Superficial temporal-middle cerebral artery bypass: clinical pre- and postoperative angiographic correlation

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Between 1974 and 1982, an anastomosis between a pedicle of the superficial temporal artery (STA) and a cortical branch of the middle cerebral artery (MCA) was performed in 163 carotid systems in 157 patients for internal carotid artery occlusion in whom postoperative angiograms were available for analysis. The angiographic opacification of the arterial system was correlated with the patient's preoperative neurological function and stroke in the follow-up period.

From this analysis, the following observations were made: 1) 96% of bypasses were patent; 2) 80% of bypasses achieved a high or medium MCA filling score; 3) there was hypertrophy of the STA in 70% of the cases; 4) greater bypass filling occurred in hemispheres with nonvisualized preoperative collateral circulation than in those with readily visualized collateral flow; 5) a meaningful correlation between angiographically assessed postoperative bypass function and stroke rate was not possible because only four patients suffered an ipsilateralhemispheric stroke in the 8-year follow-up period; and 6) patients who were neurologically unstable before the procedure were at greatest risk for a stroke in the follow-up period. It is apparent that objective analysis of the effectiveness of an STA-MCA bypass, or any other form of extracranial bypass, must await the development of new diagnostic studies in which high-resolution three-dimensional quantification of cerebral blood flow is possible. These studies will necessarily be correlated with preoperative and follow-up clinical data.

KEY WORDS • superficial temporal-middle cerebral artery bypass • cerebral ischemia • cerebrovascular disease

The precise clinical role of the superficial temporal artery (STA) to middle cerebral artery (MCA) bypass procedure has still to be defined.7,8,11,20,21,27 No data have yet been presented in the literature that would permit a correlation of a patient's preoperative neurological function, preoperative angiographic findings, the extent of angiographic opacification through a functioning bypass on postoperative studies, and the incidence of stroke in the follow-up period.

Intuitively, one would assume that those arterial systems in which a high flow had apparently been achieved, as determined from postoperative angiograms, would have better protection from stroke in the follow-up period than would those systems in which a high flow had not been achieved. All other considerations being equal, this might in fact be the case. However, it is necessary to place into the equation the patient's apparent relative need for the bypass procedure: high flows might be more likely to develop in patients who were neurologically unstable or who suffered frequent ischemic events (because they were in greater need for augmentation of flow) than in those patients who were neurologically stable and had apparently less need for additional sources of collateral flow.

It was the purpose of this investigation to answer these questions and also to explore the usefulness of postoperative angiography in assessing the effectiveness of the bypass procedure.

It is important to distinguish between angiographic opacification of vasculature and cerebral blood flow (CBF). Cerebral angiography cannot measure CBF per se but only the sources of blood flow to the brain. Except for the well-described finding of slow flow on carotid angiography, there is, to our knowledge, no means of assessing CBF by angiography alone.
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The angiographer can estimate the adequacy of CBF in general terms, but has no specific means available to him for the quantification of this flow.

Clinical Material and Methods

Case Material

Between July, 1974, and July, 1982, 403 patients underwent STA-MCA bypass surgery at the Mayo Clinic for symptoms of cerebral ischemia. The surgical results and an actuarial analysis of mortality and stroke morbidity have been reported. Out of this group, all patients with internal carotid artery (ICA) occlusion, unilateral or bilateral, in whom a diagnostic postoperative angiogram had been obtained were selected for the present study. The practice of routine postoperative angiography for all bypass patients was discontinued at a time approximating the midpoint of the series after the occurrence of a postoperative angiographic complication. Thus, only 157 patients with ICA occlusion met the inclusion criteria. Patients with siphon stenosis, MCA occlusion, MCA stenosis, or giant aneurysms were not included here. A total of 163 bypass procedures (79 on the right and 84 on the left) were performed in these 157 patients. Thus, 12 bypass procedures in six patients with two operations are considered as separate cases. Bilateral bypasses were placed in five of these, and two separate ipsilateral bypass operations were performed in one. The mean age of the group was 59.1 years with a range of 31 to 82 years; 122 were men and 35 were women.

Preoperative Clinical Evaluation

On the basis of neurological stability, all patients were assigned to one of three surgical risk groups preoperatively. In order of increasing risk, these were: Grade 1 (patients with transient ischemic attacks (TIA's) but no fixed deficit); Grade 2 (patients with TIA's and a fixed stable deficit); and Grade 3 (patients with slow stroke, progressing stroke, crescendo TIA's, or generalized cerebral ischemia).

