Inform Cerebrovascular Surgeries with Volume Flow Measurements

- Identify Inadvertent Vessel Compromise
- Confirm Flow Preservation
- Quantify Flow Augmentation

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Charbel Flowprobes® Provide On-the-Spot Quantitative Cerebrovascular Measurements

Intraoperative measurements with the bayonet-style Charbel Flowprobe® take the guesswork out of blood flow during aneurysm clipping, extracranial to intracranial (EC-IC) bypass surgeries, arteriovenous malformations (AVMs), dural fistula obliteration, and tumor resection surgeries.

During aneurysm clipping surgery, flow measurements help surgeons achieve optimal clip placement to obliterate the aneurysm without compromising flow in parent vessels and distal branches that might cause an intraoperative stroke. Measurements either confirm the surgeon's clinical assessment of flow preservation, or expose the need for immediate correction of flow deficits. Moreover, during temporary clippings, flow measurements offer an assessment of collateral flow reserve and predict the safety of the temporary clipping.

During EC-IC bypass surgery to preserve or augment distal cerebral perfusion, intraoperative flow measurements help the surgeon choose the most appropriate bypass and predict its future patency.

Intraoperative flow measurements provide invaluable quantitative flow information to augment the surgeon's clinical armamentarium. No other technology produces flow data so quickly, accurately, and non-intrusively during cerebrovascular surgery as do Transonic® intraoperative Flowmeters.

"Flow is a vital parameter during cerebrovascular surgery; including flow in my surgical approach gives me a high degree of control over surgical outcome. When I close the patient, I know the patient will recover without ischemia surprises. This translates into peace of mind for the patient and me, and saves money for the hospital."
F Charbel, MD, FACS

"... Intraoperative Flow may now constitute the most reliable tool for increasing safety in aneurysm surgery." A Pasqualin, MD

"Transit-time flow measurements are useful for surgical management during cerebrovascular surgery. The technique was simple to use and provided sensitive, stable, reliable results.. N Nakayama, MD

"One of the major risks associated with aneurysm surgery is the potential for inadvertent occlusion or compromise of the vascular branches from which the aneurysm arises, which can result in stroke." "Use of the ultrasonic flow probe provides real-time immediate feedback concerning vessel patency ... Intraoperative flow measurement is a valuable adjunct for enhancing the safety of aneurysm surgery." S Amin-Hajani, MD, FACS

TRANSIT-TIME ULTRASOUND TECHNOLOGY

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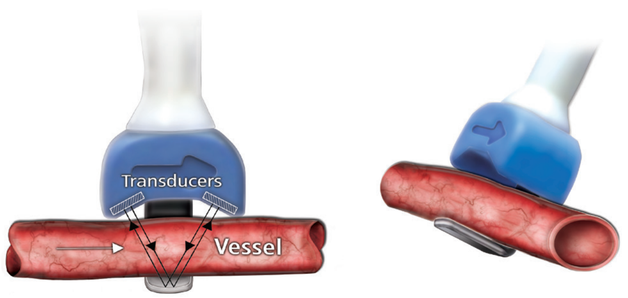

Two transducers pass ultrasonic signals, alternately intersecting the vessel in upstream and downstream directions. The difference between the two transit times yields a measure of volume flow.

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Transonic Systems Inc. is a global manufacturer of innovative biomedical flow measurement equipment. Founded in 1983, Transonic sells state-of-the-art, transit-time ultrasound devices for surgical, hemodialysis, perfusion, ECMO, and medical device testing applications, and for incorporation into leading edge medical devices.

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Cerebrovascular Cover (NS-300-fly)RevE 2023

Flow-assisted Surgical Techniques and Notes*
Aneurysm Clipping Surgery Protocol

Drawn from the clinical expertise of FT Charbel, MD, S Amin-Hanjani MD, Univ. of IL at Chicago

*Flow-Assisted Surgical Techniques ("F•A•S•T") and Protocols are drawn from surgical experiences by transit-time flow measurement users and passed along by Transonic for educational purposes. They are not intended to be used as sole basis for diagnosis. Clinical interpretation of each patient's individual case is required.

Introduction[1,4-9]

During aneurysm clipping surgery, a cerebrovascular surgeon may elect to use a non-constrictive Charbel Micro-Flowprobe® to measure blood flow in major cerebral vessels. Flow measurements help the surgeon achieve optimal clip placement to obliterate the aneurysm without compromising flow in parent vessels and distal branches that might cause an intraoperative stroke.

Measurements Steps[1-4]

1. Identify Vessels at Risk

Expose and identify parent vessels and distal outflow vessels of the aneurysm.

2. Select Flowprobe Size

Measure the vessel diameter of the target vessels with a gauge before opening the Probe package. Select Probe size(s) so that the vessel(s) will fill between 75% - 100% of the window of the Probe(s).

3. Apply Flowprobe

Examine the vessel to determine the optimal position for applying the Probe. Select a site wide enough to accommodate the Probe's acoustic reflector without compromising perforating arteries coming off the vessel. Apply the Flowprobe so that the entire vessel lies within the Probe window and aligns with the Probe body.

Bend the Flowprobe's flexible neck as needed to position the Probe on the vessel. As the Flowprobe is being applied to the vessel, listen to FlowSound®. The higher the pitch, the greater the flow.

Sterile saline or cerebrospinal fluid may be used to flood the Probe window and provide ultrasound coupling. Do not irrigate continuously because the Probe will also measure the flow of the saline. Check the Signal Quality Indicator on the Flowmeter for adequate acoustic contact. If acoustic contact falls below an acceptable minimum, the Flowmeter/monitor displays an acoustic error message.

4. Measure Baseline Flows

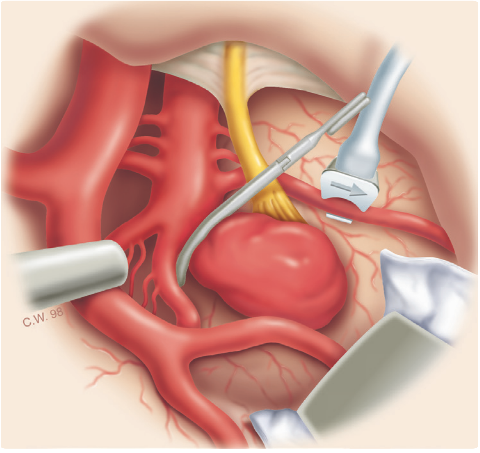
Measure baseline flows in all vessels at risk before clipping the aneurysm. Baseline flows should be measured following burst suppression, since these protective agents will decrease baseline flows. Record the baseline flow measurements and the patient's blood pressure on the Flow Record.

