Submandibular High-Flow Bypass in the Treatment of Skull Base Lesions: An Analysis of Long-term Outcome

William T. Couldwell, MD, PhD, Philipp Taussky, MD, Walavan Sivakumar, MD
Department of Neurosurgery, University of Utah, Salt Lake City, Utah

Corresponding author:
William T. Couldwell, MD, PhD
Department of Neurosurgery
University of Utah
175 N. Medical Drive East
Salt Lake City, UT 84132
Phone: 801-581-6908
Fax: 801-581-4138
Email: neuropub@hsc.utah.edu

Disclosures: The authors have no funding sources or conflicts of interest to disclose.

Acknowledgments: We thank Kristin Kraus, MS, for editorial assistance with this paper.

UU IR Author Manuscript

Abstract

Background: Cerebral bypass surgery remains an integral part of the treatment of complex skull base tumors and unclippable aneurysms.

Objective: The authors retrospectively analyzed a single-surgeon experience using a high-flow submandibular–infratemporal saphenous vein graft bypass technique after carotid artery sacrifice in the resection of complex skull base tumors and carotid isolation in unclippable aneurysms.

Methods: Data on indications, surgical technique, bypass patency, complications, and outcome were collected for patients treated with adjunctive submandibular high-flow bypass for skull base lesions.

Results: Eleven patients (age range: 13–77 years) were treated for various skull base lesions: 4 patients were treated for skull base tumors with resection of the ICA, 6 were treated for aneurysms not amenable to clipping, and one was treated for invasive *Mucor* infection. Using a saphenous vein graft, a high-flow bypass was created from the high cervical internal carotid artery (ICA) or external carotid artery to ICA or middle cerebral artery by means of a submandibular–infratemporal route. Postoperative ~~computed tomography~~ angiography indicated bypass patency in 10/11 patients. There was no operative mortality. Follow-up of up to 12 years (mean 57 months) was achieved.

Conclusion: Direct high-flow submandibular–infratemporal interpositional saphenous vein bypass graft is an effective and durable technique for the treatment of complex skull base lesions where internal carotid artery revascularization is indicated.

Keywords: Extracranial–intracranial bypass; carotid bypass; radial artery; saphenous vein

Running Title: Submandibular high-flow carotid bypass

UU IR Author Manuscript

Introduction

Extracranial–intracranial bypass techniques remain important in the surgical treatment of complex intracranial aneurysms and skull base tumors.[1-5] Specifically, giant and fusiform aneurysms that are amenable to neither clipping nor endovascular treatment may require proximal vessel occlusion and a bypass procedure for revascularization purposes. Skull base tumors involving the carotid artery may be treated with the goal of gross total resection by internal carotid artery (ICA) sacrifice.[6] In these instances, an extracranial–intracranial bypass offers revascularization of the distal vascular tree. We recently reviewed the current indications for performing high-flow bypass.[7] In the past decades, high-flow bypass techniques have undergone a number of modifications aimed at rendering the procedure safe and improving the long-term bypass rate.[1, 8-12] In addition to modifications involving preoperative evaluation, monitoring, and neuroanesthesia, these modifications relate largely but not exclusively to donor graft (saphenous vein versus radial artery), graft harvesting (open versus endoscopic), anastomosis (interrupted versus noninterrupted microsutures versus excimer laser-assisted nonocclusive anastomosis), and location and fashion of tunneling of graft (preauricular versus postauricular route).[8, 9, 13-16] Most current high-flow bypass techniques involve either a radial artery or a saphenous vein graft using one of the following revascularization points: cervical-to-petrous ICA, petrous-to-supraclinoid ICA, cervical-to-supraclinoid ICA, and cervical-to-M2 bypass.[8, 10, 12, 17]

In all but the petrous–supraclinoid routes, special attention must be paid to the subcutaneous tunneling of the saphenous vein graft, with both preauricular and postauricular routing mentioned in the literature.[8] Because tunneling affects graft length and may thus impact long-term bypass patency, the senior author (WTC) has previously described a direct submandibular–infratemporal bypass technique that eliminates the need for tunneling.[18] In the early cases using this technique, the zygoma was detached and reflected inferiorly with the masseter and temporalis muscles to allow a bone trough to be made at the middle fossa cranial base. This provided room for the graft and helped avoid compromising the graft with mandibular movement.[18] This technique has since been modified to eliminate the need for an osteotomy of the zygoma. Instead, a small middle fossa burr hole is created for the graft at the base lateral to the foramen ovale and anterior to the temporomandibular joint. This allows the graft to be routed in its submandibular–infratemporal path.[18-20]

In this study, we analyzed our long-term experience with patients who underwent the direct submandibular–infratemporal high-flow bypass technique, with special emphasis on indications, technical aspects, and long-term outcome.

