



Trends in Cerebral Revascularization in the Era of Pipeline and Carotid Occlusion Surgery Study

Timothy G. White¹, Devon O'Donnell¹, Jackie Rosenthal¹, Michael Cohen², Gunes Aygok¹, Erez Nossek³, David J. Langer¹

■ **BACKGROUND:** In the past, microsurgical bypass was the best option for revascularization of cerebrovascular lesions that required flow replacement or flow augmentation. Over the last 2 decades with advancements in the field of neuroendovascular surgery, especially with the revolution of flow diverting stents as well as the results of the Carotid Occlusion Surgery Study, indications for microvascular bypass have significantly decreased. The purpose of this study was to evaluate trends in cerebral revascularization over the past 8 years.

■ **METHODS:** We retrospectively reviewed patients with cerebral revascularization surgery during the years 2006–2014 in a single surgeon's practice. All patients who had undergone cerebral revascularization for any indication were included in the study.

■ **RESULTS:** We identified 106 patients who had undergone cerebral bypass; 2 patients were excluded. Of 104 patients, 60% were female and 40% were male. Indications for surgery were giant aneurysm in 48 patients, arterial occlusion in 30 patients, and moyamoya disease in 26 patients. In all indications except for moyamoya disease, case number per year declined. A marked decrease was noted in revascularization for treatment of giant aneurysm or occlusion.

■ **CONCLUSIONS:** This study demonstrates the impact that both scientific inquiry and technological advances have had

on a challenging and valuable technique in cerebrovascular surgery. Indications for both flow replacement and augmentative bypass remain. However, the marked decline in indications may have an indelible impact on maintenance of surgical proficiency as well as the ability for young neurosurgeons to develop this valuable skill set.

INTRODUCTION

Since the inception of microscopic cerebral revascularization in 1969, the indications for the procedure have been in constant ebb and flow, with current trends favoring the outgoing tide.¹ During the late 1970s, cerebral revascularization promptly became part of the repertoire of many cerebrovascular neurosurgeons and was established as an integral mechanism for the treatment of cerebral ischemia. Indications were ultimately expanded into aneurysm and skull base surgery. However, with the advent of flow-diverting technology as well as the findings of the International Cooperative Study of Extracranial/Intracranial Arterial Anastomosis and the Carotid Occlusion Surgery Study (COSS), there are now substantially fewer indications for extracranial (EC) to intracranial (IC) bypass.²⁻⁵

Endovascular techniques, including the development of flow-diverting stents, have become the treatment of choice for large and giant aneurysms of the proximal intracranial carotid circulation.⁶⁻⁸ Additionally, COSS showed no significant benefit in treating

Key words

- Cerebral bypass
- Cerebral revascularization
- EC-IC bypass
- Giant cerebral aneurysm
- Moyamoya disease

Abbreviations and Acronyms

COSS: Carotid Occlusion Surgery Study

EC: Extracranial

IC: Intracranial

ICA: Internal carotid artery

MCA: Middle cerebral artery

MRA: Magnetic resonance angiography

SPECT: Single-photon emission computed tomography

STA: Superficial temporal artery

^{99m}Tc: Technetium 99m

From the ¹Department of Neurosurgery, Hofstra Northwell School of Medicine, Hempstead, and Lenox Hill Hospital, New York; ²Jacobs School of Medicine and Biomedical Sciences, University at Buffalo, Buffalo; and ³Department of Neurosurgery, Maimonides Medical Center, New York, New York, USA

To whom correspondence should be addressed: David J. Langer, M.D.
[E-mail: dlanger@nshs.edu]

Citation: *World Neurosurg.* (2016) 91:285-296.

<http://dx.doi.org/10.1016/j.wneu.2016.03.090>

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

1878-8750/\$ - see front matter © 2016 Published by Elsevier Inc.

carotid occlusion with microsurgical cerebral revascularization compared with medical management.^{3,5} Despite challenges, cerebral revascularization remains the treatment of choice for various neurovascular disorders, including moyamoya angiopathy and large and giant aneurysms of the more distal posterior and anterior circulation.⁹ However, these conditions represent a small number of cases that are often managed by established neurosurgical programs that have high-volume open vascular neurosurgical groups frequently found in robust tertiary care centers.