5. Document Flows

Wait 10-15 seconds for mean readings to stabilize after applying the Probe. Document flows for the case record by recording them, printing or taking a snapshot of the phasic flows. If the meter displays a negative flow, press the INVERT button to change the polarity before printing the waveform.

6. Post-Clip Flows & Compare to Baseline

After an aneurysm has been clipped, remeasure flow in each of the vessels and compare the post-clip flows with baseline flows. Each measurement should be equal or greater than the respective baseline flow. Greater flows are expected in cases where the aneurysm has compromised flow well below the vessel's expected flow level (chart on page 4). Temporary clipping can also produce hyperemia which can cause flows to be 20-30% higher than baseline.



RIGHT SUPERIOR CEREBELLAR ANEURYSM with Flowprobe placed on superior cerebellar artery (SCA) to measure restoration of flow after clipping the aneurysm. Illustration by Christa Wellman

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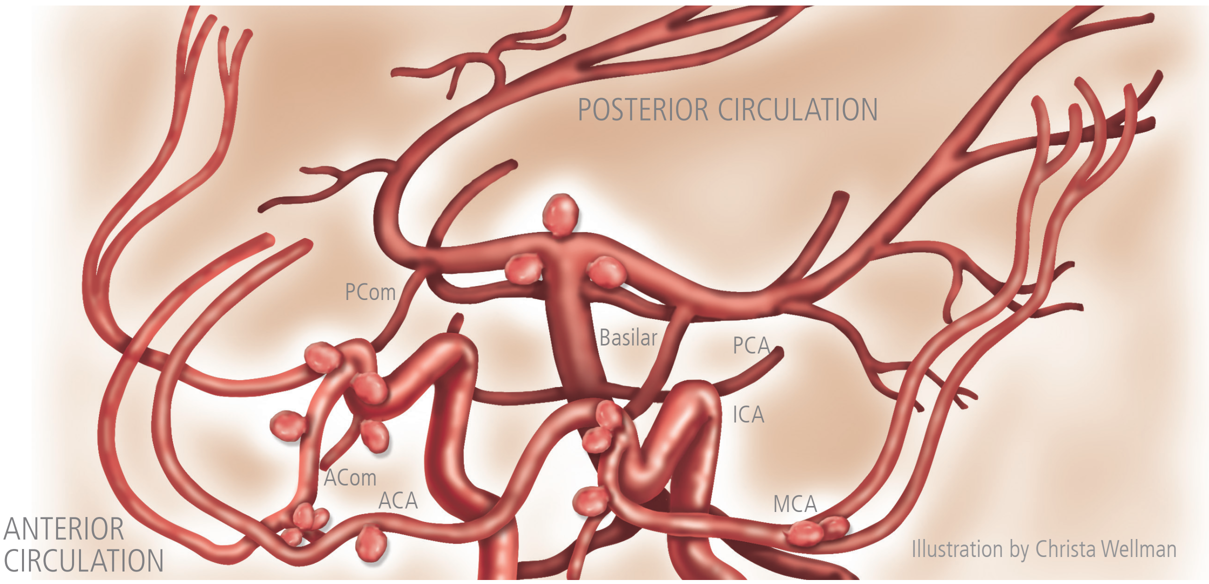
Flow-assisted Surgical Techniques and Notes*
Aneurysm Clipping Surgery Protocol cont.



Common sites for anterior circulation aneurysms include the carotid ophthalmic artery (OpthA), Internal Carotid Artery (ICA) bifurcation, Middle Cerebral Artery (MCA) bifurcation, M1 Segment MCA, Anterior Cerebral Communicating Artery (AComA), and Posterior Communicating Artery (PComA) artery. The most common sites for aneurysms in the posterior cerebral circulation include the basilar artery (BA), posterior inferior cerebellar artery (PICA) and superior cerebellar artery (SCA).

Measuring Flow[1]

Identify Vessels at Risk
↓
Select Proper Flowprobe Size
↓
Measure Baseline Flows in all vessels at risk
↓
Measure Post-clip Flows in all vessels at risk
↓
Compare Post-clip Flows to Baseline Flow

- **Flow equal or more than baseline** → Flow Preserved in vessels at risk
- **Flow less than baseline** → Re-examine/adjust clip and remeasure flow.

Flow Measurement Summary[1-3]

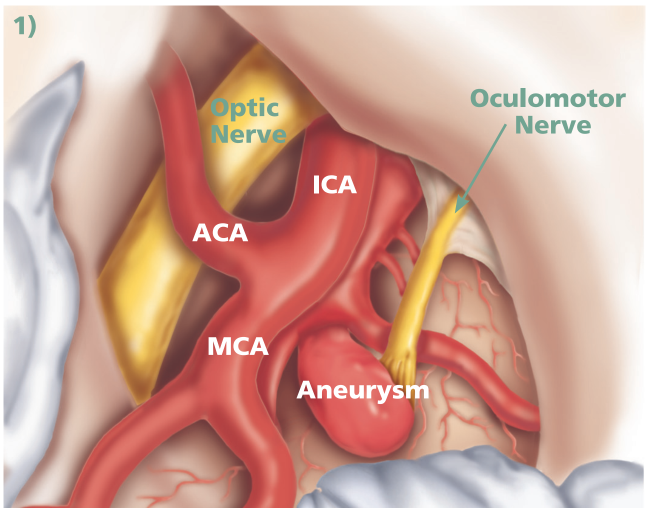
- Measure vessel and select a Flowprobe size so that the vessel will fill at least 75% of the Flowprobe's lumen. Use sterile saline or cerebrospinal fluid to obtain good ultrasonic contact between the Flowprobe and the vessel.
- Bend the Flowprobe's flexible segment to best position the probe around the vessel. Listen to FlowSound® to hear volume flow.
- When readings stabilize, flow data captured flow data by recording, taking a snapshot, or by pressing PRINT on the Flowmeter. If the Flowmeter's LED flow reading is negative, press INVERT to reverse the polarity of the flow reading from negative to positive before printing out the waveform.

Measurement Review[1]

- Measure baseline flows before clipping aneurysm.
- Measure flow after temporary clipping of an aneurysm to check integrity of flow.
- Confirm flow restoration after permanent clipping by comparing post-clipping flows with baseline flows.