Methods

Patients

Patients were identified via an Institutional Review Board-approved retrospective data review spanning the years from 1999 to 2011. All patients operated on by the senior author (WTC) with a direct submandibular–infratemporal high-flow bypass were included; some patients have been described in previous publications of the technical aspects of the technique.[18-20] Indications, technical aspects, clinical and radiological outcome, and bypass patency were analyzed. Perioperative morbidity and mortality over a 30-day period were noted. All patients were monitored with computed tomography angiography (CTA) or magnetic resonance angiography (MRA) within the first 48 hours and again at 6 months, after which bypass patency was evaluated yearly.

Surgical Technique

The surgical technique has been previously described elsewhere in detail.[18-20] In short, a standard frontotemporal craniotomy is performed, followed by wide splitting of the sylvian fissure. The proximal ICA or an M2 or M3 branch is dissected out as a recipient vessel. A high-speed drill is used to make a small craniectomy at the base of the middle fossa lateral to the foramen ovale to accommodate the tunneled saphenous vein graft. The carotid bifurcation and the external carotid artery (ECA) and ICA are exposed in the neck (Figure 1). The saphenous vein graft is tunneled from the neck incision into the intracranial cavity through the submandibular–infratemporal tunnel using a 14-French chest tube. After a dose of 5000 units of intravenous heparin is administered, the cervical ECA is ligated as high in the neck as possible. The distal end of the cervical ECA is mobilized inferiorly, and an end-to-end anastomosis is performed between the distal cervical ECA and the proximal end of the saphenous vein graft using 7–0 Prolene interrupted sutures. The distal portion of the vein graft is then brought up into the intracranial cavity through the submandibular–infratemporal tunnel, and an end-to-side anastomosis to the ICA, M2, or M3 branch is performed with 9–0 Nylon monofilament suture.

UU IR Author Manuscript

Autologous pericranium is harvested to facilitate the dura mater closure at the cranial base around the graft. Intraoperative bypass patency is assessed by Doppler ultrasound and/or in more recent cases ICG (indocyanine green) videoangiography. Early postoperative patency was confirmed with CTA or MRA in all cases (Figure 2).

Results

A total of 11 patients (4 female, 7 male) underwent a high-flow direct submandibular–infratemporal saphenous vein graft bypass procedure. Of these, 4 patients were treated for skull base tumors with resection of the ICA, 6 were treated for aneurysms not amenable to clipping, and one was treated for invasive *Mucor* infection, as part of an attempted radical salvage debridement operation (Table 1). The average age of the patient at surgery was 54 years (range 13–77 years).

All of the patients demonstrated patency of the graft at the time of insertion. Ten of 11 patients demonstrated long-term patency in follow-up (mean 57 months; Table 1). One patient (patient 7), a diabetic man with medically refractory *Mucor* infection, developed delayed thrombosis of his graft after 48 hours.

None of the patients had permanent clinical deterioration related to their revascularization procedure. Three patients died during follow-up related to the natural history of their underlying disease. No patient developed specific complications of the surgical donor site. Two patients developed surgically related infections (sepsis, pneumonia), which were treated without sequelae. Deep venous thrombosis occurred in two patients, who were treated with anticoagulation therapy. Two patients developed gastrointestinal-related problems, one bowel ischemia that required resection and a gastrointestinal bleed, which was treated with medical therapy. A right subdural hematoma ipsilateral to the site of surgery occurred in one patient, who required surgical evacuation on post-operative day 5.

Discussion

Outcome

Our case series of long-term outcome of bypasses performed by direct submandibular–infratemporal route validates the role of this approach as a safe route offering a true alternative to pre- and postauricular tunneling. Only a single patient early in our experience did not have

UU IR Author Manuscript

patency of the graft postoperatively. This was a young diabetic patient with medically refractory relentless mucormycosis infection in whom a radical debridement operation was performed. This is similar to initial intraoperative patency rates seen in other series using the saphenous vein graft.[16]

