Occlusive Cerebrovascular Disease & Cerebral Revascularization:

Moyamoya Disease
EC-IC Bypass

March 20, 2008

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Moyamoya Disease

History

- 1957 – Takeuchi & Shimizu published first description in medical literature using term "hypogenesis of bilateral ICA's"

- 1963 – Suzuki et al. proposed new disease entity to Japanese medical community

- 1969 – Suzuki & Takaku proposed term "moyamoya"

“Moyamoya”

“Something hazy just like a puff of cigarette smoke drifting in the air” (Japanese)

- Description of angiographic appearance – collateral network of blood vessels at base of brain
- Official name: spontaneous occlusion of circle of Willis

Diagnostic Guidelines

Proposed by Ministry of Health & Welfare of Japan

1. Stenosis or occlusion at terminal portion of ICA or at proximal portion of ACA or MCA
2. Abnormal vascular networks in vicinity of occlusive or stenotic lesions in the arterial phase
3. Bilateral vascular involvement
4. No other identifiable cause

Pathology

- Progressive stenosis of supraclinoid ICA & proximal MCA & ACA bilaterally
  - Fibrous deposition w/ intimal thickening
  - Internal elastic lamina becomes infolded, tortuous, & redundant
  - Minimal to no chronic inflammatory response noted
  - Findings likened to early stages of arteriosclerosis w/o lipid deposition in macrophages

- Induced cerebral ischemia results in development of abnormal collateral circulation – moyamoya vessels
  - Dilated & tortuous collaterals at base of brain involve basal ganglia & deep structures, & form complex anastomoses w/ distal intracranial vessels & leptomeningeal collaterals
  - Vessels believed to be dilated lenticulostriate & thalamoperforating arteries
  - Dilated collaterals exhibit disrupted internal elastic lamina, medial fibrosis, microaneurysms, & areas of rupture
  - These changes thought to underlie hemorrhagic subtype of disease

Pathogenesis & Etiology

- ? Deposition of smooth muscle & assoc chronic inflammatory response
- ? Angiogenic growth factors, e.g. b-FGF
- ? Genetic
  - Family history in ~10% of cases
  - May occur in monozygotic twins
    - 3p (MYMY1)
    - 17q25 (MYMY2; 607151)
    - 8q23 (MYMY3; 608796)
  - Association of HLA B51

Epidemiology

- Prevalence highest in Japan, followed by China & Korea
- Incidence higher in Asian countries
  - Japan: 0.35 per 100,000 annually

- ♀:♂ 1.8:1

- Age distribution bimodal
  - 1st peak: children < age 10 – 50%
  - 2nd peak: adults in 4th decade – 50%

Presentation

Ischemia - more common in children

- TIAs, stroke
- From insufficient blood flow thru collateral networks
- Induced by activities assoc w/ hyperventilation e.g. crying, running, straining, eating hot noodles, & singing
- End stage – CBF diffusely ↓ed in cerebral hemisphere, causing brain atrophy

- Age of onset correlated w/ severity of disease in pediatric patients
  - Normal value of CBF inversely related to age
  - The younger the child, the larger difference between required CBF & compromised CBF state
  - Incidence of completed stroke higher in patients w/ onset of symptoms < age 2

Presentation

Hemorrhage – more common in adults

- ICH (usually basal ganglia or thalamus) +/- intraventricular extension
- Risk of rebleeding ~7%/yr
- From longstanding hemodynamic stress placed on abnormally dilated fragile moyamoya vessels

Other – in children

- Seizures
- Headaches
- Visual disturbances
- Sensory changes
- Choreic-type movements
- Intellectual impairment

Associated Conditions

- Intracranial saccular aneurysms – usually in posterior circulation
  - Most common – basilar bifurcation
    - ? Added hemodynamic stress
- AVM – rare
- Primary pulmonary hypertension
- Fibromuscular dysplasia
- Fanconi's syndrome

Investigations: Imaging

- Angiography – diagnosis based primarily on angiographic findings
  - Identification of origin of hemorrhage usually difficult

- MRI / MRA
  - May see multiple, dilated abnormal vessels & flow voids in basal ganglia & thalamus, narrowing & occlusion of circle of Willis, parenchymal changes consistent w/ ischemia
  - Collateral vessels may be difficult to visualize

- CT
  - Often normal in early stages
  - May show multiple infarcts

Angiogram

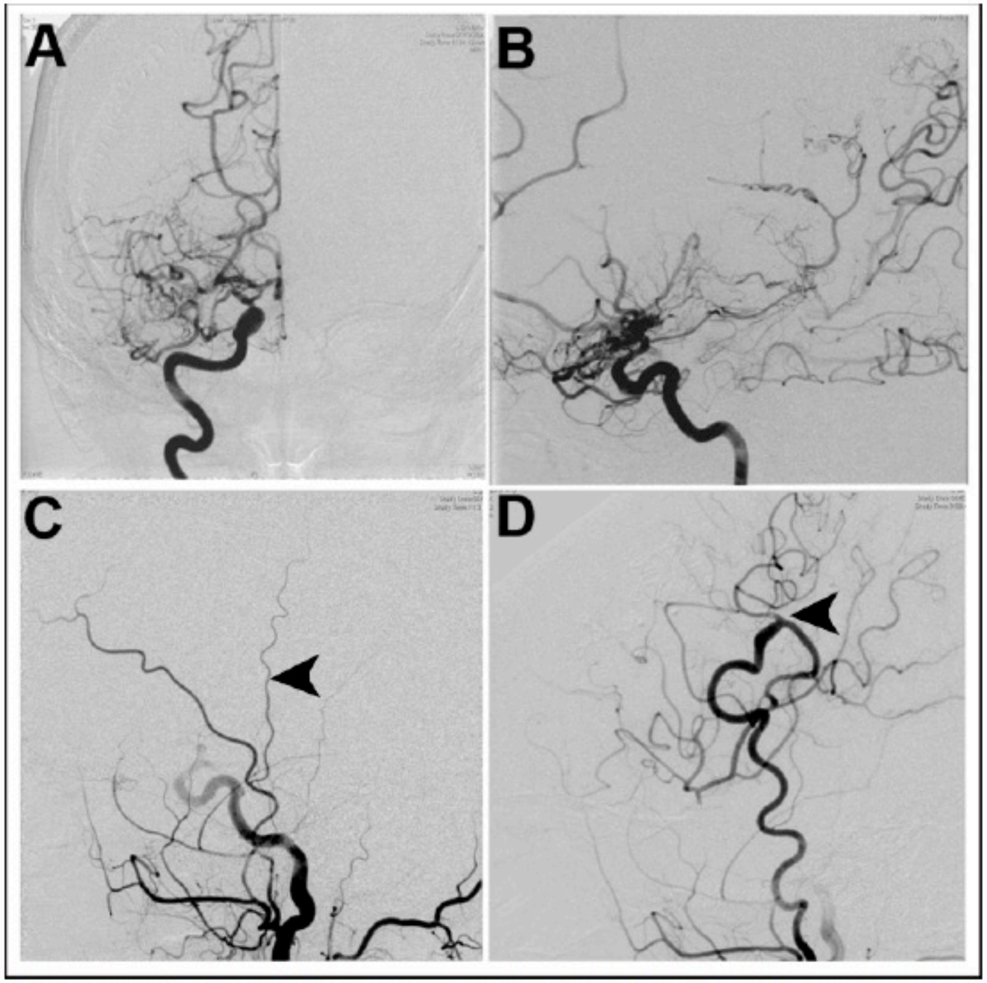


FIG. 1. Angiograms obtained prior to bypass surgery, anteroposterior (A) and lateral (B) views, showing characteristic MMD vascularization. External carotid artery injection angiogram (C) showing the STA *(arrow)*. Note the small size of the vessel. Angiogram (D) obtained 6 months after anastomosis, revealing a robust STA-MCA bypass *(arrow)* with significant enlargement of the STA.

Veeravagu A et al. Neurosurg Focus 24(2):E16, 2008.

Investigations: Other

- Studies of CBF
  - Xenon-enhanced CT
  - Single photon-emission CT
  - PET
  - CBF often ↓ed in children & relatively normal in adults
  - Autoregulation in response to hypotension & hypercapnia impaired

- EEG
  - Characteristic findings: slow waves involving posterior hemispheres & centrotemporal regions
  - Pathognomonic finding in children: re-buildup phenomenon in which a normal buildup induced by hyperventilation is followed immediately or concurrently by another buildup of slow, irregular lower voltage waves
    - Attributed to delayed response to CO2 reactivity

Suzuki Stage

Development & progression of disease
Based on angiography

Stage	Description
1	Bilateral stenosis of supraclinoid ICAs
2	Development of abnormal basal vascular network
3	Major trunks of ant circulation severely stenotic & collaterals more prominent
4	Collateral vessels progressively diminish in response to complete occlusion of intracranial vessels & abnormal extracranial-to-intracranial anastomoses develop
5	Disappearance of the major intracranial branches
6	Moyamoya collaterals & intracranial vessels have completely disappeared. Cerebrum perfused thru abnormal extracranial-to-intracranial anastomoses.

