Cerebral revascularization is playing a more substantial role in the treatment of certain conditions such as complex aneurysms, carotid artery occlusion, and moyamoya disease. Achieving good clinical results depends not only on microsurgical technique but also on the selection of the appropriate graft. The 3 principal types of grafts historically used in cerebrovascular surgery include the saphenous vein, the RA, and the STA grafts. Each of these differs with respect to: 1) hemodynamics, 2) caliber, 3) location and accessibility, and 4) risk of spasm and patency rate. Choosing the appropriate graft depends on a thorough understanding of these properties. The objective of this report is to review basic graft hemodynamics and highlight the major indications for and clinical experience with the various graft types.

Graft Hemodynamics

Vascular grafts are characterized as low, moderate, or high flow. Low-flow grafts, such as the STA or OA graft, permit a flow velocity of 15–25 ml/minute. High-flow grafts, as in the case of the SVG, allow for velocities in the range of 70–140 ml/minute. Moderate-flow grafts, such as the RA graft, have flow rates of 40–70 ml/minute (Table 1).

The degree of blood flow augmentation needed typically dictates the type of flow graft used. Multiple factors influence this including the relative area of the underperfused region, the level of underperfusion, the chronicity of the deficit, and the degree of collateral flow formation.

Key Words • cerebral revascularization • superficial temporal artery • saphenous vein • radial artery

The Principal Types of Grafts

Superficial Temporal Artery

The STA is an ideal graft choice in cerebral revascularization for several reasons, including its accessibility and its proximity to the cerebrovasculature in distance and in caliber. It is also particularly advantageous as only one anastomosis is required when this vessel is used.

Prerequisites include having good flow and caliber exhibited on angiograms, selecting small recipient vessels (≤ 2 mm), and ensuring that the low-flow volume is adequate for the recipient territory.

Bypass procedures utilizing the STA as the graft of choice have played an important role in certain cases of occlusive disease, complex aneurysms, and tumors. Despite the 1985 randomized trial that indicated no increased benefit of the STA-MCA bypass over medical therapy for atherosclerotic lesions of the ICA, this therapeutic option remains available in the management of a subset of patients with occlusive cerebrovascular disease.

Schmiedek et al. demonstrated a protective effect of extracranial-intracranial bypass with an STA graft for patients with “hemodynamic” cerebral ischemia. He defines these patients as having suffered recurrent episodes of focal cerebral ischemia due to unilateral ICA occlusion confirmed by the lack of reserve capacity using the SPECT and acetazolamide challenge test.

The STA has also been the graft of choice in most cases of revascularization for moyamoya disease. In the 2003 publication on the European experience with revascularization in moyamoya disease, Khan et al.13 reported a significant reduction in transient ischemic attacks after 2 months in 20 of 23 patients with moyamoya disease who underwent STA-MCA bypass (with some undergoing additional indirect revascularizations).
Revascularization using the STA graft is an important treatment modality in the surgical management of complex aneurysms. This includes STA anastomoses to both the anterior and posterior circulation. Patency rates of STA grafts have varied but have been reported to be as high as 95% with < 1 and 3% intraoperative morbidity and mortality rates, respectively.

Like the STA, the OA is a low-flow conduit that is particularly useful in revascularization of the posterior circulation. Advantages include the proximity to posterior vessels as well as the need for only one suture line.

### Radial Artery

The RA graft is a moderate-flow conduit that has the potential to accommodate increased flow rates. The diameter of the RA is 3.55 ± 0.45 mm. The RA thus lends itself to anastomoses with equivalent diameter vessels such as the M1 or P1 segments. Unlike the SVG, the RA graft is valveless, and it is less prone to kinking than the SVG.

In considering the use of the RA as the potential graft, the ulnar collateral blood supply to the hand must be satisfactory. This can be ascertained by either the Allen test or other noninvasive means such as Doppler ultrasound evaluation and digit pressure measurements. Doppler waveforms provide information on relative flow in the RA, ulnar artery, and palmar arch branches. Measuring digit pressures may give a more precise reflection of the changes in hand blood flow after RA compression.

Another consideration in the use of the RA graft is that it is associated with a high rate of spasm. Several techniques have been proposed to address this problem including the pressure distension technique, the balloon distension technique, and even postanastomosis angioplasty. The final point is that RA (and saphenous vein) harvesting can be performed endoscopically, with some authors reporting decreased incidence of postoperative morbidity and pain with this technique.

Published reports have demonstrated the patency rate and safety of using the RA graft in cerebral revascularization. In a series of 43 patients with intracavernous and paraclinoid giant aneurysms undergoing revascularization by means of an RA graft, Houkin et al. found no late occlusions of the graft in a 5-year follow-up period. Sekhar et al. reported a series of 17 patients who underwent bypass surgery for complex aneurysms (14 anterior and 3 posterior) using the RA graft. In all but 1 of the patients, the postoperative angiogram showed a patent graft. The authors reported no morbidity associated with graft harvesting.

### Saphenous Vein

The saphenous vein has been used in revascularization for cerebral occlusive disease, aneurysms, and even dissections. As a high-flow conduit, the SVG is suitable for cases in which extensive volume augmentation is necessary. It is, however, more prone to kinking at the distal anastomotic site. Flow mismatch may also occur if the high-flow SVG is anastomosed into smaller vessels, resulting in decreased rates of patency.

Long-term high patency rates have been reported with the SVG. Vishteh et al. performed 14 SVG bypasses (8 cervical-to-petrous, 3 cervical-to-middle cerebral artery, 3 petrous-to-supraclinoid) for symptomatic ICA dissection. They reported that all grafts were patent at 24 months’ follow-up. There was 1 death in the series (due to pulmonary embolus). At 44 months’ follow-up, all remaining patients had Glasgow Coma Scale scores of 15.

