



# Unexpected immediate postoperative resolution of long-standing neurological deficits following extracranial-intracranial bypass: a report of three cases

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Received: 25 November 2018 / Accepted: 23 January 2019 / Published online: 2 February 2019  
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## Abstract

While intracranial ischemic insults often result in neuronal death and permanent neurological deficits, some patients may develop potentially reversible neurological dysfunction from persistent hypoperfusion, as surviving neurons remain in an “idling” state. We report a unique series of three patients with long-standing neurological deficits who underwent EC-IC bypass for repeated TIAs and demonstrated unexpected, rapid resolution of long-standing pre-existing neurological deficits. We suggest that these individuals harbored regions of underperfused, idling neurons that responded rapidly to restored cerebral reperfusion.

**Keywords** Extracranial-intracranial bypass · Leg plegia · Perfusion

## Introduction

Extracranial-intracranial (EC-IC) bypass became popular in the 1970s as a method of improving blood flow to the brain to treat or prevent ischemic stroke. The Cooperative study, published in 1985, raised significant questions about the efficacy of the operation, which was all but abandoned in many centers thereafter [17]. Nevertheless, there remains a subset of patients with hypoperfusion of the brain and persistent ischemic symptoms that may benefit from bypass surgery. We have previously described our experience with EC-IC bypass in patients failing maximal medical therapy [11] and as an urgent salvage maneuver in patients with crescendo transient ischemic attacks (TIAs) or slowly progressing stroke [12]. The complication rates of cerebral revascularization range widely based on patient comorbidities and the experience of the

microneurosurgeon and institution [3, 16], but cerebral revascularization has shown consistent good outcomes as a targeted tool when performed at high-volume centers [18].

In this report, we describe our experience with three unique patients who underwent EC-IC bypass in the setting of bilateral ICA occlusion and persistent TIAs despite maximal medical therapy. Each patient had a fixed, long-standing neurological deficit (lower extremity monoplegia, severe upper extremity monoparesis, and severe expressive dysphasia) that was assumed to have resulted from an irreversible, permanent ischemic insult based on cross-sectional imaging and the long duration of fixed symptoms. In these cases, the patients demonstrated rapid and unexpected resolution of their deficits following EC-IC bypass, which indicates that the deficits had been due to underperfused, “idling” neurons.

## Case report

### Case 1

A 66-year-old male patient was considered for EC-IC bypass in the setting of bilateral carotid artery occlusion and persistent left-hemispheric TIAs despite combined antiplatelet, anticoagulant therapy. Three years earlier, the patient had suffered a right hemispheric ischemic event with resultant spastic left lower extremity monoplegia, which was assumed to be an irreversible and fixed deficit.

This article is part of the Topical Collection on *Vascular Neurosurgery - Ischemia*

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The patient was offered left-sided EC-IC bypass to diminish his risk of further ischemic injury to the left hemisphere. The patient underwent uneventful left-sided STA-MCA anastomosis and awoke from anesthesia with immediate return of left leg function, which was graded as 4/5 motor strength in the recovery room. Given the unexpected recovery of function in his ipsilateral leg, postoperative angiography was performed. It demonstrated that the bypass was robustly filling the left ICA territory as well as the opposite, right-sided ACA, which was the presumed cause of the neurological improvement (Fig. 1). At 1-year follow-up, the patient had experienced persistent improvement in his leg function, and his TIAs had resolved.

