Current Strategies for Complex Aneurysms using Intracranial Bypass and Reconstructive Techniques

Michael T. Lawton, M.D., Zsolt E. Zador M.D., and Daniel Lu, M.D., Ph.D.
Department of Neurological Surgery, University of California, San Francisco

OBJECTIVE: Extracranial-to-intracranial (EC-IC) bypasses are established techniques for treating complex aneurysms, cerebrovascular insufficiency, and moyamoya disease. Intracranial-to-intracranial (IC-IC) bypasses that are entirely intracranial and do not rely on the extracranial circulation are less established alternatives for revascularization. A consecutive clinical experience with IC-IC bypass applied to aneurysm therapy is reviewed.

METHODS: During a 9.75 year period, 64 bypasses were performed for complex aneurysms, including 25 IC-IC bypasses: in situ bypasses in 7 patients, reanastomosis in 9 patients, reimplantation in 5 patients, and intracranial bypasses using grafts in 4 patients.

RESULTS: In situ bypasses consisted of 4 PICA-PICA bypasses, 2 A3-A3 ACA bypasses, and one A3-MCA bypass. Aneurysm excision with reanastomosis of the parent artery was performed for 5 MCA aneurysms and 4 PICA aneurysms. Two PICAs were reimplanted onto vertebral arteries; one pericallosal artery was reimplanted onto a callosomarginal artery; one M2 MCA trunk was reimplanted onto another M2 MCA trunk; and one MCA bifurcation was reconstructed with a double reimplantation technique. Intracranial bypasses included two petrous-to-supraclinoid ICA bypasses using saphenous vein grafts; one vertebral artery-to-superior cerebellar artery bypass using a radial artery graft; and one ACA-to-pericallosal artery bypass using a radial artery graft, with reimplantation of the callosomarginal artery. Postoperative angiography confirmed graft patency in 23 patients (92%) and complete aneurysm occlusion in all cases. By Glasgow Outcome Scale scores, good outcomes were observed in 22 patients (88% GOS 5 or 4).

CONCLUSION: IC-IC bypasses are appealing because they are entirely intracranial, are less vulnerable to injury or occlusion, do not require harvesting an extracranial artery, and use donor and recipient arteries with diameters that are well matched. When grafts are needed, radial arteries are well suited. These bypasses often require end-to-end or side-to-side anastomoses not normally used with traditional EC-IC bypasses. When appropriate, an IC-IC bypass can be a safe and effective treatment for complex intracranial aneurysms.

(Received November 9, 2007; accepted December 7, 2007)

Key words: aneurysm, extracranial-intracranial bypass, intracranial-intracranial bypass, revascularization, microsurgery


Introduction

Intracranial bypass surgery is experiencing a clinical resurgence. The EC-IC Bypass Trial published in 1985 failed to demonstrate a benefit from extracranial-to-intracranial bypass in patients with ischemic stroke\(^1\), but this result reflected overly broad surgical indications, indiscriminate patient selection, and failure to randomize those most in need of a bypass. Finally, these problems are being addressed in the ongoing Carotid Occlusion Surgery Study (COS), a randomized, controlled, partially blinded, multicenter trial designed to demonstrate the protective effect...
of superficial temporal artery-to-middle cerebral artery (STA–MCA) bypass in patients with symptomatic carotid artery occlusion and quantitative evidence of inadequate cerebrovascular reserve. This study relies on positron emission tomographic measurements of cerebral blood flow, metabolic rate, and oxygen extraction to identify eligible candidates, and is projected to show a 25% reduction in ipsilateral stroke risk over a 4-year follow-up period. The Japanese EC–IC Trial (JET) is similar to COSS and has confirmed this beneficial effect. EC–IC bypass has become the established primary therapy for moyamoya disease, and has also become an important alternative therapy for complex aneurysms that cannot be clipped microsurgically or coiled endovascularly with conventional techniques. Bypass strategies for giant aneurysms that first revascularize the parent artery territory, then occlude the aneurysm or alter blood flow through it, have significantly curtailed the use of high-risk adjuncts like hypothermic circulatory arrest. Novel techniques like ELANA (excimer laser assisted non-occlusive anastomosis) reduce the risk of ischemic complications by using lasers to arteriotomize the recipient artery without temporarily occluding it. ELANA is technically easier than traditional sutured anastomosis, which will enable more neurosurgeons to perform bypass surgery. Furthermore, as transformative and rapidly evolving as endovascular technology is, it has yet to engineer a device or a technique that can create a new conduit for blood flow between separate arteries.

