High flow extracranial-to-intracranial brain bypass surgery

Sheau Fung Sia *, Michael Kerin Morgan

Australian School of Advanced Medicine, Macquarie University, 2 Technology Place, North Ryde, New South Wales 2109, Australia

1. Introduction

Bypass vascular anastomoses were first described and established at the turn of the 20th century by Carrel and Guthrie. Carrel, as a result of his work in vascular anastomosis, was awarded the Nobel Prize in Physiology and Medicine in 1912. However, it was not until the early 1950s (with the development of modern surgical and angiographic techniques) that the field of cerebrovascular surgery began its explosive growth. In 1951, Miller Fisher postulated the role of bypass surgery in the management of carotid disease. The early clinical attempts commenced in the 1960s. Although feasibility was established, failure with high flow bypass in preference. Until the mid-1980s, the number of patients, as yet there is no class I clinical evidence of support for EC–IC bypass remained limited. This report also generated great interest despite the threat of infarction. Moyamoya disease and intracranial occlusive disease are typical examples of where bypass may be used to augment threatened flow. Such cases may be considered for low flow bypass with STA or occipital arteries as the graft. An STA initially delivers 30 mL/minute with a proven capacity to dilate and increase this flow with time. Flow replacement may be indicated when an artery contributing to, or branching from, the Circle of Willis (CoW) will be sacrificed in the management of complex intracranial vascular pathology or skull base tumours. These HF EC–IC bypasses, using the saphenous vein or radial artery as the graft, have the potential to supply a considerable volume of blood flow to the brain. In addition, they have greater reach than smaller arterial grafts.

Despite the seemingly sound basis for low flow bypass in selected patients, as yet there is no class I clinical evidence of support for the HF EC–IC bypass grafts. Furthermore, the unfavourable published results of the EC–IC Bypass Study 11 and the Carotid Occlusion Surgery Study (COSS) 12 ensure that the current indications for EC–IC bypass remain limited. This report also generated great interest despite the threat of infarction. Moyamoya disease and intracranial occlusive disease are typical examples of where bypass may be used to augment threatened flow. Such cases may be considered for low flow bypass with STA or occipital arteries as the graft. An STA initially delivers 30 mL/minute with a proven capacity to dilate and increase this flow with time. Flow replacement may be indicated when an artery contributing to, or branching from, the Circle of Willis (CoW) will be sacrificed in the management of complex intracranial vascular pathology or skull base tumours. These HF EC–IC bypasses, using the saphenous vein or radial artery as the graft, have the potential to supply a considerable volume of blood flow to the brain. In addition, they have greater reach than smaller arterial grafts.

* Corresponding author. Tel.: +61 02 9812 3565; fax: +61 02 9812 3600.
E-mail address: sfsia02@um.edu.my (S.F. Sia).
controversy and has been widely criticised.13–15 Case series support for low flow bypass exists for patients with symptomatic Moyamoya disease and for those with occlusive disease leading to reduced blood flow with cerebral haemodynamic insufficiency in which the microcirculation of the region of interest is maximally vasodilated and there is increased oxygen extraction compared to normal. Grubb and colleagues16 used the term “stage 2 haemodynamic failure” – an increase in oxygen extraction factor (OEF) in the presence of internal carotid artery (ICA) occlusion that significantly increases the risk of stroke above that of those with ICA occlusion who do not have an increase in OEF as measured by positron emission tomography (Table 1). These results are consistent with other series that have reported patients with ICA occlusion and “misery perfusion.” The order of relative risk is increased 3-fold to 6-fold.16,18

High flow EC–IC bypasses use the long saphenous vein or radial artery as bypass graft conduits. These grafts are interposed between a cervical artery (often the common carotid artery [CCA]) and the intracranial ICA, middle cerebral artery (MCA), posterior cerebral artery (PCA), or vertebral artery. HF EC–IC bypass surgery has considerably more risk than low flow bypass. In a recent series of 152 patients with vein bypasses, the procedure-related complication rate was 8% (half of these complications were fatalities).19 Perioperative ischaemia, graft occlusion and haemorrhagic transformation of ischaemic brain account for the most serious of these complications. Long-term, HF EC–IC bypass into the intracranial circulation differs from the experience of peripheral vascular surgery in that long-term graft patency of 93% can be achieved.19–22 Our purpose is to review the current indications, selection criteria, diagnostic evaluation and long-term graft patency for HF EC–IC cerebral revascularisation.

2. Search strategy

A literature review was performed to review the origins and current uses of HF bypass procedures in neurosurgery. We searched the Cochrane Neurosurgery, Scopus and Medline databases. The date of the most recent search was 29 December 2011.