Sundt et al. performed bypass surgery using the SVG in 77 patients with posterior circulation occlusive disease, 9 patients with posterior circulation giant aneurysms, 26 patients with anterior circulation ischemia, and 20 patients with anterior circulation giant aneurysms. They determined that graft patency was 74% in their first 65 cases but 94% in the following 67 cases. They attributed the improvement to better graft preparation and suturing. Another report evaluating late patency of SVG (which included the above series) demonstrated that late graft occlusion occurred in 8% of patients; the cumulative patency was 86% at 1 year, 82% at 5 years, and 73% at 13 years.

### Ancillary Studies

Understanding the inherent properties of each vessel graft is an essential first step in graft selection. Ancillary data, derived from BTO and cerebral perfusion studies, provide additional information that may aid in appropriate graft selection.

Balloon test occlusion is used to predict the patient’s long-term tolerance of vascular occlusion of a particular artery at a specific location. It is commonly performed for the ICA proximal to the origin of the ophthalmic artery. Balloon test occlusion is performed in patients who have documented collateral blood flow capability—in the case of the ICA, via the anterior communicating artery or posterior communicating artery. The absence of angiographic collaterals obviates the need for test occlusion. The shortcomings of BTO include the following: It is a short-term test with occlusion times of 10–30 minutes attempting to predict long-term tolerance of occlusion. Second, it sometimes fails to reproduce the final occlusion (for example, test occlusion of the cervical ICA leaves the OA open; however, sacrifice of the cavernous ICA during the bypass eliminates the ability of the external carotid artery to provide retrograde flow to supplement that of the distal ICA). Third, it may not adequately reproduce downward fluctuations in blood pressure that can occur...
Graft selection in cerebral revascularization

with anesthesia, blood loss during surgery, or later in the patient’s life, in spite of the attempt to perform the BTO at a 30% reduction of normal resting blood pressure.

Measurement of hemispheric cerebral perfusion by CT, MR perfusion imaging, or PET attempts to reveal those patients who have sufficient collaterals to tolerate BTO and may be able to function with minimal vascular reserve. It also reveals patients who are asymptomatic in the face of chronic ICA occlusion despite a low vascular reserve. Low cerebrovascular reserve indicates that a low-flow graft may not provide adequate flow augmentation. Similarly, adequate reserve affords the option of using a low-flow graft such as an STA or OA graft.

Graft Selection Process

We consider patients needing bypass surgery in 3 categories: those who are functioning well but have clinical evidence of ischemia in the form of transient ischemic attacks or stroke; those who are well but are about to undergo intentional major vessel occlusion; those who are well but are about to undergo an operation with the risk of major vessel occlusion. Patients functioning well with evidence of ischemia or perfusion deficit need only supplementary perfusion, which can be provided using a simple STA-MCA bypass. Our bias based upon technical experience is to restrict this procedure to STAs with a diameter > 1.5 mm. If the STA is inadequate or absent as a result of previous surgery, we use an RA graft so as not to “overwhelm” the circulation with a vein bypass graft. Vein grafts can be hazardous, especially in patients with moyamoya disease who have “compartmentalized” circulation and inadequate run-off to tolerate the graft.

In patients who are about to undergo intentional major vessel occlusion, usually for treatment of an aneurysm or tumor, and in whom the BTO shows inadequate collateral circulation, we depend on an RA graft. We do not trust the STA graft to immediately and adequately protect the hemisphere. At a minimum, graft patency must be demonstrated by intraoperative angiography prior to major vessel occlusion. At a maximum, the graft is required to demonstrate patency for 1 or more days prior to major vessel occlusion, realizing that initial lack of demand has a negative influence on patency. The patient’s tolerance to loss of the RA from the wrist is always confirmed by Doppler ultrasound assessment prior to graft harvest. If an RA graft is not available, a lower extremity vein is used.

In patients who are about to undergo an operation in which there is only a risk (as opposed to certainty) of major vessel occlusion, we implement 1 of the following 4 stages of preparedness: Stage 1) The bypass graft is placed prior to or at the beginning of the procedure. Stage 2) The bypass graft is harvested and ready on the back table and the neck is open. Stage 3) The graft is exposed in the arm or leg ready to harvest but still in situ and the neck is open. Stage 4) The potential graft site and the neck are prepped and draped. Stage 1 patients are those who lack sufficient collateral blood supply as demonstrated by angiography or BTO and are therefore predicted to have a major stroke between the time of unexpected major vessel occlusion and completion of the bypass graft. Stage 2 patients differ from Stage 1 patients only in that major vessel occlusion will be made as an intraoperative determination, will not occur precipitously, and will allow bypass graft completion prior to occlusion. Stage 3 patients are those who have collaterals that can support them through occlusion if it occurs but are predicted to have perfusion deficits only in the longer term. Stage 4 patients differ from Stage 3 patients only in that the chance of having major vessel occlusion is very small.

Conclusions

Graft selection is a critical step in the planning of cerebral revascularization. Choosing the appropriate graft depends primarily on the understanding of graft and recipient territory hemodynamics, as well as donor vessel–recipient vessel matching. Catheter angiography, BTOs, and perfusion studies play a critical role in assessing the need for bypass as well as the type of graft needed. The STA, the RA, and the saphenous vein have all been successfully used as cerebrovascular grafts.

Disclaimer

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experience in Europe; choice of revascularization procedures. 


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