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Emergency extracranial-intracranial bypass surgery for acute ischemic stroke

Clinical article

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Object. The purpose of this study was to evaluate the safety and efficacy of urgent extracranial-intracranial (EC-IC) bypass in the management of intracranial cerebrovascular disease and acute cerebral ischemic injury in carefully selected patients.

Methods. The authors reviewed the medical records and neuroimaging studies in 13 consecutive patients who underwent urgent surgical cerebral revascularization to treat acute cerebral ischemia. None were thought to be appropriate candidates for endovascular therapy. The patients' ages ranged from 21 to 65 years (mean 41.2 years). The mean follow-up review was 3.5 years, and no patient was lost to follow-up.

Results. Preoperative angiographic evaluation identified critical narrowing of the supraclinoid internal carotid artery (ICA) in 8 patients, the M_1 segment of the middle cerebral artery (MCA) in 3, and the cervical/petrous ICA in 2. All patients had progressive, refractory symptoms associated with enlarging areas of infarction on diffusion weighted MR imaging, despite maximal medical therapy, which included anticoagulation and antiplatelet agents, blood pressure elevation, and fluid resuscitation. All patients underwent superficial temporal artery–MCA anastomosis on an urgent basis. In every case, the bypass prevented further stroke progression. In 2 cases, revascularization was followed by rapid, dramatic improvement of preoperative neurological deficits.

Conclusions. In the authors' experience, emergency EC-IC bypass in patients with acute ischemic injury was both safe and effective. This population was characterized by relatively young patients with severely limited collateral circulation. In this series of 13 carefully selected patients, bypass was successful in arresting progression of stroke, and in some cases resulted in rapid neurological improvement. *(DOI: 10.3171/2009.5.JNS081556)*

Key Words • **brain** • **bypass procedure** • **arterial dissection** • **revascularization** • **stroke**

Extracranial-intracranial bypass for atherosclerotic disease has been described predominantly as a subacute or late treatment option for patients with cerebrovascular insufficiency in whom aggressive medical therapy has failed.[5,10,13,45,50] These patients generally suffer from "borderline" perfusion and present with transient ischemic symptoms or stroke that develop when native collateral vessels are challenged and cannot adequately perfuse the territory at risk. The efficacy of cerebral revascularization in this population remains controversial, although numerous investigators have demonstrated excellent results in this setting.[2,10,38,45,50] We describe a unique experience with EC-IC bypass performed in an urgent fashion for patients presenting with acute, progressive, ischemic injury despite maximal medical therapy. The management challenges and long-term outcomes in this group of patients are highlighted.

Methods

We retrospectively reviewed the records of all patients undergoing EC-IC bypass procedures performed by a single neurosurgeon (E.S.N.) between July 1997 and December 2007. Of 208 patients undergoing 255 procedures, we identified 13 patients who underwent emergency revascularization surgery to treat acute cerebral ischemia. Hospital records, neuroimaging studies, operative reports, and follow-up clinic notes were available in all cases. Follow-up review ranged from 6 months to 9 years (mean 3.5 years). No patient was lost to follow-up review.

All patients were evaluated by a multidisciplinary neurovascular service that included an interventional neuroradiologist, neurovascular surgeon, neurologist, and neuroin-

Abbreviations used in this paper: CEA = carotid endarterectomy; EC-IC = extracranial-intracranial; ICA = internal carotid artery; STA-MCA = superficial temporal artery–middle cerebral artery; TIA = transient ischemic attack.

tensivist. In every case, endovascular options were believed to be either contraindicated or to carry a much higher risk than surgical revascularization. All patients demonstrated worsening symptoms and evidence of progressive ischemic injury on diffusion weighted MR imaging studies despite aggressive medical therapy consisting of induced arterial hypertension, fluid resuscitation, anticoagulation, and antiplatelet therapy.

All patients underwent STA-MCA anastomosis. The details of the technique used have been described previously.[38] In all cases, a simple STA-MCA bypass was performed, and no attempt was made to open into the depths of the sylvian fissure or perform a high-flow bypass. We were particularly careful to avoid hypotension or hyperventilation in this group of patients, typically opting for mild induced hypertension to maintain a systolic blood pressure > 120 mm Hg during surgery. Mild hypothermia (34°C) and barbiturate anesthesia were used in all cases. In each case, a continuous intraarterial infusion of a weight-based protocol dose of heparin was continued throughout the procedure until the anastomosis was completed. Intraoperative angiography was used to confirm patency of the anastomosis prior to discontinuing the heparin infusion. In most cases, epidural bleeding was somewhat worse than usual but never precluded successful completion of the procedure. After surgery, all patients were maintained on aspirin therapy at a dose of 325 mg/day.