Treatment

Depends on initial presentation & stage of disease

- Observation
- Medical therapy
- Surgical therapy
- Combination therapy

No definitive recommendations available because long-term follow-up studies lacking

Treatment: Medical

- Vasodilators
- Anticoagulants
- Hemostatic agents
- Anticonvulsants
- Steroids

- Until 1975, most cases of ischemic moyamoya disease managed conservatively without much success

Treatment: Surgical

- Goal: provide effective revascularization & to prevent cerebral ischemia
- Revascularization is thought to promote regression of fragile collateral moyamoya vessels & thereby ↓ risk of hemorrhage
  - No long-term studies support this conclusion

Treatment: Surgical

- Cervical carotid sympathectomy & superior cervical perivascular ganglionectomy

- Direct anastomotic bypass
  - Vein grafts
  - EC-IC arterial anastomoses
    - STA – MCA bypass
    - OA – MCA bypass
    - MMA – MCA bypass

- Indirect non-anastomotic bypass
  - Encephalomyosynangiosis (EMS) – temporalis muscle grafting
  - Encephaloduroarteriosynangiosis (EDAS) – transposition of STA
  - Encephalomyoarteriosynangiosis (EMAS)
  - Cranial burr holes
  - Transplantation of omentum

Cervical Carotid Sympathectomy & Superior Cervical Ganglionectomy

- Based on research in dogs – sup cervical ganglionectomy shows degeneration of adrenergic axons in cerebral arterial walls after 48 hrs, then disappearance of axons after 4 days
  - Purpose: to promote dilation of cerebral arteries & improve collateral channels, to ↑ CBF

- Suzuki et al.: 23 patients, 1968~1973
  - Good results in improving clinical symptoms but in most cases could not prevent disease progression

EC-IC Bypass

- 1972 – Yasargil performed 1st STA-MCA bypass for moyamoya disease
  - Patient: 4 yo ♂ w/ R hemiplegia & anarthria after waking from coma
  - End-to-end anastomosis between STA & insular branch of L MCA
  - 2 yr f/u showed improvement in patient's deficits
  - Angiography demonstrated improvement in vascularization of L hemisphere thru anastomosis

Indirect Non-anastomotic Bypass

- Evolved as result of technical difficulties of performing direct bypass, esp in children
  - Small size of vessels
  - Fear of damaging transdural anastomoses between distal STA & cortical arteries
- Goal: induce delayed collateralization

Basic Operative Technique: EDAS

- Curvilinear skin incision planned over course of STA & small strip of hair shaved
  - To decrease possibility or injuring STA, no local anesthetic infiltrated
- Skin incised over STA & using sharp technique, subcutaneous layer incised until layer harboring STA encountered
- Bleeding points from skin edges carefully coagulated using very fine jeweller bipolars
- Dissection along entire course of STA until free of subcutaneous tissues
  - Small branches from STA coagulated & divided w/ fine bipolars
- A self-retaining retractor used to retract skin edges
- Galea surrounding STA divided using needle-tip Bovie cauterization device
  - Generous cuff of soft tissue left
  - Retract STA laterally & protect under a papaverine-soaked cottonoid
- Underlying temporalis muscle & fascia divided w/ electrocauterization in line w/ incision & reflected laterally w/ self-retaining retractors
- 2 burr holes placed at inferior & superior limits of planned craniotomy flap
  - Elliptical bone flap is fashioned & removed

Basic Operative Technique: EDAS

- Dural tenting sutures placed along bone edges
- STA centered over craniotomy area
  - If undue tension on STA is apparent, vessel should be freed further by expanding dissection proximally & distally
- Dura opened in cruciate manner
  - Care is taken to avoid disturbing or inuring any naturally developed transdural collaterals
  - If middle meningeal artery is providing significant dural collaterals to brain, incision modified to preserve it
- Arachnoid layer opened
- (MCA branches inspected for suitability for direct bypass)
- STA positioned over open sulcal regions and anchored using interrupted 10-0 nylon sutures
  - Needle of suture pass thru galeal cuff & adjacent pial area
- Dural edges loosely approximated
- Gelfoam placed over dura
- Bone flap replaced w/ STA passing thru burr holes w/o undue tension or kinking

Multiple Cranial Burr Holes

- EMS, EDAS, & STA-MCA anastomoses induce vascularization of cerebral surface, esp in MCA territory, but vascularization is poor in ACA & PCA territories

- Incidental finding in 1984 – 10 yo ♂ w/ IVH needed bilateral EVDs
  - 3 months later, marked neovascularization in frontal cerebral cortex via frontal burr holes

- 1986 – 1st case performed – 12 yo ♀ who underwent bilateral EMS & additional frontal burr holes
  - Kocher's point for burr holes, dura opened in cruciate manner, & arachnoid membrane stripped from brain
  - Angiographic studies at 8 months showed neovascularization thru EMS & frontal burr holes

Intra-operative Considerations & Potential Complications

- Volume status & blood pressure maintained strictly
- Avoid:
  - Hyperventilation – vasoconstrictive effects
  - Hypotension
- Potential complications
  - Peri-operative ischemia & stroke – most significant
  - Acute & chronic subdural hematomas – esp during EMS
  - Seizures – anticonvulsant therapy

Outcomes

- Long-term surgical outcomes compared to natural history of disease controversial

Moyamoya Syndrome

- Presentation of angiographic moyamoya changes found in association w/ a known pathological state (neurofibromatosis, Down syndrome, cranial irradiation, etc.) or found only to be affecting 1 side of brain
- Up to 18% of patients w/ moyamoya may present w/ unilateral angiography-documented disease
- Few series of unilateral moyamoya syndrome in literature
- Natural history of this group not known

- Smith et al. (2008): 33 patients w/ unilateral disease (4 adults & 29 children), avg f/u post surgery 5.3 yrs
  - 10 proceeded to bilateral disease
  - Mean time until disease progression 2.2 yrs
  - Factors assoc w/ progression: contralateral abnormalities on initial angiography, previous history of congenital cardiac anomaly, cranial irradiation, Asian ancestry, & familial moyamoya syndrome

- Veeravagu et al. (2008)
  - 75% of patients w/ equivocal or mild stenotic changes in initially unaffected side progressed to bilateral disease
  - Mean f/u time 12.7 mos

Cerebral Revascularization

*Summary of the evolution of cerebral revascularization therapy**

Authors, Year	Reported Event
Kredel, 1942	temporalis flap placed over the brain surface
Woringer & Kunlin, 1963	performance of a CCA to ICA bypass utilizing saphenous graft
Donaghy & Yaşargil, 1968	STA to MCA bypass
Kikuchi & Karasawa, 1973	EC/IC bypass to treat moyamoya
Spetzler & Chater, 1974	OA to MCA bypass
Karasawa et al., 1977	temporalis used for revascularization in patients w/ moyamoya (encephalomyosynangiosis)
Story et al., 1978	ICA to MCA bypass w/ saphenous vein graft
Spetzler et al., 1980	suturing of STA adventitia to underlying arachnoid for MCA insufficiency
Sundt et al., 1980	PTA for basilar artery stenosis
Sundt et al., 1982	saphenous vein grafts for posterior circulation disease
EC/IC Bypass Study Group, 1985	publication of the International Cooperative EC/IC Bypass Study
Feldman et al., 1996	BMS for intracranial ICA stenosis
Mori et al., 1998	classification of intracranial atherosclerotic lesions demonstrating prognostic significance
Connors & Wojak, 1999	demonstrated importance of technical modifications on PTA outcomes
Phatouros et al., 1999	BMS to treat posterior circulation atherosclerosis
SSYLVIA Study Investigators, 2004	SSYLVIA study reports use of the NEUROLINK stent, one of the first specific to the cerebrovasculature
Abou-Chebl et al., 2005	use of drug-eluting stent for intracranial atherosclerosis
Chimowitz et al., 2005	WASID Trial published, demonstrating significant rates of disability & death associated w/ intracranial atherosclerosis
Fiorella et al., & Bose et al., 2007	use of the Wingspan System, the first self-exanding intracranial stent
Levy et al., 2007	increased rate of in-stent stenosis associated w/ use of supraclinoid ICA stenting

* OA = occipital artery; WASID = Warfarin, Aspirin, and Intracranial Disease.

Crowley RW et al. Neurosurg Focus. 24(2):E3, 2008.