Selection of Candidates for Bypass

The issue of universal versus selective revascularization when considering ICA sacrifice remains controversial. The senior author prefers to use a very selective approach in choosing those patients who have undergone carotid sacrifice in need of high-flow replacement.[21] Suitability is evaluated with a balloon test occlusion (BTO), paired with CT perfusion testing with acetazolamide challenge to assess cerebrovascular reserve.[22] Ischemic symptoms evident while performing the BTO or evidence of ischemia during CT perfusion imaging are a strict indication for carotid revascularization as used in this series; however, false-negative results can result in significant ischemic complications after ICA sacrifice.[23-25] Failure to adequately predict which patients will develop delayed neurological complications after carotid sacrifice and the risk of de novo aneurysm formation have led many surgeons to be generous with the indications for bypass surgery after carotid sacrifice. The risk of carotid sacrifice without revascularization, specifically the reported mortality rate of about 7% and a neurological morbidity rate of up to 17%, should be weighed against the complication rate of bypass surgery, for which a morbidity rate of 3–7% and no significant mortality have been reported.[21, 26, 27] The senior author has therefore adopted the approach of also choosing to revascularize young patients harboring benign disease who have a significant life expectancy.

Technical Considerations

It is clear that meticulous attention to all technical details is necessary to achieve an optimal long-term bypass patency rate. ~~Modifications over the years have eliminated aspects that may potentially compromise bypass patency.~~ Tunneling has the potential to constrict the bypass graft in its subcutaneous plane either by head movement, scarring, or the use of glasses.[1, 8] The technique developed by the senior author eliminates the need for subcutaneous tunneling and provides a direct plane for the bypass graft on its submandibular-to-infratemporal route. This modification has a number of additional advantages. Radial artery grafts may be rather short in nature in young women, making both pre- and postauricular routes for the bypass graft difficult in this patient population because of graft length. The direct submandibular–infratemporal route is much shorter and provides a real alternative in these cases. The shorter route in our technique may also be an advantage in achieving long-term bypass patency, because longer bypass grafts may have a high failure rate caused by thrombosis of a lengthy graft.[1, 20] The senior author often chooses a saphenous vein graft as in the present series, as it has the benefit of greater length and enables a choice for graft selection when trying to optimize the recipient–donor vessel caliber match. The specific segment of the saphenous vein is chosen after review of the caliber of the vein throughout its course in the leg by preoperative ultrasonography. End-to-end anastomosis is preferred from the external carotid artery donor site, when possible, to promote graft patency by reducing turbulent flow. This also prevents kinking of the vessel during head movement. In addition, the proximal end is anastamosed to the ECA if possible to avoid cross-clamping the ICA during this portion of the procedure. We have experienced no complications with end-to-end bypass and sacrifice of the ECA supply to the face. In our submandibular–infratemporal technique, attention is paid to a number of surgical details. Because the hole situated in the middle fossa needs to be large enough to avoid kinking of the graft by head movements, the hole is created extradurally with minimal temporal lobe retraction. No morbidity has been related to temporal lobe edema after the procedure. This technique also eliminates the need for a zygomatic osteotomy, and the insertions of the temporalis and masseter muscles are left intact, which affects cosmetic outcome. Finally, care must be taken during the submandibular passage not to injure any neural or vascular structure in the region (i.e., lingual nerve, inferior alveolar nerve, hypoglossal nerve, or internal maxillary artery). Passage of the chest tube is aided by the use of a tonsil clamp and continuous digital palpation with little or no blunt dissection required.

Conclusions

Analysis of this series of patients demonstrates the utility of the submandibular high-flow bypass routing for long-term revascularization for the treatment of skull base tumors and aneurysms.

UU IR Author Manuscript

UU IR Author Manuscript

References

1. Mohit AA, Sekhar LN, Natarajan SK, Britz GW, Ghodke B. High-flow bypass grafts in the management of complex intracranial aneurysms. *Neurosurgery.* 2007;60(2 Suppl 1):ONS105-122; discussion ONS122-123.

2. Evans JJ, Sekhar LN, Rak R, Stimac D. Bypass grafting and revascularization in the management of posterior circulation aneurysms. *Neurosurgery.* 2004;55(5):1036-1049.

3. Chang SW, Abla AA, Kakarla UK, et al. Treatment of distal posterior cerebral artery aneurysms: a critical appraisal of the occipital artery-to-posterior cerebral artery bypass. *Neurosurgery.* 2010;67(1):16-25; discussion 25-26.

4. Amin-Hanjani S, Chen PR, Chang SW, Spetzler RF. Long-term follow-up of giant serpentine MCA aneurysm treated with EC-IC bypass and proximal occlusion. *Acta Neurochir (Wien).* 2006;148(2):227-228.

