Case Report

Pre- and Postoperative Cerebral Haemodynamic Assessments and Multidisciplinary Team Management for Patients Undergoing Cerebral Revascularization Procedures: 2 Case Reports

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Background: Cerebrovascular bypasses are complex neurosurgical procedures with specific indications. Surgical risks and outcome are associated with the type of bypass intended and patient's underlying conditions. A multidisciplinary team approach is therefore pivotal in the management of these bypass patients.

Objective: The aim of this study is to provide an overview of the perioperative haemodynamic assessments and management of patients undergoing cerebral revasculaization with 2 illustrative cases.

Case Report: Case 1: A 40-year-old male with cerebrovascular occlusive condition and recurrent transient ischaemic attacks (TIA's) affecting his left side. Preoperative computed tomography (CT) brain perfusion and carbon dioxide (CO_2) inhalation technique revealed poor cerebrovascular reserve (CVR) in the right middle cerebral artery (MCA) territory. The patient underwent a right superficial temporal artery-middle cerebral artery (STA-MCA) bypass surgery. Case 2: A 56-year-old female with a left giant cavernous sinus aneurysm presented with left-sided intractable facial pain. Preoperative cerebral digital subtraction angiography (DSA) with carotid compression test revealed inadequate collateral circulation. She underwent a high flow, common carotid-middle cerebral artery bypass with saphenous vein graft and trapping of the giant aneurysm.

Results: Case 1: Postoperative computed tomography angiography (CTA) brain scan on day 1 confirmed graft patency. The patient improved rapidly in strength of the left arm and right leg. CT brain perfusion scan at 3 months showed improved brain perfusion and CVR. Case 2: Postoperative CTA brain on day 1 confirmed graft patency. On day 3 post-operatively, she developed self-limiting left-sided ophthalmoplegia, which completely resolved by 6 weeks. CTA brain at 5 months showed patency of the bypass graft. There was no further facial pain or ophthalmoplegia at the last follow-up.

Conclusion: Although many new surgical techniques had been developed, the outcome for patients undergoing bypass surgery remains highly dependent on multidisciplinary teamwork, detailed preoperative haemodynamic assessment, patient selection and perioperative care.

Keywords: Cerebrovascular bypass; EC-IC bypass; STA-MCA bypass; Cerebral ischaemia; Cerebrovacular reserve; Balloon occlusion test

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The first extracranial-intracranial (EC-IC) arterial bypass procedure was described by Yasargil in 1969[1]. In 1967, Yasargil performed the first superficial temporal artery to middle cerebral artery (STA-MCA) bypass operation on a stroke patient with complete occlusion of the internal carotid artery (ICA). Since then, many techniques have evolved for various neurological conditions, including cerebral ischaemia, complex cerebral aneurysms, skull base tumours, etc[2-17].

Until 1985, cerebrovascular bypass surgery (CBS) was carried out as a recognized treatment for cerebral ischaemia worldwide, but its use declined dramatically after the Extracranial-Intracranial (EC-IC) Bypass study failed to demonstrate the benefit of EC-IC bypass surgery over 'best medical' therapy[3,18,19]. After this major setback, the procedure remained widely disputed and lost its popularity amongst neurosurgeons. Several decades later, a resurgence of interest in CBS occurred as technology and our understanding of the pathophysiology of brain ischaemia significantly improved[11,14,15,20].

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Objective

In the present study, the authors report 2 illustrative cases, where patients underwent different types of EC-IC bypass procedures. Current concepts of cerebral haemodynamic and preoperative assessments, including the practical use of carbon dioxide (CO_2) inhalation technique for the preoperative evaluation of cerebrovascular reserve, surgical indications and selection of patients, and multidisciplinary team approach for the perioperative management for EC-IC bypass surgery are discussed.

Case Report

Case 1

A 40-year-old man with no obvious underlying vasculopathy, was admitted in February 2011 with a two-week history of progressive weakness in the left arm and right leg, and inability to walk. CT angiography demonstrated a complete occlusion of the right ICA with surrounding Moyamoya-like vessels. DSA confirmed a severe narrowing at the supraclinoid portion of the right ICA and total occlusion of the right middle cerebral artery (MCA) and A1 segments of the right anterior cerebral artery (ACA) (Figure 1). Preoperative CT brain perfusion showed a delay in mean transit time (MTT) in the right MCA territory before CO_2 inhalation (Figure 2A), with further delays in MTT after CO_2 inhalation (Figure 2B), representing a 'steal' phenomenon from the left ACA circulation. This finding was consistent with the left arm and right leg weakness. A computed tomography perfusion (CTP) scan of the brain scan pre- and post- 5% CO_2 inhalation confirmed an impairment of CVR in the right MCA and ACA distribution.