EC-IC Bypass

History

- First proposed by Fisher in 1959, but due to inadequate instruments, surgery technically not possible
- 1967 – Donaghy & Yasargil perform 1st STA-MCA anastomosis

Graft Options

- Low flow grafts:
  - Superficial temporal artery
    - Ant or post branch of distal STA may be used as in situ arterial graft
  - Occipital artery
    - Appealing choice for post circulation bypass procedures due to proximity to target recipient vessels

Graft Options

- High flow grafts:
  - Saphenous vein
    - Reversed saphenous vein end-to-end anastomosis to ECA, passed thru preauricular subcutaneous tunnel & then anastomosed in end-to-side fashion to branch of MCA
    - If ECA providing important collateral circulation to eye or brain, then vein can be sewn end-to-side to CCA so as not to disturb physiologic collateral circulation
  - Radial artery

These grafts provide higher flow, but require 2 anastomoses & harvesting

STA-MCA Bypass

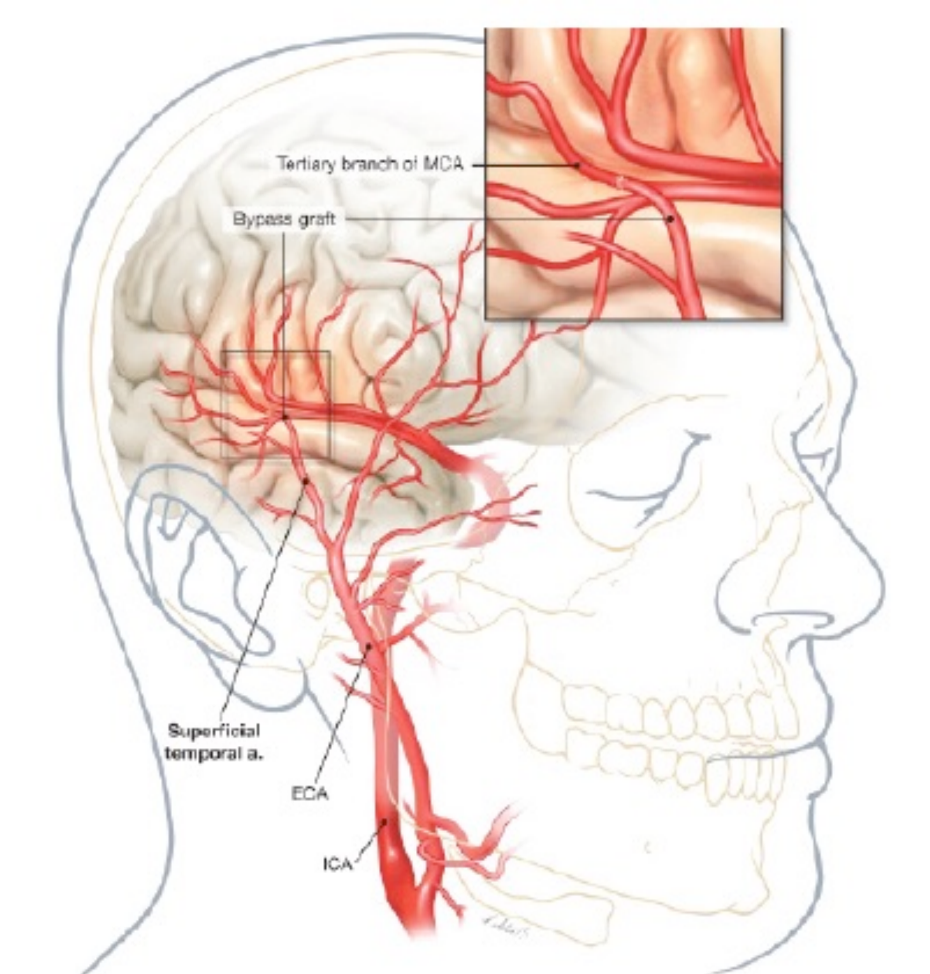
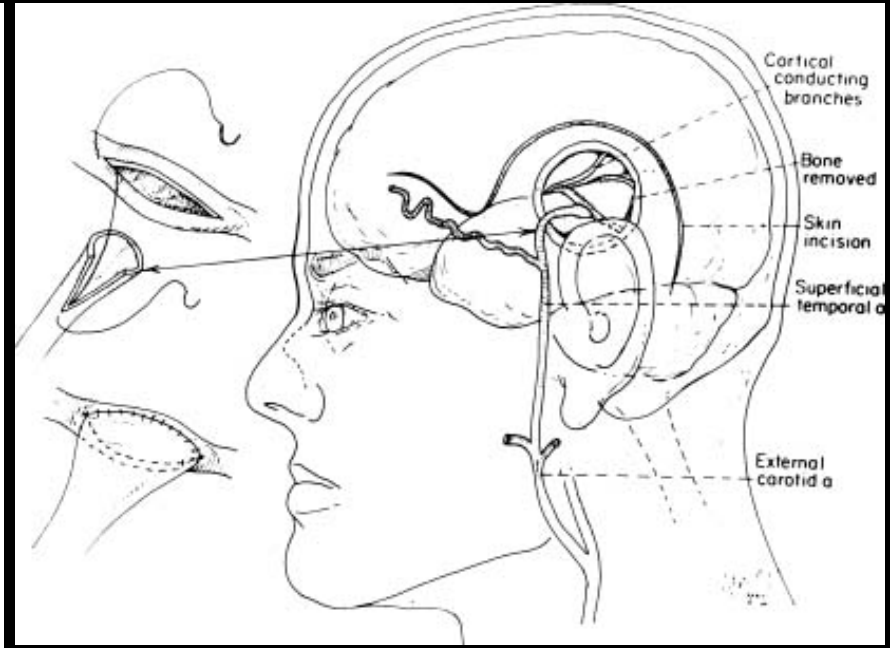


FIG. 2. Illustration depicting a completed STA–MCA. Note the frontoparietal branch of the STA, connected to a distal surface branch of the MCA, immediately after it emerges from the distal portion of the sylvian fissure. a. = artery; ECA = external carotid artery.



Link MJ et al. http://www.dcmsonline.org/jax-medicine/1998journals/november98/bypass.htm

Vilela MD et al. Neurosurg Focus. 24(2): E2, 2008.

STA-MCA Bypass: Technique

FIGURE 1. *Drawing illustrating the positioning of the patient for STA-MCA bypass. The head is maintained in a position nearly parallel to the floor.*

FIGURE 2. *Drawing illustrating how Doppler ultrasound is used to map out the course of the STA.*

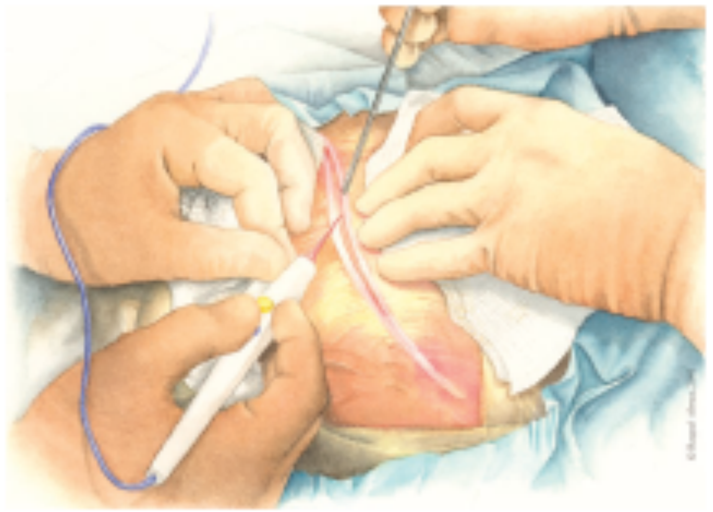


FIGURE 3. *Drawing illustrating how a needle point cautery is used to make an incision directly over the STA.*

Newell DW et al. Neurosurg. 54(6):1441-1449, 2004.

STA-MCA Bypass: Technique

FIGURES 4, 5, and 6. *Drawings illustrating how, after identification of the artery, tenotomy scissors are used to help isolate the artery and the needle point cautery is used to incise the galea adjacent to the artery on either side, which minimizes bleeding.*

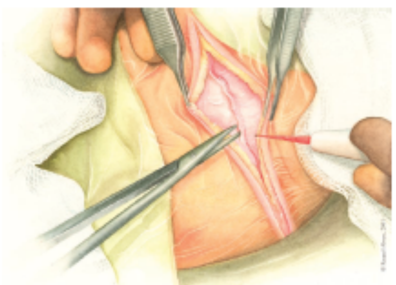
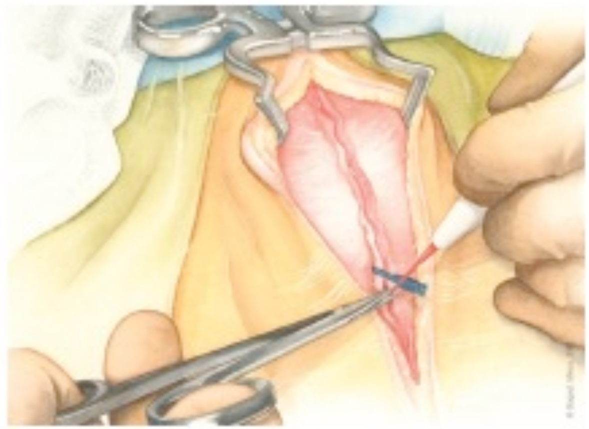


FIGURE 5.

FIGURE 6.