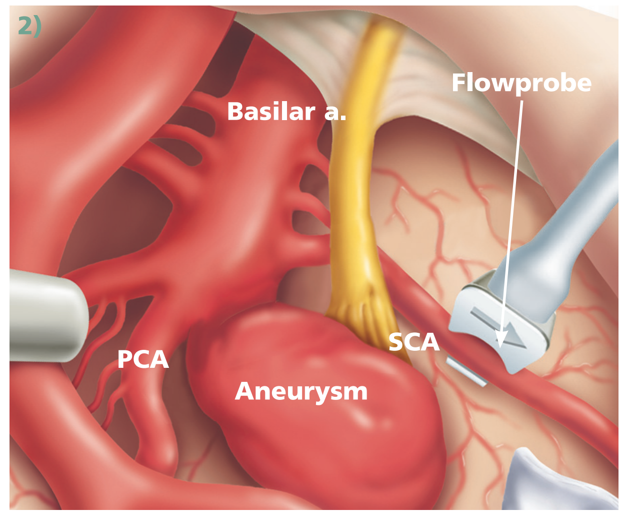
Case Report: Flow Measurement during SCA Aneurysm Clipping Surgery[1]

Illustrations by Christa Wellman

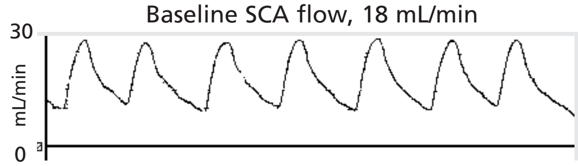


Vessel(s) at Risk Identified

A patient presented with headaches and diplopia. A cerebral angiogram confirmed a right cerebellar aneurysm. Meticulous dissection on the right side exposed an aneurysm between the superior cerebellar artery (SCA) and posterior cerebral artery (PCA).

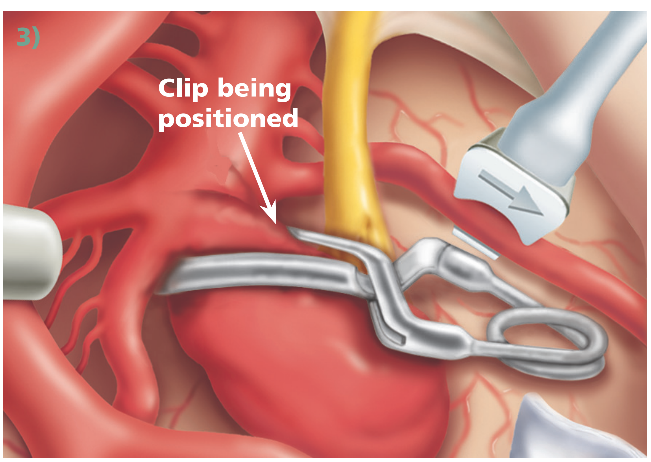


Baseline SCA flow, 18 mL/min

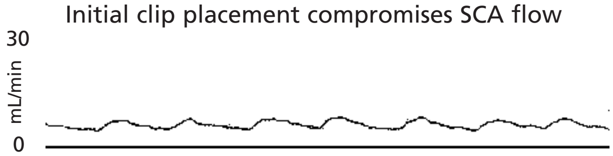


Baseline Flow Measurements

The Charbel Micro-Flowprobe® was first placed on the SCA. Flow measured 6-18 cc/min. The Flowprobe was then placed on the PCA and flow measured 34-36 cc/min.

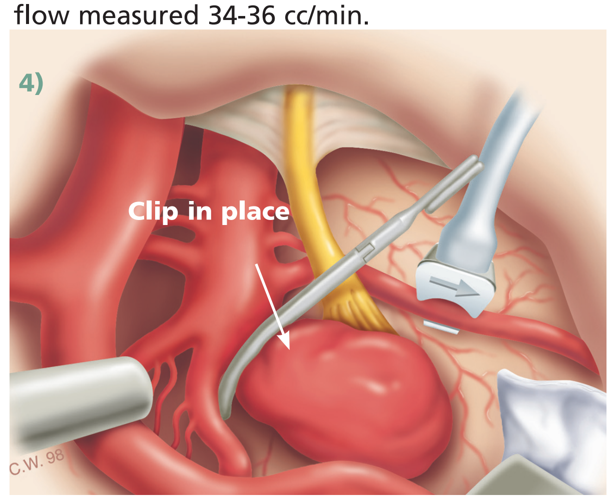


Initial clip placement compromises SCA flow

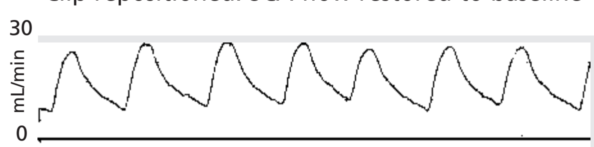


Flow Integrity Checked after Aneurysm clipping

SCA flow dropped to 2-4 cc/min.
PCA flow was recorded as 55-60 cc/min



Clip repositioned: SCA flow restored to baseline



The SCA was found to be partially incorporated in the clip. Clip repositioned and SCA and PCA flows returned almost to baseline levels.

Flow-assisted Surgical Techniques and Notes* Arterial EC-IC Bypass Surgery Protocol

Drawn from the clinical expertise of FT Charbel, MD, FACS, S Amin-Hanjani, Univ. of IL at Chicago, Chicago, IL *et al.*[1-24]

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Introduction[3]

An extracranial to intracranial (EC-IC) bypass is used during cerebrovascular surgery:

1) to augment flow for occlusive cerebrovascular disease (i.e., Moyamoya)
2) to replace flow during aneurysm clipping surgery when an aneurysm is trapped and a parent vessel (i.e., internal carotid) has to be occluded and sacrificed.

Flow Augmentation for Occlusive Cerebrovascular Disease[1-5]

In 2005, Drs. Fady Charbel and Sepideh Amin-Hanjani introduced the concept of a Cut Flow Index to evaluate the quality of an EC-IC bypass used to enhance flow during cerebral ischemia. Briefly, the free flow of the donor extracranial artery intended for use as a bypass is measured. Once the bypass is constructed, the bypass flow of the donor artery is measured. The ratio of bypass flow to free flow is the Cut Flow Index. A value greater than 0.5 indicates that the bypass should be viable.

Flow Replacement during Aneurysm Clipping Surgery[1,6]

Dr. Amin-Hanjani developed a strategy to assess the adequacy of an STA-or an occipital artery bypass to replace flow when an aneurysm has to be trapped and a parent vessel sacrificed.