Results

Information about the patients, presenting findings, and surgical results is detailed in Table 1. There were 5 men and 8 women ranging in age from 21 to 65 years. The majority were young and previously healthy without prior evidence of atherosclerotic vascular disease. All patients presented with acute ischemic symptoms consisting of unilateral hemiparesis, sensory disturbance, and/or dysphasia. Five patients were initially discharged from an emergency department with a presumptive diagnosis of "viral illness" or "TIA," only to return within 48 hours with progressive symptomatology. At the time of admission, all patients received a diagnosis of an acute ischemic stroke confirmed by diffusion weighted MR imaging. The majority of patients had patchy, watershed distribution MR abnormalities. All patients underwent CT scanning, MR angiography, and then 4-vessel cerebral angiography.

Angiography demonstrated critical narrowing of the supraclinoid ICA in 8, the M_1 segment of the MCA in 3, and the cervical/petrous ICA in 2 (Table 1). In at least 10 cases, severe irregularity of the narrowing strongly suggested an acute arterial dissection as the underlying pathological process. In addition, angiography uniformly demonstrated very limited collateral circulation to the involved territory, with leptomeningeal collateral vessels as the predominant remaining supply preventing a severe ischemic injury. Xenon-enhanced CT (first 3 cases) or dynamic CT perfusion (remaining 10 cases) studies were performed in every case and demonstrated severe hypoperfusion of the involved vascular territory, with a significant "mismatch" between the area of identified hypoperfusion and the extent of diffusion weighted abnormality on MR imaging. All patients were treated with hyperten-

TABLE 1: Demographic data, clinical characteristics, and outcomes in 13 patients treated with urgent EC-IC bypass for crescendo TIA or "slowly progressing" stroke*

				NIHSS Score				
Case No.	Age (yrs), Sex	Lesion Type	Time to Bypass (hrs)†	Admission	Immediately Preop	Immediately Postop	At 3 Mos	mRS Score At 3 Mos
1	27, M	cervical/petrous ICA dissection	4.0	4	11	5	0	0
2	41, M	M_1 dissection	5.0	4	12	12	5	2
3	29, F	supraclinoid ICA dissection extending into M_1	5.5	6	16	15	3	1
4	65, F	M_1 stenosis	4.5	5	13	15	5	2
5	54, M	cervical/petrous ICA dissection	4.5	3	10	12	2	1
6	32, F	supraclinoid ICA dissection extending into M_1	3.5	3	11	10	0	0
7	56, M	supraclinoid ICA dissection	5.0	6	14	16	4	2
8	35, F	supraclinoid ICA dissection	4.5	4	10	10	1	0
9	55, F	M_1 dissection	6.0	5	12	14	5	2
10	44, F	supraclinoid ICA stenosis	5.0	3	10	12	1	1
11	25, M	supraclinoid ICA dissection extending into M_1	4.0	4	11	12	2	1
12	21, F	supraclinoid ICA dissection	3.5	3	12	6	0	0
13	51, F	supraclinoid ICA dissection extending into M_1	5.5	6	12	12	5	2

* mRS = modified Rankin Scale; NIHSS = National Institutes of Health Stroke Scale.

† Time to bypass represents the time from the decision to proceed with surgery until completion of the anastomosis.

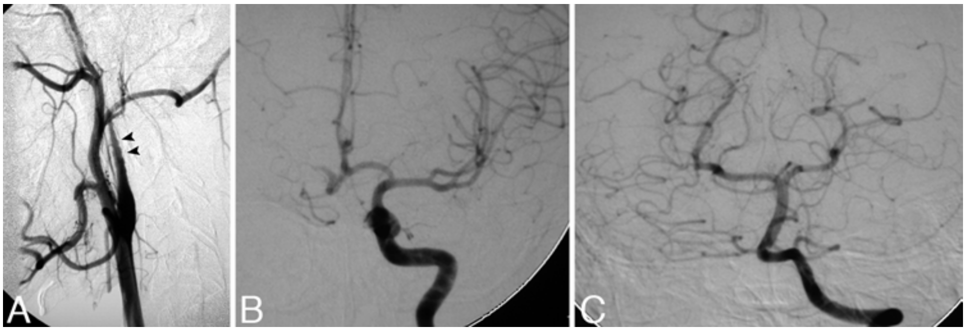

Fig. 1. Case 1. Angiographic image of the right cervical carotid artery (A) reveals tapered stenosis of the ICA *(arrowheads)* beginning just beyond the bifurcation, consistent with an arterial dissection. Anteroposterior left ICA (B) and vertebral artery (C) injections demonstrate no significant collateral flow to the right MCA territory.

