

Clinical Article

Indocyanine Green Videoangiography for Confirmation of Bypass Graft Patency

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Objective : The aim of the study is to determine the efficacy of indocyanine green (ICG) videoangiography for confirmation of vascular anastomosis patency in both extracranial-intracranial and intracranial-intracranial bypasses.

Methods : Intraoperative ICG videoangiography was used as a surgical adjunct for 56 bypasses in 47 patients to assay the patency of intracranial vascular anastomosis. These patients underwent a bypass for cerebral ischemia in 31 instances and as an adjunct to intracranial aneurysm surgery in 25. After completion of the bypass, ICG was administered to assess the patency of the graft. The findings on ICG videoangiography were then compared to intraoperative and/or postoperative imaging.

Results : ICG provided an excellent visualization of all cerebral arteries and grafts at the time of surgery. Four grafts were determined to be suboptimal and were revised at the time of surgery. Findings on ICG videoangiography correlated with intraoperative and/or postoperative imaging.

Conclusion : ICG videoangiography is rapid, effective, and reliable in determining the intraoperative patency of bypass grafts. It provides intraoperative information allowing revision to reduce the incidence of technical errors that may lead to early graft thrombosis.

Key Words : Intracranial bypass · ICG videoangiography · Intraoperative imaging.

INTRODUCTION

Since the original description of the superficial temporal artery (STA) to middle cerebral artery (MCA) bypass by Donaghy and Yasargil in 1967 a number of extracranial to intracranial (EC-IC) and intracranial to intracranial (IC-IC) bypasses have been used to augment cerebral blood flow in a variety of conditions²⁵. Adherence to meticulous microsurgical techniques is essential for high short-term and long-term patency rates²⁸. Methods to verify intraoperative patency may identify technical deficiencies and allow the surgeon to correct those problems and improve patency rates. The established methods for intraoperative assessment include observation under an operating microscope, microvascular Doppler and intraoperative digital subtraction angiography (DSA)^{1,27}. More recently, indocyanine green (ICG) video angiography has been applied to neurovascular procedures as a simple and safe technique to evaluate the intracranial circulation before and after neurosurgical management^{14,16}. Combined with the use of near-infrared video technology in

operating microscopes, surgeons can evaluate intraoperative blood flow with a simple intravenous injection.

We present our experience with the use of ICG fluorescence video angiography in the management of patients undergoing bypass procedures. ICG video angiography was used to verify patency of the bypasses after performance of the procedure and to assist in correcting technical errors. The results of ICG videoangiography were compared to intraoperative DSA, postoperative DSA, or postoperative computed tomography angiography (CTA).

MATERIALS AND METHODS

We began using ICG video angiography in Emory University Hospital in late 2006. Between January 30, 2007 and December 30, 2009 59 consecutive bypass procedures were performed by the senior author at Emory University Hospital. Fifty-six of these 59 bypass procedures were performed in 47 patients and were evaluated with intraoperative ICG video angiography as part of their procedure. Thirty-one of these procedures were performed for ischemia and 25 as an adjunct to aneurysm surgery. All patients received the standard 25 mg intravenous dose dissolved in 10 mL of aqueous solvent and given as a bolus. The dye was visualized using an OPMI Pentero Microscope (Carl Zeiss, Inc., Oberkochen, Germany). The 3 patients excluded had surgery during a time of unavailability of ICG due to manufacturing

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constraints. In four cases ICG demonstrated either poor filling or occlusion of the bypass. Two of the four were able to be successfully revised, the other two were occluded. All patients underwent intra- or postoperative DSA or CTA to verify the results.

The bypass procedures included in this series that underwent intraoperative evaluation with ICG included 43 STA-MCA bypasses, 1 occipital artery to posterior inferior cerebellar artery (PICA) bypass, 9 radial artery bypass grafts, 1 saphenous vein graft and 5 other IC-IC bypasses. The five IC-IC procedures included 2 PICA-PICA side to side bypasses, an anterior temporal artery to MCA bypass and 2 re-implantations of the PICA into the vertebral artery.

The findings on ICG videoangiography were compared to either intraoperative and/or postoperative DSA or CTA. Table 1, 2 outline the clinical data, bypass type, and imaging findings for patients undergoing bypasses for ischemia and as an adjunct for aneurysm surgery, respectively.

