Ultrasonic Evaluation of Superficial Temporal Artery-Middle Cerebral Artery Anastomosis

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SUMMARY Ultrasonic Doppler studies were made pre- and postoperatively in 22 patients undergoing STA-MCA anastomosis. A quantitative evaluation of the bypass was attempted by determining the STA blood flow velocity and pattern. The STA velocity on the Doppler sonogram was compared with the degree of intracranial vascular filling via anastomotic channels and the STA diameter on angiogram. The STA velocity was increased and the blood flow pattern of the STA altered from an external carotid pattern to an internal carotid pattern in a patent bypass. The results were in good agreement with angiographic findings. The area of intracranial vascular filling via a newly formed bypass on angiogram was proportional to the increase in STA velocity. As the STA diameter enlarged, the STA velocity increased progressively. It is suggested that Doppler flowmetry is reliable as a semi-quantitative means of evaluating the STA-MCA anastomosis.

EXTRA-INTRACRANIAL microanastomosis between the superficial temporal artery (STA) and cortical branches of the middle cerebral artery (MCA) has been performed by many neurosurgeons. The bypass procedure has been applied to the treatment of patients with extra- or intracranial occlusive arterial lesions, and to the prevention of stroke resulting from surgical occlusion of cerebral arteries in patients with giant aneurysms or tumors.

The technical success of the STA-MCA anastomosis has been evaluated chiefly by clinical symptoms, cerebral angiography, and cerebral blood flow studies using radioactive tracers. Cerebral angiography is traumatic and difficult to perform repeatedly. Cerebral blood flow studies are quantitative, but extracranial contamination is inevitable.

Ultrasonic Doppler flowmetry has been gaining acceptance as a non-invasive method for determining the patency of the STA-MCA anastomosis. The accuracy of Doppler sonography has already been investigated by comparison with angiography and the bypass patency checked by detecting the change in the Doppler flow pattern of the STA. In these studies, the objective was to determine by a qualitative evaluation whether the bypass was patent. If a quantitative value could be attained by Doppler technique, the findings might give information useful in selection of candidates for a bypass and assist in long term follow up.

This study evaluated the effect of the shunt operation quantitatively using the Doppler flowmetry and the findings were compared with the results achieved by cerebral angiography.

Clinical Materials and Methods

Ultrasonic Doppler studies were performed pre- and postoperatively in 22 patients who had STA-MCA anastomosis. Twenty-four STA-MCA anastomoses were performed in these patients (2 patients having bilateral procedures). The age of the patients ranged from 38 to 65 with a mean of 52.0 years; 2 patients were females, 20 males.

Table 1 shows the preoperative findings in the patients. Clinical manifestations were transient ischemic attacks (11 patients), mild to moderate neurological deficit (10 patients), and eye-lid ptosis and double vi-
TABLE 1 Preoperative Clinical and Angiographical Findings in Patients

<table>
<thead>
<tr>
<th>Findings</th>
<th>No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preop. clinical manifestations</td>
<td></td>
</tr>
<tr>
<td>transient ischemic attacks</td>
<td>11</td>
</tr>
<tr>
<td>mild to moderate neurological deficit</td>
<td>10</td>
</tr>
<tr>
<td>eye-lid ptosis and double vision</td>
<td>1</td>
</tr>
<tr>
<td>Preop. major vascular lesions</td>
<td></td>
</tr>
<tr>
<td>bilateral ICA occlusion</td>
<td>2</td>
</tr>
<tr>
<td>unilateral ICA occlusion at bifurcation</td>
<td>10</td>
</tr>
<tr>
<td>carotid siphon or MCA stenosis or occlusion</td>
<td>9</td>
</tr>
<tr>
<td>giant aneurysm in ICA</td>
<td>1</td>
</tr>
</tbody>
</table>

ICA: internal carotid artery, MCA: middle cerebral artery.

* Aneurysm.

...tion due to aneurysm (one patient). Preoperative major vascular lesions in these patients are also listed in table 1.

The blood flow velocities in the STA were measured by a directional Doppler flowmeter (Hitachi, EUD-3B, 5 MHz) before and after the operation. The blood flow in the STA was determined by placing the probe on the skin of the anterior margin of the auricle.