sive hypervolemic therapy as well as anticoagulation and antiplatelet therapy. Mineralocorticoid-induced volume expansion was initiated in all cases as well.

In 11 cases, the patients demonstrated rapidly progressing deficits during the first 2–12 hours after admission. Two patients had "slowly progressing" strokes characterized by gradual but progressive loss of neurological function over a 48-hour period. In all cases, serial MR imaging demonstrated either progressive enlargement or the appearance of new areas of diffusion weighted changes. The majority of patients had patchy, watershed distribution, diffusion weighted MR changes, with a neurological deficit that was disproportionately severe compared with the relatively limited MR imaging findings.

Once it became clear that the ischemic injury was progressively worsening despite maximal medical therapy, patients were offered the option of continued medical treatment or emergency surgical revascularization. En route to the operating room, an emergency, limited, repeat MR imaging study consisting of only diffusion weighted sequences was then obtained to exclude the development of a large MCA infarction. The length of time from the point a decision was made to proceed with surgery until the completion of the anastomosis (including the time to obtain the repeat MR imaging) ranged from 3.5 to 6 hours. A successful bypass was achieved in all cases, as documented by intraoperative angiography. The National Institutes of Health Stroke Scale scores obtained at admission, immediately before surgery, immediately after surgery, and at 3-month follow-up are shown in Table 1.

Five patients awoke with transient worsening of their preoperative deficit, which recovered rapidly back to baseline over the ensuing 96 hours. Six patients demonstrated no change in their preoperative deficit, and 2 had immediate resolution of their preoperative symptoms in the postanesthesia care unit. All patients were evaluated with postoperative MR imaging, demonstrating no new significant areas of infarction related to surgery. Two patients had small new areas of diffusion change (1 in the contralateral hemisphere, presumably related to catheter angiography). At the time of 6-month follow-up, all patients had improved from their preoperative condition. Five were left with a limited fixed neurological deficit (mild hemiparesis, monoparesis, or dysphasia). The remaining 8 had recovered completely. The MR imaging follow-up studies obtained at 1 year demonstrated a stable, old, watershed injury in all cases, without evidence of more recent ischemic changes.

Illustrative Cases

Case 1

History and Examination. This 27-year-old, right-handed man presented with difficulty using his left hand. He underwent MR imaging demonstrating a small area of diffusion weighted change in the right basal ganglia. Cerebral angiography revealed dissection of the right cervical/petrous ICA, with no intracranial filling through the dissected artery and very limited collateral circulation to the right MCA territory (Fig. 1). The patient was admitted to the hospital and started on intravenous heparin, oral aspirin, induced hypertension, and volume expansion. Over the ensuing 48 hours, he developed steadily progressive left hemiparesis, with follow-up MR imaging demonstrating enlargement of the area of diffusion weighted abnormality (Fig. 2).

Operation and Postoperative Course. Urgent revascularization was offered, and by the time the patient was brought to the operating room, he was hemiplegic. The patient underwent uneventful EC-IC bypass, with intraoperative angiography demonstrating robust filling of the entire MCA territory (Fig. 3). The patient awoke in the recovery room with immediate and dramatic improvement of his preoperative weakness. He was maintained on oral aspirin at a dose of 325 mg/day, and discharged home 2 days later. At the 6-year follow-up visit, the patient was normal neurologically.

Case 2

History and Examination. This 41-year-old, right-handed man presented with several episodes of speech arrest. He was transferred to our center after cerebral angiography performed at another facility revealed significant stenosis of the left M_1 consistent with an acute arterial dissection (Fig. 4A and B). An MR imaging study obtained at the other facility had revealed several tiny foci of diffusion weighted abnormality in the deep left hemisphere white matter.

