Superficial temporal-middle cerebral artery bypass

A detailed analysis of multiple pre- and postoperative angiograms in 40 consecutive patients

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Pre- and postoperative angiograms on 40 patients undergoing superficial temporal-middle cerebral artery (STA-MCA) bypass surgery have been examined in detail. Multiple postoperative angiograms have been obtained to evaluate the change in both the bypass circuit and the intracranial circulation over time. A reproducible system for evaluating the degree of intracranial vascular filling via the bypass is introduced.

The study shows that the STA and its anastomotic branch increase in size over time, measured in months, in the majority of patients. This is paralleled by a progressive increase in the degree of intracranial vascular filling. These changes are proportional to the severity of the vascular disease before surgery. The pattern of preoperative collateral circulation may change over time following the addition of the bypass circuit. The progressive change over time suggests that a static analysis at one time may belie the true effect of the surgery. The change of collateral circulation, with augmentation of blood supply to areas of the brain other than those affected by the recent ischemic event, means that a total cerebral evaluation including neuropsychological testing may be necessary for adequate evaluation of the effect of the bypass surgery.

KEY WORDS • arterial anastomosis • arterial bypass • cerebral blood flow • cerebral ischemia • cerebral angiography

EXTRACRANIAL to intracranial bypass surgery is becoming an important mode of treatment for some patients with extra- or intracranial occlusive arterial lesions not amenable to other forms of therapy. While many such procedures have been performed throughout the world, the postsurgical changes over a period of time of both the bypass circuit and intracranial circulation have not been well defined angiographically in a large series of patients. There are no studies to date in which a large number of patients have undergone multiple postoperative angiograms in order to determine these progressive angiographic changes.

The ultimate goal of any angiographic evaluation is its correlation with the clinical state. The angiographic analysis of the 40 patients described in this report is part of a larger prospective study of all patients undergoing surgical cerebral revascularization at the University of Minnesota. All of the patients have had extensive pre- and postoperative angiographic, neurological, and neuropsychological examinations.

The results of the latter examinations are published elsewhere. For the angiographic correlation with these clinical examinations to be meaningful, a thorough understanding of the angiographic changes over time is necessary, since a static analysis based on a single angiographic examination may be very misleading.

In this report, postoperative changes in the size and tortuosity of the superficial temporal artery (STA) anastomotic branch as a first approximation of increased blood supply to the brain will be described. In addition, a simple and reproducible system for evaluating the degree of revascularization in the postoperative patient, based on the degree of vascular filling via the surgical anastomosis, is detailed. Using the three parameters of patency, STA size, patency of anastomosis, and intracranial vascular filling, it is hoped that a better understanding of the changes in the bypass circuit and the intracranial circulation over time can be obtained, allowing for a more accurate angiographic-clinical correlation in the future.
formed in the 40 patients, five patients having bilateral procedures. All of the patients have been followed postoperatively for a period of 2 to 40 months, with a median of 23 months, by means of a combination of angiography, and neurological and neuropsychological examinations.

Thirty-eight of the 40 patients (95%) had postoperative angiography, almost always via transfemoral catheterization and usually consisting of only unilateral carotid angiography on the side of surgery. Since postoperative angiography was being used to evaluate the presurgical side of symptoms and the anastomosis, and since most patients had not developed symptoms in other vascular distributions postoperatively, more extensive angiography was not considered justified in most patients. The median day of this postoperative angiogram was 12 days following surgery, ranging from 5 days to 10 months postoperatively. Eighteen patients (45%) had a second postoperative study, at a median time of 5 months. An additional four patients (10%) had a third and two (5%) had a fourth angiogram 8 to 21 months following surgery. The postsurgical timing for angiography was not standardized. There were no angiographic complications.