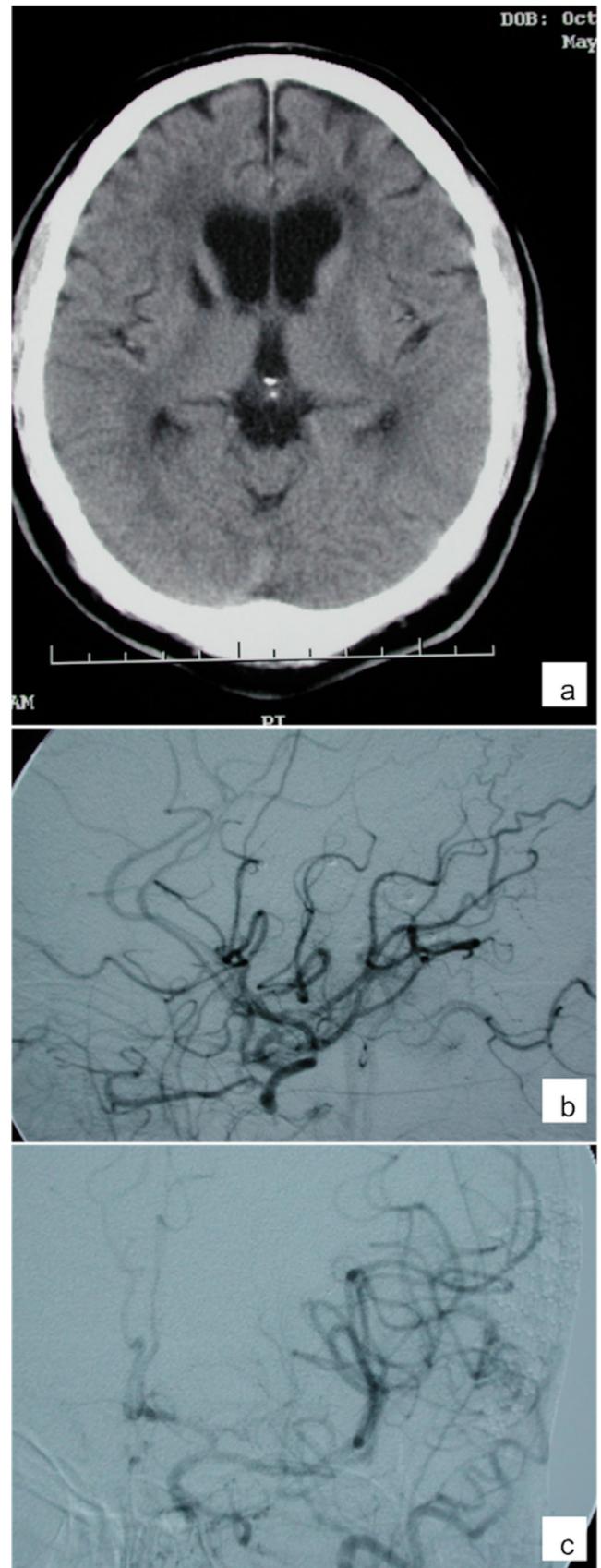
## Case 2

A 49-year-old female with bilateral ICA occlusions experienced severe upper extremity monoparesis that was assumed to be the result of a completed stroke 6 months earlier. Despite anticoagulant and antiplatelet therapy, she had repeated TIAs, poor collateral flow from the external carotid system and posterior circulation, and impaired CBF on CT perfusion. She was counseled regarding EC-IC bypass and consented to surgery.