Neuroimaging Results and Operation. A CT perfu-

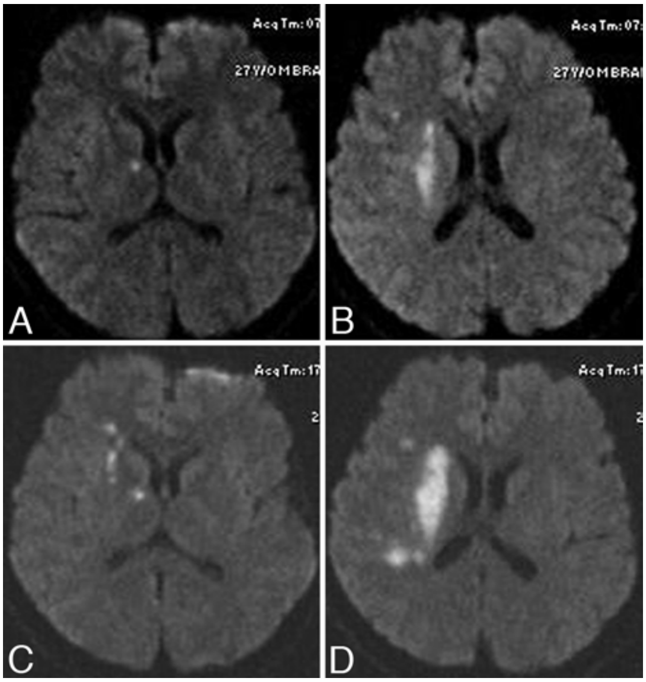

Fig. 2. Case 1. Comparably selected axial diffusion weighted MR images obtained on Day 1 (A and B) and Day 2 (C and D) after presentation demonstrate increasing areas of ischemic injury matching the patient's symptomatic clinical progression.

sion study obtained shortly after arrival demonstrated dramatic elevation of the mean transit time and decreased regional cerebral blood flow in the involved territory (Fig. 5). Over the next 6 hours, the patient developed severe dysphasia and profound right hemiparesis. An MR image revealed several new small areas of diffusion weighted changes that were disproportionately unimpressive compared with his severe neurological deficits, and with the degree of abnormality on the CT perfusion study obtained just hours earlier. Repeat angiography now showed occlusion of the M_1 segment (Fig. 4C and D). An emergency EC-IC bypass was performed, with intraoperative angiography revealing restored filling of the MCA branches (Fig. 4E).

Postoperative Course. Postoperatively, the patient awoke with persistent dysphasia and hemiparesis, but demonstrated dramatic improvement of his preoperative weakness and language difficulty over the next 48 hours. Postoperative MR imaging demonstrated no change in the preoperative diffusion weighted abnormalities (Fig. 6). The patient was maintained on oral aspirin, 325 mg/day. He was discharged to the rehabilitation service on the 5th postoperative day. At his 1-year follow-up, the patient had slight speech hesitancy, with normal strength, and was fully independent.

Discussion

In patients with acute or evolving stroke, it has become clear that outcome may be dependent on the urgent reestablishment of cerebral perfusion.[1,9,27] Reperfusion of existing ischemic areas may be accomplished either through

