Indications and Results of Direct Cerebral Revascularization in the Modern Era

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Key words
- Aneurysm
- Bypass
- Cerebral
- Dissection
- Ischemia
- Moyamoya
- Revascularization

Abbreviations and Acronyms
EC-IC: Extracranial-intracranial
GOS: Glasgow Outcome Scale
ICA: Internal carotid artery
MCA: Middle cerebral artery
OA: Occipital artery
STA: Superior temporal artery
TIA: Transient ischemic attack

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BACKGROUND: **There has been a progressive decrease in the indications for cerebral revascularization during the past 30 years, particularly with the advance of endovascular techniques. Our objective was to define indications for and evaluate outcomes of patients treated with bypass surgery in the modern endovascular era.**

METHODS: **We retrospectively reviewed the charts of all patients who underwent direct cerebral revascularization procedures between January 2006 and March 2013.**

RESULTS: **In total, 121 patients underwent 131 direct microsurgical revascularization procedures. The indications for bypass surgery were moyamoya angiopathy (40 patients, 47 bypasses), complex aneurysms (54 patients, 56 bypasses), and occlusive vascular disease (27 patients, 28 bypasses). Revascularization resulted in improvement of symptoms in 77.5% of patients with moyamoya angiopathy (mean clinical follow-up 18.8 months) and 55.5% of patients with occlusive vascular disease (mean clinical follow-up 10.4 months). Among the aneurysm patients treated with revascularization, 81.5% had a favorable outcome (Glasgow Outcome Scale score 4–5) at long-term follow-up (mean clinical followup 18.5 months).**

CONCLUSIONS: **Although microvascular cerebral revascularization is no longer performed as commonly as in the past, it remains an essential part of the skill set required to treat select vascular pathologies. Complex aneurysms are the single largest indication for direct bypass procedures. Moyamoya disease is by far the largest indication if indirect bypass procedures are included in the analysis. In experienced hands, the morbidity and mortality of patients undergoing cerebral revascularization procedures are low and long-term outcomes generally excellent.**

INTRODUCTION

Microvascular bypass surgery was introduced by Yaşargil in 1970 (30) and rapidly became a mainstay in the treatment of patients with intracranial ischemia. However, improvements in medical management and the publication of results from the extracranial-intracranial (EC-IC) bypass trial and subsequent Carotid Occlusion Surgery Study trial have dampened enthusiasm for the use of bypasses for intracranial ischemias (2, 23). At the same time, advances in chemotherapy combined with better and more precise radiation techniques have reduced the use of cerebral revascularization for treating complex skull base tumors (15). The introduction and refinement of endovascular techniques that began in the 1990s also led to a decrease in the use of bypass techniques for giant and complex aneurysms, where revascularization and trapping was once the definitive treatment (14, 16-18).

Cerebral revascularization remains the primary treatment in certain neurovascular diseases, such as moyamoya angiopathy, but these cases are uncommon, and patients are rarely treated outside of major tertiary care centers (4, 7, 13, 27). The changes in the aforementioned practice paradigms outlined and the decrease in the use of bypass techniques beget 2 important and related questions: What are the current indications for cerebral revascularization? With a decreasing number of bypass procedures being performed, do the results of microvascular bypass surgery remain comparable to historical controls?

To address these questions, we retrospectively reviewed all direct cerebral revascularization procedures performed at our center in the modern endovascular era (2006–2013) to evaluate indications for their use and the outcome of patients, with special emphasis on the rates of morbidity and mortality associated with the use of bypass.

MATERIAL AND METHODS

Patient Population

Between January 2006 and March 2013, 121 consecutive patients underwent direct microsurgical cerebral revascularization alone or in combination with other procedures. Patients with penetrating intracranial trauma were excluded from this analysis. Medical records, neurological

examinations, and radiographic studies were reviewed retrospectively. Pre- and postoperative neurological function was evaluated via Glasgow Outcome Scale (GOS) scores. Patients undergoing cerebral revascularization in this study sample could be categorized by 3 clinical indications: moyamoya angiopathy, complex aneurysm, or occlusive vascular disease.

Pathology-Specific Consideration

Moyamoya Disease. Patients who were symptomatic, had a perfusion deficit on computed tomography perfusion, and who had the characteristic findings of moyamoya disease on angiography were evaluated for bypass surgery. Given the natural history of untreated symptomatic moyamoya disease, we aggressively treat these patients with revascularization when indicated. The type of bypass (direct vs. indirect) was determined at the time of surgery, depending on the size and fragility of the available recipient vessels. Here, we discuss the results of direct revascularization for this disease process. Our center's protocol for treating patients with moyamoya disease and our experience with indirect revascularization in this population has recently been published (4).