Two online databases were searched using the following strategies:

1. Ovid Medline (1948–2011) was searched using the following MeSH terms and keywords: (cerebral revasculari*ation.mp or cerebral revascularisation) AND (exp saphenous vein OR (Vascular patency/ or veins/or vascular surgical procedures/ or saphenous vein) OR (artery graft.mp) OR (interposition graft.mp). The results were limited to humans and the English language.

2. Scopus was searched using the following title, Abstract, and keyword terms:

("Cerebral revasculari*ation") OR ("Brain Bypass") AND ("saphenous venous") OR ("arterial graft") OR ("interpos* graft").

Table 1

<table>
<thead>
<tr>
<th>Stage (irreversible ischaemia and infarction)</th>
<th>rCBV</th>
<th>rCBV/ rCBF</th>
<th>rOEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>1</td>
<td>↑</td>
<td>↑</td>
<td>Normal</td>
</tr>
<tr>
<td>2</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>3 (irreversible ischaemia and infarction)</td>
<td>Maximum</td>
<td>Maximum</td>
<td>Decreased</td>
</tr>
</tbody>
</table>

rCBF = regional cerebral blood flow, rCBV = regional cerebral blood volume, rOEF = regional oxygen extraction ratio.

Results were limited to articles, reviews, conference papers and English language.

3. History

Brain bypass surgery has been available for treating patients with selective intracranial vascular pathology for more than 50 years (Table 2). The introduction of microneurovascular techniques in the early 1960s was a major advance in the development of cerebral revascularisation. Woringer4 reported the first HF EC–IC bypass surgery in the early 1960s. However, this technique remained obscure because of its complexity and high morbidity. Revascularisation failed to gain popularity until Donaghy6 and Yasargil9 demonstrated in the late 1960s that a STA–MCA bypass was feasible at a relatively low risk. HF bypass was attempted again by William Lougheed7 in Toronto, who reported a patient with a CCA to intracranial ICA interposition saphenous vein graft (SVG) in 1971. This larger conduit EC–IC bypass technique remained unpopular until described by Sundt and Piepgras, who pioneered many cerebral revascularisation procedures for the treatment of unclippable large aneurysms.27 Since then, several authors have reported using venous conduit EC–IC bypass surgery for the treatment of patients with intracranial pathology needing vessel trapping and sacrifice.31,39–47 Various innovative techniques have been reported, including: Spetzler and colleagues’ bonnet bypass for the treatment of complex MCA aneurysms;40 Sekhar and colleagues’ direct petrous-to-supracranioid ICA bypass in the treatment of intracavernous aneurysm;48 Morgan’s CCA to intracranial ICA bypass with an end-to-end distal anastomosis on the ICA between the ophthalmic and posterior communicating arteries;21 sutureless48 or excimer laser-assisted non-occlusive EC–IC bypass;49 and a novel approach of U-clip endoscopic radial artery harvesting for HF EC–IC bypass to simplify the intracranial microanastomosis and to reduce temporary occlusion time.36,37 Unlike the arterial pedicle low flow bypass, which requires a period of maturation to enlarge and supply an adequate blood flow to distal territory, a HF EC–IC using interposition conduits can produce an immediate substantive increase in flow to the hemisphere.

Table 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Reported event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963</td>
<td>Performance of a CCA to ICA bypass utilising saphenous graft</td>
</tr>
<tr>
<td>1971</td>
<td>Venous bypass graft between CCA to intracranial ICA</td>
</tr>
<tr>
<td>1976</td>
<td>1. ICA to cortical branch of MCA bypass with SVG 2.ICA to MCA with synthetic tube of PTFE</td>
</tr>
<tr>
<td>1980</td>
<td>Subclavian artery to MCA using saphenous vein and Bonnet bypass</td>
</tr>
<tr>
<td>1980</td>
<td>Bypass between the cervical and petrous ICA</td>
</tr>
<tr>
<td>1982</td>
<td>SVG for posterior circulation disease</td>
</tr>
<tr>
<td>1986</td>
<td>Treatment of intracranial aneurysms by combined proximal ligation and EC–IC bypass with vein graft</td>
</tr>
<tr>
<td>1990</td>
<td>Bypass between the petrous and supracranial ICA</td>
</tr>
<tr>
<td>1990</td>
<td>Venous bypass for intracavernous or unclippable giant aneurysms of ICA</td>
</tr>
<tr>
<td>1996</td>
<td>Interposition saphenous vein bypass graft between the common and end-to-end intracranial ICA</td>
</tr>
<tr>
<td>1996</td>
<td>Cervical-to-petrous ICA saphenous vein in situ bypass</td>
</tr>
<tr>
<td>1996</td>
<td>ELANA high flow bypass</td>
</tr>
<tr>
<td>2004</td>
<td>Innovation technique on radial artery graft for bypass of the maxillary artery to MCA and PCA</td>
</tr>
<tr>
<td>2009</td>
<td>Endoscopic radial artery harvesting for U-clip</td>
</tr>
<tr>
<td>2010</td>
<td>SELANA</td>
</tr>
</tbody>
</table>