5. Wanebo JE, Zabramski JM, Spetzler RF. Superficial temporal artery-to-middle cerebral artery bypass grafting for cerebral revascularization. *Neurosurgery.* 2004;55(2):395-398; discussion 398-399.

6. Feiz-Erfan I, Han PP, Spetzler RF, et al. Salvage of advanced squamous cell carcinomas of the head and neck: internal carotid artery sacrifice and extracranial-intracranial revascularization. *Neurosurg Focus.* 2003;14(3):e6.

7. Taussky P, Couldwell W. Decision-making strategies for EC-IC bypass in the treatment of skull base tumors. In: Abdulrauf S, ed. *Cerebral Revascularization: Techniques in Extracranial-to-Intracranial Bypass Surgery*. Philadelphia: Elsevier; 2010.

8. Sekhar LN, Natarajan SK, Ellenbogen RG, Ghodke B. Cerebral revascularization for ischemia, aneurysms, and cranial base tumors. *Neurosurgery.* 2008;62(6 Suppl 3):1373-1408; discussion 1408-1410.

9. Sekhar LN, Kalavakonda C. Cerebral revascularization for aneurysms and tumors. *Neurosurgery.* 2002;50(2):321-331.

10. Friedman JA, Piepgras DG. Current neurosurgical indications for saphenous vein graft bypass. *Neurosurg Focus.* 2003;14(3):e1.

11. Sundt TM, Jr., Piepgras DG, Marsh WR, Fode NC. Saphenous vein bypass grafts for giant aneurysms and intracranial occlusive disease. *J Neurosurg.* 1986;65(4):439-450.

12. Bulsara KR, Patel T, Fukushima T. Cerebral bypass surgery for skull base lesions: technical notes incorporating lessons learned over two decades. *Neurosurg Focus.* 2008;24(2):E11.

13. Gonzalez LF, Patterson DL, Lekovic GP, Nakaji P, Spetzler RF. Endoscopic harvesting of the radial artery for neurovascular bypass. *Neurosurg Focus.* 2008;24(2):E10.

14. Vajkoczy P. Revival of extra-intracranial bypass surgery. *Curr Opin Neurol.* 2009;22(1):90-95.

15. Bremmer JP, Verweij BH, Klijn CJ, van der Zwan A, Kappelle LJ, Tulleken CA. Predictors of patency of excimer laser-assisted nonocclusive extracranial-to-intracranial bypasses. *J Neurosurg.* 2009;110(5):887-895.

16. Sekhar LN, Duff JM, Kalavakonda C, Olding M. Cerebral revascularization using radial artery grafts for the treatment of complex intracranial aneurysms: techniques and outcomes for 17 patients. *Neurosurgery.* 2001;49(3):646-658; discussion 658-659.

17. Liu JK, Couldwell WT. Interpositional carotid artery bypass strategies in the surgical management of aneurysms and tumors of the skull base. *Neurosurg Focus.* 2003;14(3):e2.

UU IR Author Manuscript

18. Couldwell WT, Zuback J, Onios E, Ahluwalia BS, Tenner M, Moscatello A. Giant petrous carotid aneurysm treated by submandibular carotid-saphenous vein bypass. Case report. *J Neurosurg.* 2001;94(5):806-810.

19. Kan P, Liu JK, Couldwell WT. Giant fusiform aneurysm in an adolescent with PHACES syndrome treated with a high-flow external carotid artery-M3 bypass. Case report and review of the literature. *J Neurosurg.* 2007;106(6 Suppl):495-500.

20. Couldwell WT, Liu JK, Amini A, Kan P. Submandibular-infratemporal interpositional carotid artery bypass for cranial base tumors and giant aneurysms. *Neurosurgery.* 2006;59(4 Suppl 2):ONS353-359; discussion ONS359-360.

21. Taussky P, Couldwell W. Decision-making strategies for EC-IC bypass in the treatment of skull base tumors. In: Abdelrauf S, ed. *Cerebral Revascularization: Techniques in Extracranial-to-Intracranial Bypass Surgery*. Philadelphia: Saunders; 2010:349-354.

22. Jain R, Hoeffner EG, Deveikis JP, Harrigan MR, Thompson BG, Mukherji SK. Carotid perfusion CT with balloon occlusion and acetazolamide challenge test: feasibility. *Radiology.* 2004;231(3):906-913.

23. Linskey ME, Jungreis CA, Yonas H, et al. Stroke risk after abrupt internal carotid artery sacrifice: accuracy of preoperative assessment with balloon test occlusion and stable xenon-enhanced CT. *AJNR Am J Neuroradiol.* 1994;15(5):829-843.