A right sided STA-MCA bypass surgery was performed 4 days after admission. Postoperatively, a CTA scan on day 1 confirmed patency of the bypass graft. The patient improved rapidly in strength of the left arm and right leg. His walking continued to improve steadily. CTP brain scan at 3 months showed improved perfusion and CVR within the right MCA territory (Figure 2C]. CTA brain and cerebral DSA at 4 months revealed a markedly increased flow through the bypass, supplying the entire right MCA territory (Figure 3A and 3B), and there was no further evidence of 'steal' from the left ACA territory (Figure 2D). His last follow-up CTA brain in June 2018 confirmed graft patency, and his clinical symptoms remained stable at his last outpatient follow-up in June 2019.

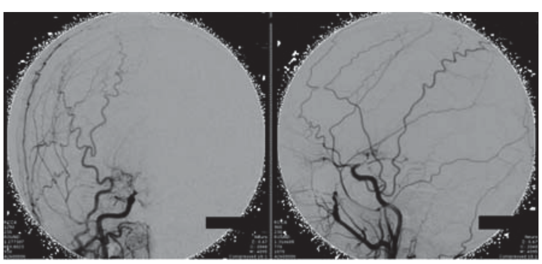

Figure 1. A right common carotid angiogram showing a severe narrowing at the supraclinoid portion of the right ICA and total occlusion of the right MCA and A1 segment of the right ACA with basal perforators type of collateral vessels demonstrated.

Case 2

A 56-year-old lady initially presented in November 2010, with a chronic left sided facial pain and episodes of diplopia over several years. CTA brain and DSA confirmed a 4x3x3cm giant left cavernous ICA aneurysm (Figure 4). Carotid Compression test showed inadequate collateral circulation; thus, the balloon occlusion test was not performed. She underwent a common carotid artery-M2 segment (CCA-M2) of middle cerebral artery bypass surgery with interpositional saphenous vein graft (IPSVG) with trapping of the giant aneurysm in January 2011. During surgery, she was kept mildly hypothermic and under barbiturate coma during the cross-clamping period. Postoperatively she made an uneventful recovery. CTA on day 1 confirmed graft patency and demonstrated a large thrombus within the cavernous aneurysm with no contrast filling (Figure 5). On day 3 post-operatively, she developed self-limiting ophthalmoplegia with

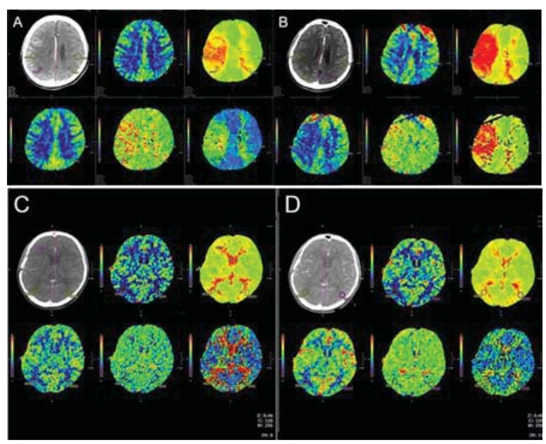

Figure 2. Pre- and post-operative CT brain perfusion scans with pre- and post-CO_2 inhalation at 3 months showed improvements in the CVR and cerebral perfusion in the right MCA territory after right STA-MCA bypass. A) preoperative delayed in MTT in the right MCA territory before CO_2 inhalation, B) further delay in MTT after CO_2 inhalation with 'Steal' phenomenon, C) and D) postoperative normalization of CT brain perfusion with no delay in MTT pre- and post-CO_2 inhalation with preservation of CVR.