The Doppler signals were analyzed by a sound spectrograph (Rion, SG-07) and were represented as a sonogram. The outline of the sonogram was equal to the maximum flow velocity at each instant during the cardiac cycle. The area under the sonogram outline of the STA is called $A$ (mm²) and the length of a single cardiac cycle is called $L$ (mm). The value $A$ divided by $L$ corresponds to the mean value of the maximum flow velocity and is referred to as the STA velocity (fig. 1).

The Doppler studies were chosen for comparison with postoperative angiography. We chose the Doppler studies done within a day before the angiograms. Nine of 33 Doppler studies were the second postoperative ones. The median interval between the bypass surgery and these postoperative Doppler studies was 5.2 months, ranging from one week to 30 months.

![Figure 1. Schema of the STA flow pattern. $A$: area under the sonogram outline. $L$: Length of a single cardiac cycle.](image)

Table 2: Quantification of Intracranial Vascular Filling Via Anastomosis

<table>
<thead>
<tr>
<th>Grade</th>
<th>Angiographical findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>occluded anastomosis</td>
</tr>
<tr>
<td>I</td>
<td>only antegrade flow in a MCA branch</td>
</tr>
<tr>
<td>II</td>
<td>bidirectional flow and subsystem opacification</td>
</tr>
<tr>
<td>III</td>
<td>full MCA system or MCA plus adjacent system opacification</td>
</tr>
</tbody>
</table>

A modification of the quantitative value assigned by Thompson et al.³

Results

Of the 24 STA-MCA anastomoses, 22 anastomoses were judged to be patent by the first postoperative Doppler sonogram of the STA. The STA velocity on the side of the anastomosis was measured by a slide caliper at the level of the internal auditory meatus, because the STA flow was detected transcutaneously at the anterior margin of the auricle. Correction for magnification was accomplished by measuring the anthropological line pre- and postoperatively. The patients with hypo- or hyperventilated state during angiography were excluded.

![Figure 2. Normal sonograms of internal carotid and external carotid arteries (ICA and ECA). The ECA sonogram was markedly pulsatile and the ICA sonogram was characterized by relatively higher diastolic flow velocity level.](image)

All the patients had pre- and postoperative angiography. Later angiography was carried out in 7 patients with 9 anastomoses (2 patients having bilateral procedures). In the patient with carotid siphon or MCA stenosis, selective internal and external carotid angiography was performed to clarify the intracranial vascular filling via the anastomotic channel.

Intracranial vascular filling through the anastomosed STA and the change in STA caliber were determined in all patients and defined as follows.

1. Intracranial Vascular Filling Through the Anastomosed STA. The intracranial vascular filling via the anastomosis was divided into 4 grades angiographically according to the degree of visible opacification in the MCA territory (table 2). This was a modification of the quantitative value assigned by Thompson et al.³

2. Change in STA Diameter. The diameter of the STA used for the anastomosis was measured by a slide caliper at the level of the internal auditory meatus, because the STA flow was detected transcutaneously at the anterior margin of the auricle. Correction for magnification was accomplished by measuring the anthropological line pre- and postoperatively. The patients with hypo- or hyperventilated state during angiography were excluded.

![Figure 3. Normal sonograms of internal carotid and external carotid arteries (ICA and ECA). The ECA sonogram was markedly pulsatile and the ICA sonogram was characterized by relatively higher diastolic flow velocity level.](image)
ULTRASONIC EVALUATION OF STA-MCA ANASTOMOSIS/Tanaka et al.

Postoperative angiograms showed no augmentation of extra-intracranial collateral circulation except by the STA-MCA anastomosis. The findings of the postoperative Doppler studies were consistent with the postoperative angiograms and well represented the bypass patency.

The relationship between the percent increase in postoperative STA velocity compared with the preoperative state and the angiographical degree of the intracranial vascular filling via the STA are illustrated in figure 5. The percent changes of the STA velocity in the anastomoses with grade 0 (no patency) were $-13$ and $-50\%$. The percent changes of the STA velocity in grade I, II, and III were $37 \pm 31, 126 \pm 46$, and $310 \pm 101\%$ (mean $\pm$ standard deviation), respectively. There were highly significant differences in the change of the STA velocity among the grades I, II, and III ($p < 0.001$, Student's $t$-test). The relationship between the percent increase in the STA velocity and the change in STA diameter following the bypass surgery is illustrated in fig. 6. As the STA diameter extended, the STA velocity increased progressively.