In this report, we summarize the bypass experience of a single vascular neurosurgeon performed over a nearly ten-year period. Many of these bypass techniques have been in use for decades. This report focuses on the techniques used to treat intracranial aneurysms, and in particular, focuses on bypasses that are entirely intracranial and do not rely on the extracranial circulation. These intracranial-to-intracranial (IC–IC) bypass techniques are a subset of the overall experience and are relatively recent, developed as bypass surgeons have become more comfortable and creative with other strategies for revascularization.

Patients and Methods

During a 9.75 year period between August 1997 and May 2007 at the University of California–San Francisco, 156 bypasses were performed, with 64 bypasses for complex aneurysms representing the largest indication (41%). Other indications included: internal carotid artery (ICA) occlusion, n=36 (23%); moyamoya disease, n=35 (22%); middle cerebral artery occlusion, n=14 (9%); vertebrobasilar ischemia, n=2 (1%); and skull base tumor resection where the ICA was intentionally sacrificed, n=5 (3%).

During this time period, 1,650 aneurysms were treated microsurgically by the senior author (MTL) in 1,312 patients. Only 64 of these aneurysms (4%) required a bypass as part of their aneurysm treatment, indicating that bypass techniques were used infrequently and that conventional clipping techniques were successful with the vast majority of aneurysms.

Overall, 39 bypasses for aneurysms were performed with extracranial donor arteries. Fourteen low-flow bypasses were performed: STA–MCA, n=7; STA–PCA (posterior cerebral artery), n=3; STA–SCA (superior cerebellar artery), n=3; and occipital artery-to–PCA, n=1. Twenty-five high-flow bypasses were performed: ECA–MCA (external carotid artery), n=13; CCA–MCA (common carotid artery), n=5; ICA–MCA, n=5; and subclavian artery-to–MCA, n=2. These EC–IC bypasses are more conventional and frequently reported, and consequently, will not be the focus of this review. Twenty-five bypasses for aneurysms were performed with intercranial donor arteries, which will be the focus of this review. These bypasses were categorized into four types: in situ bypass, reimplantation, reanastomosis, and intracranial bypass using a graft.

There were 13 men and 12 women, with a mean age of 44.3 years (range, 15–78 years). Eight patients (32%) presented with subarachnoid hemorrhage. Aneurysm locations included: cavernous internal carotid artery, n=2 (8%); anterior communicating artery, n=2 (8%); pericallosal artery, n=2 (8%); MCA, n=8 (32%); posterior inferior cerebellar artery (PICA), n=10 (40%); and basilar trunk, n=1 (4%). Morphologically, 10 aneurysms were giant in size, 14 aneurysms were fusiform or dolichoectatic, 4 were thrombotic, 3 were recurrent after endovascular coiling, 2 were mycotic, and one was a traumatic pseudoaneurysm.
**Fig. 1** In situ bypass. This 78 year-old woman presented with aphasia and headaches. Her head CT scan demonstrated a giant, partially thrombosed anterior communicating artery (ACoA) aneurysm and obstructive hydrocephalus due to compression of the foramen of Monro by the aneurysm (A). Left internal carotid artery angiogram (anterior oblique view) revealed a superiorly-projecting aneurysm without a clippable neck (B). A multimodality strategy was planned, with a bypass to the distal ACA as the first stage and endovascular coil occlusion of the aneurysm and the left A1 ACA as the second stage. She underwent bifrontal craniotomy, interhemispheric approach, and A3-A3 anterior cerebral artery (ACA) side-to-side anastomosis to revascularize the ACA territory distal to the aneurysm. The back walls of the anastomosis were sutured from within the arterial lumen first (C), followed by the front walls (D). The depth of this surgical corridor is shown (E). Postoperative left carotid artery angiography demonstrated a patent anastomosis (circle) with good distal flow in the bilateral ACA territories, which enabled coil occlusion of the aneurysm and the proximal left A1 ACA, with right carotid artery angiography demonstrating obliteration of the aneurysm and blood flow in the bilateral ACA territories that originates from the right A2 ACA and crosses to the left hemisphere through the bypass (F).