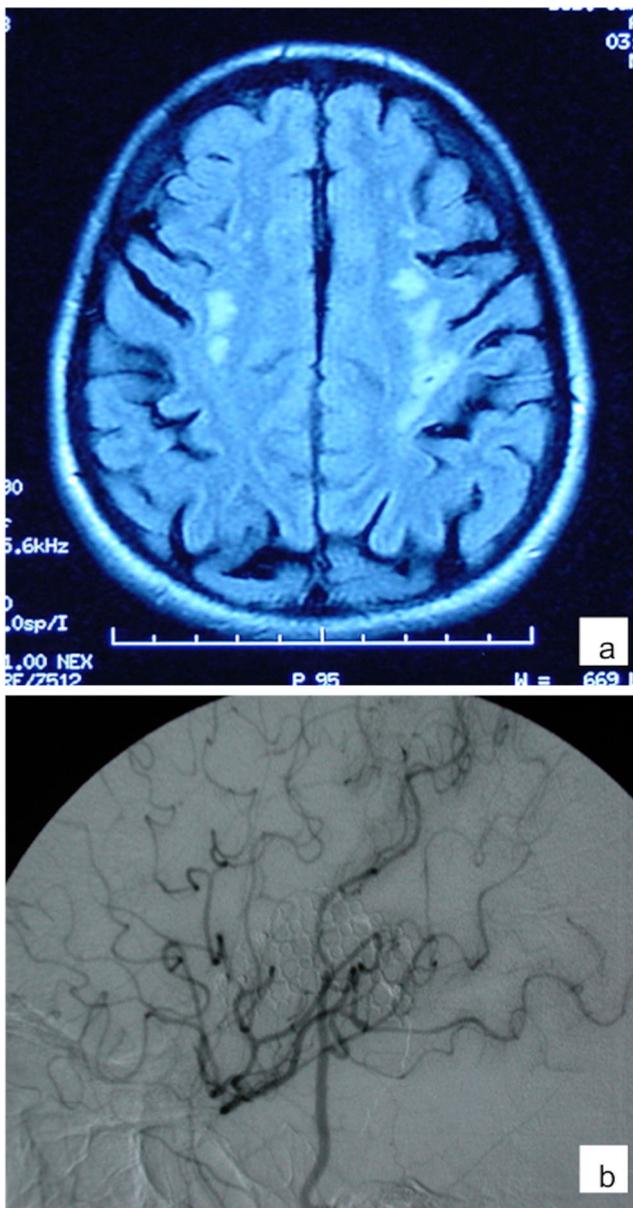
The patient underwent STA-MCA anastomosis with the purpose of diminishing her risk of stroke. There were no notable complications during surgery. Within 8 h, the patient reported improvement in her arm weakness, which improved from grade 2/5 preoperatively to grade 4/5. Additionally, she was able to open and close her hand, which had been impossible pre-surgery. At a 6-month follow-up, she demonstrated stable, improved strength with no further TIAs. Postoperative angiography demonstrated that the bypass had robustly filled the ipsilateral MCA territory presumably resulting in the improvements in her arm's function (Fig. 2).

## Case 3

A 69-year-old male had severe expressive dysphasia that had remained unchanged following an ischemic insult 18 months previously. The patient was referred for surgical consideration due to repeated left hemispheric TIAs,



**Fig. 1** Case 1, 66-year-old male. **a** Anteroposterior and **b** lateral left external carotid artery cerebral angiogram showing postoperative change of the left sided superior temporal artery-middle cerebral artery (STA-MCA) bypass with saphenous vein graft. The bypass is widely patent, and there is rapid filling of the entirety of the left MCA territory. There is also filling of the distal left internal carotid and anterior cerebral arteries, likely from meningeal artery to ophthalmic artery collaterals. **c** Postoperative computed tomography scan showing no evidence of ischemic infarct in the left MCA territory following bypass