4. Who should be considered for an HF EC–IC bypass?

4.1. Rationale for bypass surgery

The basis for bypass surgery is haemodynamic security.Physiological and functional imaging is commonly employed to assess the need for a bypass. The volume of flow determines the net volume of brain protected. The brain receives about one-fifth of the cardiac output, and consumes 20% of total body resting oxygen consumption. Quantitative assessment of cerebral blood flow (CBF) reveals an average flow per minute of 50 mL/100 g to 55 mL/100 g. This results in a normal vertebral and ICA combined blood flow of 700 mL/minute. The normal oxygen extraction ratio is approximately 40% and the glucose extraction ratio is 10% to 15%. In vitro studies have shown that protein metabolism is inhibited at a 50% reduction of CBF and is completely suppressed when flow is < 15 mL/100 g per minute. Below the rate of 10–12 mL/100 g per minute, irreversible neuronal damage (ionic pump failure and cytotoxic oedema) and infarction will occur if sufficient time elapses without restoration of flow. It is becoming apparent that when assessing these patients not only a quantitative evaluation of CBF is necessary but also preoperative radiological evaluation of the anticipated physiological state (cerebrovascular reserve) and adequacy of the collateral circulation using balloon test occlusion (BTO). This technique was first described and used in humans by Serbinenko in 1974. BTO has been described with variations both at normal blood pressure and during temporarily lowered blood pressure (hypotensive challenge, lowering mean arterial pressure by 20 mmHg with a nitroprusside infusion, or 25% of mean arterial pressure, whichever was greater.) Other common tests include neurological examination, angiographic anatomical assessment of collateral circulation from the Circle of Willis or leptomeningeal connections, time delay imaging of angiographic venous filling, electroencephalography, single-photon emission CT scans, stump pressure and CBF determination. However, the indications for BTO are controversial. One approach favours a HF EC–IC bypass in patients who fail the BTO (selective approach). Alternatively, some authors advocate revascularisation surgery in all patients undergoing a planned vessel sacrifice for tumour or aneurysm management (universal approach). BTO techniques, however, have a small but significant risk (for example, in dissected vessels or where there is significant thrombus within an aneurysm). The BTO has both false positives and false negatives in determining stroke risk after occlusion: it fails to predict the potential for propagated thrombo-embolic complications from distal stasis in an occluded artery deemed sacrificial by the BTO, and cannot estimate the potential risk for accelerating degenerative disease through contralateral arteries as a result of increasing the shear stress through the Circle of Willis (for example, contralateral or midline aneurysm development after occlusion). What the BTO can predict well is whether an HF EC–IC bypass will have sufficient velocity following anastomosis (as determined by the driving pressure gradient) for graft occlusion to be unlikely, and the depth of cerebral protection required during cross-clamping in establishing the bypass. There is clearly no reason to perform a bypass if there is no pressure gradient to maintain flow and patency. However, a BTO is not always necessary or desirable due to the associated arterial anatomy or arterial disease (including ipsilateral aneurysmal thrombus, contralateral occlusive disease and aneurysms present on the collateral supply to the artery under consideration).

4.2. Indication for HF EC–IC bypass

An HF EC–IC bypass has been used in four clinical settings.

4.2.1. Planned vessel sacrifice for tumour or aneurysm management

In tumour or aneurysm management, the planned surgical or endovascular occlusion of an artery may require a bypass procedure to secure the CBF. Creation of an interposition HF bypass is the typical method of choice when flow requirements are likely to be significantly greater than 30 mL/minute. The strategy of Hunt-Kerma ligation, which Drake described in the treatment of inoperable intracranial aneurysms, has been effective with a high obliteration rate in all the main intracranial arteries.

4.2.2. Planned vessel sacrifice for reducing the risk of stroke in carotid arterial injuries including post-traumatic dissections and pseudoaneurysms

Vessel replacement or sacrifice can be required to reduce the risk of stroke in patients with carotid dissection not amenable to conservative or endovascular management (for example, in those with persistent pseudoaneurysms for more than 3 months, symptomatic cerebral ischaemia resulting from high grade stenosis despite maximum anticoagulation, bilateral acute dissection where progression on one side would likely to lead to decompenation of CBF with poor collateral circulation). Vishteh and colleagues have shown the role of bypass in the management of persistently symptomatic traumatic ICA dissection with reduction of ischaemia and with excellent long-term outcomes and graft patency rates. Morgan and Sekhon reported that HF EC–IC bypass in the management of carotid or vertebral artery dissection has potential benefits over other treatments because of the maintenance of high flow, the avoidance of abnormal watershed areas of flow, and the elimination of the risk of emboli. This indication may diminish with the introduction of flow-diverting stents.