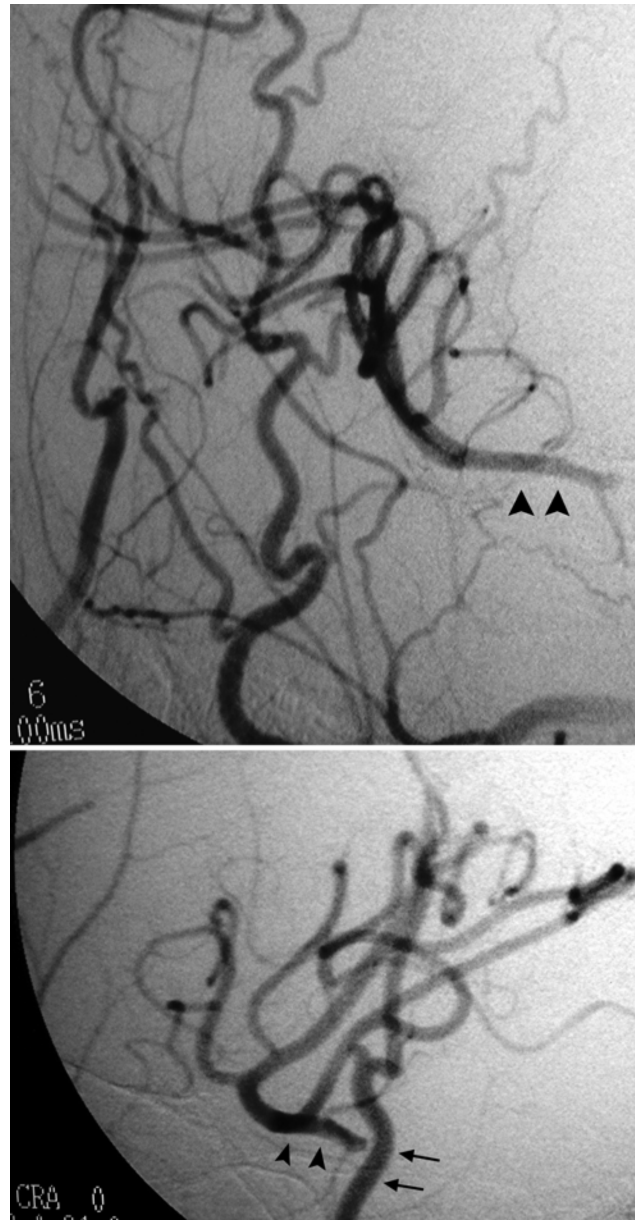

Fig. 3. Case 1. Anteroposterior *(upper)* and lateral *(lower)* external carotid injection angiographic images demonstrating robust filling of the right MCA territory all the way back to the M_1 segment *(arrowheads)* via the STA *(arrows)*.

intravenous or intraarterial thrombolysis with drugs such as recombinant tissue plasminogen activator, mechanical thrombolysis, CEA, angioplasty/stenting, surgical embolectomy, or, in theory, EC-IC bypass.[21,22,25,27,28,37] Although emergency CEA has been well described in the literature, there is little information regarding urgent EC-IC bypass for emergency cerebral revascularization.[6,8,11,14,16,20,36,37,40,43,48,51] This report details our experience with this technique in a unique group of 13 patients presenting with acutely worsening ischemic injury refractory to aggressive medical treatment.

Previous Work

The use of surgical cerebral revascularization in pa-

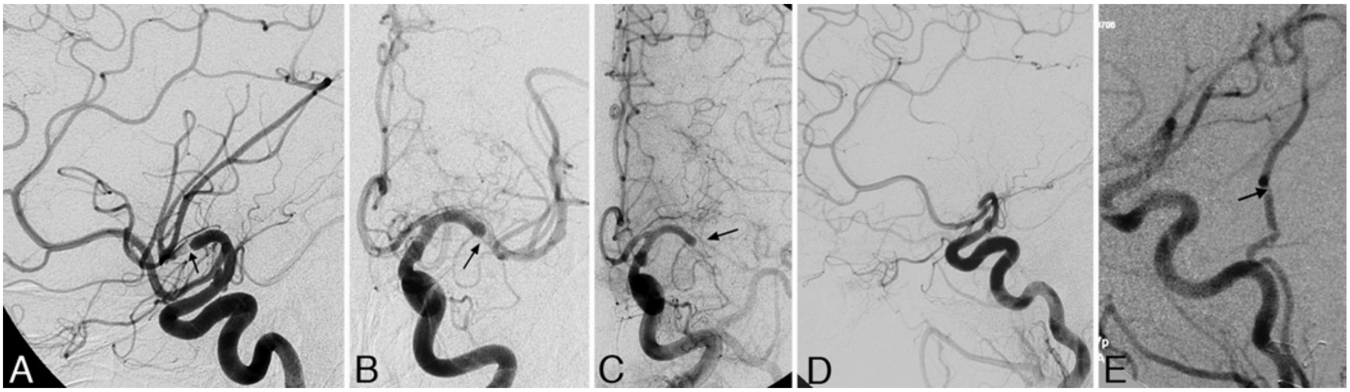

FIG. 4. Case 2. Anteroposterior (A) and lateral (B) angiographic images obtained at another facility demonstrating dissection *(arrows)* of the M_1 segment of the left MCA, with associated flow limitation. Comparable angiographic images (C and D) obtained after significant neurological decline, demonstrating occlusion of the M_1 segment *(arrow)* at the site of the dissection. Intraoperative lateral angiographic injection of the left common carotid artery (E) demonstrating restored filling of the MCA branches via the STA *(arrow)*.