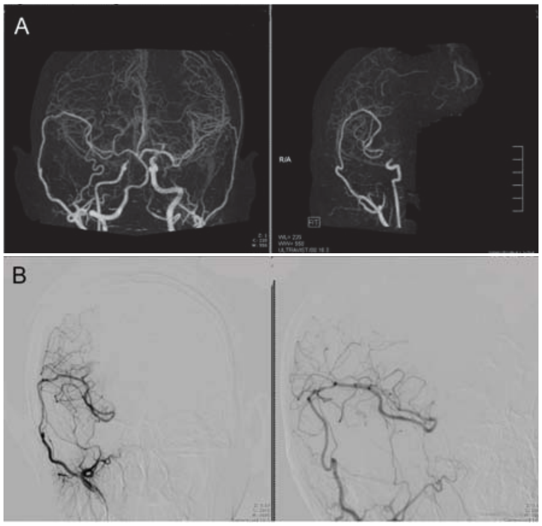

Figure 3. A) Postoperative CTA brain, and B) a right external carotid angiogram demonstrates good flow through the right STA-MCA bypass, supplying most of the right MCA territory.

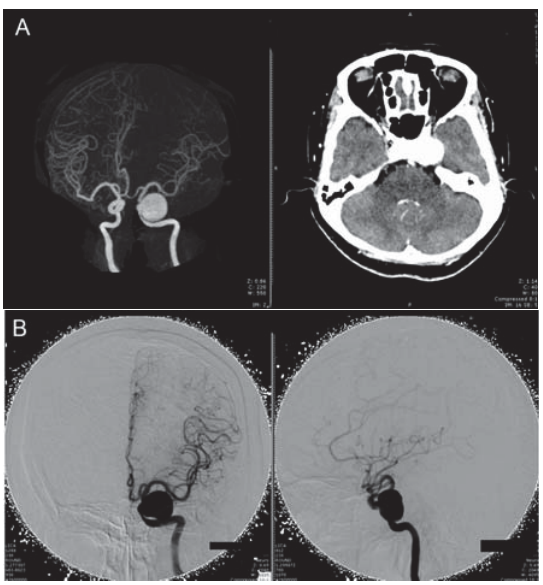

Figure 4. A) CTA brain and B) DSA-left internal carotid showed a 4x3x3 cm giant cavernous ICA aneurysm.

partial left 3^{rd}, 4^{th} and 6^{th} cranial nerve palsies, which completely resolved by 6 weeks. DSA at 2 weeks confirmed patency of the graft (Figure 6). CTA brain at 5 months showed

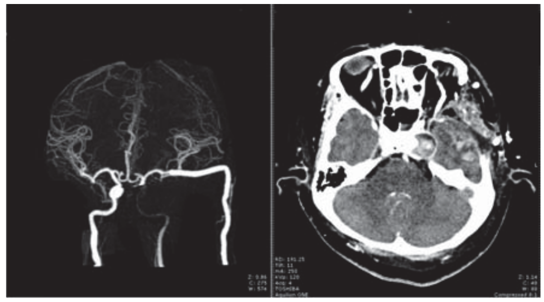

Figure 5. Postoperative CTA brain at day 1 shows patency of the left CCA-M2 saphenous vein graft. Contrasted CT brain demonstrated a large thrombus within the cavernous aneurysm without contrast filling.

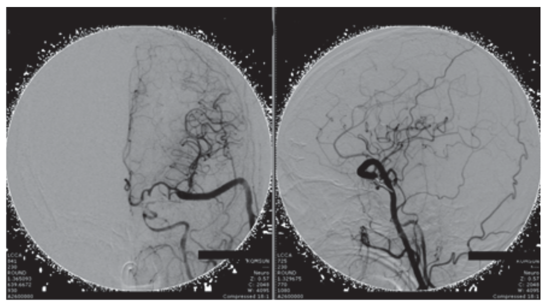

Figure 6. Left common carotid angiography at 2 weeks postoperatively shows patency of the left CCA-M2 saphenous graft with good distal flow of the left MCA and retrograde flow into left ACA. There was no contrast filling of the giant cavernous ICA aneurysm

patency of the bypass graft with good distal flow of the left ACA and left MCA, with a decrease in size of the left thrombosed cavernous ICA aneurysm. Her last follow-up MRA in May 2021 confirmed good patency of the bypass graft and a total obliteration of the giant left cavernous ICA aneurysm. There were no neurological deficits, and no further facial pain or ophthalmoplegia at the last clinical follow-up in June 2021. The present study was approved by the Ethics committee of the institutions (No. MURA2021/237).