**Angiographic Studies**

Three parameters have been evaluated in all cases undergoing postoperative angiography and are defined as follows:

**Change in STA Diameter.** The largest diameter of the branch of the STA used for anastomosis was measured to the nearest 0.5 mm on the preoperative angiogram. The same region was measured on all postoperative studies. Almost all of the pre- and postoperative angiograms were performed at our institution, using the same angiographic equipment, so that there was no change in magnification in most cases. In situations where the degree of magnification on the pre- and postoperative studies differed, a correction factor was determined by measuring the caliber of the anterior branch of the STA which was not used for anastomosis in most cases.

**Patency of Anastomosis.** Any intracranial vascular filling via the STA branch used for anastomosis had to be present for the anastomosis to be considered patent.

**Intracranial Vascular Filling.** A diagram of the areas of cerebral perfusion by branches of the MCA has been used as a guide to assess the degree of intracranial vascular filling on any carotid angiogram (Fig. 1). Only the vascular filling from the surgical anastomosis was evaluated; generally, the more rapid circulation time and greater degree of opacification allowed distinction of vessels filled via the bypass from vasculature filled from collateral sources such as the ophthalmic artery. Only the presence of vascular filling in an area was considered, not the extent of filling. Since the degree of filling in any one area was subjec-
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tive and may have been dependent not only upon technique, but also on the degree of non-opacified collateral flow from other sources, only the presence or absence of opacified vasculature in an area was recorded. There were six areas in the MCA distribution, and filling in one area scored one point; filling of the anterior cerebral artery (ACA) scored an additional point, for a potential maximum of seven points.

Although technique-dependent considerations must be given to such an analysis, the majority of technical factors were held constant for all patients. Almost all of the pre- and postoperative studies were performed at this institution. In those cases with ICA occlusion, present in over 80% of our cases, all pre- and postoperative carotid injections at this institution were made in the common carotid artery, generally a few centimeters below the common carotid artery bifurcation. A power injector was used, delivering 12 cc of contrast material in 1 second. In the few patients with carotid siphon or MCA stenosis, selective internal and external carotid angiography was performed. A No. 7 French Cordis catheter* was used in most of the transfemoral studies.

The score of the area filled via the bypass has been tabulated for all postoperative angiograms. For those patients with two or more postoperative angiograms, the change in the number of areas filled by the bypass over the time following surgery has been evaluated. Comparison has also been made between these vascular-filling scores and the severity of the preoperative vascular disease listed in Table 1.

The three parameters defined above, change in STA diameter, patency of anastomosis, and intracranial vascular filling, were evaluated in all cases. In addition, other angiographic observations were made in selected cases and will be discussed.

Results

Change in STA Diameter

The changes in STA diameter following surgery are listed in Table 2. Of the 36 patients who had both pre- and postoperative angiography available for comparison, 29 (81%) had STA anastomotic branch enlargement on the first postoperative study, performed at a median of 12 days following surgery (Fig. 2). In those 29 cases, there was an average increase in diameter over the preoperative size of 70%. In four patients there was no change in STA caliber, and in three there was a decrease. The average change in STA diameter for all 36 cases, including those arteries that decreased in size or stayed the same, was a 53% increase in size on the first postoperative angiogram relative to preoperative measurements.

*No. 7 French Cordis catheter manufactured by Cordis Corporation, Miami, Florida.

Table 2

<table>
<thead>
<tr>
<th>Examination</th>
<th>No.</th>
<th>Percent</th>
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<tbody>
<tr>
<td>first postop angiogram:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>enlargement relative to preop size</td>
<td>29/36</td>
<td>81</td>
</tr>
<tr>
<td>average % enlargement (29 cases)</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>second postop angiogram:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>enlargement relative to preop size</td>
<td>31/36</td>
<td>86</td>
</tr>
<tr>
<td>enlargement relative to first postop angiogram</td>
<td>12/18</td>
<td>66</td>
</tr>
<tr>
<td>additional % enlargement between 1st &amp; 2nd postop angiograms (12 cases)</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>% enlargement relative to preop size (12 cases)</td>
<td></td>
<td>86</td>
</tr>
<tr>
<td>third or fourth postop angiograms:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% with progressive enlargement (8-17 mos postop)</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>summary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>average % increase, 31 patients with STA enlargement after surgery</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>range of increase</td>
<td>20-300</td>
<td></td>
</tr>
<tr>
<td>at least double preop size</td>
<td>38</td>
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</table>
Preoperative right common carotid angiography demonstrates complete occlusion of the right internal carotid artery, no intracranial collateral, and a moderate-sized superficial temporal artery (arrow). Ten months after surgery, there has been marked enlargement of the superficial temporal artery (straight closed arrow), patency of the anastomosis (open arrow), and abundant filling of multiple middle cerebral artery branches (curved closed arrow).