Postoperative Clinical Evaluation

The maximum follow-up period from the time of surgery to the last neurological evaluation was 8 years. Details of the method of follow-up monitoring have been published. Six patients had a stroke within the first 30 days of surgery: four ipsilateral to the surgery and two contralateral. These events were classified as perioperative morbidity. Four strokes occurred ipsilateral to the bypass in the follow-up period beginning 31 days after surgery, and were considered strokes in the follow-up period.

Preoperative Angiographic Evaluation

The preoperative angiogram could be retrieved for review in 110 of the 157 patients in this study. In most patients selective common carotid (and in many cases vertebral) artery injections were performed with a transfemoral catheter technique; however, in early cases angiography was performed by brachial and direct common carotid artery puncture.

For each hemisphere considered for surgery, four potential pathways of collateral circulation were evaluated on the preoperative angiogram: anterior and posterior communicating arteries, and external carotid artery (usually through the ophthalmic artery). Lepptomeningeal supply was also considered; however, angiographically visible contribution from this source was usually minimal, if present at all. Preoperative collateral circulation was quantified, and each hemisphere subsequently undergoing surgery was assigned a Collateral Filling Score on a scale from 1 to 10. A score of 10 was given for luxuriant collateral supply, when the collateral circulation produced dense angiographic opacification with rapid flow and washout of the symptomatic MCA territory, or when the MCA territory was supplied by more than one major collateral pathway. A score of 4 was assigned when the entire MCA territory was supplied by a single small-caliber pathway, but with slow circulation time. A score of 3 or less was assigned for poor collateral supply, with slow circulation time, only one small-caliber collateral pathway, and faint, incomplete opacification of the MCA territory.

Hemispheres in which this evaluation could be adequately performed were assigned to one of two Collateral Filling Categories, either "visualized" or "nonvisualized." A score of 3 or less in which all four potential collateral pathways were investigated angiographically was assigned to the "nonvisualized" category because all potential collateral pathways failed to opacify the entire MCA distribution. Conversely, a hemisphere with a score of 4 or greater was assigned to the "visualized" category regardless of whether all four potential collateral pathways were evaluated. Because of the more stringent requirements for completeness of the preoperative angiogram, only a small number of hemispheres could unquestionably be assigned to the "nonvisualized" category. In contrast, 58 hemispheres achieved a score of 4 or greater and were classified as "visualized." Hemispheres that did not achieve a score of 4 or greater, and in which the evaluation of all four potential collateral pathways was not complete, were excluded from the preoperative collateral circulation evaluation. Of the 110 hemispheres with available preoperative angiograms, data from 64 were therefore utilized and data from 46 were excluded from analysis.

Postoperative Angiographic Evaluation

Most studies were performed by a transfemoral catheter technique and were limited to injection of the common carotid artery on the side of the bypass. A minority of angiograms were done by brachial injection. Three parameters of each bypass were reviewed in 110 of the 157 patients in this study. In most cases vertebral artery injections were performed with a transfemoral catheter technique; however, in early cases angiography was performed by brachial and direct common carotid artery puncture.

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sphere was assigned a score on a Bypass Filling Scale from 0 to 8. Filling of the MCA from routes other than the bypass (that is, from the ophthalmic collateral circulation) was strictly disregarded. One point was assigned for opacification of each of six potential MCA vascular territories (as described by Waddington). One point was assigned for opacification of the M segment of the MCA or lenticulostriate arteries and one for the anterior cerebral artery, for a potential maximum score of 8. A score of 0 was assigned when the donor vessel was opacified to the level of the STA-MCA anastomosis but the recipient MCA territory was not. Occluded bypasses (no opacification of the donor vessel) were considered separately and excluded from bypass filling analysis. On the basis of the Bypass Filling Scale score, each hemisphere was assigned to one of three Bypass Filling Categories: low (scores 0 to 2); medium (score 3 or 4); or high (scores 5 to 8). All postoperative angiograms were obtained with the same equipment and by the same individuals, therefore technique-dependent variation in angiographic bypass filling was held to a minimum.

The outer diameter of the donor STA was measured on film to the nearest 0.5 mm at the same location on both pre- and postoperative angiograms. The degree of STA hypertrophy on the postoperative angiogram, if any, was noted and each bypass was assigned an STA Hypertrophy Score of 0, 1, or 2: 0 indicated no change in size; 1 indicated STA hypertrophy between 0.5 mm and 1.5 mm; and 2 indicated hypertrophy greater than 1.5 mm. Appropriate correction for magnification differences between pre- and postoperative angiograms was made when necessary. Any increase in the STA diameter that occurred between the first and second postoperative angiograms was noted.