RESULTS

Videoangiography was useful in demonstrating patency (Fig. 1) or potential technical deficiencies for which correction was attempted (Fig. 2). In our series, 4 of 56 bypasses were demonstrated to be occluded or have inadequate flow in the graft at the time of surgery and were revised at that time. Despite revision, two STA-MCA bypass remained occluded. In each case, a

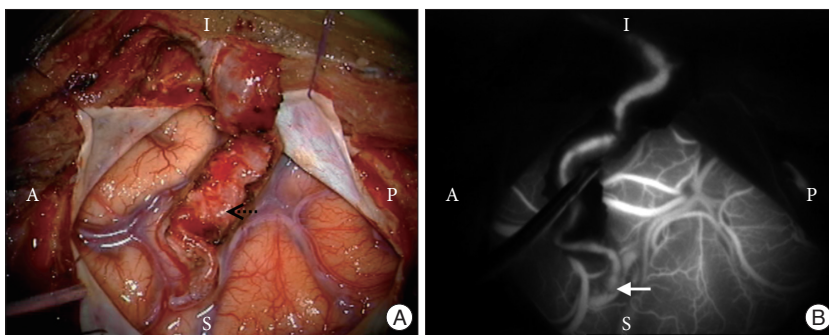


Fig. 1. Patent STA-MCA bypass. A : Intraoperative photo of STA-MCA bypass. Solid arrow denotes anastomosis and dotted arrow denotes STA. A : anterior, P : posterior, I : inferior, S : superior. B : ICG videoangiography demonstrates patency. Arrow denotes anastomosis. STA : superficial temporal artery, MCA : middle cerebral artery, ICG : indocyanine green.

Table 1. Patient demographics and results for bypasses completed as an adjunct to aneurysm surgery

Pt	Bypass	Diagnosis	Sex	Age	ICG Findings	Postop imaging
1	L STAMCA×2	Giant MCA	F	51	1 patent/1 occluded	IOA-1 patent/1 occluded
2	PICA reimplant	Coiled fusiform PICA	M	58	Patent	IOA-patent
3	R STAMCA	Giant MCA	F	40	Patent	IOA-patent
4	L STAMCA	Mycotic fusiform MCA	M	31	Patent	IOA and POA-patent
5	Saph vein CCA-MCA	Giant Cavernous	M	11	Patent	IOA and CTA-patent
6	L STAMCA	Giant ICA	F	67	Patent	POA-patent
7	R STAMCA×2	Coiled fusiform MCA	M	11	1 patent/1 occluded	IOA-1 patent/1 occluded
8	OA-PICA	Coiled fusiform PICA	M	54	Patent	IOA and POA-patent
9	Radial a. CCA-MCA	Giant MCA	M	44	Patent	IOA and POA-patent
10	ATA-MCA	MCA	F	55	Patent	IOA-patent
11	L STAMCA	Fusiform MCA	M	44	Patent	IOA-patent
12	L STAMCA	Large ICA-SHA	F	46	Patent	IOA-patent
13	L STAMCA	Giant ICA-OA	F	58	Patent	IOA-patent
14	L STAMCA	Giant cavernous	F	56	Patent	POA-patent
15	Radial a. ICA-MCA	Giant cavernous	F	64	Patent	IOA and CTA-patent
16	R STAMCA	Giant MCA	F	69	Patent	IOA-patent
17	Radial a. ICA-MCA	Giant coiled ICA-SHA	F	61	Occluded-clot removed-patent	IOA-patent
18	PICA-PICA	Giant VA	M	77	Patent	IOA and POA-patent
19	R STAMCA	Giant MCA	F	42	Patent	IOA and POA-patent
20	Radial a. CCA-MCA	Giant Coiled ICA	F	48	Patent	IOA and POA-patent
21	Radial a. CCA-MCA	ICA Blister	M	42	Patent	IOA and POA-patent
22	PICA-PICA	Fusiform VA	F	56	Patent	IOA-patent
23	Radial a. ICA-MCA	Giant cavernous	F	58	Patent	IOA and CTA-patent
24	PICA reimplant	Fusiform PICA	M	47	Patent	IOA and POA-patent
25	L STAMCA	Giant ICA-SHA	F	62	Patent	IOA-patent

POA : postoperative angiogram, ICG : indocyanine green, STA : superficial temporal artery, MCA : middle cerebral artery, PICA : posterior inferior cerebellar artery, CTA : computed tomography angiography

double bypass had been performed and one bypass was patent. In the other two cases, the bypass was revised successfully. ICG videoangiography added less than 10 minutes to operative time. There were no complications related to the use of ICG. At last followup, all grafts that were demonstrated to be patent intraoperatively remained patent.