Two months after surgery, the superficial temporal artery (STA) anastomotic branch (double arrowheads) is moderately large, with filling of a number of middle cerebral artery (MCA) branches (single arrowhead). Seven months postoperatively, the STA branch (double arrowheads) has increased in size and tortuosity as have multiple MCA branches (single arrowheads). The number of MCA areas filled has also increased.
Two or more postoperative angiograms were performed in 18 patients, with the second study at a median of 5 months after surgery. Two patients had had an unchanged STA diameter on the initial postoperative study relative to the preoperative angiogram, but showed enlargement on the second postsurgical study, so that a total of 31 of 36 patients (86%) with comparable pre- and postoperative angiography had an enlarged STA following surgery. Enlargement of STA diameter over time was found in this group with multiple postoperative studies (Fig. 3). Of the 18 patients in this group, 12 (66%) showed an increase on the second postoperative study relative to the first postsurgical examination, amounting to an additional 53% increase in size; when combined with an average of 58% on the initial postoperative study relative to preoperative measurements for these 12 cases, there was an overall 86% increase in size over preoperative diameters. There was no change in six cases. None of the STA's decreased with passage of time.

Four patients had three postoperative studies and two had four postsurgical examinations. Half of each group showed further increased STA diameter 8 to 17 months following surgery. This progressive increase in size continued to elevate the percentage increase in STA, so that there was an average increase in diameter of 90% for the patients who showed an increase in STA diameter relative to the preoperative size.

In summary, for the entire group of 31 patients with one or more postoperative angiograms having an increased postoperative STA diameter relative to the preoperative size, the average increase was 83%, with the range of increase 20% to 300%. In 38% of the cases there was at least a doubling in size. The enlargement was limited to the branch of the STA used for anastomosis; the other branch or branches of the main trunk did not enlarge. Not only did the STA diameter increase over time, but the tortuosity of the STA increased as well (Fig. 4). These findings were frequently accompanied by increased size and tortuosity of MCA branches (Fig. 4).

**Patency of Anastomosis**

Of the 38 patients undergoing postoperative angiography at the median time of 12 days, 34 (89%) had a patent STA-MCA bypass, with filling of one or more MCA branches. All of the four non-patent anastomoses were angiogrammed within the first postoperative week and had a patent STA up to the craniotomy site, but no apparent filling of MCA branches. However, three of these four patients underwent repeat angiography within 5 months after surgery, and patency of the anastomoses was demonstrated (Fig. 5) for an overall patency rate of 97%. The one remaining patient with filling of only the STA did not have a second postoperative angiogram, and the subsequent patency of the anastomosis is unknown.

None of the patent anastomoses in patients undergoing more than one postoperative angiogram became occluded. Once the anastomosis was open, it stayed open.

**Fig. 4.** Left: Four months following surgery, the superficial temporal artery (STA, arrowheads) is moderately large, the anastomosis (open arrow) is patent, and there is filling of multiple middle cerebral artery branches (closed arrows). Right: Six months later, the STA (arrowheads) has increased in tortuosity, and the STA branches (closed arrows) have increased in size, even when accounting for magnification differences.
FIG. 5. Left: One week following superficial temporal-middle cerebral artery (STA-MCA) bypass there is filling of the anastomotic branch of the STA (arrows) but no intracranial filling. Right: Five months later, the STA and its anastomotic branch (straight closed arrows) have enlarged. The anastomosis (open arrow) is patent and there is filling of the MCA branches (curved closed arrows). Note also the enlarged external carotid branches to the scalp flap.