**Methodology**

Quantitative angiographic and clinical data were entered into a computer and the following items were analyzed: 1) short- and long-term bypass performance by quantitative angiographic criteria; 2) relationship of bypass filling to preoperative collateral circulation; 3) relationship of the preoperative surgical risk grade to both bypass filling and collateral circulation; and 4) the occurrence of stroke in the follow-up period. Angiographic data were collected independent of (without knowledge of) the clinical data for each patient and vice versa.

**Results**

By definition of study inclusion criteria, a technically adequate first postoperative angiogram was performed on all 163 bypasses (157 patients) a median of 8 days (range 1 to 1149 days) after surgery. This angiogram showed that 157 bypasses were patent and six were occluded (two in the same patient), for a patency rate of 96%. Eighteen bypasses were excluded from Bypass Filling Score analysis, six of these were occluded and 12 were brachial injections with overlapping bypass and collateral MCA circulation. The mean Bypass Filling Scale score for the 145 remaining bypasses (± standard deviation) was 4.2 ± 2.0 (Table 1), and 80% of bypasses achieved a medium or high score. An STA Hypertrophy Score could be accurately determined from the first postoperative angiogram for 77 bypasses: a score of 0 (no change in STA outer diameter) was seen in 23 bypasses; 1 (STA hypertrophy of 0.5 to 1.5 mm) was seen in 16 bypasses; and 2 (STA hypertrophy > 1.5 mm) was seen in 38 bypasses. Overall, STA hypertrophy of 0.5 mm or greater (score of 1 or 2) was present in 70% of the 77 bypasses.

A second postoperative angiogram was performed on 12 bypasses (12 patients) a median of 64.5 days (range 7 to 216 days) postoperatively. Between the first and second postoperative angiograms, the Bypass Filling Scale score increased by 0 (that is, no change) in five bypasses, by 1 in three bypasses, by 2 in three bypasses, and by 4 in one bypass. In no case did the Bypass Filling Scale score decrease between the first and second postoperative angiograms. Some degree of STA enlargement between the first and second postoperative angiograms was present in six bypasses and none in six.

The relationship of collateral filling to bypass filling on the first postoperative angiogram indicated greater bypass filling in hemispheres with "nonvisualized" than in those with "visualized" preoperative collateral circulation (Table 2). No relationship was seen between the preoperative surgical risk grade and either the degree of preoperative collateral circulation or bypass filling of the symptomatic hemisphere.

An ipsilateral stroke occurred in the follow-up period in only four of the 163 hemispheres that underwent surgery. All four patients were having multiple TIA's.
Preoperatively; three were considered as having a Grade 3 surgical risk and the fourth was in Grade 2. Two of these four patients had “visualized” preoperative collateral circulation (unknown in two). Postoperatively, three had high and one medium Bypass Filling Scale scores, and two had Grade 2 STA hypertrophy (unknown in 2). This small group of patients with stroke in the follow-up period is distinguished from the remainder of the study group by the marked incidence (75%) of a high preoperative surgical risk group. No ipsilateral stroke in the follow-up period occurred in any of the 46 surgical hemispheres of patients who had a Grade 1 preoperative surgical risk. A stroke in the follow-up period did occur in one of 62 hemispheres in Grade 2 patients, and three of 55 hemispheres in Grade 3 patients. This results in a rate of stroke in the follow-up period of 0.9% for Grade 1 or 2 patients (hemispheres) and 5.5% for Grade 3 patients. The least stable patients were therefore 5.9 times as likely to suffer an ipsilateral stroke in the follow-up period than were more stable patients.

Discussion

We have carefully refrained from using the term “flow” to describe angiographic findings in this report. The angiogram may provide a first-order approximation of CBF, but it cannot measure actual blood flow or cerebral perfusion.\textsuperscript{15,22} We are thus left with the awkward but physiologically correct terms “collateral filling” and “bypass filling” to describe pre- and postoperative angiographic opacification of the symptomatic vascular territory.