tients with acute cerebral ischemia has been described rarely, and the results have ranged from encouraging to disappointing.[6,14,17,40,51] Early experimental work evaluating revascularization for acute ischemic injury in animal models produced varying degrees of success.[11,15,31] Using a canine model of acute MCA occlusion, Crowell and Olsson[11] examined the impact of early EC-IC bypass and found that animals undergoing early revascularization fared better than nonsurgical controls. Subsequent work by other investigators yielded mixed results.[15,17,31,43] Several clinical series evaluated the use of EC-IC bypass performed at various intervals following acute stroke, with most of this work being done prior to the publication of the Cooperative Trial on EC-IC Bypass and before the introduction of sophisticated physiological imaging to evaluate for potentially reversible ischemic injury.[11,14,15,23,24,40,43,46,49,51] These reports described heterogeneous groups of patients with underlying sources of ischemia ranging from acute embolic stroke to iatrogenic intracranial vascular occlusion during aneurysm surgery, to severe vasospasm following aneurysmal subarachnoid hemorrhage. In most reports the results were mixed, and some patients responded well, whereas many suffered poor outcomes.

Rationale for Urgent EC-IC Bypass

The use of intravenous, intraarterial, and mechanical thrombolysis in patients with acute ischemic stroke has now become accepted as standard care.[1,9,22,27] Over the past decade, the percentage of patients with acute stroke who undergo some form of acute thrombolytic therapy has increased exponentially. As a result of this growing experience, there has been a significant shift in philosophy toward an increasingly aggressive approach to the management of acute stroke. In patients with high-grade stenosis of the cervical ICA, the use of CEA as an emergency procedure in patients with crescendo symptoms refractory to medical therapy has been described extensively in the past.[20,37,48] In multiple studies, patients undergoing CEA on an urgent basis for acute stroke, progressive stroke in evolution, or crescendo TIA have higher complication rates than patients undergoing elective CEA, but the ones undergoing emergency CEA still appear to have better outcomes than matched patients whose disease is managed without surgery.[20,36,37]

In theory, patients with severe cerebrovascular ischemia due to an anatomical lesion not amenable to CEA or endovascular therapy might benefit from EC-IC bypass. Although urgent CEA has been reported in the past, and endovascular therapy has become an increasingly important option in this setting, there is almost no information on the use of EC-IC bypass for urgent cerebral revascularization. Because EC-IC bypass is performed infrequently at most centers, even as an elective procedure, experience with urgent surgical bypass has been extremely limited. When performed rarely, bypass becomes a challenging technique because of the very small size of the vessels being anastomosed and the demanding microvascular suture techniques required. The disappointing findings of the Cooperative study further tempered enthusiasm for revascularization surgery, even under optimal conditions, let alone in the middle of the night.[2–4,12,13,18,19,39] As a result of these factors, there has been a progressive loss of facility with the operation over time.[2]

Despite these points, some centers have continued to use EC-IC bypass on a routine basis in the management of ischemic cerebrovascular disease and in the treatment of complex intracranial aneurysms and skull base tumors.[26,32,35,38,39,41,42] Coincidentally, the benefits of urgent cerebral revascularization have been increasingly recognized, with the progressive improvement of endovascular techniques. At the present time, there remains a subset of patients who might benefit from urgent revascularization but who are not appropriate candidates for CEA or endovascular revascularization techniques. It is this population that may benefit from EC-IC bypass, if the procedure can be performed quickly enough to prevent irreversible ischemic injury, and with low enough morbidity and mortality rates.

From a technical perspective, neurovascular surgeons performing STA-MCA anastomosis procedures on a regular basis have traditionally reported extremely low surgical complication rates.[10,23,38,39,42,45] In addition, patency rates > 95% can be expected.[38,45] Because the operation requires only a small craniotomy, and the entire procedure is per-