Flow Deficit Determined

Flow in the artery or territory distal to the aneurysm is measured and recorded. The vessel to be sacrificed is temporarily occluded and flow is again measured in the distal artery or territory. The difference between the two flows represents the amount of flow deficit that can be expected if the parent vessel is sacrificed. This is the flow that the bypass will have to replace.

Free Flow Determined

The "Free" or "Cut Flow" of the intended bypass is then measured. This Cut Flow value is compared to Deficit Flow. If the Cut Flow value equals or exceeds the potential flow deficit, the EC-IC bypass is completed and the vessel can be sacrificed with reasonable assurance that the bypass flow will compensate for the flow deficit from the sacrificed parent vessel.

Example: STA to M3 Bypass (ICA Aneurysm Clipped, Trapped and ICA Sacrificed)[1,6]

1)	M1 baseline flow measured	70mL/min
2)	M1 flow measured with ICA temporarily occluded	50 mL/min
3)	Anticipated Flow Deficit Calculated (if aneurysm trapped and parent vessel sacrificed)	20 mL/min
4)	STA Cut Flow measured (STA bypass should be able to supply the flow deficit)	44 mL/min
5)	STA Bypass to M3 completed; aneurysm clipped and trapped	
6)	STA Bypass Graft Flow measured (bypass flow can compensate for anticipated flow deficit)	24 mL/min

Dr. Amin-Hanjani reported that this selective strategy allows the surgeon to:

1) Assess the adequacy of a bypass before completing its construction
2) Select the best match for a bypass
3) Evaluate the bypass immediately

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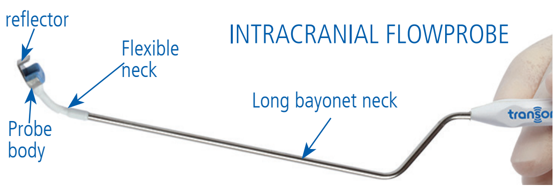
Flow-assisted Surgical Techniques and Notes Arterial EC-IC Bypass Surgery Protocol cont.

When a surgeon selects an arterial extracranial-intracranial (EC-IC) Bypass to preserve flow during aneurysm clipping or trapping surgery, Charbel Probes® assess the adequacy of flow(s) during and after construction of the bypass.[1-5]

Extracranial Donor Artery[1-7]

1. Choose an appropriate-sized Charbel Probe® for the donor (STA) artery.

Probe Size	Vessel Range, Outer Diameter
1.5 mm	1.1 - 1.6 mm
2 mm	1.6 - 2.4 mm
3 mm	2.6 - 3.8 mm



2. Measure baseline flow in the donor artery. Record on the EC-IC Bypass Record.
3. Cut the donor extracranial artery and measure the artery's "Free Flow" by allowing the cut distal end to bleed freely for 15-20 seconds (Fig. 1). This free flow or "Cut Flow"is the amount of flow at zero resistance or the "carrying" capacity or maximum flow the artery can deliver. Record flow on the EC-IC Bypass Record.[5]

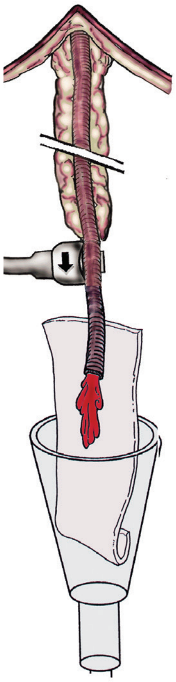
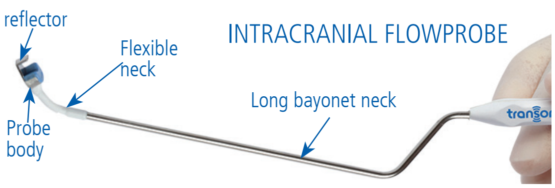


Fig. 1: Measurement of "cut" flow in donor artery.

Intracranial Recipient Artery[1-7]

1. Choose an appropriate size Charbel Probe® for recipient artery.

Probe Size	Vessel Range, Outer Diameter
1.5 mm	1.1 - 1.6 mm
2 mm	1.6 - 2.4 mm
3 mm	2.6 - 3.8 mm



2. Measure and record baseline flow in recipient intracranial artery distal to target anastomotic site.
3. Re-measure, record baseline flow in recipient intracranial artery distal to target anastomotic site with vessel to be sacrificed occluded.
4. Calculate anticipated flow deficit by substracting flow with vessel occluded from baseline recipient arterial flow.