FIGURES 7 and 8. *Drawings illustrating how, after a suitable length of artery has been mobilized, a temporary clamp is placed distally and the artery is divided, retracted inferiorly, and placed in wet gauze.*

FIGURE 8.

FIGURES 9 and 10. *Drawings illustrating how the temporalis muscle is then divided and retracted laterally. A craniotomy centered 6 cm above the external auditory meatus and over the sylvian fissure is then performed.*

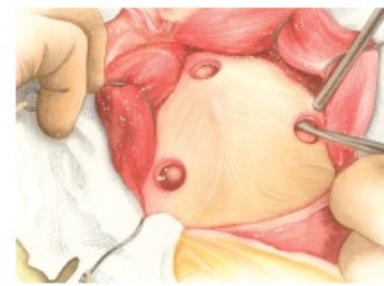


FIGURE 10.

FIGURES 11 and 12. *Drawings illustrating how the dura is secured to the edges of the bone flap and opened to expose the distal aspect of the sylvian fissure.*

STA-MCA Bypass: Technique

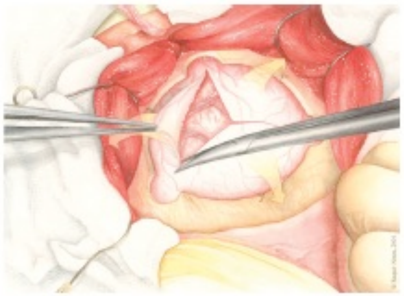
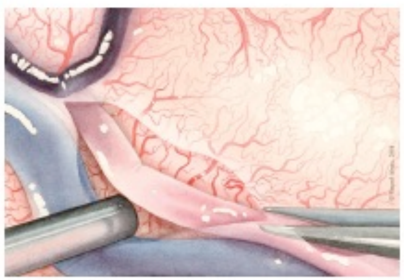


FIGURE 12.



FIGURES 13 and 14. *A surface artery is chosen for the recipient vessel, which is preferably the largest on the surface with a relatively long surface course and devoid of major branches. The drawings illustrate how the arachnoid membrane is divided along the surface of the artery, and small side branches are cauterized with a jeweler's forceps cautery.*

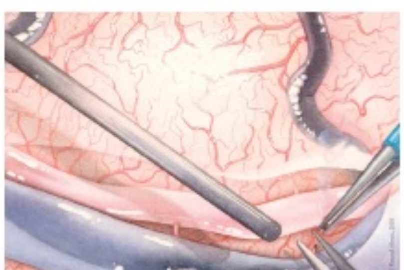
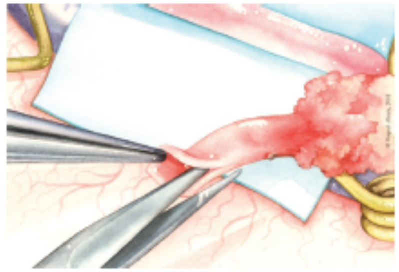


FIGURE 14.



FIGURES 15 and 16. *Drawings illustrating how final preparation of the donor artery is performed by spatulating the end and irrigation of the lumen with heparinized saline.*

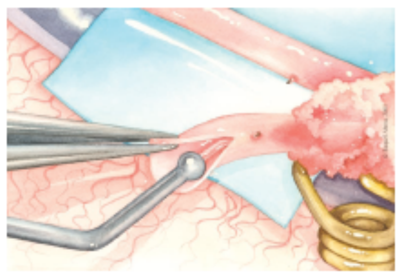
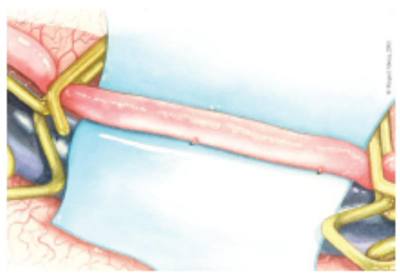


FIGURE 16.



FIGURES 17, 18, and 19. *Drawings illustrating how the recipient artery is then cross-clamped and an arteriotomy is made using small curved Van Ness scissors. The length of the arteriotomy should be 2 to 2.5 times the diameter of the artery.*

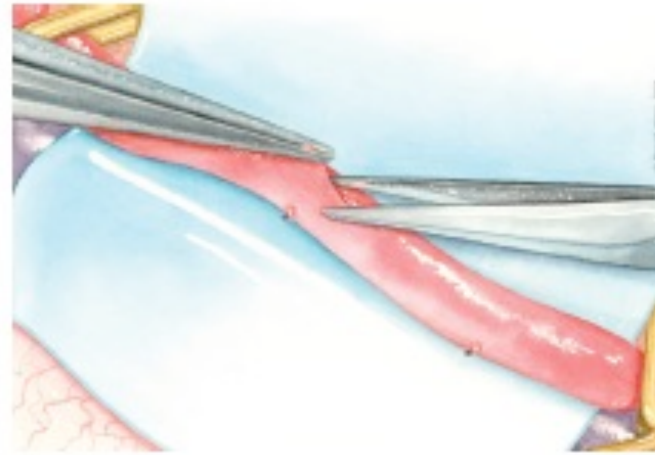
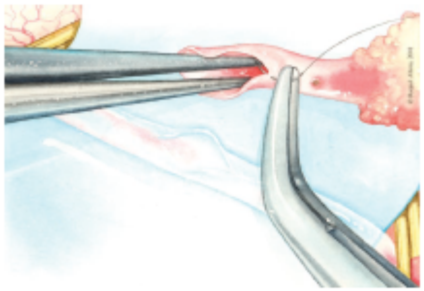


FIGURE 18.

FIGURE 19.

STA-MCA Bypass: Technique



FIGURES 20, 21, and 22. *Drawings illustrating how the donor artery is then brought down in an end-to-side fashion against the recipient artery and initially secured with a "heel stitch" using a 10-0 suture tied with a surgeon's knot.*

FIGURE 21.

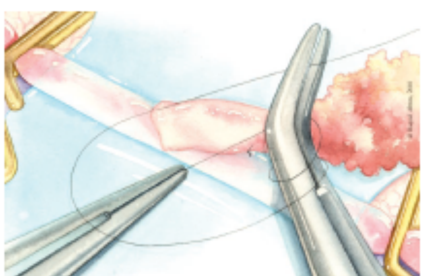
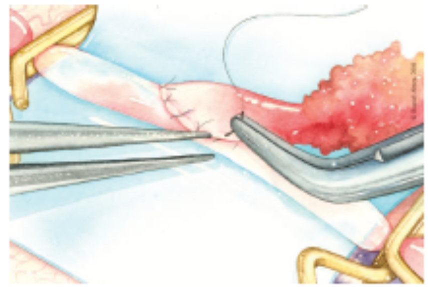


FIGURE 22.



FIGURES 23 and 24. *Drawings illustrating how interrupted 10-0 sutures are then placed in the front wall, followed by placement in the back wall.*

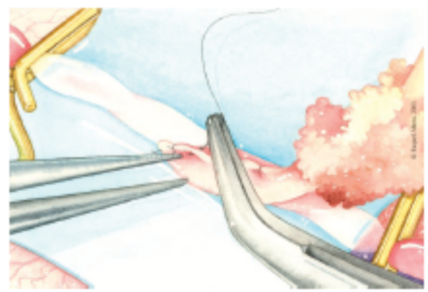


FIGURE 24.

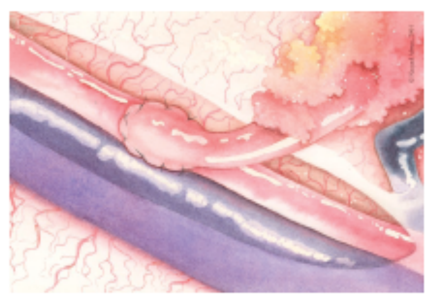
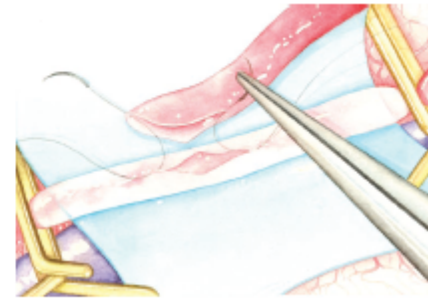


FIGURE 25. *Drawing illustrating how the final anastomosis is visualized after all the clamps are removed. It is common to have some bleeding initially from the anastomotic site, which can be stopped by applying a small amount of Surgicel.*



FIGURES 26, 27, 28, and 29. *Alternatively, a running suture technique can be employed. The drawings illustrate how separate running sutures are used to secure the back wall and the front wall of the anastomosis.*

FIGURE 27.

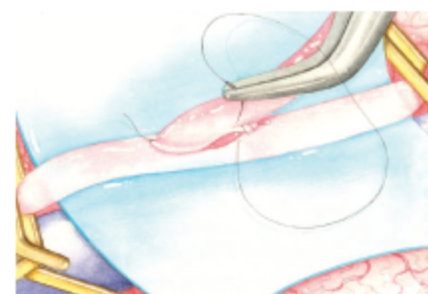


FIGURE 28.