Findings on First Postoperative Angiograms

A mean Bypass Filling Scale score of 4.2 out of a possible 8 compares favorably with data from the only other published study, by Latchaw, et al.,\textsuperscript{15} in which this type of quantitative analysis was done. In that study, a mean Bypass Filling Scale score of 2.5 out of a possible 7 was found at the first postoperative angiogram in 18 patients at a median time of 12 days after surgery. In that same study, STA hypertrophy was present in 81% of cases on the first postoperative angiogram, similar to the 70% figure in this study. If a parallel is drawn between angiographic opacification and actual CBF, then the 70% STA hypertrophy and 80% high or medium bypass filling seen here would indicate considerable blood flow augmentation in the majority of cases (Figs. 1 and 2). Results of studies that do measure CBF indicate this to be an accurate assumption; an ipsilateral increase in CBF after STA-MCA bypass has been demonstrated by the xenon-133 (\textsuperscript{133}Xe) inhalation technique, the direct intra-arterial \textsuperscript{133}Xe injection method, and the stable Xe computerized tomography technique.\textsuperscript{12,17,28} Studies with \textsuperscript{133}Xe inhalation performed up to 3 months postoperatively have shown an increase in CBF of 12.8% ipsilateral and 8% contralateral to the bypass, indicating postoperative reversal of interhemisphere steal as well.\textsuperscript{17} Positron emission tomography studies carried out within the first 4 weeks postoperatively have shown reversal of preop-
operative findings consistent with decreased cerebral perfusion pressure (decreased ipsilateral CBF, increased cerebral blood volume, and increased oxygen extraction fraction), indicating that the bypass does increase cerebral perfusion pressure.\textsuperscript{16,18}

**Bypass Maturation**

Increased STA hypertrophy and better bypass filling between the first and second postoperative angiograms were present in six of 12 and seven of 12 hemispheres, respectively. These changes in the angiographic appearance of a bypass over time ("bypass maturation") have been clearly documented in other series as well.\textsuperscript{1,6,10,15} While these changes are thought by many to reflect increased flow through the bypass with time, we know of no study that definitely correlates angiographically documented bypass maturation with increased hemispheric blood flow or cerebral perfusion.\textsuperscript{1,6,10,13,15,17}

**Relationship of Preoperative Collateral Circulation to Postoperative Bypass Filling**

The data in Table 2 show greater bypass filling in hemispheres with "nonvisualized" than those with "visualized" preoperative collateral circulation. The most logical explanation for this is that the bypass appropriately provides greater flow to hemispheres with greater need; that is, those with lower preoperative perfusion pressure. Although other factors influence the Bypass Filling Scale score, such as the MCA branching pattern, the quality of the donor vessel, and the quality of the surgical anastomosis, this finding would indicate a direct relationship between preoperative need for flow and the flow provided by the bypass.\textsuperscript{19} Latchaw, et al.,\textsuperscript{15} found a similar trend, citing greater postoperative bypass filling "proportional to the severity of the vascular disease before surgery." Fox, et al.,\textsuperscript{10} disagreed, however; they found no relationship between preoperative collateral filling and postoperative bypass function.

**Relationship of Preoperative Surgical Risk To Collateral Filling and Bypass Filling Score**

Overall, the most neurologically unstable patients (Grade 3 surgical risk) should be those with the greatest cerebrovascular hemodynamic compromise. In fact, a positive correlation between the severity of angiographically demonstrated cerebrovascular occlusive disease and poor clinical condition has been reported.\textsuperscript{5,14} A trend toward lower preoperative collateral filling and higher postoperative Bypass Filling Scores with increasing Surgical Risk Grade was therefore expected. There was no logical explanation for our data, which did not clearly substantiate either of these expected trends.

**Stroke in Follow-Up Period**

Patency of aortocoronary bypass grafts relates directly to improvement in symptoms,\textsuperscript{2,4} left ventricular function,\textsuperscript{5,26} and survival.\textsuperscript{3} Encouraged by these findings, we had initially hoped to correlate the rate of stroke in the follow-up period between patients with excellent and poor bypass function as assessed at postoperative angiography. Unfortunately (or fortunately), only four ipsilateral strokes occurred in the follow-up period in this study group. That small number precluded meaningful generalizations about the relationship between postoperative stroke and angiographically assessed bypass function. No study to our knowledge has unequivocally documented the usefulness of postoperative angiography in assessing the value of this bypass procedure. It would appear that a high-resolution diagnostic modality that can accurately quantify CBF is necessary to objectively analyze bypass function. It seems clear from even this small group, however, that the least neurologically stable patients prior to surgery are at greatest risk for stroke in the follow-up period.

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