24. Origitano TC, al-Mefty O, Leonetti JP, DeMonte F, Reichman OH. Vascular considerations and complications in cranial base surgery. *Neurosurgery.* 1994;35(3):351-362; discussion 362-353.

25. Sekhar LN, Patel SJ. Permanent occlusion of the internal carotid artery during skull-base and vascular surgery: is it really safe? *Am J Otol.* 1993;14(5):421-422.

UU IR Author Manuscript

26. Lawton MT, Spetzler RF. Internal carotid artery sacrifice for radical resection of skull base tumors. *Skull Base Surg.* 1996;6(2):119-123.

27. Mendelowitsch A, Taussky P, Rem JA, Gratzl O. Clinical outcome of standard extracranial-intracranial bypass surgery in patients with symptomatic atherosclerotic occlusion of the internal carotid artery. *Acta Neurochir (Wien).* 2004;146(2):95-101.

UU IR Author Manuscript

Figure Legends

Figure 1. The submandibular bypass technique. Illustration showing the cervical-to-supraclinoid ICA bypass using an interpositional saphenous vein graft. The graft is tunneled through the submandibular–infratemporal route via a middle fossa craniectomy (shaded region, see inset) that is located lateral to the foramen ovale. In this example, the graft is anastomosed to the supraclinoid ICA in an end-to-side fashion. An aneurysm clip is placed just proximal to the ophthalmic artery takeoff. ICA, internal carotid artery; ECA, external carotid artery; SVG, saphenous vein graft; OA, ophthalmic artery; FO, foramen ovale. Reprinted with permission from Couldwell et al.[20]

Figure 2. Representative case (patient 5). (A) Axial and coronal T1-weighted MR images with gadolinium enhancement obtained 1 month before resection demonstrating recurrent tumor of the cavernous sinus and posterolateral orbit. Axial (B) and coronal (C) postoperative CT images demonstrating resection of cavernous sinus and tumor and patency of the submandibular graft.

UU IR Author Manuscript

Table 1. Patient characteristics and surgical results in patients who underwent submandibular high-flow bypass with a saphenous vein graft[1]

Case #	**Sex**	**Age**	**Indication**	**Donor Vessel, Recipient Vessel**	**Side**	**Intraoperative Bypass Evaluation**	**30-day Postoperative Complications**	**Follow-Up (months); Outcome**
1	F	43	cavernous sinus tumor (hemangiopericytoma)	cervical carotid, supraclinoid carotid	R	Doppler	none	112 died from recurrent disease; bypass patent on MRA
2	M	56	nasopharyngeal carcinoma recurrence after radiation therapy	cervical carotid, supraclinoid carotid	R	Doppler	DVT, HIT, sepsis	9 died of systemic disease at 9 months
3	M	60	giant ICA bifurcation aneurysm	external carotid, M1	R	Doppler	DVT, lower gastrointestinal bleed	78 neurologically intact; bypass patent on CTA
4	M	13	giant cavernous/supraclinoid aneurysm	external carotid, M3	R	Doppler	none	71 neurologically stable/glioma; bypass patent on MRA
5	F	51	recurrent meningioma, sarcomatous change	external carotid, distal MCA	R	Doppler, ICG angio	none	34 neurologically stable; bypass patent on MRA
6	F	69	expanding unruptured cavernous sinus aneurysm after coiling	external carotid, M3	L	Doppler, ICG angio	bowel ischemia, resection	29 neurologically intact; bypass patent on CTA

7	M	40	skull base mucormycosis, carotid occlusion	common carotid, cervical carotid	L	Doppler, ICG angio	thrombosed graft	death/atrial fibrillation
8	M	77	atypical meningioma/cavernous sinus invasion	external carotid, M2	L	ICG angio	MRSA pneumonia	18 death/withdrawal of care; bypass patent
9	F	68	giant unruptured MCA aneurysm	external carotid, M2	R	Doppler	none	70 neurologically stable; CTA incidental stenosis
10	M	74	giant unruptured ICA aneurysm	external carotid, M2	R	Doppler	SDH	63 neurologically intact; bypass patent on CTA
11	M	46	petrous aneurysm	left internal carotid, supraclinoid carotid	L	Doppler	none	144 neurologically intact; bypass patent on CTA

CT, computed tomography; CTA, computed tomography angiography; DVT, deep venous thrombosis; HIT, heparin-induced thrombocytopenia; ICA, internal carotid artery; ICG, indocyanine green; MCA, middle cerebral artery; MRI, magnetic resonance imaging; MRSA, methicillin-resistant *Staphylococcus aureus*; SDH, subdural hematoma