Illustrative case reports

Case one

A 59-year-old male presented with a subarachnoid hemorrhage and was discovered to have a dissecting pseudo-aneurysm of the left vertebral artery (Fig. 3A). This was treated by partial endovascular coiling with sparing of the dominant PICA (Fig. 3B). Follow-up

angiography three months following his endovascular procedure demonstrated recurrence of the pseudo-aneurysm (Fig. 3C). The patient’s aneurysm was exposed through a left transcondylar approach with trapping of the left vertebral artery dis-

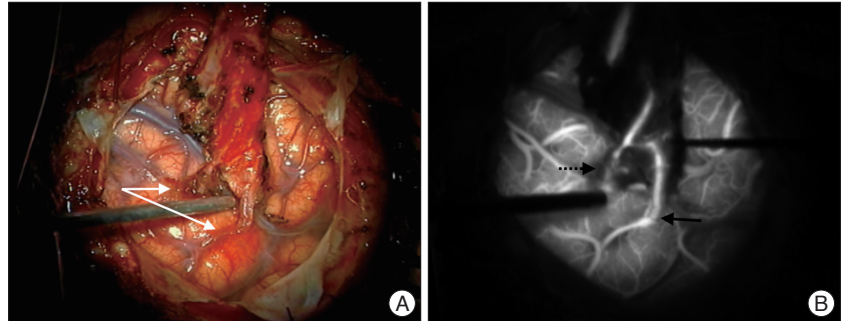


Fig. 2. Occluded STA-MCA bypass. A : Intraoperative photo of “double barrel” STA-MCA bypass. B : ICG videoangiography documents patency of the bypass on the right side (solid arrow) of image and occlusion of the bypass on the left (dotted arrow). STA : superficial temporal artery, MCA : middle cerebral artery, ICG : indocyanine green.

Table 2. Patient demographics and results for bypass procedures done for ischemia

Pt	Bypass	Diagnosis	Sex	Age	ICG	Postop imaging
1	R STAMCA	Moyamoya	F	39	Patent	CTA-patent
2	R STAMCA	Moyamoya	M	30	Patent	CTA-patent
	L STAMCA				Patent	CTA-patent
3	L STAMCA	MCA stenosis	M	73	Patent	DSA and CTA-patent
4	R STAMCA	Moyamoya	F	30	Patent	DSA-patent
5	R STAMCA	Moyamoya	F	58	Patent	CTA-patent
6	R STAMCA	Moyamoya	F	47	Patent	CTA-patent
	L STAMCA				Patent	CTA-patent
7	R STAMCA	Moyamoya	F	35	Slow filling	CTA-patent
	L STAMCA				Patent	CTA-patent
8	L STAMCA	MCA occlusion	M	57	Patent	CTA-patent
9	R STAMCA	ICA occlusion	F	61	Patent	CTA-patent
10	R STAMCA	Moyamoya	F	14	Patent	CTA-patent
11	L STAMCA	Moyamoya	F	11	Patent	CTA-patent
12	R STAMCA	Moyamoya	M	33	Patent	CTA-patent
13	L STAMCA	Moyamoya	M	44	Patent	CTA-patent
	R STAMCA				Patent	CTA-patent
14	R STAMCA	Moyamoya	F	53	Patent	CTA-patent
	L STAMCA				Patent	CTA-patent
15	R STAMCA	Carotid dissection	F	51	Patent	CTA-patent
16	L STAMCA	Moyamoya	F	57	Patent	CTA-patent
	R STAMCA				Patent	CTA-patent
17	L STAMCA	Moyamoya	F	22	Patent	CTA-patent
18	R STAMCA	Moyamoya	M	32	Patent	CTA-patent
	L STAMCA				Patent	CTA-patent
19	L STAMCA	Moyamoya	F	25	Patent	CTA-patent
20	L STAMCA	Moyamoya	F	32	Patent	CTA-patent
	R STAMCA				Patent	CTA-patent
21	L STAMCA	Carotid occlusion	M	68	Patent	DSA-patent
22	R STAMCA	Moyamoya	F	30	Patent	CTA-patent
	L STAMCA				Patent	CTA-patent

STA : superficial temporal artery, MCA : middle cerebral artery, DSA : digital subtraction angiography, CTA : computed tomography angiography, ICG : indocyanine green, ICA : inferior cerebellar artery