Discussion

The EC-IC bypass study in 1985 failed to demonstrate the benefit of superficial EC-IC bypass surgery over 'best medical' treatment for cerebral ischaemia[18,19]. Since then, we have gained much knowledge on the pathophysiology of brain ischaemia. The main drawbacks of the EC-IC bypass study include the failure to differentiate between embolic TIA's and cerebral hypoperfusion, partly due to the lack of diagnostic capabilities such as cerebral perfusion and CVR assessments at that time. A renaissance in bypass surgery occurred as diagnostic technology improved significantly in recent years[2,3]. In highly selected cases, bypass surgery can be performed with good results[20-23].

Current indications for bypass surgery

Bypass surgery is performed in a number of neurological conditions[2,3,5,7-10,13-17,20,24], with highly specific indications, when either the disease itself or vessel sacrification may create insufficient blood supply to the brain. The aim of bypass surgery is either to augment cerebral blood flow or to replace blood flow using a new blood vessel (Table 1).

Flow augmentation

In cerebral vascular insufficiency or cerebral hypoperfusion syndrome, patients may or may not have adequate cerebral blood flow at rest (misery perfusion). Ischaemic symptoms become apparent during activity or during systemic hypotension as the CVR is impaired. This is to a certain extent analogous to a situation seen in patients with unstable angina, where cardiac symptoms do not occur at rest, but appear during activity, which can be assessed by performing an exercise stress test. Patients with cerebral hypoperfusion are at risk from acute TIA's or cerebrovascular accident (CVA), as collateral flow and cerebrovascular reserve may not be sufficient enough to match the metabolic activity of the brain. Patients with chronic cerebral hypoperfusion can present in a more subtle manner with vague symptoms of lethargy, mental dysfunction and chronic headaches. With further ischaemia, patients can progress to develop TIA's or CVA's. The aim of bypass surgery in this group of patients is to augment blood flow to meet the cerebral metabolic demands, to improve symptoms by restoring normal brain function at rest and during activity, and ultimately to reduce the risk of TIA's and stroke[3,20,25].

Pathophysiology of brain ischaemia

Since the EC-IC bypass study, the authors have gained more knowledge about the pathophysiology of brain ischaemia and realized that there were major drawbacks of this study. These include the lack of understanding of the pathophysiology of brain ischaemia, and failure to differentiate between embolic TIA's from cerebral hypoperfusion. Patients with embolic TIA's were included into the study, where a bypass procedure would not have addressed the underlying pathology. For an embolic aetiology, the treatment is either anticoagulation or surgery (e.g., carotid endarterectomy) to remove the underlying source of emboli. For cerebral hypoperfusion, the treatment is flow augmentation bypass surgery. Therefore, it is necessary to make a distinction between embolic TIA and cerebral hypoperfusion. This can be difficult to do clinically; specialized investigations are often required to differentiate the two processes[11,26].

Assessment of the haemodynamic of cerebral circulation

Cerebral blood flow (CBF)

Global and regional cerebral blood flow can be assessed quantitatively or non-quantitatively by various techniques, such as with ^{133}Xenon-CT scan, SPECT scan, transcranial Doppler sonography, etc[20,25,27,28]. More recently, CT and MRI brain perfusion scans have made cerebral perfusion and CVR assessments more available, faster, and less invasive[10,15,24,26,27,29] (Table 2).

Cerebrovascular reserve (CVR)/CO^2 reactivity

For an assessment of brain ischaemia, cerebrovascular reserve is extremely important, as cerebral perfusion measurements alone are not adequate. Cerebral perfusion is tightly coupled with cerebral metabolism, therefore, an area of low cerebral perfusion is not always ischaemic. The low cerebral perfusion may be appropriate for the low cerebral metabolic activity in that area at that particular time. More importantly, the assessment of CVR can provide more information on whether the brain vascular system can compensate during blood flow reduction. CVR can be assessed by looking at the CO_2 reactivity of a region of the cerebral vasculature. With adequate CVR, the vessels can further dilate to increase blood flow. With poor CVR, the affected cerebral vessels are already maximally dilated and any further increase