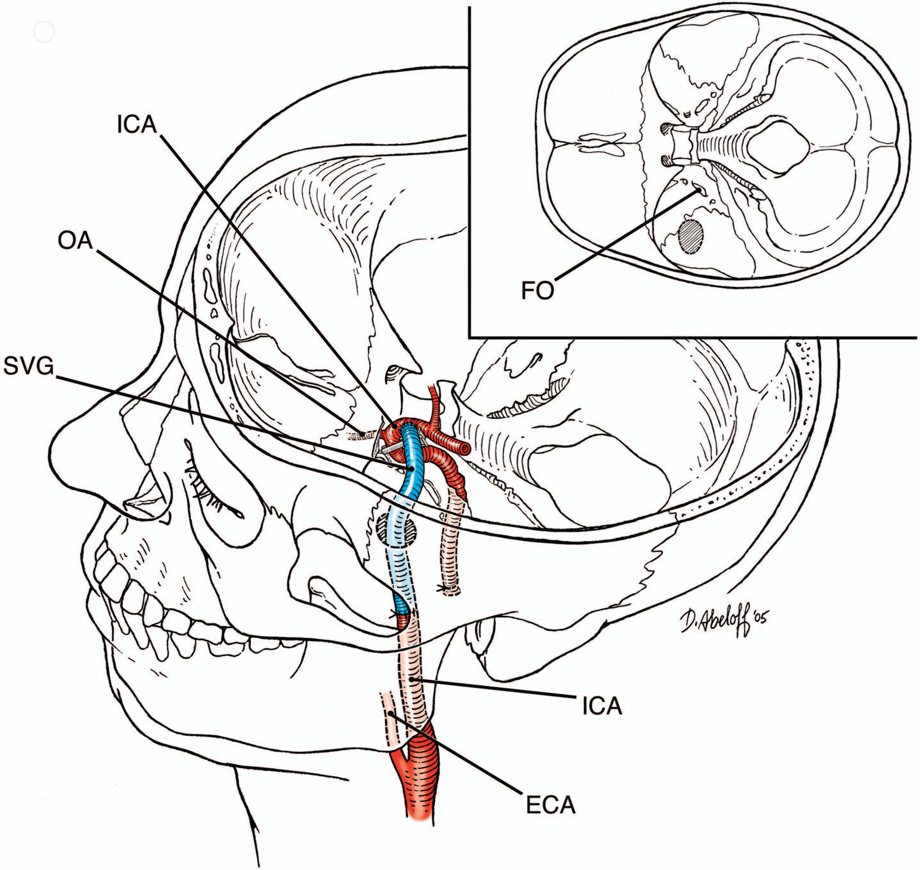
[1]Several patients have been described in previous publications of the technical aspects of the technique.[18-20]