STA-MCA Bypass: Technique

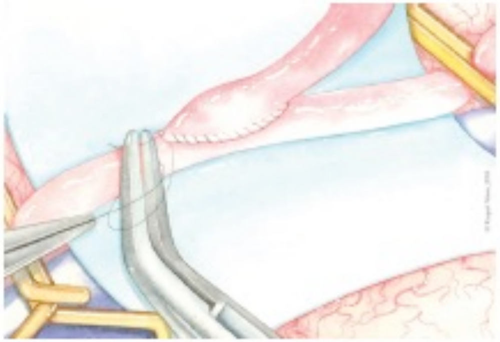


FIGURE 29.

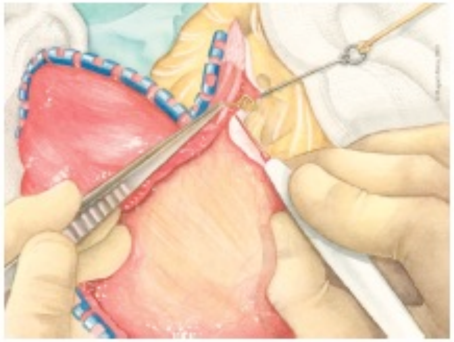


FIGURE 30. *Drawing illustrating how the incision is continued lower to the tragus of the ear and the tragal point is located. The STA should be found coursing just anterior to the tragal point, which is also a landmark to locate the facial nerve before it enters the parotid gland.*

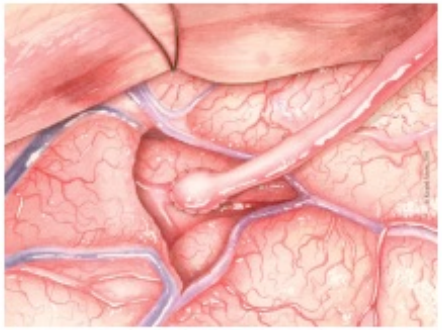


FIGURE 31. *Drawing illustrating how a craniotomy is performed anterior to the craniotomy for the classic STA-MCA bypass, and the MCA M3 branches are exposed in the distal sylvian fissure. These branches provide a better size match for the saphenous vein. The vein graft is then temporarily clamped, and the distal anastomosis is performed in a similar manner as described previously.*

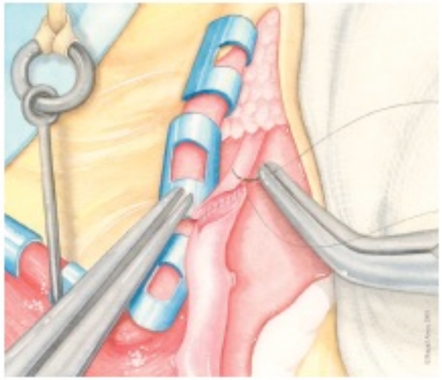


FIGURE 32. *Drawing illustrating how an end-to-end anastomosis is then performed between the saphenous vein and the proximal STA at the tragal point.*

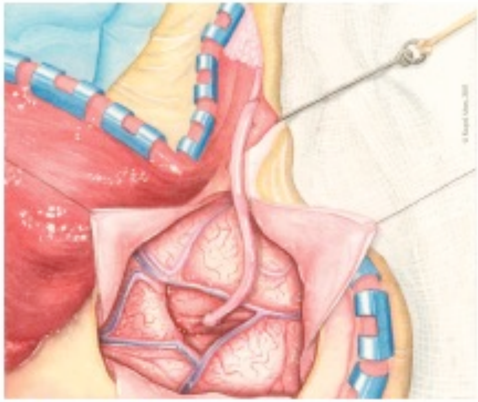


FIGURE 33. *Drawing illustrating the completed anastomosis after the clamps have been removed.*

Indications

- Cerebrovascular occlusive disease
  - Moyamoya
  - ICA &/or MCA stenosis not amenable to stenting / direct surgery
- Aneurysms
  - Giant aneurysms
  - Repair of mycotic or traumatic aneurysms of distal cortical vessels
- Skull base tumors
- Trauma to cervical ICA
- Surgical repair of carotid-cavernous fistulas

Purpose: augment cerebral blood flow

EC-IC Bypass: Cerebrovascular Occlusive Disease

- ~10% of stroke due to presence of intracranial atherosclerosis
- Warfarin, Aspirin, & Intracranial Disease Trial (2005): compared warfarin vs. ASA in tx of symptomatic intracranial atherosclerosis
  - In patients w/ >50% stenosis of an intracranial vessel, recurrent strokes in assoc vascular territory were 11% & 14% at 1 & 2 yrs respectively
- Treatment options available for stroke from intracranial disease limited

International Cooperative EC-IC Bypass Study, NEJM 1985

- 1977– 1985
- 71 centers
- Prospective randomized trial looking at effectiveness of EC-IC bypass in reducing stroke & stroke related death cmong patients w/ symptomatic surgically inaccessible (to CEA) atherosclerotic stenosis or occlusion of ICA or MCA

- Inclusion criteria:
  - History of TIAs or ≥1 minor or completed strokes in carotid distribution
  - Presence of at least 1 of several atherosclerotic angiographic lesions, e.g. stenosis or occlusion of trunk or major branches before the bi-or trifurcation of MCA, stenosis of ICA at or above C2 vertebral body, or occlusion of ICA

International Cooperative EC-IC Bypass Study, NEJM 1985

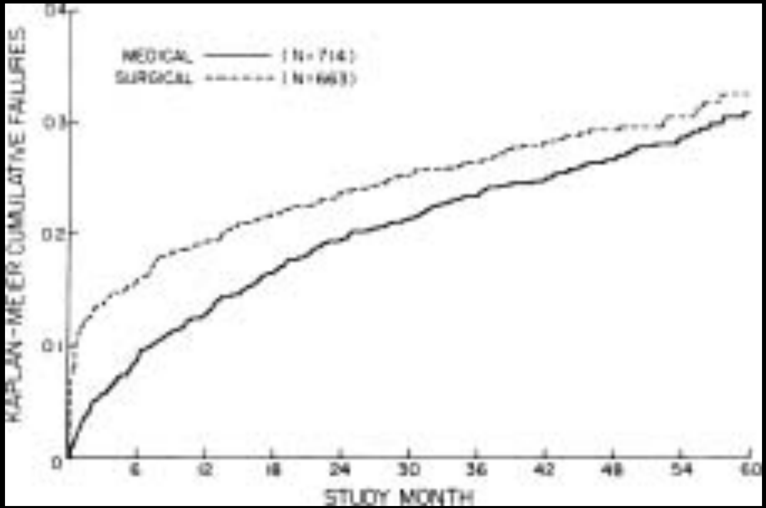
- 1,495 patients entered between 1977 & 1982
  - 118 subsequently excluded
- 1,377 eligible patients: 714 randomized to best medical therapy alone vs. 663 underwent STA-MCA bypass + best medical therapy

- Follow-up:
  - Clinic visits q6 months by neurologist
  - Repeat angiograms performed in 92% of surgical patients at median time of 32 days post-op
  - Angiograms reviewed to determine size & patency of anatomosis, degree of retrograde flow in MCA, & number of branches of MCA filled
- Avg duration of f/u 55.8 months
- No patient lost to f/u

- Analyses: intention to treat

International Cooperative EC-IC Bypass Study, NEJM 1985

- Nonfatal & fatal strokes occurred both more frequently & earlier for surgical group
  - 30 day risk death / major stroke: 0.6% vs. 2.5%
  - ≥1 strokes during follow-up: 29% vs. 31%



- 2 subgroups fared substantially worse in surgical group:
  - Severe MCA stenosis
  - Persistence of ischemic symptoms after ICA occlusion had been demonstrated

Link MJ et al. http://www.dcmsonline.org/jax-medicine/1998journals/november98/bypass.htm

International Cooperative EC-IC Bypass Study, NEJM 1985

- Technical results of surgery excellent
  - 96% of patients w/ post-op angiograms had patent STA-MCA anastomoses

- Comparison of 200 patients w/ worst post-op angiograms w/ 225 patients w/ best angiograms: those w/ good perfusion did no better than those w/ small or occluded anastomoses

The conclusions of the study changed the reimbursement for & subsequently the practice of EC-IC bypass

Criticisms of EC-IC Bypass Trial

- Only ½ of patients were receiving antiplatelet agents at time of entry into study & the other ½ were not receiving any medical therapy
- Patients were not evaluated preoperatively in terms of their cerebrovascular hemodynamic status. Patients w/ symptoms due to hemodynamic insufficiency, the group that would most benefit from a bypass augmentation procedure, were therefore not differentiated from those w symptoms caused by thromboembolic mechanisms
- Both patient & therapist were not blinded & therefore potential for underreporting or overreporting was possible
- Randomization to treatment bias could have occurred in which a larger number of patients randomized to surgery had major morbidity events that happened before operation
- No angiographic determinants for entry – severity of stenosis was not measured & vertebral artery angiography was not performed in all patients
- Larger percentage of patients had no symptoms between angiographic demonstration ICA occlusion & randomization
- Large number of patients underwent surgery outside of study, ~2500 patients at the participating centers w/ at least 50% believed to have been eligible
- High percentage of patients had tandem lesions demonstrated on angiography which may be a condition not very suitable for bypass