Intracranial Vascular Filling

The frequency of postanastomosis vascular filling of the seven MCA and ACA areas previously defined is shown in Fig. 6. Multiple areas may be filled in any one case. The highest frequencies occurred in Areas 3, 4, and 5, corresponding to the frontoparietal junction and parietal lobe. Since the majority of anastomoses were performed in the anterior-inferior parietal region, the area filled is related to the site of anastomosis.

For those 18 patients with two or more postoperative angiograms, a comparison of the number of areas filled on the second postsurgical study was made with those seen on the first. On the first study, performed at a median time of 12 days following surgery, the average number of areas filled was 2.5 of a possible 7 areas (36%). The second study was performed at a median time of 5 months and the average number of areas filled was 4.5 of 7 (64%), almost a doubling of the number of areas filled. Therefore, there was increased vascular filling with time (Figs. 3 and 7); in no case was there a decrease on the second study relative to the first. Furthermore, in two of the four cases with three postoperative angiograms and one of the two cases with four postsurgical studies, the number of areas filled continued to increase 8 to 17 months following surgery, demonstrating the slow but progressive addition of collateral circulation via the surgical anastomosis.

The 18 patients with two or more postoperative angiograms, and with an average of 2.5 of 7 areas filled (36%) on the first postoperative angiogram, had an average STA diameter increase of 39% on the first postoperative angiogram relative to the preoperative study. While the number of areas filled on the second postoperative study was increasing to 64%, the average STA change in these 18 patients had increased to 76% above the preoperative diameter. Thus, increasing intracranial filling over time paralleled the increasing diameter of the STA.
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The number of areas filled in those patients with two or more postsurgical studies has been correlated with the preoperative distribution of vascular disease (Table 3). In the four patients with MCA or carotid siphon stenosis or occlusion, a median of three of seven areas filled on the last study obtained. Those patients with unilateral ICA occlusion had a median area filled of four of a possible seven, while those with multiple vessel or bilateral ICA occlusion had a median of six of seven possible areas filled. Therefore, the greater the number of major vessels occluded preoperatively, the greater the number of areas filled via the surgical anastomosis on the postoperative studies.

Additional Observations

In two patients there was a tremendous influx of vascularity to the brain from the meninges and from temporalis muscle and/or subcutaneous tissue overlying the craniotomy defect (Figs. 5 and 8). The bone flap was not replaced in all patients, including these.
two. To avoid constricting the vascular pedicle bearing the anastomotic branch of the STA, the dura was only partially closed in all the operative procedures. These factors may have allowed this spontaneous revascularization to occur more easily and more profusely than in the usual transdural collateralization ("rete mirabile") with an intact cranium and dura.

In one patient there was compression of the anastomotic branch of the STA at the edge of the craniotomy site a number of months after surgery (Fig. 9). Early postoperative angiography had demonstrated a widely patent STA branch, but a later angiogram showed the STA narrowing at the bone margin, which was confirmed at surgery. A computerized tomographic (CT) scan demonstrated progressive atrophy of the cerebral hemisphere in this patient with moyamoya syndrome. It was thought that as atrophy progressed, the brain fell away from the inner table of the skull, compressing the STA branch against the craniotomy edge.

Anastomosis of two ipsilateral STA branches to two different MCA vessels was performed in two cases. There was no better filling of intracranial vessels than in the other cases with a single STA-MCA anastomosis.