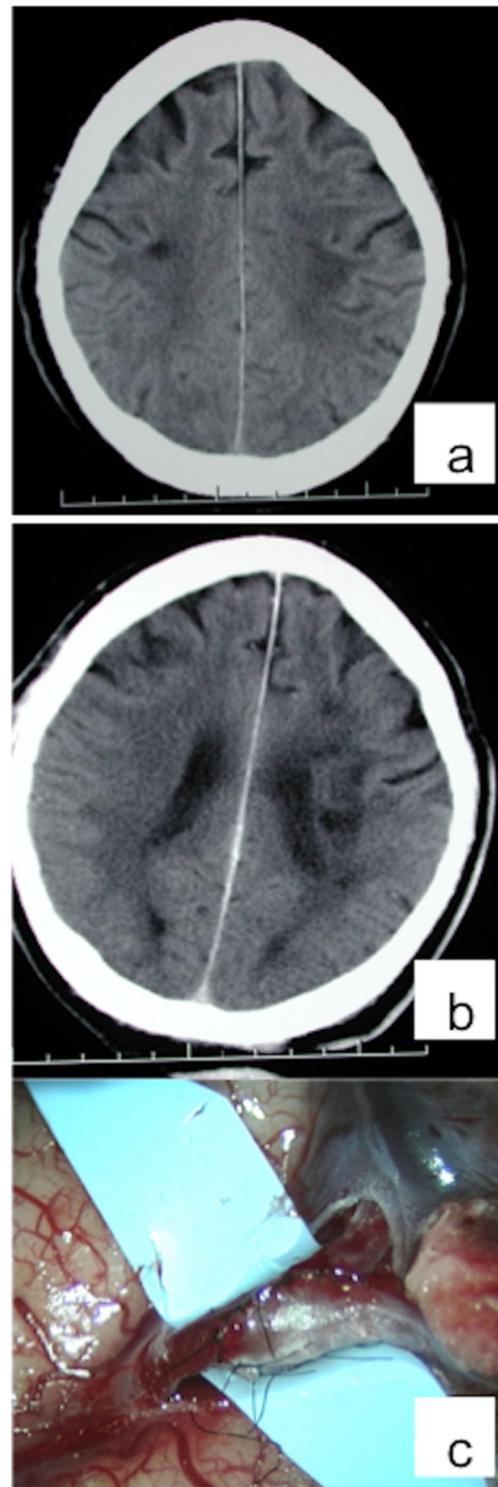


**Fig. 2** Case 2, 49-year-old female. **a** Postoperative axial FLAIR sequence MRI showing limited ischemic lesions in bilateral junctional zones at the junctions between ACA and MCA territories. **b** Lateral left ECA angiogram showing total filling of the left MCA territory

poor collateral blood flow, and impaired CBF on CT perfusion imaging. He underwent STA-MCA anastomosis to the left hemisphere, and the patient noticed immediate postoperative improvement in his language function. Before surgery, his speech had been limited and almost unintelligible.

Although the degree of speech improvement was subjective, his speech became much clearer immediately after surgery and continued to improve over time. The patient had a single episode of transient weakness the day after surgery (which may have been a TIA or a seizure), but he had had no further episodes at the time of the 1-year follow-up.

Postoperative angiography demonstrated a patent bypass that had nicely filled the ipsilateral MCA territory (Fig. 3).



**Fig. 3** Case 3, 69-year-old male. **a** and **b** Postoperative axial CT scan images showing limited ischemic lesions in bilateral junctional zones at the junctions between ACA and MCA territories. **c** Peri-operative photograph shows the permeability of the temporal artery-middle cerebral artery (STA-MCA) bypass with saphenous vein graft

## Discussion

Current indications for EC-IC bypass are controversial. Although the operation has been well-accepted in the management of selected unclippable aneurysms and skull base tumors involving the ICA, it remains unclear which patients with cerebrovascular occlusive disease may benefit from revascularization [11, 18]. Traditionally, EC-IC bypass has been offered to patients with Moyamoya disease and to patients with occlusive cerebrovascular disease who fail maximal medical therapy [11, 16, 18]. We have also used bypass in patients with crescendo TIA and slowly progressing stroke syndromes [12]. In all these cases, the goal of bypass surgery is to limit the patient's future risk of stroke by improving the local cerebral blood flow. In those patients with slowly progressing strokes, we have at times noted relatively rapid improvement in neurological dysfunction, and we have hypothesized that an area of local hypoperfusion resulted in "idling" neurons receiving enough CBF to remain alive but inadequate blood supply to function normally [12]. This theory is further supported by this group of patients demonstrating disproportionately severe neurological deficits when compared with the areas of actual DWI ischemic changes on MR imaging.

In this report, we describe three patients who experienced unexpected recovery of neurological function shortly after revascularization. In all cases, the patients had prolonged (6 months to 3 years) stable deficits, and we, in no way, expected the surgery to result in improvement in these long-standing deficits. These unique cases suggest that it may be possible for neurons to remain in an "idling" state for very prolonged periods, maintaining the potential to improve rapidly if blood flow is restored. This observation may have implications in terms of the potential for revascularization and even cell transplantation procedures to improve function even years after injury, as neurons may remain viable and improvement may remain feasible even in very delayed fashion. We suggest that the presence of bilateral ICA occlusions in the cases described in this report may have predisposed our patients to a chronic state of cerebral hypoperfusion [4].