Criticisms: Hemodynamics

- Cerebral ischemic events experienced by patients could be of either hemodynamic origin (resulting from poor circulatory perfusion & inadequate collateral vessels) or thromboembolic origin – not possible w/ angiography to determine which mechanism was responsible

- Angiographic lesions are static representation & do not capture complex hemodynamics of cerebral circulation. Degree of stenosis or presence of arterial occlusion does not accurately predict hemodynamic status of distal circulation. Due to collateral circulation, may have no evidence of hemodynamic compromise

- Study included patients w/ cerebral ischemias as well those w/ completed infarctions. In these patients state of "luxury perfusion" exists where cerebral oxygen metabolism & arterial oxygen extraction fall to low levels while blood flow paradoxically rises & use of surgical intervention to increase CBF is inappropriate because tissue not salvageable. In the ischemic state, CBF falls, oxygen extraction rises to 100% so that cerebral metabolism becomes totally flow dependent – ideal state for bypass graft to increase flow.

- Ad hoc committee of American Association of Neurological Surgeons convened to review validity of study
  - Study was internally valid, however, could the conclusions of the study be generalizable to the population at large?

Resurgence of EC-IC Bypass

- EC-IC bypass may be an effective tx for certain patient populations
  - Moyamoya disease
  - Atherosclerotic occlusion w/ poor cerebrovascular reserve & collateral blood flow
  - Posterior circulation disease

St. Louis Carotid Occlusion Study

- Grubb et al. (1998): prospective blinded study, evaluated relationship between state of "misery perfusion" (↑ed O2 extraction fraction on PET scanning) & stroke risk in patients w/ symptomatic carotid artery occlusion
  - ↑ risk of ipsilateral stroke in group w/ ↑ O2 extraction fraction
  - State of misery perfusion significant independent predictor of subsequent risk of stroke in medically treated patients w/ carotid artery occlusion

- Carotid Occlusion Surgery Study (ongoing) – multicenter randomized prospective study initiated to determine whether STA-MCA anastomosis reduces risk of ipsilateral ischemic stroke in these types of patients

Investigation of Cerebral Blood Flow

- SPECT scan
- Xenon-enhanced CT scan
- PET scan – O_2 extraction fraction
- Transcranial doppler ultrasonography
- MRI

- +/- Acetazolamide challenge test
  - Acetazolamide acts a potent vasodilator of cerebral vasculature & globally ↑ CBF

- Balloon test occlusion

EC-IC Bypass: Aneurysms

- ICA ligation is an option for tx of some intracranial aneurysms of ant circulation
  - ↓ blood flow would leave to eventual thrombosis of aneurysm
- Cooperative Study of Intracranial Aneurysms & SAH:
  - Tx of intracranial aneurysms by occlusion of CA in neck – overall incidence of ischemic neurological deficits 33% in patients w/ ruptured aneurysms & 12% in those w/ unruptured aneurysms
  - Ischemic deficits higher in patients w/ occlusion of ICA vs. CCA (abrupt occlusion 59% vs. 32%, gradual occlusion 41% vs. 24%)

- Yasargil popularized STA-MCA bypass for patients w/ giant supraclinoid ICA aneurysms
- STA-MCA bypass prevents ischemic neurological deficits during major parent vessel occlusion for tx of intracranial aneurysms

EC-IC Bypass: Aneurysms

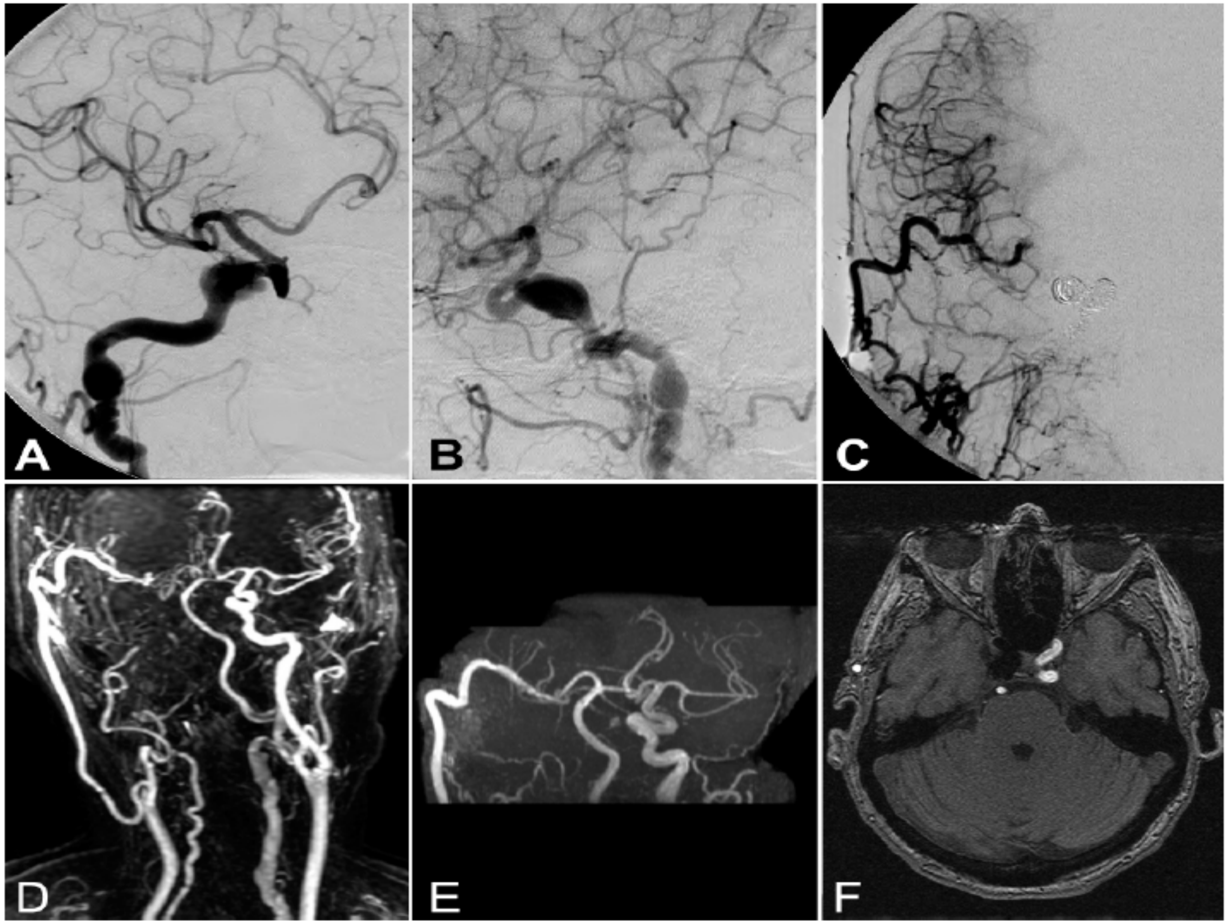


FIG. 1. Case 6. Cavernous ICA aneurysm treated with an ECA–MCA bypass for which an RA graft was used. Preoperative anteroposterior (A) and lateral (B) oblique view angiograms demonstrating a partially thrombosed aneurysm of the cavernous segment of the right ICA. Postoperative conventional (C) and MR angiograms (D and E) demonstrating a patent ECA–MCA (M_2 segment) bypass, and coil occlusion of the right ICA. An MR angiogram (F) obtained at the 3-year follow-up evaluation demonstrates that the bypass is patent and the aneurysm is completely thrombosed. (Reprinted with permission from the Mayfield Clinic; originally published at http://www.mayfieldclinic.com/DNS/ClinTrial_COSS.htm.)

E5

Kocaeli H et al. Neurosurg Focus 24(2):E5, 2008.