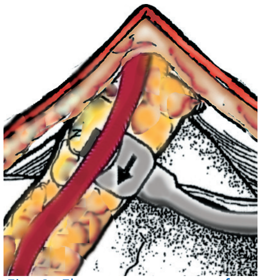


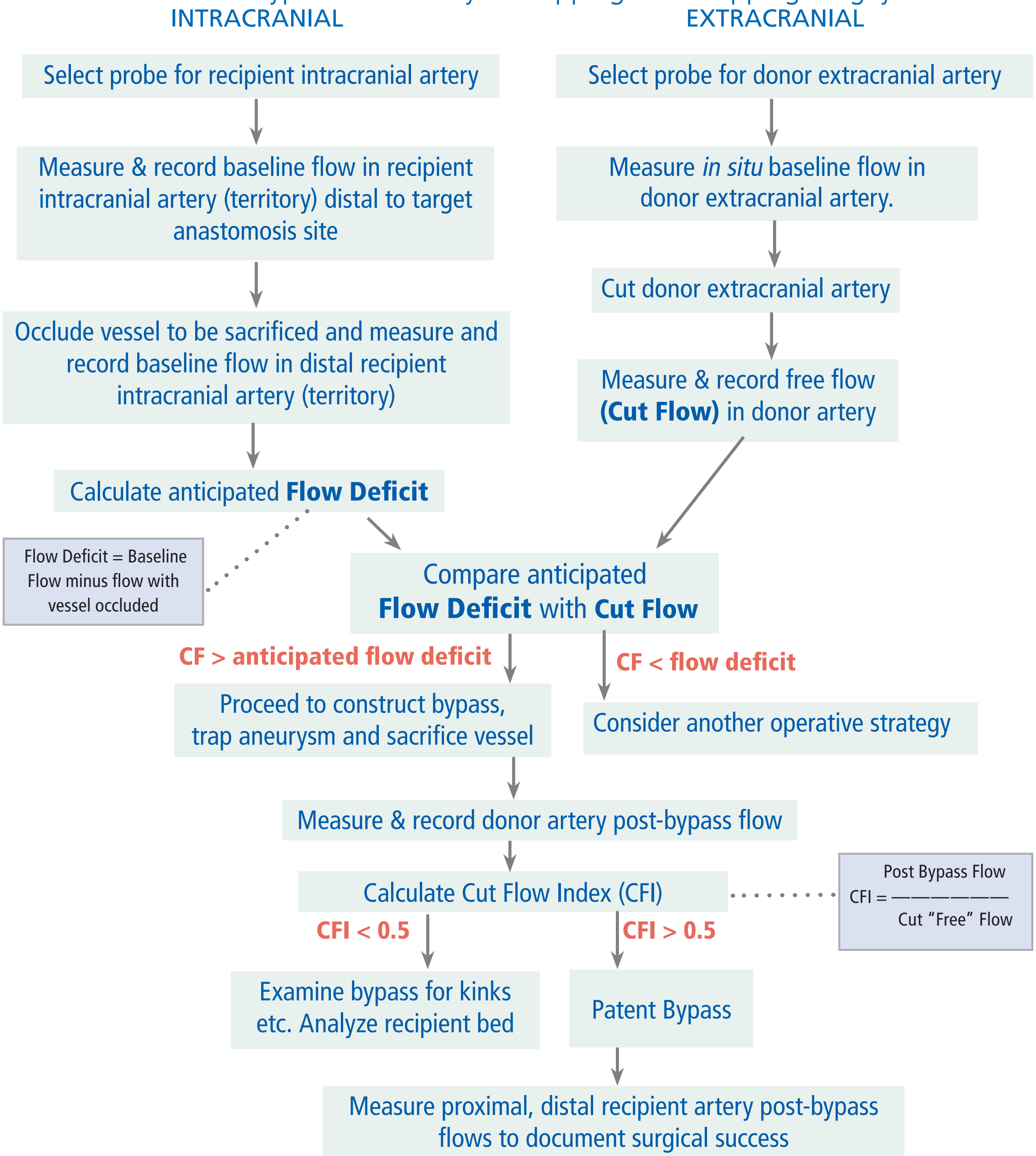
Fig. 2: Flow measurement of bypass after anastomosis to recipient artery.

Construct EC-IC Bypass[1-7]

1. Anastomose the extracranial bypass to the recipient arterial vessel.
2. Measure post-bypass flow in the donor artery (Fig. 2). Record flow.
3. Calculate the Cut Flow Index (CFI) by dividing the Post-Bypass Flow by the Free or Cut Flow (Fig. 1).
   - If post-bypass flow exceeds 50% of (CFI > 0.5), the bypass can be considered successful.
   - If bypass flow is below 50% of free flow (CFI < 0.5), examine bypass for kinks, analyze recipient bed.

Flow-assisted Surgical Techniques and Notes
Arterial EC-IC Bypass Surgery Protocol cont.

EC-IC Bypass for Aneurysm Clipping and Trapping Surgey[1-7]



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Flow-Assisted Surgical Techniques and Notes* STA-MCA Bypass for Moyamoya Protocol

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Introduction[1,3]

One strategy a surgeon may elect to use to alleviate the symptoms of Moyamoya syndrome is the surgical creation of an arterial extracranial to intracranial (EC-IC) bypass from the superficial temporal artery (STA) to the cerebral artery branches. The bypass is designed to augment flow in the intracranial territories. During surgery, the Charbel Micro-Flowprobe® is used to measure direct volume blood flow in the STA bypass and small target MCA branch vessels. Intraoperative blood flow measurements confirm the quality of the anastomosis and assure that the target area is receiving sufficient blood from the bypass. Measurements also prompt revision if a technical error is suspected.

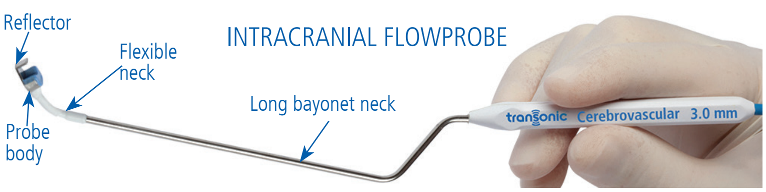
Flow Measurement Steps[1,2]

Measure mean arterial pressure (MAP), end-tidal CO_2 and temperature. Record values on an Bypass Flow Record.

Pre-anastomosis: Intracranial Recipient Arteries

1. Measure the diameter of the intracranial recipient arteries and choose appropriately-sized Charbel Micro-Flowprobes to measure recipient vessel flows.

Probe Size	Vessel Range, Outer Diameter
1.5 mm	1.1 - 1.6 mm
2 mm	1.6 - 2.4 mm



2. Measure recipient vessels (M4branches/MCA) flow.
3. Record flow and flow direction on EC-IC Bypass Record.

Extracranial Donor Artery[1,2]

4. Dissect the extracranial STA artery free. Skeletonize a segment for application of the Flowprobe.
5. Measure the diameter of the STA and choose the appropriately-sized Flowprobe to measure STA baseline flow. See table above for probe sizes.

Post-anastomotic Flow Measurements

6. After construction of a one donor artery (STA) to two recipient arteries (M4 branches/MCA) with a side-to-side and an end-to-side anastomoses (1D2R) bypass[3,4], measure post-anastomotic flows in the intracranial and extracranial arteries sequentially in the following order:
   1) distal M4 branch/MCA;
   2) proximal M4 branch/MCA;
   3) distal STA;
   4) proximal STA.
7. If post-bypass flow in the recipient arteries (sum of absolute values of distal and proximal M4/MCA recipient flows) is not significantly above the pre-bypass flow, re-examine the anastomoses and the bypass for kinks or twists and redo, if necessary. Apply a vasodilator (papaverine) when there is vasospasm due to manipulation of the vessel and/or if flow measurements seem to be low or absent.
8. Record flow rates and flow directions, MAP, end-tidal CO_2, and occlusion time on the EC-IC Bypass Record.

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Flow-Assisted Surgical Techniques and Notes* STA-MCA Bypass for Moyamoya Protocol cont.

Flow Measurement during EC-IC Bypass Revascularization for Moyamoya Syndrome[1-4]

Measure size of recipient intracranial arteries (M4 branches/ MCA) and choose appropriate size Flowprobe(s).

↓

Measure baseline flow of recipient intracranial arteries (M4 branches/MCA) at anastomotic site. Record flow.