**Surgical Technique**

1. **In Situ Bypass**

   In situ bypass requires that donor and recipient arteries lie parallel and in close proximity to one another. Anatomically, there are at least 4 sites where this requirement is met: the anterior cerebral arteries (ACA) as they course over the genu and rostrum of the corpus callosum (A2 and A3 segments) (Fig. 1); MCA branches, including the anterior temporal artery (ATA), as they course through the Sylvian fissure; the PCA and SCA as they course around the midbrain through the ambient cistern; and the posterior inferior cerebellar arteries as they course around the posterior medulla and tonsils in the cisterna magna (Fig. 2). These in situ bypasses are appealing because they are entirely intracranial, are less vulnerable to injury or occlusion, do not require harvesting an extracranial artery or graft, use donor and recipient arteries with diameters that are well matched, and require just one anastomosis. One drawback of in situ bypasses is that they require some ischemia time in an adjacent arterial territory that might not otherwise be involved in the aneurysm's repair.

2. **Reanastomosis**

   Reanastomosis requires excision of the aneurysm, or complete detachment of the afferent and efferent arteries from the aneurysm. Then, the ends of the parent artery must be brought together and sutured with an end-to-end anastomosis. These requirements are met with fusiform aneurysms that are small or medium in size. Saccular aneu-
In situ bypass. This 78-year-old man presented with cerebellar ischemic symptoms and a thrombotic R posterior inferior cerebellar artery (PICA) aneurysm. The aneurysm's intralumen size as seen angiographically (A) (right vertebral artery injection, anterior–posterior view) was smaller than its extraluminal size as seen on magnetic resonance imaging (B) (T1-weighted images, axial view). The PICA originated from the side of the aneurysm, and the likelihood of preserving this branch with either direct clipping or coiling was deemed low. A multimodality strategy was planned, with a PICA–PICA bypass as the first stage and endovascular coil occlusion of the aneurysm as the second stage. (C) Through a simple suboccipital craniotomy, the PICA's were brought together between the tonsils with a side–to–side anastomosis to allow the contralateral PICA to supply the ipsilateral PICA in a retrograde fashion (D, E). His postoperative angiogram (left vertebral artery injection, anterior–posterior view) demonstrated a patent anastomosis (circle), which enabled complete coil occlusion of the aneurysm without having to preserve the PICA origin at the aneurysm's base (F).

Aneurysms at bifurcations with more than one efferent artery are more difficult to reconstruct with primary reanastomosis because the second branch must either be reimplemented or bypassed with an extracranial donor artery. Larger aneurysms are also difficult to reanastomose because the ends of the parent artery are more difficult to reapproximate after excising a large or giant aneurysm. These ends of afferent and efferent arteries must be extensively mobilized to enable the first stitch to pull them together. If there is too large a gap in the parent artery, or too much tension from branch arteries, the suture will tear through the artery wall as it is tightened and will complicate the repair. Still, some large aneurysms have unusually redundant parent arteries that will allow primary reanastomosis. PICA and MCA (Fig. 3) often have this redundancy to facilitate reconstruction at these locations. Reanastomosis is appealing because, like in situ bypass, it is entirely intracranial, is less vulnerable to injury or occlusion, does not
Fig. 3 Reanastomosis. This 63 year-old woman presented with a thrombotic right middle cerebral artery aneurysm. (A) Computed tomography angiogram (sagittal view) demonstrated the enhancing lumen with surrounding thrombus within the aneurysm sac, and (B) digital subtraction angiography (right internal carotid artery injection, anterior-posterior view) confirmed the aneurysm's location on the M1 segment of the MCA. The aneurysm was easily exposed and clipped through a perisonal craniotomy, but subsequently the MCA lumen occluded with thrombus. The aneurysm was transected, and thrombus in the parent artery was removed, but the aneurysm could not be clipped directly without re-occluding the M1 segment. Therefore, the aneurysm was resected and the ends of parent artery were reanastomosed (C, D). Thrombus within the excised aneurysm and parent MCA can be seen in cross-section (C, arrow). Intraoperative angiography with indocyanine green dye confirmed patency of the reanastomosis.