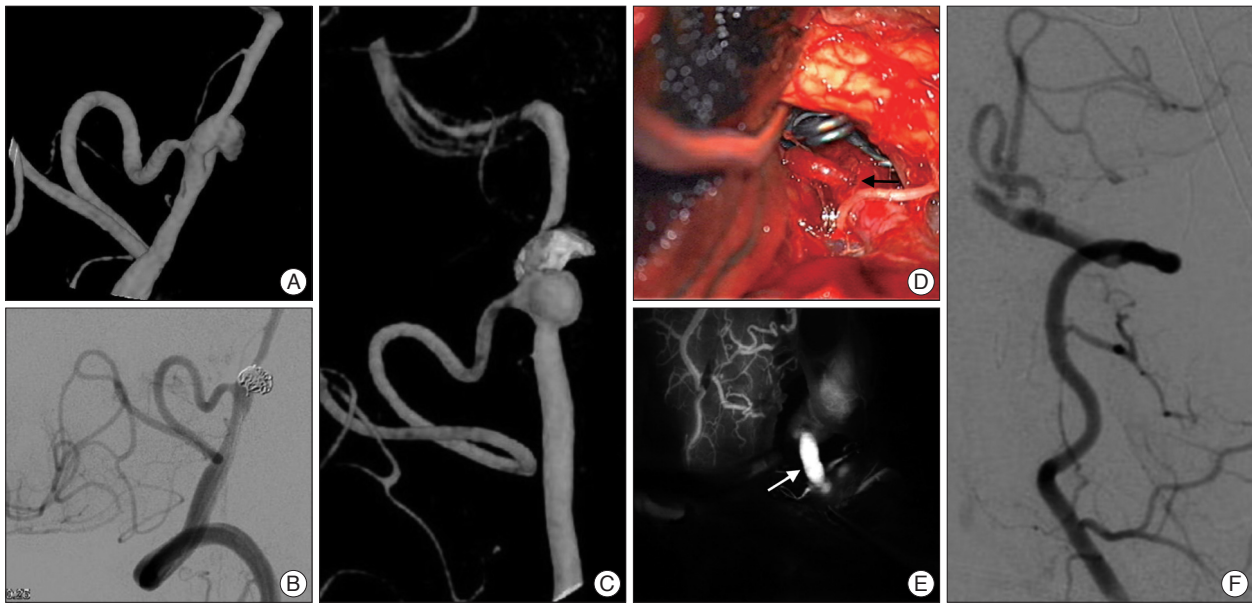


Fig. 3. Case One. A : Oblique 3-D DSA illustrates a left vertebral dissecting aneurysm at the origin of PICA. B : Oblique left vertebral angiogram after endovascular coiling of the aneurysm. C : Follow-up 3-D DSA demonstrates significant recurrence 3 months after endovascular treatment. D : Intraoperative photograph of PICA re-implanted into the left vertebral artery with clip distal to the bypass trapping the vertebral artery and aneurysm. Solid arrow denotes PICA-left vertebral anastomosis. E : ICG videoangiography demonstrates patency of re-implanted PICA (solid arrow). F : Intraoperative left vertebral DSA confirms patency of re-implanted PICA. DSA : digital subtraction angiography, PICA : posterior inferior cerebellar artery, ICG : indocyanine green.