Algorithm Giant Aneurysms

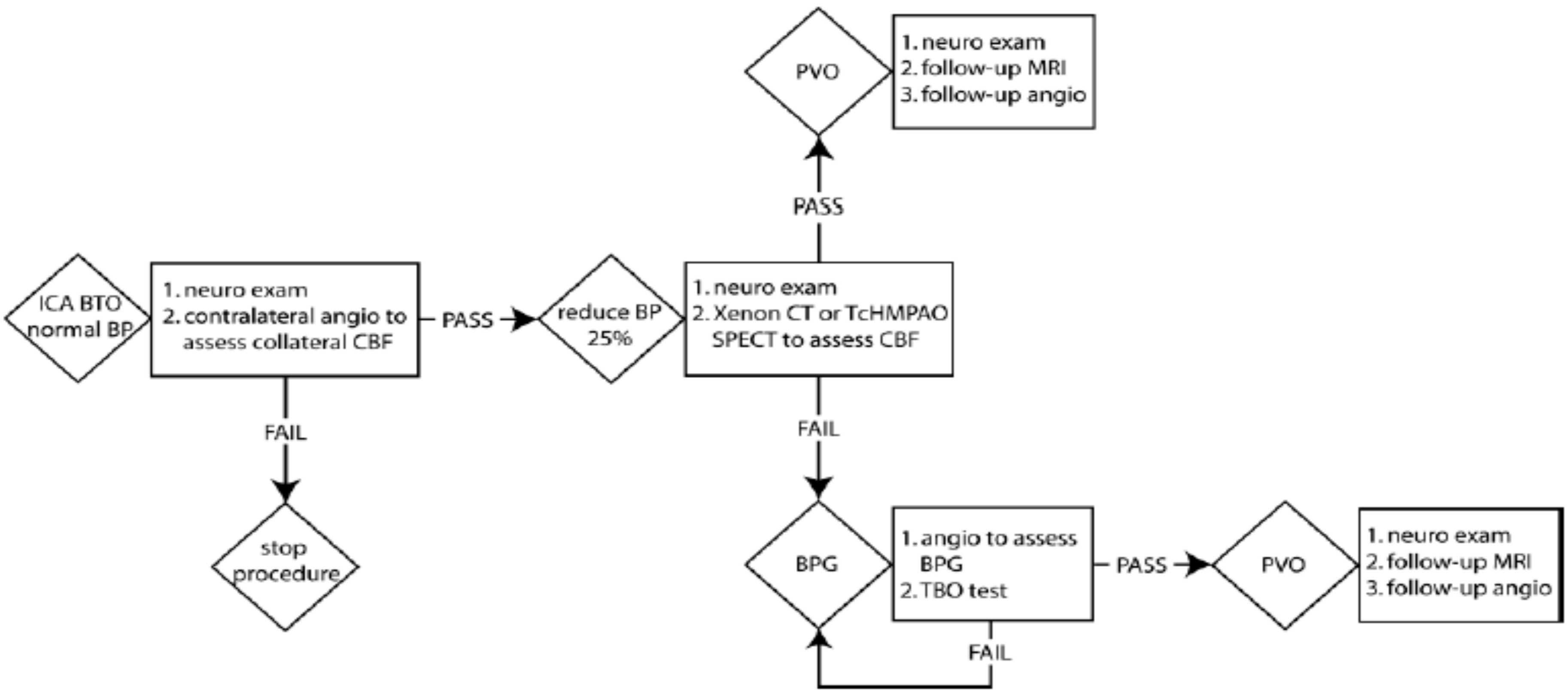


FIG. 4. Algorithm showing the protocol for BTO in the treatment of large and giant unclippable aneurysms. angio = angiography; BP = blood pressure; BPG = bypass graft; neuro = neurological; PVO = permanent vessel occlusion; SPECT = single-photon emission computed tomography; TBO = temporary balloon occlusion; TcHMPAO = technetium–hexamethylpropyleneamine oxime. (Reprinted with permission from the Mayfield Clinic; originally published in Link MJ, Tomsick TA, Tew JM Jr: Honored guest presentation: therapeutic carotid occlusion. **Clin Neurosurg 46:** 326–338, 2000.

EC-IC Bypass: Moyamoya

- Improvement of clinical symptoms & cerebral hemodynamics in ischemic moyamoya disease in both children & adults observed
  - Effectiveness of revascularization in preventing hemorrhage controversial
- Large retrospective study in Japan: 57 neurosurgical centers, 290 patients w/ hemorrhagic form of moyamoya – 138 patients w/ conservative tx vs. 152 surgical revascularization
  - Recurrent hemorrhage: 28.3% vs. 19.1%
  - Japan Adult Moyamoya Trial (prospective study) in Japan currently underway

Failure of Bypass

- Presence of a patent STA-MCA bypass may not offer complete protection from ischemia, when a major intracranial or extracranial vessel has been occluded

- Mechanisms of ischemia
  - Embolic phenomena
  - Failure to provide enough blood supply to entire MCA territory
  - Retrograde thrombosis of M1 segment when MCA clipped just proximal to its bifurcation

Excimer Laser-Assisted Nonocclusive Anastomosis (ELANA)

- Major advancement of prior bypass techniques by Tulleken et al.
- Allows for EC-IC bypass w/o temporary occlusion of recipient vessel by using an excimer laser/catheter system
  - Potentially reduces incidence of ischemia-related complications assoc w/ vessel occlusion
- 1993 – epigastric artery used in an STA-ICA bypass in patient w/ bilateral carotid occlusion
  - Later applied to bypass of larger intracranial aneurysms
- Limited long term data available

ELANA

Fig. 1. Photograph showing the ELANA catheter tip. Note inner suction surrounded by outer laser array.

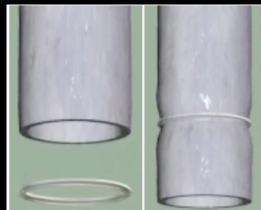


Fig. 2. *Left:* Computer-generated drawing of donor vessel and ring prior to creating donor/ring complex. *Right:* Computer-generated drawing of ring being placed over donor at distal end prior to the suturing step.

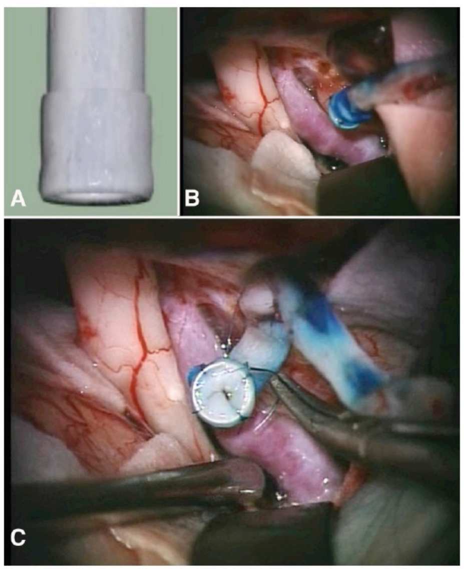


Fig. 3. A: Computer-generated drawing of ring after the distal donor vessel was reflected over it, with subsequent microsuturing. B: Intraoperative photograph showing the vein graft, with the platinum ring sewn to it, being brought to the operative field next to the right ICA. C: The platinum ring has been secured in place at a side table by using 4 interrupted sutures.

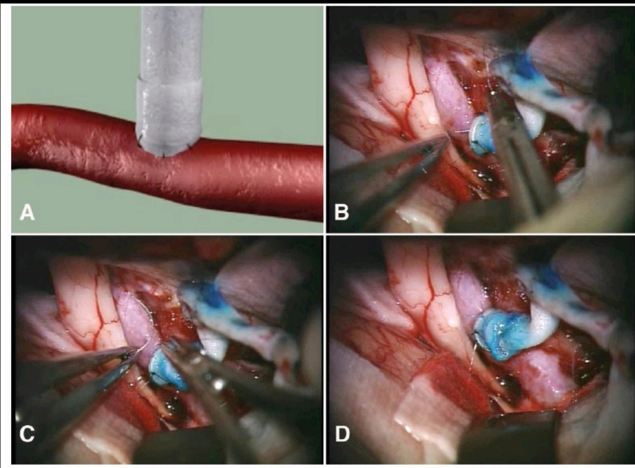


Fig. 4. A: Computer-generated drawing of the donor/ring complex following anastomosis to recipient artery. B– D: Intraoperative photographs showing the ring/graft complex being sewn to the ICA wall with 8 interrupted microsutures.

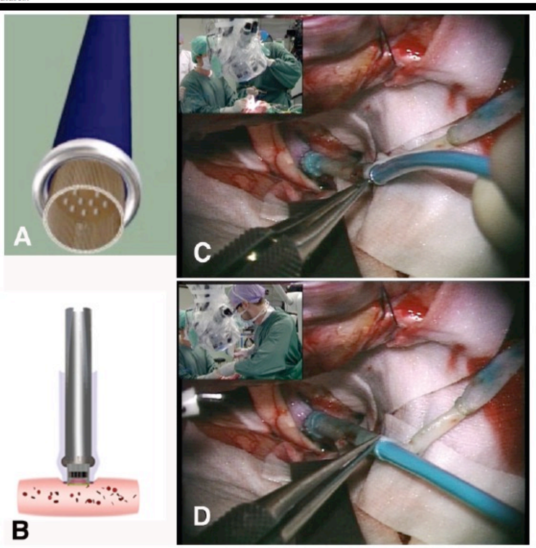


Fig. 5. A: Computer-generated drawing of the ELANA catheter (compare with actual picture of catheter in Fig. 1). B: Schematic side view showing catheter/recipient interface allowing laser arteriotomy to be performed. Note position of the catheter within the donor vessel, entering through the open distal end. The catheter can be placed through a donor side slit or through an artificial side branch at the surgeon's discretion. C and D: Intraoperative photographs showing the laser catheter being passed through a side slit in the vein graft onto the side wall of the recipient artery. The *insets* here and in Figs. 6–8 consist of photographs taken during the operation to show the equipment and personnel.