Table 1. Indications for cerebrovascular bypass surgery

Aim of bypass	Indications	Conditions
Flow augmentation	Chronic Cerebral ischaemia	- Moyamoya disease/syndrome
		- Intracranial vascular stenosis/occlusion
		- Carotid stenosis/occlusion
Flow Replacement	Complex intracranial aneurysms	- Fusiform aneurysms
		- Giant aneurysms
	Carotid dissection	- Carotid pseudoaneurysm
	Others	- Dysplastic arteries
		- Infecitive aneurysms
		- Penetrating/iatrogenic vascular injuries

Table 2. Various methods for assessing cerebral circulation

Cerebral blood flow assessments	- Trancranial doppler (TCD) and duplex ultrasound
	- Xenon-133 Single positron emission computed tomography (SPECT)
	- Xenon-enhanced CT scan
	- CT or Magnet resonance imaging (MRI) Brain perfusion scans
Cerebrovascular reserve/CO_2 reactivity assessments	- Breath holding index (BHI) with TCD
	- Hexamethylpropyleneamine (HMPAO)
	- SPECT scan with Acetazolamide challenge
	- CT/MRI Brain perfusion scan with Acetazolamide challenge
	- CT brain perfusion scan with 5% CO_2 inhalation
Assessment for cerebral haemodynamic failure	- Oxygen extraction factor (OEF) on positron emission tomography (PET) scan
Assessment for collateral circulation	- CTA and MRA brain
	- 4-vessel digital subtraction cerebral angiography ±balloon occlusion test

in partial pressure of carbon dioxide (PCO_2) cannot increase the blood flow. Paradoxically, vessels in normal parts of the brain will dilate in response to an increase in PCO_2 causing a ‘steal’ effect which shunts away blood from the already compromised area of the brain, thus reducing perfusion further causing cerebral ischaemia[26,27]. This group of patients is at highest risk of developing TIA’s and stroke, and may benefit most from flow augmentation surgery[23].

There are many methods to assess CVR. A list of investigations to measure cerebral perfusion and CVR is shown below (Table 2). In general, CVR can be measured by comparing regional cerebral perfusion before and after intravenous acetazolamide administration[26]. Acetazolamide is a potent cerebral vasodilator and acts by inhibiting carbonic anhydrase enzyme in erythrocytes. Others have used instead, CO_2 inhalation or breath holding techniques to increase the PCO_2 level and cerebral vasodilatation. The CO_2 inhalation technique is simple but it relies on patient’s compliance, monitoring of end-tidal CO_2 measurements, and anaesthetic supervision during CO_2 inhalation via a facial mask. In addition, this technique is usually performed with CT brain perfusion imaging modality, and not MR perfusion due to the use of a CO_2 tank. However, due to the unavailability of intravenous preparation of acetazolamide in Thailand, this technique has become the most practical and cost-effective method of assessing the CVR in our centre.

In some centres, positron emission tomography (PET) can be used for the measurement of oxygen extraction fraction (OEF) in place of CVR, to detect cerebral haemodynamic failure[10,15,20,26,30]. However, the availability of PET scanning is often limited.

Balloon occlusion test (BOT)[10,11,20,31-33]