Reimplantation

Reimplantation is useful when the clip application can repair the parent artery, but fails to preserve an important branch artery. This problem is encountered with dysmorphic aneurysms and with branches that originate from the aneurysm base or side wall, like with many PICA aneurysms. Most of the time, tandem clipping techniques reconstruct and preserve the branch artery using a fenestrated clip to encircle its origin and a straight clip to close the fenestration. In cases of large, giant, or complex aneurysms where this reconstruction fails, the aneurysm can be clipped to reconstruct the parent artery, and the branch artery can be reconstituted with end-to-side reanastomosis onto the parent artery. Alternatively, the branch artery can be reimplanted to an adjacent donor artery that is not the parent artery, as long as that donor artery lies in close proximity to the branch artery (Fig. 4). Like in situ bypasses, this favorable anatomy occurs with MCA, ACA, and PICA aneurysms. Reimplantation is appealing because it is entirely intracranial, is less vulnerable to injury or occlusion, does not require harvesting an extracranial artery or graft, may not need a donor artery, and requires just one anastomosis.

4 Intracranial Bypass with Grafts

These bypasses use grafts that are entirely intracranial and tap into intracranial donor arteries (Fig. 5), differentiating them from traditional EC-IC bypasses that utilize the cervical carotid artery as a donor artery. High-flow EC-IC bypasses typically rely on saphenous vein grafts to provide sufficient length to span from the neck to the Sylvian fissure. The length of radial artery grafts can sometimes be marginal for this use. In contrast, intracranial bypasses are much shorter and radial artery grafts are sufficiently long (Fig. 6). Radial artery grafts are better than saphenous vein grafts because they are composed of arterial tissue, remain patent longer than vein grafts, and have calibers that match the intracranial arteries. The forearm can usually be accessed to harvest the radial artery more easily than the thigh, particularly when the patient is in lateral or prone positions for posterior circulation aneurysms. Vasospasm in radial artery grafts has been described, but this complication has not been encountered in our experience using pressure distension to dilate the graft before implantation and bathing the graft in a mixture of nitroprus-
Fig. 4  Reimplantation. This 74 year-old woman presented with a sudden, severe headache and a subarachnoid hemorrhage was shown on her computed tomography scan.
A : The CT angiogram (axial view) demonstrated a giant, thrombotic middle cerebral artery (MCA) aneurysm with thickened and heavily calcified walls.
B : Digital subtraction angiography (left internal carotid artery injection, anterior–posterior view) demonstrated frontal and temporal M2 MCA trunks originating from the base of the aneurysm.
C : The double reimplantation technique, summarized in this diagram, was used to reconstruct the anatomy of the MCA bifurcation and trap the aneurysm. The external carotid artery was then exposed and connected to a saphenous vein graft with an end-to-end anastomosis. After exposing the aneurysm in the Sylvian fissure, the temporal M2 MCA trunk was transected at its origin from the aneurysm and connected to the vein graft with an end-to-side anastomosis. The vein graft was then connected to the frontal M2 MCA trunk with an end-to-side anastomosis.
D : A postoperative angiogram demonstrates the reconstruction, with the two M2 MCA branches reimplemented onto the bypass graft (circles) with good blood flow in the MCA territories.
E : Intraoperative photographs demonstrate the anatomy of the aneurysm, which had atherosclerotic changes in the walls and widely separated frontal and temporal trunks.
F : The completed anastomosis is shown reimplanting the temporal trunk to the saphenous vein graft with an end-to-side anastomosis.
G : A final overview photograph demonstrates the tortuous course of the saphenous vein graft within the Sylvian fissure, the two reimplantations (arrows), and the clip that proximally occluded the aneurysm.

Unlike the other techniques, intracranial bypasses with grafts require at least two anastomoses and may require end-to-side, end-to-end, or side-to-side anastomoses, depending on the interconnections. The anastomoses are planned so as to minimize ischemia during the time that intracranial arteries are temporarily occluded and sutured. These grafts are less vulnerable to injury or occlusion than EC–IC grafts because they are entirely intracranial.