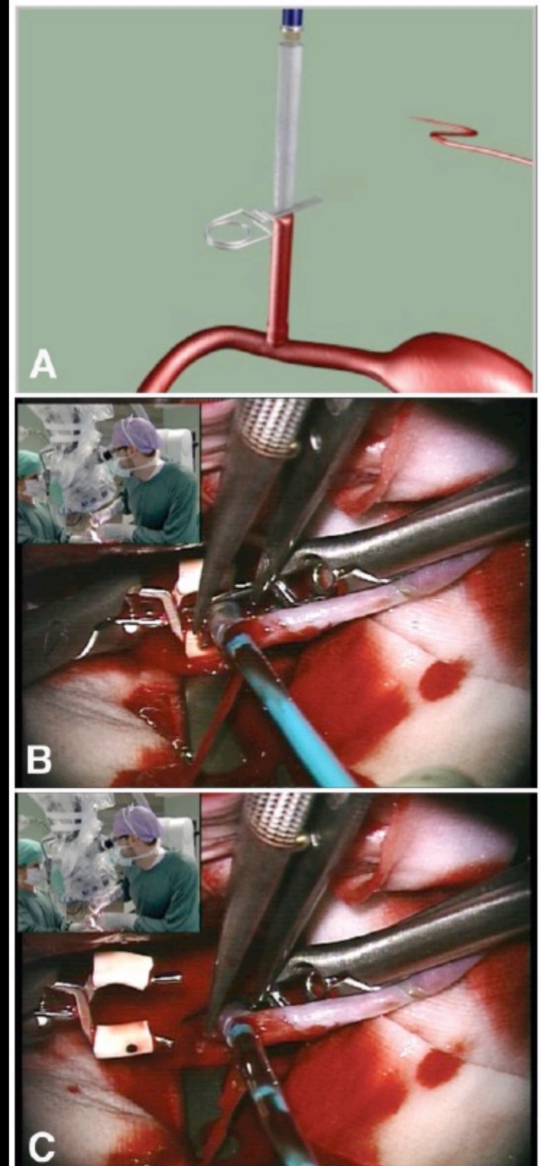


Fig. 7. A: Computer-generated drawing showing removal of catheter following arteriotomy, with a temporary clip applied to the donor vessel to prevent backbleeding. B: Intraoperative photograph showing a silicone tube–covered fenestrated clip used to hold the vein graft around the catheter. The clip is removed prior to withdrawal of the catheter. C: The laser catheter is then withdrawn and a temporary clip is placed on the graft.

Langer DJ et al. Neurosurg Focus. 24(2):E6, 2008.

ELANA

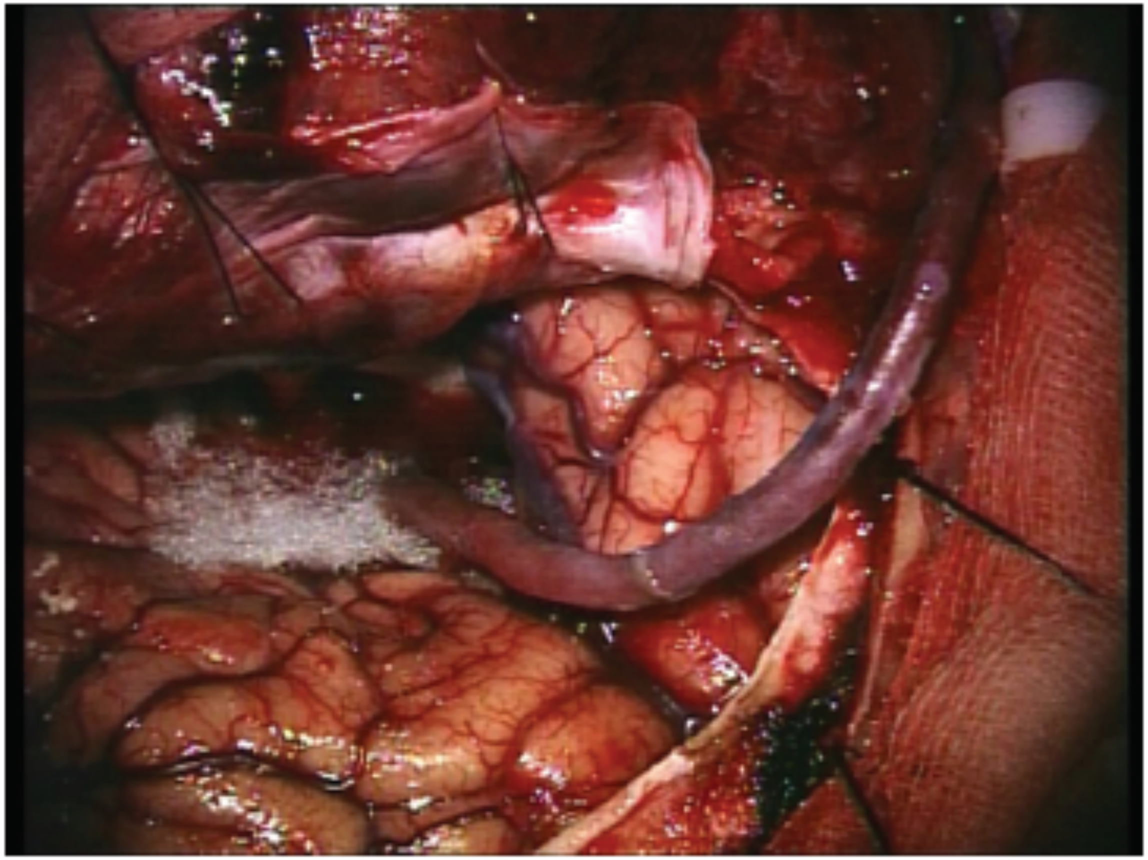


FIG. 9. Intraoperative photograph taken after the side slit of the vein graft has been closed with a continuous suture, the temporary clips are removed, and the bypass is opened. The proximal anastomosis in the ECA has been completed before the lasering step is performed.

ELANA

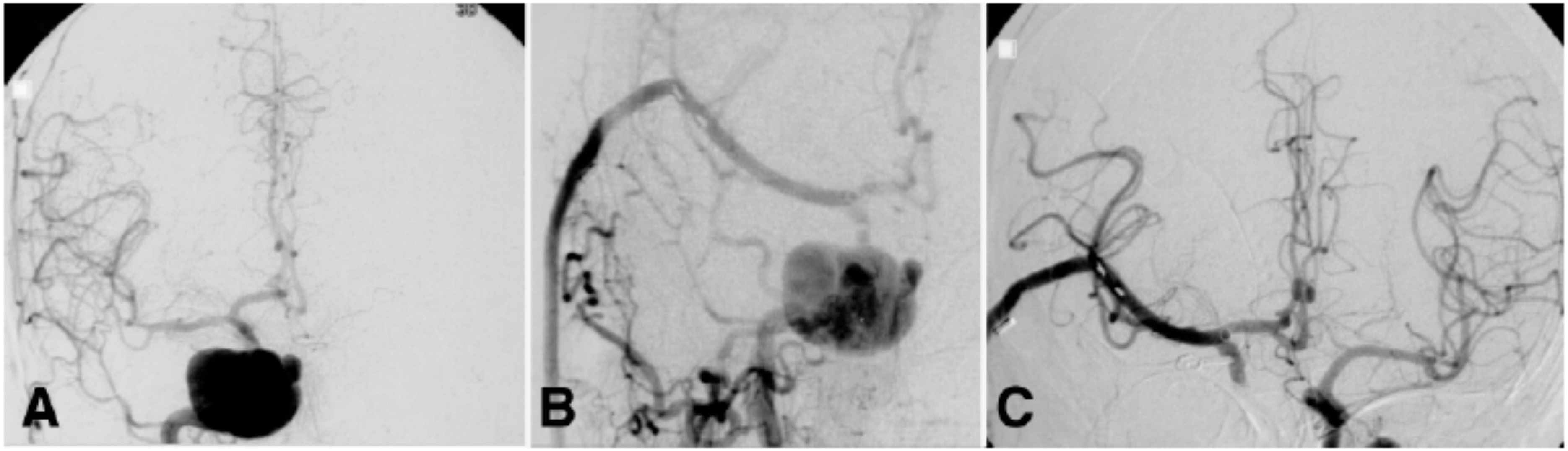


FIG . 10. A: Right ICA angiogram revealing a giant cavernous carotid aneurysm. B: Postoperative right ICA angiogram demonstrating the ELANA EC–IC bypass. Note platinum ring at carotid artery bifurcation at distal anastomosis. C: Postoperative angiogram of the aortic arch. The right ICA has been surgically occluded. Bypass fills the right MCA and bilateral ACA with a diminutive left A1 segment.

Langer DJ et al. Neurosurg Focus. 24(2):E6, 2008.

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