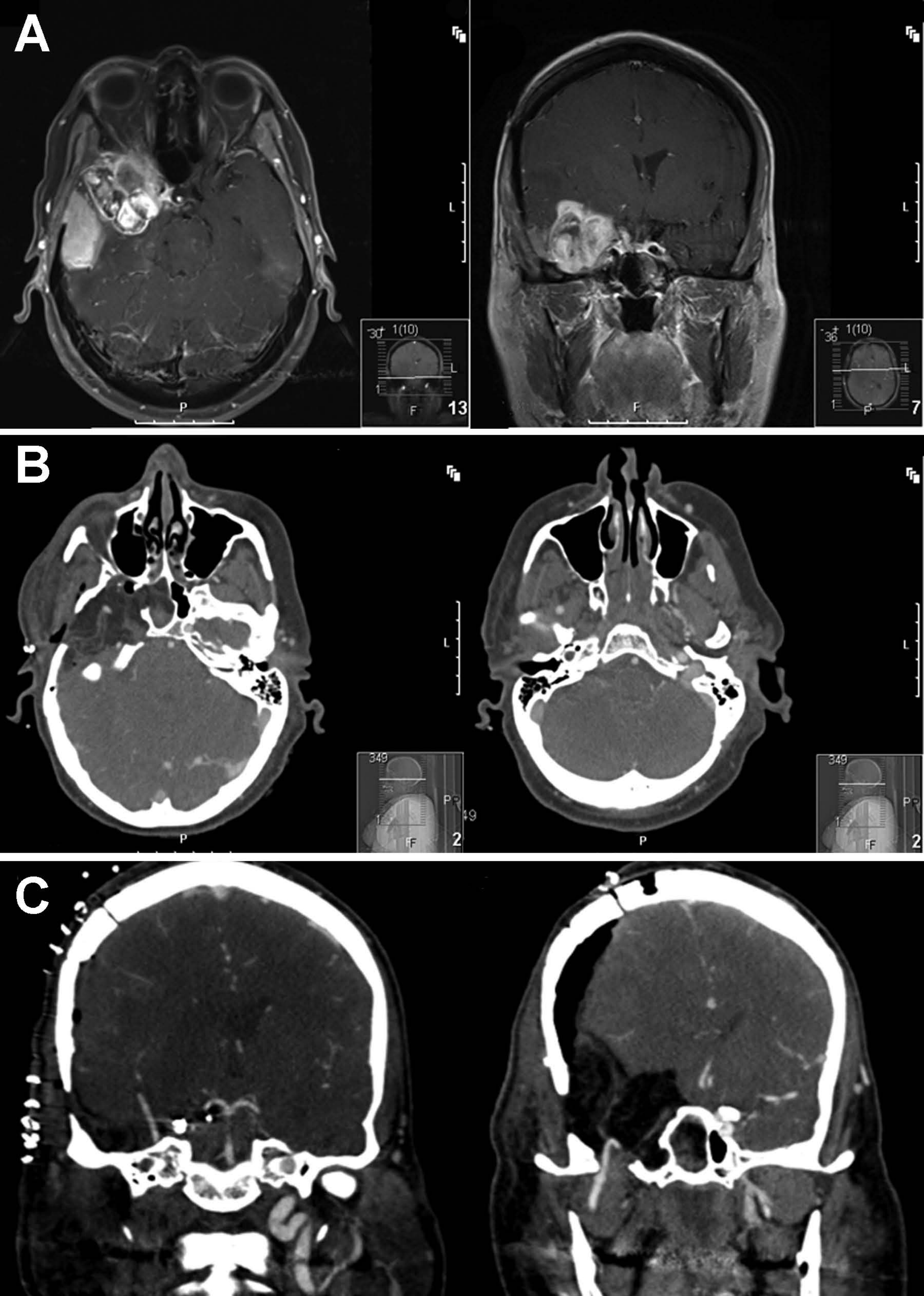
Table 1. Patient characteristics and surgical results in patients who underwent submandibular high-flow bypass with a saphenous vein graft

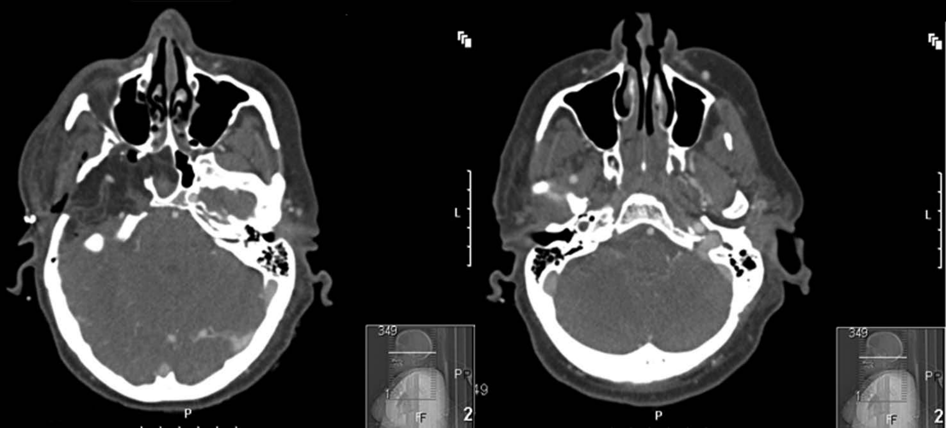
Case #	Sex	Age	Indication	Donor Vessel, Recipient Vessel	Side	Intraoperative Bypass Evaluation	30-day Postoperative Complications	Follow-Up (months); Outcome
1	F	43	cavernous sinus tumor (hemangiopericytoma)	cervical carotid, supraclinoid carotid	R	Doppler	none	112 died from recurrent disease; bypass patent on MRA
2	M	56	nasopharyngeal carcinoma recurrence after radiation therapy	cervical carotid, supraclinoid carotid	R	Doppler	DVT, HIT, sepsis	9 died of systemic disease at 9 months
3	M	60	giant ICA bifurcation aneurysm	external carotid, M1	R	Doppler	DVT, lower gastrointestinal bleed	78 neurologically intact; bypass patent on CTA
4	M	13	giant cavernous/supraclinoid aneurysm	external carotid, M3	R	Doppler	none	71 neurologically stable/glioma; bypass patent on MRA
5	F	51	recurrent meningioma, sarcomatous change	external carotid, distal MCA	R	Doppler, ICG angio	none	34 neurologically stable; bypass patent on MRA
6	F	69	expanding unruptured cavernous sinus aneurysm after coiling	external carotid, M3	L	Doppler, ICG angio	bowel ischemia, resection	29 neurologically intact; bypass patent on CTA
7	M	40	skull base mucormycosis, carotid occlusion	common carotid, cervical carotid	L	Doppler, ICG angio	thrombosed graft	death/atrial fibrillation
8	M	77	atypical meningioma/cavernous sinus invasion	external carotid, M2	L	ICG angio	MRSA pneumonia	18 death/withdrawal of care; bypass patent