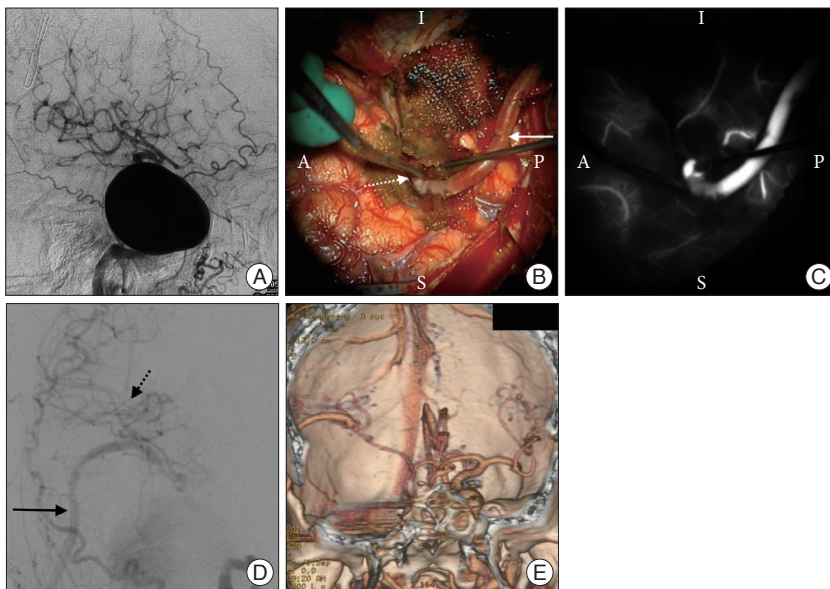


Fig. 4. Case Two. A : Lateral right common carotid angiogram shows giant intracavernous aneurysm. B : Intraoperative photograph of radial artery bypass from common carotid to middle cerebral artery. Radial artery denoted by solid arrow and anastomotic site shown by dotted arrow. C : ICG videoangiography of bypass demonstrates patency. D : Intraoperative DSA confirms patency of bypass. Solid arrow points to radial graft and dotted arrow points to filling MCA branches. E : Postoperative CTA AP verifies patency of the bypass and thrombosis of the aneurysm. ICG : indocyanine green, DSA : digital subtraction angiography, MCA : middle cerebral artery, CTA : computed tomography angiography.

secting aneurysm and division of the proximal PICA with reimplantation into the vertebral artery proximal to the aneurysm (Fig. 3D). ICG videoangiography demonstrated patency of the re-implanted PICA (Fig. 3E) and verified by both intraopera-

tive and postoperative DSA (Fig. 3F). The patient developed some transient worsening of his preoperative left-sided weakness. An MRI demonstrated no evidence of ischemia. At two month follow-up he had made a complete recovery.

Case two

A 64-year-old woman was known to have a giant intracavernous aneurysm on the right internal carotid artery with a smaller contralateral intracavernous aneurysm (Fig. 4A). She presented with progressively worsening retro-orbital pain and diplopia. The patient underwent a right frontotemporal craniotomy and exposure of the cervical carotid with harvesting of a radial artery graft for a common carotid to MCA bypass in preparation for endovascular occlusion of the internal carotid artery (Fig. 4B, C, D). Intraoperative ICG videoangiography and DSA demonstrated patency of the radial artery bypass graft.

Two days later she underwent carotid artery and aneurysm occlusion by endovascular coiling. With progressive thrombosis of the aneurysm, she developed transient worsening of her cranial neuropathy including the 3rd and 6th cranial nerves. At

two month follow-up the ophthalmoparesis was improving and her headaches had resolved. CTA demonstrated patency of the bypass and complete thrombosis of the aneurysm (Fig. 4E).

Case three

A 77-year-old man presented with progressive dizziness and ataxia for one year. He had experienced a number of falls more recently. CT and MRI demonstrated a giant right vertebral artery aneurysm causing significant brainstem compression. DSA illustrated the angioarchitecture of the aneurysm which arose just beyond the origin of PICA (Fig. 5A). Endovascular occlusion of the right vertebral artery was considered but would likely have occluded the PICA.

The patient underwent a right transcondylar approach to the aneurysm. A PICA-PICA side-to-side bypass was performed and documented by intraoperative ICG videoangiography and DSA to be patent before trapping the giant aneurysm (Fig. 5B-E). Postoperative angiography confirmed patency of the bypass (Fig. 5F).

DISCUSSION

The role of intracranial bypasses grew after the introduction of microsurgical techniques in the 1960s and 1970s²⁵. In 1967, Yasargil performed the first STA-MCA bypass in a patient with complete occlusion of the MCA^{28,29}. Subsequently, the indications for EC-IC bypasses expanded to include inaccessible extracranial carotid stenosis or occlusion, occlusive intracranial disease, complex aneurysms not amenable to simple clip ligation, skull base tumors, cerebral vasospasm, carotid dissection, carotid-cavernous fistulas, and moyamoya disease^{7,20,25}. The EC-IC bypass trial in 1985 failed to show surgical benefit over medical therapy leading to a decrease in the performance of the procedure²³. Though used in a limited fashion today, this procedure remains vital in many cases.