Progressive take-over of preoperative intracranial collateral circulation by the surgical anastomotic circuit could be observed. For example, leptomeningeal collateral flow between posterior cerebral and MCA branches was observed on the preoperative study; postoperatively, these collateral channels were filled.
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Fig. 10. *Left:* Preoperative vertebral angiography demonstrates leptomeningeal collateral flow from right posterior cerebral to right middle cerebral artery (MCA) branches (arrows). Other MCA branches fill via the posterior communicating artery. *Right:* The superficial temporal artery (STA)-MCA anastomosis (open arrow) provides filling of MCA branches (lower closed arrows) previously filled via the posterior communicating artery, and antegrade filling of distal MCA branches (upper closed arrows) previously filled from the posterior cerebral collateral.

from MCA branches that opacified via the STA anastomosis (Fig. 10).

One of the most impressive changes in a few cases where postoperative bilateral carotid angiography was performed was the reversal of the collateral filling from the contralateral carotid circulation. Preoperatively, there was marked cross-flow from one carotid circulation to the other via the anterior communicating artery (ACoA) (Fig. 11 *left*). Postoperatively, the middle cerebral vessels on the side of surgery filled via the anastomosis, and cross-flow did not occur (Fig. 11 *center* and *right*).

**TABLE 3**

<table>
<thead>
<tr>
<th>Vascular Lesions*</th>
<th>Median No. of Areas Filled</th>
</tr>
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<tbody>
<tr>
<td>single MCA or ICA stenosis or occlusion</td>
<td>3/7</td>
</tr>
<tr>
<td>unilateral ICA occlusion</td>
<td>4/7</td>
</tr>
<tr>
<td>bilateral ICA occlusion</td>
<td>6/7</td>
</tr>
</tbody>
</table>

*MCA = middle cerebral artery; ICA = internal carotid artery.

Fig. 11. *Left:* Preoperative right carotid angiography demonstrates excellent cross-flow from right to left in this patient with a complete left internal carotid artery occlusion. *Center:* After left superficial temporal-middle cerebral artery (STA-MCA) anastomosis there is no longer cross-flow to the left MCA. *Right:* The left MCA and its branches are filled via the anastomosis. The pressure in the system prevents the cross-flow from the right.
Discussion

Angiographic evaluation of the surgical anastomosis in the immediate post-revascularization period may be misleading. Apparent non-patency of the anastomosis or a tight anastomosis with little intracranial filling may change on future angiograms to a widely patent anastomatic circuit. The four patients in this series without intracranial filling from the anastomosis on the initial postoperative angiogram were studied 5 to 7 days after surgery. In all four cases, the STA anastomotic branch was patent up to the craniotomy site. In each case the anastomotic branch was an end-artery, without other major branches to the scalp to permit flow and sustain patency. The persistent patency to the craniotomy site would suggest the presence of actual patency of the anastomosis itself and intracranial flow not angiographically demonstrable. Three of these cases were restudied months later and found to have patent anastomoses, with enlargement of the STA anastomotic branch; one case has never been restudied. While occlusion with subsequent recanalization cannot be ruled out as a cause of late patency, the patent STA to the level of the craniotomy and the experience of others suggest that spasm at the operative site may play a role.

While patency of an arterial bypass is of prime importance, some measurement of the augmented blood supply must be made so that meaningful correlations between the extent of revascularization and the postsurgical clinical state can be determined. What is needed is a reproducible method of measuring the increased blood flow provided by the bypass. It is well known that radioisotopic cerebral blood flow values suffer from considerable fluctuation, as evidenced by the large discrepancies in testing and retesting the same normal subject; differences of at least 14% must be present to be significant. Evaluation of other bypass circuits has been made angiographically; for example, a combination of graft patency and extent of revascularization as determined on an angiogram has been related to the postsurgical clinical state of coronary artery bypass patients. In a similar fashion, we have attempted to derive a simple and reproducible system of evaluating the postoperative STA-MCA bypass patient by using a combination of change in STA diameter and extent of intracranial vascular filling. We do not maintain, however, that we are describing cerebral perfusion or even cerebral blood flow by using this system. We are simply defining a method based on change in anastomotic branch diameter and intracranial vascular filling as seen angiographically which, while undoubtedly paralleling blood flow in the bypass circuit, will allow correlation with postoperative clinical results to be made.