↓

Measure size of donor artery (STA) at distal end and choose appropriate-size Flowprobe.

↓

Cut donor STA.

↓

Optional: measure/record free (cut) flow in donor STA.

↓

Construct EC-IC bypass by anastomosing donor STA to two M4 branches of the MCA. The proximal M4 branch is anastomosed with a side-by-side anastomosis. The distal M4 branch is anastomosed with an end-to-side anastomosis.

↓

Measure post-bypass flows proximal and distal to the anastomoses in the recipient vessels and donor STA. Record all flow rates.

- **M4 flows did not increase** → Examine anastomoses; examine bypass for kinks etc. Analyze recipient beds.
- **M4 flows increased** → Good bypass.
- **M4 flows increased significantly** → Aggressive post-op management indicated to avoid complications.

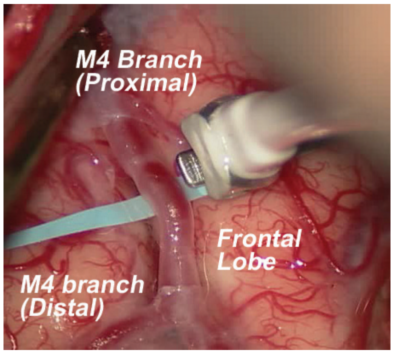


Photo shows the M4/MCA site just before the Flowprobe is slipped around the vessel to measure baseline M4 flow before anastomosing the bypass to the vessel. The blue background is placed to help visibility during sewing of the anastomosis and as the Flowprobe is applied to the vessel.

Flow-assisted Surgical Techniques and Notes* Venous EC-IC Bypass Surgery Protocol

*Flow-Assisted Surgical Techniques ("F•A•S•T") and Protocols are drawn from surgical experiences by transit-time flow measurement users and passed along by Transonic for educational purposes. They are not intended to be used as sole basis for diagnosis. Clinical interpretation of each patient's individual case is required.

Introduction[1,3-4]

When construction of an arterial extracranial to intracranial (EC-IC) bypass graft is contraindicated due to artheroschlerosis, twisting or a poor section of the superficial temporal artery, the surgeon may elect to harvest a vein and construct a venous EC-IC Bypass graft to preserve or augment intracranial flow. Intraoperative flow measurements provide on-the-spot feedback as the surgeon identifies and defines the specific hemodynamic requirements for each case.

Venous Bypass[1]

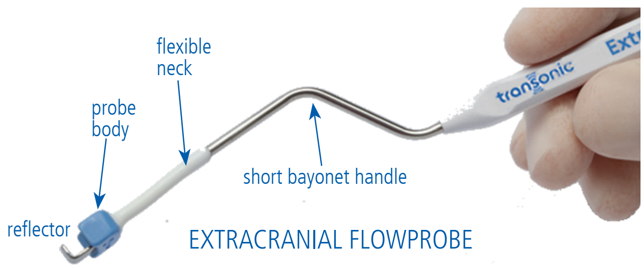
Since the proximal end of the vein graft is generally anastomosed to a carotid artery, a concern is that the graft will produce too much flow for the recipient vasculature and cause hyperemia. Therefore, free graft flow after the graft has been sewn to the carotid artery is measured in order to determine the maximum flow capacity for the graft and its hemodynamic match to the recipient artery. Baseline flows are also measured in the intracranial recipient artery before anastomosis. After the venous graft has been anastomosed intracranially to the recipient cerebral artery, post-anastomotic flows are measured in both the graft and recipient artery and are compared with baseline flows.

Flow Measurement Steps[1,2]

Extracranial Donor Venous Graft

1. Choose the appropriate size flowprobe to measure baseline flow in the extracranial venous graft. Record flow on the EC-IC Bypass Record (Fig. 1).

PROBE SIZE (MRS/MBS)	VESSEL RANGE, OUTER DIAMETER
3 mm	2.7 - 4.0 mm
4 mm	3.0 - 5.0 mm
6 mm	4.0 - 7.3 mm



EXTRACRANIAL FLOWPROBE

2. After the venous graft is anastomosed to the carotid artery, measure "Free Flow" in the vein graft by allowing the distal end to bleed freely for 15-20 seconds. This "Free Flow" is the amount of flow at zero resistance and indicates the "carrying" capacity or maximum flow the vein will deliver. Record flow on the EC-IC Bypass Record (Fig. 2, next page).
3. After the venous bypass has been anastomosed to the recipient cerebral artery, measure post-bypass flow in the donor graft. Record flow.

Measurement Technique[2]

- Select a Probe size so that the vessel will fill at least 75% of the lumen of the Probe. Use sterile saline or cerebrospinal fluid to obtain good ultrasonic contact between the Probe and vessel.
- Bend the Probe's flexible segment to best position the Flowprobe around the vessel. Listen to FlowSound® to hear volume flow.
- Wait about 30 seconds after Flowprobe application for readings to stabilize. Take a snapshot of mean flow readings or record readings displayed on the Flowmeter's LED.
- Press PRINT or take a snapshot to document flows. If a negative flow reading is displayed, press the Invert button to reverse the polarity of the flow reading from negative to positive before printing out the flow waveform.

References:

1. Cerebrovascular Surgery Handbook NS-59-hb, Rev F, 2018
2. Measuring PeriFlowprobe (CV-180-mn)RevA 2018 USltr
3. Amin-Hanjani S, "Cerebral revascularization: extracranial-intracranial bypass," J Neurosurg Sci. 2011 Jun; 55(2): 107-16. (Transonic Reference # 11097AH)
4. van der Zwan A, "How I Do It:" Non-occlusive High Flow Bypass Surgery," Acta Neurochir Suppl. 2014; 119:71-6. (Transonic Reference # 10086AH)

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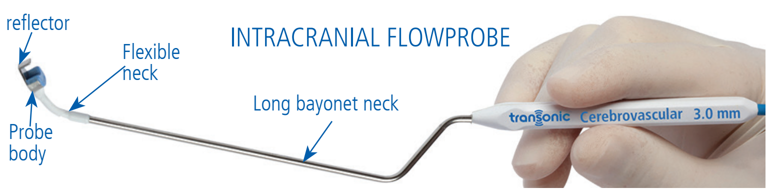
Flow-assisted Surgical Techniques & Notes*
Venous EC-IC Bypass Surgery Protocol cont.