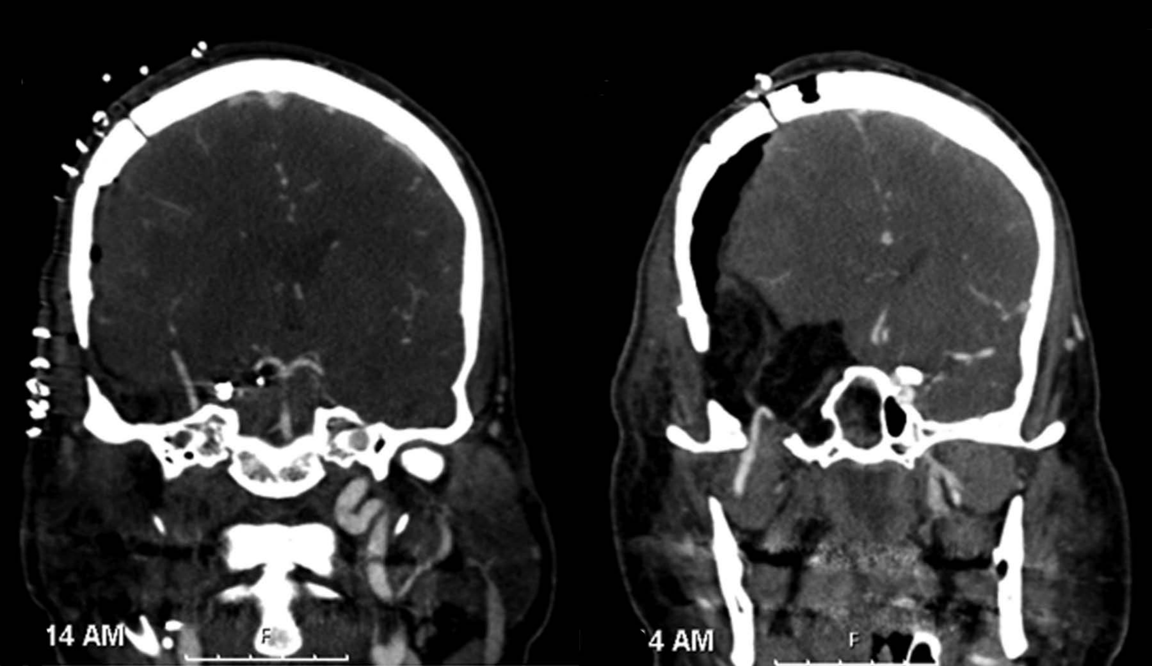
9	F	68	giant unruptured MCA aneurysm	external carotid, M2	R	Doppler	none	70 neurologically stable; CTA incidental stenosis
10	M	74	giant unruptured ICA aneurysm	external carotid, M2	R	Doppler	SDH	63 neurologically intact; bypass patent on CTA
11	M	46	petrous aneurysm	left internal carotid, supraclinoid carotid	L	Doppler	none	144 neurologically intact; bypass patent on CTA

CT, computed tomography; CTA, computed tomography angiography; DVT, deep venous thrombosis; HIT, heparin-induced thrombocytopenia; ICA, internal carotid artery; ICG, indocyanine green; MCA, middle cerebral artery; MRI, magnetic resonance imaging; MRSA, methicillin-resistant *Staphylococcus aureus*; SDH, subdural hematoma


ICA
OA
SVG
FO
ICA
ECA
D. Abeloff '05


A
L
1(10)
P
F
13
7
B
L
349
P
C


L
P
349
PR
FF
L
P
349
PR
FF


14 AM
F
4 AM
F