At the present time, intracranial bypass grafts are performed primarily by cerebrovascular neurosurgeons. Through evaluation of the blood flow demand, the surgeon may utilize a low flow bypass such as the superficial temporal artery or occipital artery with flow rates between 15 and 30 mL/min⁸. In cases requiring higher demands, the surgeon may employ a radial artery graft with flow rates of 40-70 mL/min or a saphenous vein graft with rates between 70 and 140 mL/min^{8,21}. Finally, a side-to-side or end-to-side anastomoses within the vessels of the circle of Willis can be completed without the need of graft har-

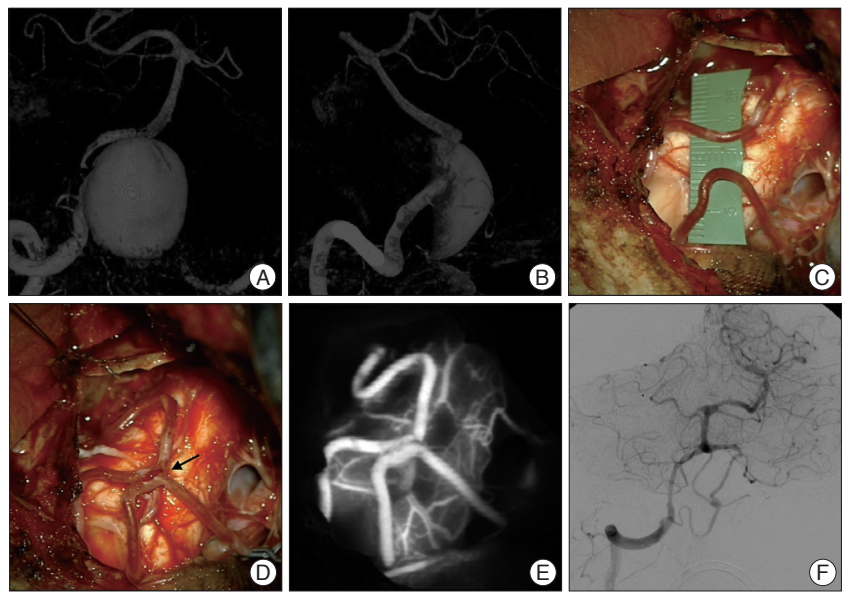


Fig. 5. Case Three. A : AP and B : Lateral vertebral 3-D angiogram demonstrates a giant left vertebral aneurysm. C : Intraoperative photograph of bilateral PICAs prepared for side-to side. D : Intraoperative photograph of PICA side-to side anastomosis (solid arrow) after completion. E : ICG videoangiography of bypass demonstrates patency. F : AP DSA showing patency of the bypass and trapping of the aneurysm. PICA : posterior inferior cerebellar artery, ICG : indocyanine green, DSA : digital subtraction angiography.

vest^{13,21}. The majority of bypasses are performed for complex aneurysms or tumors, moyamoya disease, and recently, occlusive disease in a specific subpopulation of atherosclerotic patients^{12,13,17,19}. The benefit of the bypass is dependent on low rates of surgical complications and high patency rates of the graft⁵.

In efforts to minimize early graft occlusion, multiple adjuncts can be employed to test patency. In the past, the majority of studies were performed postoperatively. With improvements in technology, intraoperative assessment can be completed in a reliable manner allowing higher early patency rates than the current range of 90 and 96%^{9,18,23}.

Currently, the primary means of graft assessment after completion of the procedure include 32 and 64 slice multidetector CTA, quantitative magnetic resonance (MR) angiography, and conventional cerebral angiography^{6,24,27}. Both CTA and MR angiography provide noninvasive means of assessing bypass patency with results comparable to conventional angiography. Unfortunately, both methods are compromised in patients where there is clip artifact in complex aneurysm cases²¹. In all postoperative imaging, the information is acquired at a point where it is difficult to correct the technical error.

Numerous techniques are available to the surgeon for intraoperative confirmation of graft patency at the time of surgery. The most simple means of which is direct visualization. Though the surgeon can easily determine the pulsatility of the donor vessel and recipient under the microscope, this method is known to be unreliable²¹. With varying results, surgeons have also employed duplex sonography, thermal imaging, and flow determi-

nation by ultrasonic transit times^{1,3,10}.

Intraoperative DSA was first described in the 1960s for cranial procedures and has been used with excellent results for neurovascular disorders since that time^{2,22,27}. Used primarily as an adjunct in aneurysm surgery, DSA can reliably evaluate the patency of bypass grafts. The use of intraoperative DSA requires a dedicated neuroangiography team and operative time for both sheath placement and the angiogram itself. Complication rates remain small (0.4%), but not inconsequential, as this is an invasive test using ionizing radiation and contrast agents²².