In addition, the degree of CBF impairment and the potential for reversibility may be more difficult to identify on ancillary CBF imaging when both hemispheres are affected given the inability to compare to the opposite hemisphere. In more common situations of unilateral occlusion, a comparison of blood flow parameters between the affected and normal hemispheres can be helpful in assessing the degree of CBF impairment.

Importantly, penumbral tissues, even long after ischemic damage occurs, may have salvageable function, which should be considered in the prognosis and treatment decision of patients who suffer neurological deficits and are at risk of further ischemic damage. Improvements in neurological function have been previously reported following bypass surgery [5, 6, 9, 14, 15], which are caused by significant increases in

rCBF in the ipsilateral territory of the brain [7]. Greenhalgh et al. reported that 9 of 13 (77%) patients experienced partial recovery from neurological deficits, including improved walking skill and motor strength, following complete hemisphere stroke up to a year after ischemic events [5]. However, a larger series found that only 49% (24/49) of patients with a complete stroke undergoing prophylactic cerebral revascularization to treat TIAs from 3 to 60 months after ischemic insult experienced improvements over their stable neurological deficits within 72 h [15]. Consistent, if slight, improvements from cognitive deficits and even symptoms of depression have also been observed [13]. Two case reports and our previously published experience with emergency EC-IC bypass show that speech, motor, and visual impairment could show significant improvement following STA-MCA anastomosis, exhibiting that neurons can remain stable and viable but lack electric activity under conditions of stable hypoperfusion; speech recovery was slower than motor recovery [6, 14].

The concept that bypass surgery can improve brain dysfunction has been electrophysiologically demonstrated previously. In an observational study by Jussen et al. [9], motor plasticity was documented following EC-IC bypass surgery for patients suffering from unilateral occlusive cerebrovascular disease with no or mild paresis, by using navigated transcranial magnetic stimulation. The patients experienced reversible reduction in motor cortical excitability that was normalized postsurgically, as evidenced by improved motor output, motor neuron disinhibition, and more defined motor cortical representation. These changes were accompanied by decreased TIA frequency and improvement of paresis. The authors similarly suggested that neuronal performance is reversibly decreased in response to hypoperfusion, which may enter a state of metabolic "hibernation" in situations of inadequate oxygenation, prior to permanent loss of function [9]. In the present study, the immediate improvement of lower extremity monoplegia, severe upper extremity monoparesis, and severe expressive dysphasia might be similarly explained, at least in part, by neuronal plasticity.

Unfortunately, partial recovery from neurological deficits is dependent on neuron survival in hypoperfused territory; recovery of function in fully infarcted tissue is extremely rare [1]. Neuron survival after hypoxia and other ischemia-induced metabolic disruptions may be linked to astrocyte-mediated glycolysis and lactate production [2]. Subsequent angiogenesis may allow the neurons to continue functioning [8]. The rapid rate of onset of and recovery from (as seen in our cases) neurological deficits following intracranial ischemic insults may result from the extremely high metabolic rate of neurons [10]. This suggests that CBF is directly linked to neuron function based on neurons' metabolic needs. Our report shows that, even under consistent hypoperfusion, neurons appear to be able to "idle," and although functionally inactive, structure and connectivity with surrounding brain regions are often preserved in tissue with selective neuron survival [1].

## Conclusions

Following ischemic insults, if tissue is not fully infarcted, neurons can survive and “idle” for prolonged periods of time and maintain the potential for dramatic, delayed recovery. On rare occasions, cerebral revascularization may reverse even long-standing, fixed neurological deficits in rapid and somewhat unexpected fashion.

**Acknowledgments** We would like to acknowledge Superior Medical Experts for their editing, formatting, and research support.

**Contributorship** All authors made substantial contributions to the conception or design of the work, or the acquisition, analysis, or interpretation of data for the work; drafted the work or revised it critically for important intellectual content; provided final approval of the version to be published; and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

**Sources of support** We received a grant from the United Hospital Foundation to support this work.

## Compliance with ethical standards

**Conflict of interest** Kevin Kallmes works for and holds equity in Superior Medical Experts. The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

**Patient consent** Consents to the public use of deidentified information were obtained from all patients prior to submission to the journal.

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