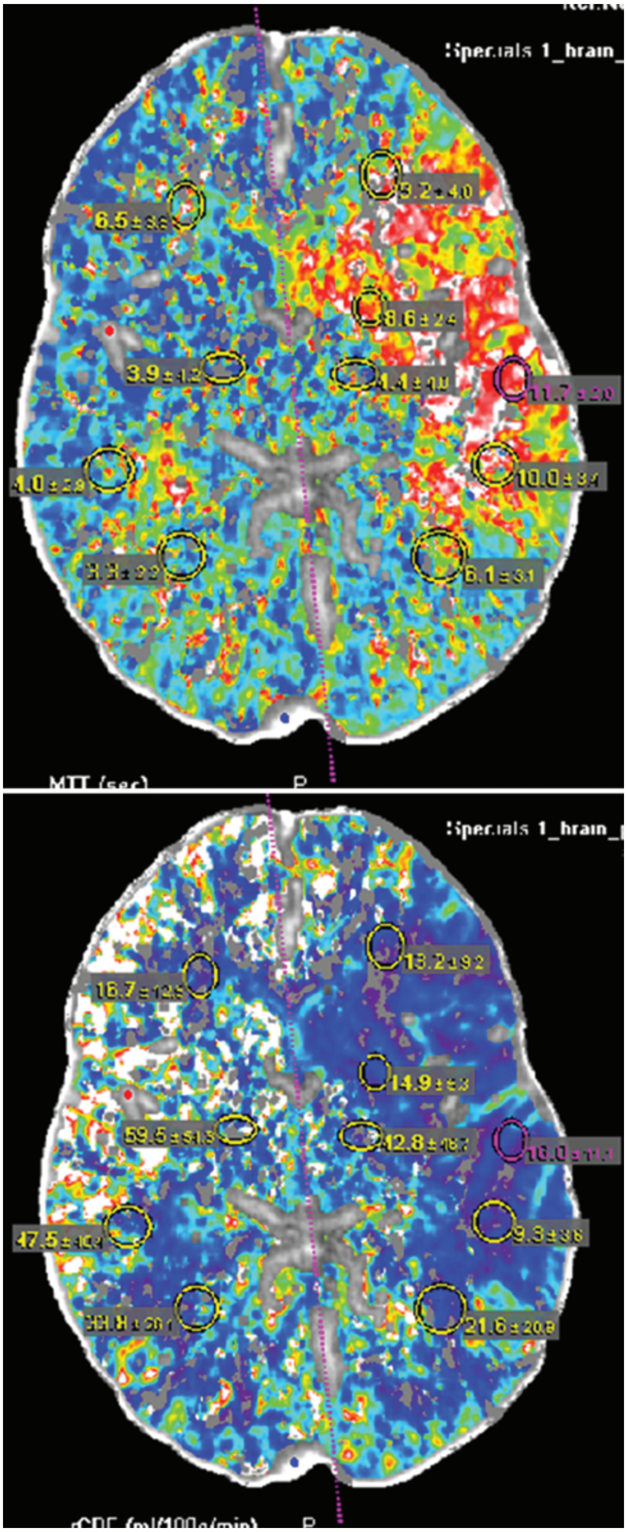

Fig. 5. Case 2. Dynamic perfusion CT scans revealing significant elevation in mean transit time *(upper)* and decreased regional cerebral blood flow *(lower)* in the involved left hemisphere.

formed on the cortical surface, we have found that an EC-IC bypass can be performed safely and quickly, even under urgent circumstances. Of note, in our experience, perioperative quantitative evaluation has demonstrated that an

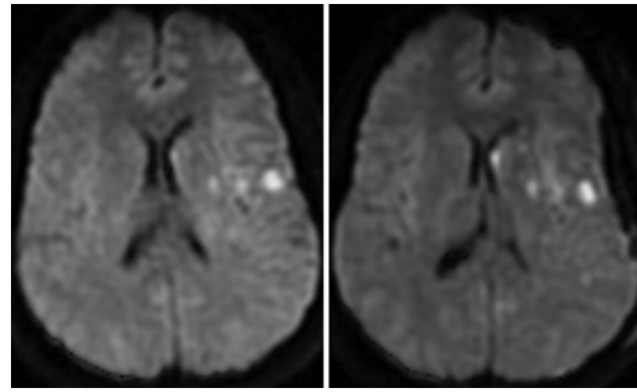

Fig. 6. Case 2. Preoperative *(left)* axial diffusion weighted MR image revealing limited ischemic injury, which is essentially unchanged on a comparable image obtained postoperatively *(right)*.