Originally approved for cardiac flow studies, ICG is a fluorescent tracer with applications in ophthalmology, cardiology, and gastroenterology¹¹. The dye is highly protein bound with intense fluorescence and a short half life of 150 to 180 seconds⁴. Cherrick et al.⁴ found the dye produced no adverse effects when introduced subcutaneously or intravenously. The dye does contain iodine and care should be taken in patients with iodine allergies. To view the fluorescence, a specialized near-infrared light source and camera must be used. Its first use in neurosurgical procedures was by Raabe et al.¹⁴ in 2003.

At that time, a separate camera was needed to view the dye. Presently, intraoperative microscopes can be modified to view ICG¹⁵. Surgeons have reported good results using ICG for intraoperative assessment in intracranial aneurysms, arteriovenous malformations, and EC-IC bypasses^{16,26}. The low cost, high spatial resolution, and ease of use makes ICG an attractive tool in the treatment of neurovascular disorders.

We report here the results from our use of ICG as an adjunct for assessment of the patency of IC-IC and EC-IC bypasses. We found the procedure to be reliable and comparable to intraoperative DSA. The ICG can be dosed in two to five minutes as compared to about 30 minutes for standard intraoperative DSA. The dye can also be easily redosed after the fluorescence has washed out of the vessels. The dosing of ICG resulted in no adverse effects compared to the 0.4% risk of stroke associated with intraoperative angiography. In 4 cases, ICG videoangiography determined that the graft was compromised or occluded or there was a technical error that could be corrected. In 2 of the cases, intraoperative revision of the graft resulted in graft patency. These results were comparable to Woitzik et al.²⁶ in their series of 45 patients who received ICG for EC-IC bypass grafts.

Additionally, ICG provides benefits over duplex sonography. The primary disadvantages of intraoperative doppler is the lack of a live dynamic picture of blood flow and is limited in small caliber vessels¹. ICG provides excellent visualization of small caliber vessels, though it also remains inferior to DSA in dynamic blood flow.

It is important to understand that ICG videoangiography provides an image limited to the size of the surgical field. If the view to the vessel is obstructed by bone or hematoma, the fluorescence cannot be visualized. Further studies are needed to determine to what extent ICG videoangiography can replace or supersede other imaging methods.

CONCLUSION

ICG videoangiography provides a surgeon with an effective means to determine graft patency at the time of surgery allowing the surgeon to correct any technical shortcomings. Use of this intraoperative technique provides a simple and reproducible means to assess intraoperative patency for both EC-IC and IC-IC bypasses.

References

- Badie B, Lee FT Jr, Pozniak MA, Strother CM : Intraoperative sonographic assessment of graft patency during extracranial-intracranial bypass. *AJNR Am J Neuroradiol* 21 : 1457-1459, 2000
- Barrow DL, Boyer KL, Joseph GJ : Intraoperative angiography in the management of neurovascular disorders. *Neurosurgery* 30 : 153-159, 1992
- Charbel FT, Misra M, Clarke ME, Ausman JI : Computer simulation of cerebral blood flow in moyamoya and the results of surgical therapies. *Clin Neurol Neurosurg* 99 Suppl 2 : S68-S73, 1997
- Cherrick GR, Stein SW, Leevy CM, Davidson CS : Indocyanine green : observations on its physical properties, plasma decay, and hepatic extraction. *J Clin Invest* 39 : 592-600, 1960
- Garrett MC, Komotar RJ, Starke RM, Merkow MB, Otten ML, Sciacca RR, et al. : The efficacy of direct extracranial-intracranial bypass in the treatment of symptomatic hemodynamic failure secondary to atherosclerotic disease : a systematic review. *Clin Neurol Neurosurg* 111 : 319-326, 2009
- Horn P, Vajkoczy P, Schmiedek P, Neff W : Evaluation of extracranial-intracranial arterial bypass function with magnetic resonance angiography. *Neuroradiology* 46 : 723-729, 2004
- Little JR, Yamamoto YL, Feindel W, Meyer E, Hodge CP : Sphenoidal temporal artery to middle cerebral artery anastomosis. Intraoperative evaluation by fluorescein angiography and xenon-133 clearance. *J Neurosurg* 50 : 560-569, 1979
- Liu JK, Kan P, Karwande SV, Couldwell WT : Conduits for cerebrovascular bypass and lessons learned from the cardiovascular experience. *Neurosurg Focus* 14 : e3, 2003
- Mendelovitsch 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)* 146 : 95-101, 2004
- Nakagawa A, Hirano T, Uenohara H, Sato M, Kusaka Y, Shirane R, et al. : Intraoperative thermal artery imaging of an EC-IC bypass in beagles with infrared camera with detectable wave-length band of 7-14 microm: possibilities as novel blood flow monitoring system. *Minim Invasive Neurosurg* 46 : 231-234, 2003
- Owens SL : Indocyanine green angiography. *Br J Ophthalmol* 80 : 263-266, 1996
- Quinones-Hinojosa A, Du R, Lawton MT : Revascularization with saphenous vein bypasses for complex intracranial aneurysms. *Skull Base* 15 : 119-132, 2005
- Quinones-Hinojosa A, Lawton MT : In situ bypass in the management of complex intracranial aneurysms: technique application in 13 patients. *Neurosurgery* 57 : 140-145; discussion 140-145, 2005
- Raabe A, Beck J, Gerlach R, Zimmermann M, Seifert V : Near-infrared indocyanine green video angiography : a new method for intraoperative assessment of vascular flow. *Neurosurgery* 52 : 132-139; discussion 139, 2003
- Raabe A, Beck J, Seifert V : Technique and image quality of intraoperative indocyanine green angiography during aneurysm surgery using