Results
Intracranial bypasses consisted of the following: in situ bypasses in 7 patients, reanastomosis in 9 patients, reimplantation in 5 patients, and intracranial bypasses
Fig. 5 Intracranial bypass with grafts. This 15-year-old boy presented with diplopia. A giant, intracavernous internal carotid artery aneurysm was identified on magnetic resonance imaging and confirmed with digital subtraction angiography (A) (left ICA injection, anterior–posterior view). The aneurysm was trapped and bypassed, using a petrous–to–supraclinoid ICA bypass with a short saphenous vein graft to optimize long-term patency in this young patient. (B) The petrous ICA is exposed through the middle fossa floor by drilling the bone in Glasscock’s triangle and unroofing the carotid canal. End-to-side anastomoses are used for both the proximal (C) and distal (D) ends of the bypass. (E) The completed bypass is shown coursing around a cavernous sinus distended by the giant aneurysm, with aneurysm clips trapping the aneurysm. (F) The postoperative angiogram shows this short bypass restoring blood flow to the anterior and middle cerebral artery territories (left ICA injection, anterior–posterior view).

In situ bypasses consisted of 4 PICA–PICA bypasses, 2 A3–A3 ACA bypasses, and one ATA–MCA bypass. PICA–PICA bypasses were performed through either a suboccipital craniotomy (if only the bypass was performed) or a far lateral craniotomy (if aneurysm trapping was performed with the bypass). A3–A3 ACA bypasses were performed through bifrontal craniotomies with the head rotated 90 degrees to the right, aligning the midline parallel to the floor, and with the neck angled up 45 degrees, placing the right hemisphere in the dependent position and allowing gravity to open the anterior interhemispheric fissure. The ATA–MCA bypass was performed through a pterional craniotomy. All bypasses were completed with a single side–to–side anastomosis. Two aneurysms were trapped with clips during the surgery, and 5 aneurysms were occluded endovascularly in a separate stage after first confirming patency of the bypass. Staged endovascular...
Fig. 6 Intracranial bypass with grafts. This 24-year-old man had an enlarging mycotic aneurysm located at the bifurcation of the anterior cerebral artery into the pericallosal and callosomarginal arteries.

A: Preoperative digital subtraction angiography (right internal carotid artery injection, anterior–posterior view) demonstrated the dolichoectatic morphology of this aneurysm, with the callosomarginal artery originating from the anterior side of the aneurysm and the pericallosal artery originating from the posterior side of the aneurysm.

B: Intraoperative photographs illustrate the surgical exposure obtained with an anterior interhemispheric approach. The patient was positioned with the midline parallel to the floor and the right hemisphere in the dependent position. The paired anterior cerebral arteries are seen at the depths of the field, and a large anterior internal frontal artery (on top of yellow stage) was selected as the donor artery for the bypass.

C: A radial artery graft (RAG) was connected to this branch of the ACA with an end–to–side anastomosis.

D: The callosomarginal artery was transected from the aneurysm and reimplanted onto the bypass graft with an end–to–side anastomosis.

E: The RAG was connected to the pericallosal artery with an end–to–side anastomosis, distal to the aneurysm, allowing the proximal ACA to be occluded with a permanent aneurysm clip.

F: Postoperative angiography (right internal carotid artery injection, lateral view) showed the radial artery graft connected to the anterior internal frontal artery proximally and supplying the pericallosal and callosomarginal arteries distally. The aneurysm was completely thrombosed without opacification.

occlusion of the aneurysm was particularly useful with A3–A3 ACA bypasses, where the aneurysm was located beyond the surgical exposure.

Aneurysm excision with reanastomosis of the parent artery was performed for 5 MCA aneurysms and 4 PICA aneurysms. The ends of the parent artery of one giant MCA aneurysm could not be pulled together and required an interposition graft using the superficial temporal artery. Six aneurysms were fusiform and only 2 were giant in size. All reanastomoses were planned except one, whose MCA thrombosed after clipping a large M1 MCA aneurysm. Patency was restored after thrombectomizing this artery and reanastomosing the ends.