In specific circumstances, flow replacement may be necessary when a major cerebral artery is sacrificed such as during a removal of a complex skull base brain tumour, trapping of a complex aneurysm or trapping of a diseased segment of a large artery, e.g. carotid dissection or pseudoaneurysm. Carotid cross compression or balloon occlusion test (BOT) is often performed prior to vessel sacrifice to assess the adequacy of collateral circulation and the need for a flow replacement bypass procedure. There are many variations of the BOT. To assess the adequacy of collateral circulation, an endovascular balloon is temporarily inflated to occlude the vessel planned to be sacrificed. There are two types of evaluation by BOT; angiographic criteria and clinical criteria. For angiographic criteria, evaluation starts from interpreting the circulation of the ipsilateral brain (that was occluded by balloon) via collateral circulation, the major pathway being the Circle of Willis. Bilateral femoral arterial route approaches are mandatory for running angiogram in the contralateral ICA and dominant vertebral artery (VA) to visualize the ipsilateral brain circulation from arterial to capillary and venous phases. After interpreting both the anterior and posterior communicating systems and there is significant delay of the circulation time of each phase for more than 3 seconds, then we can predict that there will a high chance of an ischaemic stroke on the ipsilateral side if the vessel sacrifice is performed alone without a bypass procedure. For clinical criteria, if the patient develops ischaemic symptoms or signs within 30 minutes of balloon occlusion, the test is considered a ‘failed’ BOT, implying that collateral circulation is not adequate and a bypass procedure is necessary before sacrificing the vessel. If the patient remains asymptomatic after 30 minutes of balloon occlusion, the test is considered a ‘passed’ BOT, suggesting that a vessel sacrifice can be carried out without having to perform a prior bypass procedure. However, it can be argued that BOTs are not carried out under entirely normal physiological conditions. A ‘passed’ balloon test may show adequate collateral flow at rest, at a certain blood pressure; it does not take into account of the normal fluctuations of blood pressure or assess the adequacy of blood flow during hypotensive episodes or during activities. There is some evidence to suggest that a small proportion of patients undergoing carotid ligation after a 'passed' balloon test, subsequently go on to develop ischaemic episodes and CVA's. In addition to ischaemic sequelae, carotid artery ligation imposes significant haemodynamic stress on the remaining cerebral circulation. It is well established that 'berry' aneurysms frequently form on the contralateral circulation many years after a Hunterian ligation. Whether a bypass procedure in these circumstances will prevent the formation of these aneurysms remains unknown.

To take these points further, BOT can be performed under induced hypotensive state to clinically assess the adequacy of blood flow. Some clinicians do not simply rely on the clinical findings of BOT, but also look at physiological aspects of the test, by combining BOT with perfusion scans and CVR assessments[29,31-33].

Classification of bypass surgery

Cerebrovascular bypass surgery can be classified according to the surgical technique i.e., direct or indirect bypass procedure, the flow rate of the bypass, the type of graft used, and the anastomotic location of the bypass (Table 3)[11,15].

Perioperative management and anaesthetic considerations[7,8,10,11,15]

Preoperative preparation

Patients should undergo thorough preoperative cardiac assessments such as electrocardiography (ECG) and echocardiography, as the use of barbiturates during surgery can be associated with significant myocardial suppression. A 4-vessel cerebral angiography (DSA) is performed to assess the size and position of the superficial temporal artery and the recipient cerebral artery to be used in the bypass, and to assess the state of the cervical carotid arteries in high flow bypass cases to ensure that there are no plaques or carotid stenosis. In addition, DSA will provide information on the collateral circulation, and a carotid cross compression or a balloon occlusion test may be indicated. All patients receive Aspirin 325 mg the night before surgery. For high flow bypasses, saphenous veins are marked on both legs with indelible ink under ultrasound guidance a day before surgery.

Table 3. Classification of cerebrovascular bypasses

Types of classification	Description	Examples of bypasses
Direct or Indirect bypass	A direct bypass is an anastomosis between 2 blood vessels, surgically created by using microsuturing techniques.	- STA-MCA bypass
	An indirect bypass occurs as a result of pial synangiosis via a natural adaptation process promoted by surgical approximation of vessels, muscles or fat onto the surface of the brain.	- Pial synangiosis - Encephalomyosynangiosis (EMS) - Encephaloduroarteriosynangiosis (EDAS) - Encephaloduroarteriomyosynangiosis (EDAMS) - Encephalogaleoperiosteal synangiosis - Multiple burrholes
Flow rate (Low, medium or high flow)	Low flow (20 to 70 ml/min)	- STA-MCA bypass cerebellar artery - Occipital artery- posterior inferior (OA-PICA) bypass
	Medium flow (60 to 100 ml/min)	- External carotid artery - Middle cerebral artery (ECA-MCA) bypass with radial artery interposition graft
	High flow (100 to 140 ml/min)	- CCA-M2 bypass - Common carotid artery- internal carotid artery (CCA-ICA) bypass with saphenous interposition graft
Type of graft vessels	Direct	- Superficial temporal artery (STA) graft - Occipital artery (OA) graft - Radial artery (RA) graft
	Interpositional graft	- Saphenous vein graft (SVG)
Anatomical location of donor/recipient vessels	Extracranial-Intracranial (EC-IC) bypass	- STA-MCA bypass - OA-PICA bypass - CCA-M2 or CCA-ICA bypass with SVG/RA graft bypass
	Intracranial-intracranial (IC-IC) IC-IC bypass	- Petrous ICA-supraclinoid ICA with graft - In-situ side-to-side anastomosis of A4-A4 segment of ACA or posterior inferior cerebellar artery- posterior inferior cerebellar artery (PICA-PICA)