- surgical microscope integrated near-infrared video technology. **Zentralbl Neurochir** 66 : 1-6; discussion 7-8, 2005
16. Raabe A, Nakaji P, Beck J, Kim LJ, Hsu FP, Kamerman JD, et al. : Prospective evaluation of surgical microscope-integrated intraoperative near-infrared indocyanine green videoangiography during aneurysm surgery. **J Neurosurg** 103 : 982-989, 2005
 17. Regli L, Piepgras DG, Hansen KK : Late patency of long saphenous vein bypass grafts to the anterior and posterior cerebral circulation. **J Neurosurg** 83 : 806-811, 1995
 18. Schmiedek P, Piepgras A, Leinsinger G, Kirsch CM, Einhuopl K : Improvement of cerebrovascular reserve capacity by EC-IC arterial bypass surgery in patients with ICA occlusion and hemodynamic cerebral ischemia. **J Neurosurg** 81 : 236-244, 1994
 19. 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** 49 : 646-658; discussion 658-659, 2001
 20. Sundt TM Jr, Siekert RG, Piepgras DG, Sharbrough FW, Houser OW : Bypass surgery for vascular disease of the carotid system. **Mayo Clin Proc** 51 : 677-692, 1976
 21. Surdell DL, Hage ZA, Eddleman CS, Gupta DK, Bendok BR, Batjer HH : Revascularization for complex intracranial aneurysms. **Neurosurg Focus** 24 : E21, 2008
 22. Tang G, Cawley CM, Dion JE, Barrow DL : Intraoperative angiography during aneurysm surgery : a prospective evaluation of efficacy. **J Neurosurg** 96 : 993-999, 2002
 23. The EC/IC Bypass Study Group : Failure of extracranial-intracranial arterial bypass to reduce the risk of ischemic stroke: Results of an international randomized trial. **N Engl J Med** 313 : 1191-1200, 1985
 24. Thines L, Agid R, Dehdashti AR, da Costa L, Wallace MC, Terbrugge KG, et al. : Assessment of extracranial-intracranial bypass patency with 64-slice multidetector computerized tomography angiography. **Neuroradiology** 51 : 505-515, 2009
 25. Vilela MD, Newell DW : Superficial temporal artery to middle cerebral artery bypass : past, present, and future. **Neurosurg Focus** 24 : E2, 2008
 26. Woitzik J, Horn P, Vajkoczy P, Schmiedek P : Intraoperative control of extracranial-intracranial bypass patency by near-infrared indocyanine green videoangiography. **J Neurosurg** 102 : 692-698, 2005
 27. Yanaka K, Fujita K, Noguchi S, Matsumaru Y, Asakawa H, Anno I, et al. : Intraoperative angiographic assessment of graft patency during extracranial-intracranial bypass procedures. **Neurol Med Chir (Tokyo)** 43 : 509-512; discussion 513, 2003
 28. Yasargil MG : A legacy of microneurosurgery : memoirs, lessons, and axioms. **Neurosurgery** 45 : 1025-1092, 1999
 29. Yasargil MG, Krayenbuhl HA, Jacobson JH 2nd : Microneurosurgical arterial reconstruction. **Surgery** 67 : 221-233, 1970