Five aneurysms were reconstructed with reimplantation of branch arteries. Two PICAs were reimplanted onto vertebral arteries; one pericallosal artery was reimplanted onto a callosomarginal artery; one M2 MCA trunk was reimplanted onto another M2 MCA trunk; and two M2 MCA trunks were reimplanted onto a saphenous vein graft that was anastomosed first to the ECA (double reimplantation technique). All 5 aneurysms were completely excluded with clipping.

Intracranial bypasses included two petrous–to–supraclinoid ICA bypasses using saphenous vein grafts; one ve-
tebral artery-to-superior cerebellar artery bypass using a radial artery graft; and one ACA-to-pericallosal artery bypass using a radial artery graft, with reimplantation of the callosomarginal artery.

Postoperative angiography confirmed graft patency in 23 patients (92%). Occlusion was seen in the patient with the unexpected M1 MCA thrombosis with thrombectomy and reanastomosis. Her reocclusion resulted in an MCA infarction. Bypass occlusion was also seen with the giant MCA aneurysm that required an STA interposition graft to reanastomose the parent artery, but no adverse ischemic complications were evident clinically. Angiography demonstrated complete aneurysm occlusion in all cases. By Glasgow Outcome Scale scores, good outcomes were observed in 22 patients (88% GOS 5 or 4).

Discussion

1 Advantages of Intracranial Bypass and Reconstruction

Intracranial bypasses that do not use extracranial arteries as donor vessels have clear advantages. Scalp arteries like the temporal and occipital arteries are often unreliable, due to diminutive caliber or inadequate length\(^8\)\(^9\). Deep bypasses routed to recipient arteries other than cortical MCA branches can require 8 cm of donor artery length, and the caliber often becomes too small at the anastomotic depth to replace normal blood flow. For this reason, there are no good scalp arteries for midline bypasses to the ACA. Instead, unusual bypasses like the bonnet bypass are needed\(^1\), requiring lengthy interposition grafts and non-anatomical reconstructions that do not recreate normal vascular interconnections. Scalp arteries are tedious to harvest, particularly the occipital artery, and are frequently compromised or occluded in patients who have had prior surgery\(^3\).

Cervical carotid arteries are good donor arteries, but their location often requires long grafts with lower patency rates. Saphenous vein grafts are long enough to span the two surgical sites\(^3\), but these grafts can have dramatic mismatches in caliber with intracranial recipient arteries, which can affect graft patency. In addition, these grafts can lie in the neck wound at unfavorable angles that might also compromise graft patency\(^2\). Radial artery grafts are advantageous, but the length of artery is often barely enough to span the two surgical sites without tension on the graft. The caliber of this graft is better matched to intracranial arteries than the saphenous vein. For these reasons, bypasses that are entirely intracranial and do not need an extracranial connection are elegant and appealing.

IC-IC bypasses are, in general, simpler anatomically and can often be accomplished without additional incisions in the neck, forearm, or thigh. They eliminate the need to harvest a donor artery extracranially, saving the neurosurgeon time and effort, and they also spare the patient a second or third incision when saphenous vein or radial artery grafts are utilized.

2 Technique

The anastomoses are often side-to-side or end-to-end with IC-IC bypasses, which differ from EC-IC bypasses that use end-to-side anastomoses. The end-to-end anastomosis is performed easiest after two stay sutures are placed superficially and deeply to bring together the ends of the parent artery. The sutures can then be used to rotate the arteries 90 degrees and visualize the suture line from one end to the other. Simple, continuous sutures are placed loosely, then tightened after all bites have been taken. The first suture is tied to the tail of the second suture. Rotating the arteries 90 degrees in the opposite direction allows the remaining half of the anastomosis to be completed all extraluminally.

In contrast, the side-to-side anastomosis is not as familiar to neurosurgeons as the end-to-end anastomosis. It requires suturing the back wall of the anastomosis from inside the lumen. The first bite after approximating the two arteries passes the needle from outside the lumen to inside the lumen. The following sutures are then placed in a continuous fashion to the opposite end of the arteriotomies, where the needle is again passed from inside the lumen to outside the lumen. These two reversing passes must be remembered. Once these sutures are loosely placed along the entire line, they are then tightened and tied to a second suture at the other end of the arteriotomy. The front wall of the anastomosis is performed with a simple continuous suture from outside the lumen. This anastomosis is often performed in a deep surgical corridor, making it essential to position a continuous suction drain at the depths of the field to keep it clear of blood.