Intracranial Recipient Artery[1,2]

1. Choose an appropriate size flowprobe and measure and record baseline flow in the intracranial recipient artery .

PROBE SIZE(3MB/3MR)	VESSEL RANGE, OUTER DIAMETER
1.5 mm	1.1 - 1.6 mm
2 mm	1.6 - 2.4 mm
3 mm	2.6 - 3.8 mm



2. After the bypass has been constructed, measure flows in the donor vein. Record flows on the EC-IC Bypass Record.
3. Evaluate the hemodynamic match between donor venous flow and recipient arterial flows per flow chart on the right.

Date	Type of Bypass		Reason for Bypass		Surgeon
Extracranial Donor	**Probe Size**	**BP Mean**	**Pre-Bypass Flow** ml/min	**Post-Bypass Flow1** ml/min	**Post-Bypass Flow2** ml/min
Intracranial Recipient Artery	**Probe Size**	**BP Mean**	**Pre-Bypass Flow** ml/min	**Post-Bypass Flow1** ml/min	**Post-Bypass Flow2** ml/min
Comments/Observations/History					

Fig.1: Example of a Flow Record to record flow readings during EC-IC Bypass.

Flow Measurements during Venous EC-IC Bypass[1,2]

Measure and record baseline flows in recipient intracranial artery proximal and distal to target anastomosis site.

↓

Select probe size for donor extracranial vein.

↓

Anastomose vein graft to carotid artery

↓

Anastomose donor vein graft to intracranial recipient artery to create EC-IC bypass

↓

Measure and record post-bypass flow in the donor vein.

↓

Assess bypass flow hemodynamically in relation to recipient artery.

- **Flows did not increase** → Check anastomosis; examine bypass for kinks etc. Analyze recipient bed.
- **M4 flows increased** → Good bypass. → Measure post-bypass flows at proximal and distal recipient artery sites to document surgical success.
- **Flows increased significantly** → Aggressive post-op management indicated to avoid complications.

Flow-assisted Surgical Techniques and Notes* AVM Resection Protocol

*Flow-Assisted Surgical Techniques ("F•A•S•T") and Protocols are drawn from surgical experiences by transit-time flow measurement users and passed along by Transonic for educational purposes. They are not intended to be used as sole basis for diagnosis. Clinical interpretation of each patient's individual case is required.

Introduction[1,3-4]

During a microsurgical resection/obliteration of an arteriovenous malformation (AVM), a cerebrovascular surgeon may elect to use a Charbel Micro-Flowprobe® (Fig. 1) as a quantitative tool to directly measure volume blood flow in cerebral vessels in order to guide the surgical strategies.

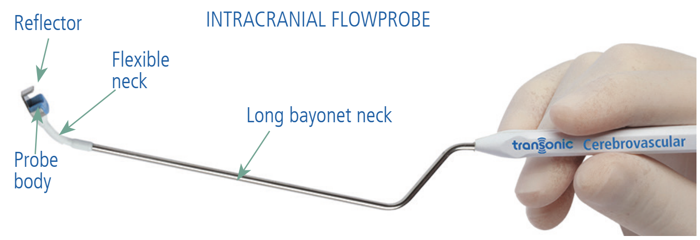


Fig. 1: The Charbel Micro-Flowprobe® is designed for deep intracranial surgery. Their long bayonet handle permits use under a surgical microscope. A flexible neck segment permits the Flowprobe neck to be bent, as needed, to optimally position the probe around a vessel.

Measurements Steps[1-3]

Pre-resection:

1. Identify Vessels to be measured

   Expose and identify afferent vessels and venous outflow vessels of an AVM.

2. Select Flowprobe Size

   Measure the vessel diameter of the vessels with a gauge before opening the Flowprobe package. Select a Flowprobe size so that the vessel will fill between 75% - 100% of the ultrasonic sensing window of the Flowprobe.

3. Apply Flowprobe

   Determine the optimal position for applying the Probe on the vessel by selecting a site wide enough to accommodate the Flowprobe's acoustic reflector without compromising perforating arteries coming off the vessel. Apply the Flowprobe so that the entire vessel lies within the ultrasonic sensing window of the Flowprobe and aligns with the Probe body (Fig. 2).

   Fig. 2

   Bend the Flowprobe's flexible neck segment as needed (Fig. 1). As the Flowprobe is being applied to the vessel, listen to FlowSound®. The higher the pitch, the greater the flow.

   Sterile saline or cerebrospinal fluid may be used to flood the Flowprobe's lumen and provide ultrasound coupling. Do not irrigate continuously because the Flowprobe will also measure saline flowing around the vessel. The Signal Quality Indicator on the Flowmeter or Monitor indicates acoustic contact. If acoustic contact falls below an acceptable value, an acoustic error message will be displayed.

4. Measure Baseline Flows before Resection

   Before AVM resection, and following burst suppression, measure baseline flows in all afferent, transit and venous vessels. Record the baseline flow measurements and the patient's blood pressure on a Flow Record.

5. Measure Flows during and Post Resection

   During resection, measure flows as needed in each of the vessels. In possible transit arteries measure at different sites along the vessel. A drop in flow between two points on the vessel might identify an additional feeder into the AVM. Compare flows with baseline flows to guide the surgical procedure. Measure flows post resection to ensure total obliteration of the AVM.

6. Document Flows

   Document flow phasic flow patterns for the case record by waiting 10-15 seconds after applying the Flowprobe for mean readings to stabilize. If a negative flow is displayed, press the INVERT button to change the polarity before printing the waveform.

References:

1. Cerebrovascular Surgery Handbook NS-59-hb, Rev F, 2018
2 Measuring PeriFlowprobe(CV-180-mn)RevA2018USltr
3 Della Puppa A et al, "Intraoperative Flow Measurement by Microflow Probe During Surgery for Brain Arteriovenous Malformations," Neurosurg 2015; Jun; 11 Suppl 2:268-73. (Transonic Reference # 10288AH)
4.Kirk HJ *et al*, "Intra-operative transit time flowmetry reduces the risk of ischemic neurological deficits in neurosurgery." Br J Neurosurg. 2009; 23(1): 40-7. (Transonic Reference # 7744AH)