Studies suggest that the incidence of moyamoya disease in the United States is 0.086 per 100,000 person years with incidence varying between ethnicities.¹⁰ The ethnic-specific incidence in the US was 0.28/100,000 for Asian Americans, 0.13/100,000 for African Americans, and 0.03% for Hispanics.¹⁰ Similarly, the number of aneurysms for which bypass is the preferred treatment is low, with giant aneurysms representing only 5% of intracranial aneurysms.¹¹ Although surgical intervention remains the gold standard for the treatment of moyamoya disease, the advancement of endovascular technique has resulted in a rapidly shrinking number of indications for cerebral revascularization in the management of giant aneurysms.^{12,13}

Ultimately, the decrease in indications for cerebral revascularization may pose a challenge for clinical practice and training in cerebrovascular bypass surgery, limiting the future availability of this neurosurgical intervention. To evaluate changing trends in this field, we retrospectively reviewed the case volume and types of cerebrovascular surgeries of a single neurosurgeon over 8 years to assess the impact that endovascular technology and cerebrovascular trial data have had on microscopic cerebral revascularization.

MATERIALS AND METHODS

We performed a retrospective review of 106 patients who underwent cerebral revascularization surgery in a single surgeon's practice (D.J.L.) between 2006 and 2014. All patients who had undergone cerebral revascularization and who had complete patient records were included in the study. Two patients were excluded based on incomplete data sets. Medical records, physicians' notes, and radiographic studies were reviewed for analysis. Institutional review board approval was obtained. Diagnoses in this patient population included giant aneurysms, moyamoya disease, arterial occlusion, and arterial stenosis.

The clinical data evaluated for this study were collected from the surgeon's records, which included 3–6 months of follow-up. Patient demographics and symptoms, date of surgery, disease etiology, location of pathology, type of bypass procedure, mortality, intraoperative complications, and need for second surgery, if applicable, were recorded and analyzed using descriptive statistics. Mean \pm SD or median with interquartile range (25th percentile, 75th percentile) was calculated for continuous data, and frequencies and percentages were calculated for categorical data. A linear regression was used to analyze trends over time.

Indications for Moyamoya Disease

Surgical management of moyamoya disease was indicated in patients after hemorrhage or ischemic insult or in patients with asymptomatic disease contralateral to an already treated symptomatic hemisphere. The latter patients generally underwent

indirect bypass after their primary bypass on the symptomatic side. In cases where robust encephaloduroarteriosynangiosis revascularization on the symptomatic side was seen, indirect grafting was recommended and performed on the asymptomatic side. Patients who demonstrated hypoperfusion on their asymptomatic side by single-photon emission computed tomography (SPECT) or who did not have an anatomic parietal superficial temporal artery (STA) branch were considered for direct grafting. Patients with asymptomatic moyamoya disease were managed conservatively after a complete radiographic work-up including quantitative magnetic resonance angiography (MRA) with noninvasive optimal vessel analysis software (NOVA; VasSol, River Forest, Chicago, USA), magnetic resonance SPECT, and angiography.

Indications for Aneurysm

Bypass surgery was performed for complex aneurysms not amenable neurointerventional treatment or direct clipping. Intraoperative exploration was often utilized to confirm need for bypass. Treatment considerations included direct vessel reconstruction (in situ bypass), EC-IC bypass with trapping, or EC-IC bypass with proximal or distal vessel occlusion (Figures 3–5). A bypass with acute or subacute vessel sacrifice (postcraniotomy endovascular deconstruction) was preferred. The type of bypass performed depended on the location of the aneurysm, the viability of the collateral circulation as measured intraoperatively, and the potential graft flow primarily measured by STA cut flow.^{14,15,17}

Indications for Ischemia and Occlusion

The indications for revascularization in the presence of middle cerebral artery (MCA) or internal carotid artery (ICA) occlusion included hemispheric hypoperfusion as assessed by SPECT hemispheric flow imaging with and without acetazolamide, magnetic resonance imaging evidence of acute or chronic stroke in the distribution of the MCA, and symptomatic presentation, such as transient ischemic attack or ischemic stroke.

All patients underwent SPECT with and without Diamox, but bypass was recommended only when Diamox failed to reverse hypoperfusion or where perfusion worsened after Diamox administration.

Table 1. Patient and Procedure Details

Characteristic	Value
Number of patients	104
Number of revascularizations	110
Male-to-female ratio	42:62
Mean age, years (range)	50.6 (11–80)
Indication	
Moyamoya disease	26 patients, 32 procedures
Complex aneurysm	48 patients, 48 procedures
Occlusive vascular disease	30 patients, 30 procedures

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