Reimplantations and bypasses with grafts utilize more
familiar end-to-side anastomoses that are part of conventional EC–IC bypasses. Simple reimplantations, like PICA reimplanted to the vertebral artery or MCA reimplanted to another MCA trunk, are performed by spatulating the end of the reimplanted artery, arteriotomizing the donor artery, and suturing with simple, continuous stitches. More complex reimplantations, like the double reimplantation technique\(^1\), require multiple anastomoses and careful planning to minimize occlusion time. For example, interruption of blood flow with the double reimplantation technique was minimized by completing the proximal anastomosis first (Fig. 4). Normally with ECA–MCA bypasses, the cranial anastomosis between the graft and the recipient artery is performed first to allow graft mobility and to facilitate the suturing. Once completed, this end-to-side anastomosis allows the cerebral circulation to continue normally while the proximal cervical anastomosis is performed. With the double reimplantation technique, the cervical anastomosis between the ECA and the graft is performed first to ready the bypass graft to restore blood flow to each MCA trunk as soon as it is reimplanted. Consequently, the ischemia time for each of the two trunks is only the time needed to complete the anastomosis. Similarly with the ACA reconstruction, ischemia times are minimized by performing the proximal ACA anastomosis first to a major branch like the anterior internal frontal artery (Fig. 6).

Minimizing ischemia depends on successive reimplantation, meaning that the second distal anastomosis is positioned distally on the bypass graft, allowing the first distal anastomosis to feed off of the graft while the second one is being performed. Placement of a temporary clip distal to the first and proximal to the second anastomosis redirects blood flow to the reimplanted trunk while keeping the other surgical site dry. This double reimplantation technique can be easily adapted to triple reimplantation in other patients with trifurcated anatomy. As with double reimplantation, successive reimplantation enables each anastomosis to feed its recipient trunk while distal trunks are reimplanted.

IC–IC bypass often requires temporary occlusion of two major intracranial arteries to perform the anastomosis, instead of just temporarily occluding one recipient artery with a traditional EC–IC bypass. Furthermore, any complication with the anastomosis that compromises the flow or patency of the donor and recipient arteries is potentially more dangerous because of the extra artery involved. However, this concern did not materialize in this clinical experience\(^1\). There were no occlusions in the side-to-side anastomoses. We attributed this to a long arteriotomy, with a length that is typically three times the diameter of the arteries. When bringing together two separate arteries, they must be mobilized extensively to approximate the tissues without tension and without an interposition graft. If sutures are required to pull the arteries together, there is a risk of the sutures breaking or tearing through the arterial wall as they are tightened, and a risk of kinking the afferent and/or efferent arteries which can compromise their blood flow. Blood flow through the anastomosis is optimal when arteries approximate without tension on the sutures.

3 Indications

It is important to remember that cerebral revascularization is considered only when sacrifice of the parent artery or one of the major branches is necessary during treatment of an intracranial aneurysm, and it has been determined through a test occlusion that the patient will not tolerate that sacrifice. When an artery cannot be test occluded, we prefer to be cautious and protect the patient with a bypass first.

The ability to revascularize an intracranial artery creates options in aneurysm management beyond direct clipping or coiling. Bypasses allow for deliberate arterial occlusion with minimal risk of ischemic stroke and neurological morbidity that would likely occur without a bypass. Many of the patients in this series were managed with a multidisciplinary approach combining microsurgical and endovascular techniques\(^2\). The advantages of this strategy include minimizing the invasiveness of surgery, sometimes eliminating a second craniotomy, and delaying the aneurysm occlusion until the patient’s hemodynamics and general medical conditions have been optimized. These strategies should be considered in the management of complex aneurysms and these techniques belong in the armamentarium of vascular neurosurgeons.

References

1) Failure of extracranial–intracranial arterial bypass to reduce the risk of ischemic stroke. Results of an international randomized trial. The EC/IC Bypass Study Group. N

610 腦外誌 17 巻 8 号 2008 年 8 月