Intraoperative considerations

For STA-MCA bypasses, brain relaxation is avoided by maintaining a normocapnic state (PCO_2 35 to 40 mmHg); mannitol is not used. This reduces the working distance for the surgeon to perform the anastomosis, by allowing the brain to surface into the operative field. For both low-flow and high-low bypasses, heparin (2,500 to 5,000 iu) can be given before cross-clamping of the cerebral artery. Several neuroprotective measures are employed during the cross-clamping for the bypass anastomosis, to increase the ischaemic tolerance time. These include mild hypothermia (32 to 34°C), the use of barbiturate coma to achieve electroencephalography (EEG) burst suppression, and induced hypertension (20% increase above the baseline) to increase collateral circulation during cross-clamping. Various other monitoring techniques can also be used during surgery, for example, somatosensory evoked potentials (SSEPs), brainstem auditory evoked response (BAER), intraoperative angiography and micro-dopplers. A dilute solution of papaverine is applied topically on the anastomotic site after the release of the cross-clamp, to prevent vasospasm and to promote flow through the bypass. At the end of the operation, a reversal of heparin with protamine sulfate may be necessary in case of excessive soft tissue bleeding, guided by the activated clotting time (ACT) measurements.

Postoperative management

Postoperatively, all patients are monitored in intensive care unit (ICU). The arterial systolic blood pressure is kept strictly between 120 and 150 mmHg, to ensure good flow through the graft. 325 mg Aspirin is given daily and to continue indefinitely. In addition, Dextran solution may be given for 3 to 5 days postoperatively to inhibit platelet function and prevent graft thrombosis. Head position is turned with the operative side up to avoid pressure on the graft. Transparent wound dressings allow Doppler flow assessment of the graft at hourly interval. A CTA of the brain is performed on the postoperative day 1, to assess graft anatomy and patency from the neck up to the cranial site. A 4-vessel cerebral DSA is then performed at 6 weeks, postoperatively.

Complications

Complications of cerebrovascular bypass surgery can be medical, anaesthetic, or surgical technique related, and can occur intraoperatively, immediately postoperatively or in a delayed fashion (Table 4)[15].

Graft patency rates and surgical outcome

From large series, the overall patency rate for cerebrovascular bypass surgery is generally excellent at 87 to 100%, with surgical mortality of 0 to 4.4%. Morbidity includes stroke (2.7%), TIA's (7.3%), seizures (5.4%), haemorrhages (4%), and wound infections (1%)[35]. For low-flow bypass with superficial scalp or subcutaneous donor artery graft (e.g., STA or OA), the patency rate is 95% at 5 years. However, the success for a low-flow bypass anastomosis is highly dependent on the caliber of the STA and the recipient M3/M4 segment of the MCA, with good results for vessels greater than 7mm in diameter. In the EC-IC bypass study, the patency rate for STA-MCA bypass was 96% with 0.6% mortality[19]. For medium-flow bypass using radial artery or small saphenous vein grafts, the 5-year patency rate is 90 to 95%. For large saphenous vein graft high-flow bypass, the patency rate is good at 80 to 85%[11,12,15,16,20,36-38].

The Carotid Occlusion Surgery Study (COSS)[39], a randomized controlled trial, compared between STA-MCA bypass surgery plus best medical therapy and best medical therapy alone, in a highly selected group of patients of proven ICA occlusion with haemodynamic cerebral ischaemia, with increased OEF ratio on PET. This trial showed no benefit