STA–MCA graft provides between 15 and 50 ml/minute of additional blood flow to the MCA territory. Although this may not seem to be a significant amount, this incremental increase in blood flow has generally been adequate to arrest ongoing ischemic symptoms and to stop and/or reverse slowly progressing stroke symptoms. The amount of flow through the bypass may increase over time as the anastomosis matures, based on demand. In addition, the limited initial flow may actually be a favorable point, minimizing the risk of cerebral hyperperfusion in patients with acute ischemic injury. We have not encountered a clear example of a hyperperfusion syndrome or hemorrhage into an area of ischemia in any of our patients.

It should be noted that complication rates associated with emergency endovascular intracranial angioplasty and stent placement procedures are significant.[21,29,30,33,34,44,47] Periprocedural stroke and death rates have generally exceeded 4.5% in this fragile population.[7,21,29,30,33,44] In-stent restenosis has been reported in up to 29% of patients and, for reasons that remain uncertain, may be a particular problem in patients with anterior circulation disease, in whom restenosis rates as high as 42% have been described.[34,47] In one large series, 4 (5.1%) of 78 patients who were treated developed complete stent thrombosis.[34] If microsurgical revascularization can be achieved with lower complication and higher patency rates in carefully selected patients, EC-IC bypass may represent a reasonable, possibly safer option in this population.

Patient Selection and Management Considerations

In general, we have found that the majority of patients selected for urgent EC-IC bypass in our series were young individuals with extremely limited collateral circulation to the involved territory. Although selection bias may have played a role in this process, we suggest that the majority of patients whom we treated most likely suffered an acute alteration in their cerebral circulation, most commonly related to a sudden arterial dissection. As opposed to a gradually progressive atherosclerotic stenosis, which may allow time for collateral development, such an acute change may be more likely to result in severe hemodynamic failure, with associated crescendo symptoms.

In addition, we found that the majority of patients had a neurological deficit that was disproportionately significant when compared with the patchy, watershed type injury identified on diffusion weighted MR imaging. Of note, patients with the greatest disparity in this regard (those who had a severe deficit with limited MR changes) did exceptionally well, with rapid recovery of function following urgent bypass surgery. We would suggest that these patients may be demonstrating a classic example of "idling" neurons in a vascular territory that is inadequately perfused to allow for normal functioning, but still maintained by enough blood flow to avoid irreversible injury.[5,38,49] As a result, these patients may be ideal candidates for urgent revascularization.

Limitations of the Present Study

A number of important points should be emphasized regarding our experience. First, only an extreme minority of patients presenting to our center with acute ischemic symptoms were considered reasonable candidates for urgent surgical revascularization. Thus, even in a busy regional referral center, we only encountered 1 or 2 patients per year who were considered appropriate for emergency bypass as outlined in this paper. These rare patients must have enough collateral supply to avoid a devastating and irreversible complete MCA infarction prior to intervention, yet must have inadequate collateral flow to prevent progressive symptomatic ischemic injury. It should also be noted that the patients described in this report were substantially younger than the average population of patients with stroke, and the results described herein are probably not applicable to older patients.

Our study is composed of a small series of patients treated over a 10-year period. As a result, it is difficult to define strict criteria to determine which patients should be offered surgery, and the final decision regarding whether to consider urgent bypass remains relatively subjective. If urgent revascularization is considered, surgeons must be able to perform bypass quickly and with low enough complication rates to benefit patients. Although the operation was common in the past, facility with EC-IC bypass at the present time is limited, and this may in turn limit the applicability of our results to those centers where bypass is still performed with some frequency. Finally, improving the endovascular option will probably provide less invasive treatment alternatives in the future, further limiting the potential population of patients who might benefit from emergency surgery.

Conclusions

As part of a large series of patients referred for surgical revascularization, we have encountered a unique subgroup of 13 patients with acute ischemic injury that progressed despite maximally aggressive medical therapy. These patients were treated with truly emergency EC-IC bypass, a technique that has been performed rarely in such a setting. In our experience, EC-IC bypass stabilized or reversed the symptoms in the majority of cases, and no patient suffered a major complication or a significant perioperative stroke. In an era when newer, more aggressive endovascular options are being used to revacularize the ischemic brain, neurovascular surgeons should consider emergency EC-IC bypass as an option in carefully selected cases such as those presented in this report. In general, patients selected for treatment in our series were young and had extremely poor collateral circulation. The finding of limited, patchy watershed changes on diffusion weighted MR imaging in association with unexpectedly, disproportionately significant neurological deficit may be helpful in identifying those patients who may benefit most from the procedure.

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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