4.2.3. Emergency revascularisation due to stroke in evolution or possible stroke in evolution

When the likelihood of stroke is evident or anticipated in the management of unplanned major arterial loss at surgery, an SVG provides higher flow and better approximate physiological conditions than does an STA bypass. Morgan et al. performed 23 emergency revascularisation surgeries for stroke in evolution in his vein bypass series. Of these, 20 procedures were performed as a consequence of technical problems encountered during aneurysmal repair, whereas three patients had symptomatic ischaemic symptoms suggesting early infarction due to high grade ICA stenosis from dissection with poor angiographic collaterals. It is important that this surgery proceeds urgently as the surgery is difficult, if not impossible, with brain swelling associated with ischaemia. Effective relaxation with mannitol and diligent anaesthetic care are critical to the technical success of this surgery.

4.2.4. Augmentation of cerebral blood flow in chronic haemodynamic ischaemia where a scalp artery is unavailable or too short

A small group of patients with chronic cerebrovascular compromise resulting in transient ischaemic attacks or border-zone infarction, who have failed medical therapy (antiplatelet agents and maximising modifiable risks factors) and whose lesions are not amendable to conventional surgical and endovascular therapy may be considered candidates for HF EC–IC bypass. The role of surgical revascularisation with HF EC–IC bypass for patients who have ischaemic disease remains controversial. The most common indication is symptomatic vertebrobasilar occlusive disease where endovascular stenting is not possible.

5. Bypass patency

Studies on the short-term and long-term patency of HF EC–IC bypass grafts have shown that for the experienced
HF EC–IC bypass remains important in the treatment of intracranial occlusive disease and in flow replacement in the setting of planned vessel sacrifice for intracranial pathology. Cerebral revascularisation is an important treatment modality in the management of complex aneurysm, skull base tumour and stroke prevention. Graft selection and bypass strategy are critical steps in the management of complex aneurysm, skull base tumour and stroke prevention. In properly selected patients, the surgical outcome for 152 intracranial vein bypass procedures using vein bypasses has been good with an acceptable complication rate. The senior author (M.K.M.) has performed vein bypasses in the broad categories of planned vessel sacrifice for tumour or aneurysm or stroke risk reduction (105 patients), augmentation of CBF in those with chronic haemodynamic ischaemia (23 patients) and emergency revascularisation due to stroke in evolution (24 patients). The long-term clinical outcome includes a downgrade in function (modified Rankin Scale score >1) as a complication of HF EC–IC bypass surgery in 7.9% (95% CI, 4.5–13.4%). This included six patients who died. Most graft failures occurred within the first week following surgery. For bypasses that were patent at 1 week after surgery, the 6-week and 6-month patency was 99%.19

6. Conclusion

neurovascular surgeon, patencies of 90% to 95% can be obtained. For smaller vessels and deeper anatomy, slightly lower patencies are expected. Sundt and Sundt reported that early graft failure is generally attributable to thrombosis and precipitating factors such as intimal desquamation on the graft wall with loss of protective fibrinolytic activity and exposure of underlying thrombogenic collagen fibres, slow graft flow and coagulopathy, has been well documented.61 Thus, mechanical trauma to the vein must be minimised during surgery. The reported long-term graft patency ranges from 73% to 100% after salvage (Table 3).19–21,31,42,55,60,62–67 in our experience, the surgical outcome for 152 intracranial vein bypass procedures using vein bypasses has been good with an acceptable complication rate. The senior author (M.K.M.) has performed vein bypasses in the broad categories of planned vessel sacrifice for tumour or aneurysm or stroke risk reduction (105 patients), augmentation of CBF in those with chronic haemodynamic ischaemia (23 patients) and emergency revascularisation due to stroke in evolution (24 patients). The long-term clinical outcome includes a downgrade in function (modified Rankin Scale score >1) as a complication of HF EC–IC bypass surgery in 7.9% (95% CI, 4.5–13.4%). This included six patients who died.19 Most graft failures occurred within the first week following surgery. For bypasses that were patent at 1 week after surgery, the 6-week and 6-month patency was 99%.19

7. Conflicts of interest/Disclosures

The authors declare that they have no financial or other conflicts of interest in relation to this research and its publication.

Acknowledgement

Dr. Sia receives a scholarship from the University of Malaya, Kuala Lumpur, Malaysia.

References


