in the postoperative period.

References


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