Table 4. Surgical complications from cerebral revascularization

Intraoperative	Surgical technique	-Anastomotic leakage -Graft occlusion -Vasospasm of donor graft and/or recipient arteries -Vascular injury
	Medical	-Nuisance bleeding (aspirin and heparin use) -Intraventricular bleed (hypertension) -Brain oedema (hypocapnia)
Postoperative	Immediate/short-term	-Acute graft stenosis/occlusion (surgical technique, hypotension) -Subdural haematoma (anastomotic leakage and coagulation) -Wound haematoma (coagulopathy) -Wound infection -Cerebrospinal fluid (CSF) leakage -Prolonged coma (intraoperative barbiturate use) -Hyperperfusion syndrome(leading to brain oedema, seizures, or intracerebral haemorrhage (ICH))
	Long-term	-Delayed graft stenosis/occlusionfrom various causes, e.g. surgical technique and arthrosclerosis(risk factors: hypertension, hyperlipidaemia, diabetes mellitus, smoking)

of EC-IC bypass surgery over best medical therapy in this population[30,40]. The 2-year ipsilateral stroke was 21% for the surgical group, while the medical group was 22.7%. Perioperative ipsilateral stroke rates for the surgical group and medical groups were 14.4% and 2.0%, respectively. Possible explanations for this included the technical performance of the anastomosis, non-graft related infarcts such as embolism or hypoperfusion, and haemodynamic fragility of the patient population in this study[41-43]. In contrast, the Japanese EC-IC Bypass Trial (JET), a randomized controlled study similar to the COSS study, reported an interim analysis, and revealed stroke reduction in the surgical group when compared to the medical group, with a 2-year stroke rate of 5.4% and 14.3%, respectively. The final results of the JET study remain to be seen. Thus far, there is still conflicting evidence in the literature to support or refute the role of EC-IC bypass surgery as a means to prevent ischaemic stroke in cerebrovascular occlusive disease[21-23,43-45]. Treatment recommendation should therefore be individualized on a case-by-case basis, based on clinical discretion[44,46].

Conclusion

Recently, there has been a re-emergence of interests in cerebrovascular bypass surgery due to a better understanding of the pathophysiology of brain ischaemia, the improvements and increased availability of diagnostic imaging, e.g., perfusion scans, PET scan and CVR assessments, and the advances in neuroanaesthesia, such as neuroprotection and brain monitoring. More detailed evaluation of patients with cerebral ischemia using perfusion scans and CVR assessments will help to identify a subgroup patient who may benefit most from bypass surgery. Currently, the efficacy of EC-IC bypass surgery in the prevention of TIA's and stroke, for a highly selected group of patients with chronic cerebral ischaemia continues to be under evaluation. Long-term patency of EC-IC bypass graft has been shown to be excellent. A multidisciplinary approach with a team of neuroanaesthetists, neurologists, interventional and diagnostic neuroradiologists, intensivists, and cerebrovascular neurosurgeons is vital for the success of a bypass surgery. Although many new surgical techniques had been developed for CBS, the outcome for patients undergoing bypass surgery remains highly dependent on multi-disciplinary teamwork, detailed preoperative haemodynamic assessment and patient selection.

What is already known on this topic?

Cerebrovascular bypass surgery is a well-established procedure in the neurosurgical field with many variations in techniques and indications. However, the evidence for surgery in cerebrovascular occlusive disease is currently still debatable and conflicting. Recent evidence suggests that in a highly specific group, patients may benefit from this procedure, and preoperative assessment of the cerebral haemodynamics is vital in the patient selection process for surgery.

What this study adds?

In the present study, the authors present 2 cases, with different pathologies, who underwent cerebrovascular bypass surgery. In case 1, the method we employed to assess CVR or CO_2 reactivity is different from previous studies. We used CO_2 inhalation technique instead of intravenous acetazolamide during CT perfusion of the brain. The reason being that intravenous acetazolamide is not available in Thailand, and we adapted the CO_2 reactivity assessment by using 5% CO_2 inhalation technique. In our study, we demonstrate that STA-MCA bypass surgery has reversed and normalized the preoperative CVR/CO_2 impairment in case 1, in concordance with the patient's postoperative neurological improvements. To the best of our knowledge, this is the first time a reversal of CVR impairment after bypass surgery is reported using CO_2 inhalation technique. In addition, our paper provides an update on the evidence for the role of CBS in brain ischaemia and provide current strategies and concept in the pre and postoperative assessment of cerebral haemodynamics for both low-flow and high-flow cerebrovascular bypasses as demonstrated in case 2.

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Potential conflict of interest

The authors declare no conflict of interest.

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