Intracranial Aneurysms. Bypass surgery was performed for complex aneurysms not amenable to direct clipping or clip reconstruction. If, during intraoperative evaluation, the surgeon concluded that the aneurysm could not be directly clipped or clip reconstructed, a decision was made to perform excision with direct vessel reconstruction (in situ bypass), EC-IC bypass with trapping, or EC-IC bypass with proximal or distal vessel occlusion. Our institutional preference is to perform a bypass in all patients who require acute vessel sacrifice for management of an aneurysm. The type of bypass performed (high-flow or low-flow) depended on the location of the aneurysm and available collateral circulation. Imaging assessments of patients included combinations of magnetic resonance imaging, magnetic resonance angiography, computed tomographic angiography, and digital subtraction angiography.

Intracranial Occlusive Disease. These patients had vascular imaging demonstrating complete occlusion of an internal carotid artery (ICA), a main trunk of the middle cerebral artery (MCA), or the anterior cerebral artery, and they had symptoms of focal cerebral ischemia (e.g., transient ischemic attack [TIA] or ischemic stroke in the territory of the occluded intracranial artery) that were unresponsive to best medical therapies. Patients generally underwent computed tomography perfusion or positron emission tomography, but these studies were not performed in every patient.

RESULTS

Altogether, 121 patients (75 female, 46 male) with a mean age of 46.6 years (range, 1–87 years) underwent 131 direct cerebral revascularization procedures. The indications for revascularization and overall patient characteristics are summarized in Table 1. In total we performed 47 (35.9%) revascularization procedures for 40 patients with moyamoya disease, 56 (42.7%) procedures for 54 patients with complex aneurysms, and 28 (21.4%) procedures for 27 patients with occlusive vascular disease including intracranial or extracranial vessel occlusion. Patient characteristics and outcomes by these 3 indications are summarized in Table 2.

Table 1. Patient Characteristics and Indications for Revascularization

	N
Number of patients	121
Number of revascularization procedures	131
Male:female	46:75
Mean age, years	46.6 (range, 1–87)
Indication	
Moyamoya angiopathy	40 patients (33.1%) 47 bypasses (35.9%)
Complex aneurysm	54 patients (44.6%) 56 bypasses (42.7)
Occlusive vascular disease	27 patients (22.3%) 28 bypasses (21.4%)

Moyamoya Disease

Forty patients (23 females, 17 males) with a diagnosis of moyamoya disease underwent 47 bypass procedures. The mean age was 42 years (range, 12–69). The most common clinical presentations included TIA, confirmed stroke, headaches and cognitive decline, intraparenchymal hemorrhage, seizures, syncope, and chorea. The mean preoperative GOS was 4.2.

We have previously published our surgical technique for both direct and indirect bypass in this population (4). The bypass donor vessel was a superior temporal artery (STA) branch and the recipient was a cortical branch of the MCA. Two patients had a double-barrel STA-MCA bypass (Figure 1). Only one patient underwent a high-flow ICA-MCA bypass with a radial artery graft.

No patient died perioperatively. Two patients (5% of moyamoya disease patients) had perioperative complications: 1 stroke and 1 case of postoperative status epilepticus. Symptoms improved in 77.5% of patients and were unchanged in the remaining at follow-up. Angiographic follow-up information beyond the immediate postoperative period was not available for 16 patients. In the remaining 24 patients, at a mean angiographic follow-up of 23.1 months (range, 1–60 months), the bypass patency rate was 96.8% (30/31 patent bypasses). At a mean clinical follow-up of 18.8 months (range, 2–53 months) the mean GOS was 4.6.

Intracranial Aneurysms

In 54 patients with 55 complex aneurysms not amenable to direct clipping or clip reconstruction, 56 revascularization procedures were performed (Figure 2). There were 38 females and 16 males with a mean age of 46.8 years (range, 1–77 years). The most common clinical presentations included headaches, cranial neuropathy, and subarachnoid hemorrhage. The preoperative mean GOS was 4.4.

Aneurysms were located along the cervical ICA (n = 1), petrous/cavernous ICA (n = 1), cavernous ICA (n = 15), supraclinoid ICA (n = 7), posterior communicating artery (n = 2), anterior cerebral artery (n = 4), MCA (n = 13), posterior cerebral artery (PCA) (n = 3), posterior inferior cerebellar artery (n = 4), and vertebrobasilar arteries (n = 5).

The anatomical locations of the bypasses included the following: 24 STA-MCA (including 1 double-barrel STA-MCA), STA-SCA (n = 3), STA-PCA (n = 1), STA-SCA/STA-PCA (n = 1), occipital artery (OA)-PCA (n = 2), external carotid artery/ICA-MCA (n = 15; 14 using a radial artery and 1 using a saphenous vein graft), OA-MCA (n = 1), OA-posterior inferior