The results show that the diameter of the STA anastomotic branch certainly increases in the majority of patients. This is paralleled by increasing intracranial vascular filling via the anastomosis over time. The important phrase is “over time.” The multiple postoperative examinations in this study demonstrate that there is a steady increase in both parameters in many patients, and that the time period is not measured in weeks but months. The vascular changes may start slowly but often show a steady and persistent increase over time. This is not to say, however, that the initial intracranial filling postoperatively is of no clinical value. As expected, the degree of intracranial vascular filling is proportional to the extent of the preoperative vascular disease, with vascular filling being greater for those patients with more compromised vessels.

A number of conclusions can be drawn from these findings. First, a single angiographic analysis may belittle the true effect of the surgical anastomosis. Second, early clinical improvement may not be seen, but may await the progressive vascular changes. Conversely, apparent early clinical improvement without angiographic verification may bring into question the role of the surgery in the improved clinical state versus spontaneous improvement. Correlation of early improvement with angiographically demonstrable intracranial filling would be necessary in such cases.

There has been no attempt to compare the degree of postoperative vascular filling with the extent of preoperative collateral circulation as defined angiographically. For example, in patients with unilateral carotid artery occlusion, preoperative complete cerebral angiography frequently demonstrates collateral flow from a number of sources: through the circle of Willis, via leptomeningeal branches of the anterior or posterior cerebral arteries, from retrograde flow through the ophthalmic artery, or, rarely, via small transdural collateral channels. Preoperative angiographic evaluation of the extent of vascular filling in the ICA distribution via these collateral sources is extremely difficult, since the different collateral supply is visualized on multiple injections and the collateral vascular filling is technique-dependent on any one injection. In our opinion, it is not possible to adequately quantify this preoperative collateral flow on angiography to allow adequate comparison with the postoperative studies. Hence, our vascular-filling analysis has been limited to comparable postoperative studies of unilateral common carotid artery injections, in most patients, and evaluation of filling of well-defined areas via the bypass circuit alone.

We have not attempted to rigorously compare the preoperative collateral with the postoperative vascular filling via the bypass circuit, but a number of observations have been made. Frequently, the preoperative collateral flow appeared abundant, with opacification in the distribution of the primary vascular occlusion from many sources. The inadequacy of the collateral flow was suggested, however, by the symptoms of intermittent ischemia which were superimposed on a
stable neurological deficit. In addition, the fact that the bypass circuit stayed open even with this "adequate" preoperative collateral supply, that the postoperative STA and vascular filling via the anastomosis increased over time, and that there was a change in the pattern of preoperative collateral circulation with a reversal of intracranial collateral filling, all confirmed that the preoperative collateral flow was, in fact, not adequate. The preoperative angiographic evaluation of the adequacy of collateral circulation is difficult at best. An accurate measure of cerebral blood flow would be of immense value in predicting those patients who would derive benefit from the extracranial-intracranial bypass; if this cannot be provided by studies using gamma-emitting radioisotopes, the method in most centers, computerized tomography with positron-emitting radioisotopes to measure cerebral perfusion may provide essential answers.  

A previous publication has reported the clinical results in this series of 40 patients. An attempt will be made in the future to correlate the angiographic findings described herein with the patients' clinical outcome. The fact that leptomeningeal collateral flow changes postoperatively, with the reversal of intracranial collateral flow in some patients, suggests that more than just a change in the neurological examination must be measured for this correlation to be meaningful. Many patients have preoperative fixed neurological deficits that may not change after bypass surgery. In addition, the standard neurological examination is heavily weighted on motor function. However, a change in frontal and temporal lobe function, as defined by extensive pre- and postoperative neuropsychological testing, in addition to a change in the frequency of TIA's and the alteration of objective neurological findings, gives a much more complete analysis of cerebral function. All of these clinical parameters must be used in comparing the clinical result to angiographic findings.

References


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