A typical patient is shown in figure 7. The percent change of the STA velocity on sonogram was very high ($+315\%$). The angiograms demonstrated marked enlargement of the STA ($+115\%$) and abundant filling of multiple middle and anterior cerebral artery branches (grade III). The STA velocity was consistent with angiographic opacification and STA enlargement.

Discussion

Although cerebral angiography is invasive and has some risks, it is still the best method for evaluating postoperative hemodynamics. Thompson et al. adopted the angiographic parameters of STA size and the degree of intracranial vascular filling via the surgical anastomosis, and attempted to quantify collateral flow derived from the newly formed shunt. Latchaw and co-workers evaluated the effect of the bypass surgery, based on the same measures.
Intracranial vascular filling

FIGURE 5. The relationship between the changes in percentage of the STA velocities before and after the operation and the angiographic grade (G) of intracranial vascular filling via the STA. pre = preoperative STA velocity; post = postoperative STA velocity. The value represents the mean ± SA.

Ultrasound Doppler flowmetry has been developed and permits an estimate of the patency of STA-MCA anastomosis. Hopman et al. tested the bypass patency by placing the probe on the STA, and described the technique as highly accurate. The change in flow pattern of the STA (from an external carotid artery pattern to an internal carotid artery pattern) in a patent bypass was reported in our previous study, and in another report. The main object of these Doppler studies was to determine whether the bypass was patent. Müller and Gratzi calculated the shunt flow and discussed the limitation of their quantitative method. The method is based on the assumption that the diameter of the STA lumen remains constant. They considered that an exact measurement of STA caliper was required to improve the technique and make it suitable for follow up investigation.

The area under the sonogram outline (A) divided by the length of the cardiac cycle (L) is the average of the maximum flow velocity. The value A/L was first introduced to cerebral blood flow analysis by Kaneko et al., and was applied to cerebral hemodynamic investigations by several investigators. The value does not approach absolute flow values, but it is possible to obtain approximate flow values. In this study, we chose the value A/L as an index of STA velocity for evaluation of STA-MCA anastomosis.

The patency of the shunt was readily assessed by the changes of the blood flow velocity and pattern. The blood flow velocity of the STA showed increased flow velocity and the blood flow pattern of the STA changed from an external carotid artery pattern to an internal carotid pattern in a patent bypass. We previously reported the results and noted that the decrease in the peripheral vascular resistance due to postoperative alteration of the perfusion area could result in the change in the STA’s flow pattern.

There were significant differences in the change of the STA velocity among the angiographic grades I, II, and III. The STA velocity in grade 0 (no patency) showed decreased velocity compared with the preoperative one and could easily be differentiated from the other grades. It is believed that the high pressure gradient between the donor and recipient artery leads

![Graph showing the relationship between percent change of the STA velocity and diameter](image-url)
to the abundant filling of MCA territory. Moritake et al. suggested that the larger the pressure gradient, the greater the blood flow supply through the bypass. There was no augmentation of any extra-intracranial collateral channel except through the STA-MCA anastomosis on postoperative angiograms. It seems probable that STA velocity was proportional to the degree of intracranial vascular filling.

It was found in the investigation of the relation between the STA velocity and diameter that the STA velocity increased progressively as the STA diameter enlarged. Arteriograms demonstrate enlargement of the STA bypass graft in most patients. A 2-fold increase in the STA diameter, commonly observed angiographically, would allow for a 16-fold flow increase. This might be sufficient blood flow to avoid cerebral ischemia. This theoretical increase in flow is, however, in excess of the actual flow measured by electromagnetic flow studies. Postoperative changes in the STA should be regarded as one of the parameters which indicates an increased blood flow.

STA flow velocity was in good agreement with the degree of intracranial vascular filling via the anastomosis and the STA size seen on angiograms. The results suggested that the Doppler flowmetry was reliable and offered a semi-quantitative means for evaluating patency of an STA-MCA anastomosis.

References


Figure 7. Pre- and postoperative Doppler sonograms and angiograms in a patient with a well functioning bypass (Right STA-MCA anastomosis). Upper: Doppler sonograms of the right STA. The blood flow pattern of the STA changed from an external carotid artery type to an internal carotid type. The STA velocity showed an increase over the preoperative velocity of 315%. Lower: Right carotid angiograms (R-CAG). The right STA showed enlargement (+115%), with filling of a number of MCA branches and a part of anterior cerebral artery (Grade III).
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