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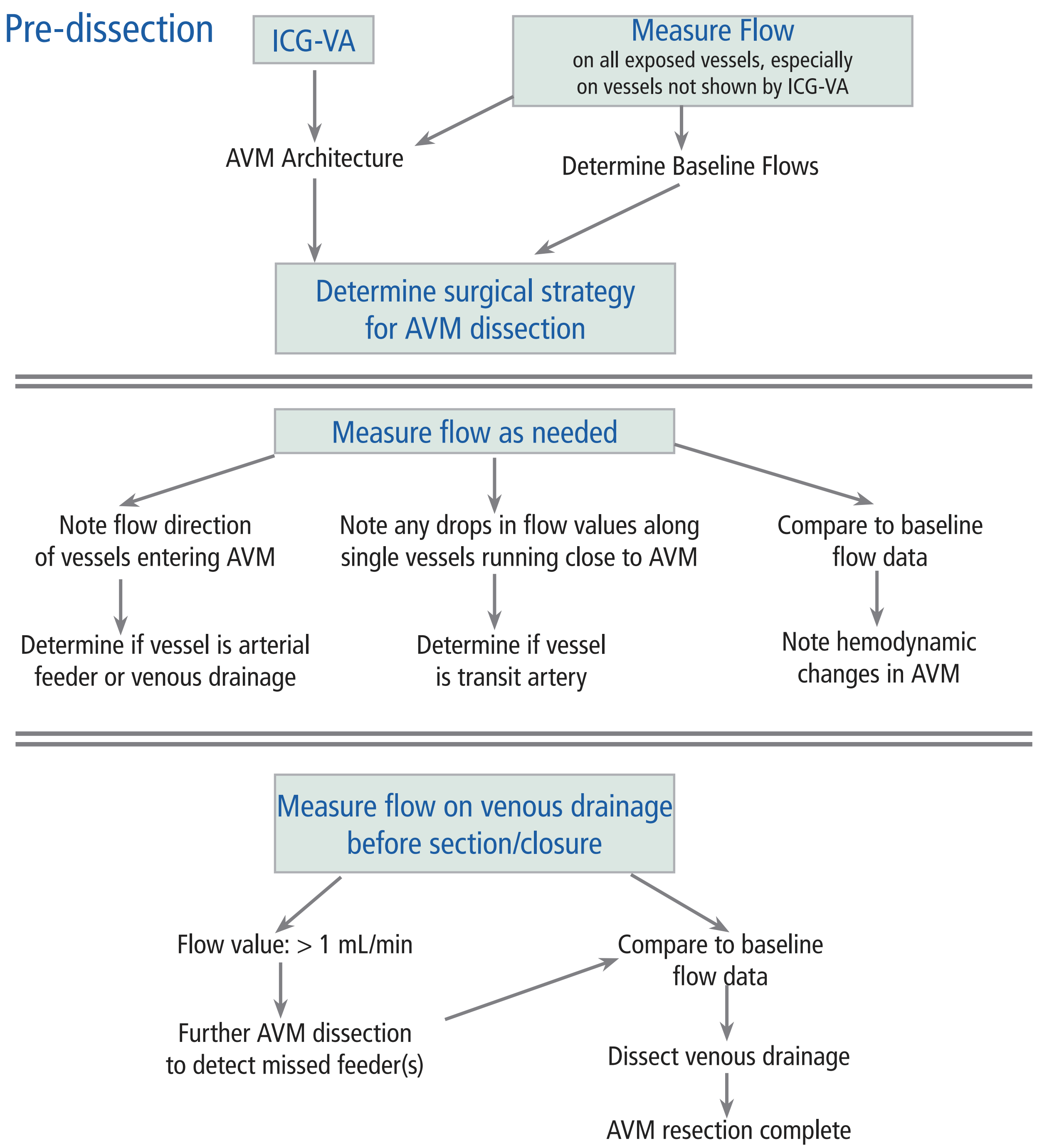
Flow-assisted Surgical Techniques and Notes* AVM Resection Protocol cont.

Flow-Guided AVM Resection[3]



3 Modified from Fig. 3, page 273 of Della Puppa A, Rustemi O, Scienza R, "Intraoperative Flow Measurement by Microflow Probe During Surgery for Brain Arteriovenous Malformations," Neurosurg 2015; Jun;11 Suppl 2:268-73. (Transonic Reference # 10288AH)

Signature Annotated Cerebrovascular References

1 Pasqualin A, Meneghelli P, Musumeci A, Della Puppa A, Pavesi G, Pinna G, Scienza R, "Intraoperative Measurement of Arterial Blood Flow in Aneurysm Surgery," Acta Neurochir Suppl. 2018;129:43-52. (Transonic Reference # 113658AH); *"...Combined with intraoperative neurophysiological monitoring, intraoperative blood flow measurements may now constitute the most reliable tool for increasing safety in aneurysm surgery."*

2 Amin-Hanjani S, Meglio G, Gatto R, Bauer A, Charbel FT, "The utility of intraoperative blood flow measurement during aneurysm surgery using an ultrasonic perivascular flow probe," Neurosurgery 2008; 62(6 Suppl 3): 1346-53. (Transonic Reference # 7226AH) *"Use of the ultrasonic flow probe provides real-time immediate feedback concerning vessel patency. Vessel compromise is easier to interpret than with Doppler, and faster/less invasive than intraoperative angiography. Intraoperative flow measurement is a valuable adjunct for enhancing the safety of aneurysm surgery."*

3 Charbel FT, Meglio G, Amin-Hanjani S,"Superficial temporal artery-to-middle cerebral artery bypass," Neurosurgery 2005; 56(1 Suppl): 186-90; discussion 186-90. (Transonic Reference # 2921AH) *Careful attention to technique at every stage of the operation is crucial for successful EC-IC bypass. "Adherence to a stereotyped step-by-step approach to this operation, with recognition of the importance of every step, can result in consistent technical success."*

4 Della Puppa A, Scienza R, "Multimodal Flow-Assisted Resection of Brain AVMs," Acta Neurochir Suppl 2016; 123: 141-5 (Transonic Reference # 11012AH). "Intraoperative Flow Measurement by Microflow Probe During Surgery for Brain Arteriovenous Malformations," Neurosurg 2015; 11 Suppl 2: 268-73. (Transonic Reference # 10288AH) *"The multimodal AVM flow-assisted approach was safe, feasible and reliable to achieve AVM resection with a high radical resection rate, lack of intraoperative complications and low morbidity."*

5 Nakayama N, Kuroda S, Houkin K, Takikawa S, Abe H, "Intraoperative Measurement of Arterial Blood Flow Using a Transit-Time Flowmeter: Monitoring of Hemodynamic Changes during Cerebrovascular Surgery," Acta Neurochiurgica 2001; 143: 17-24.(Transonic Reference # 1831AH)
Transit-time flow measurements are useful for surgical management during cerebrovascular surgery. The technique was simple to use and provided sensitive, stable, reliable results. The method revealed distal branch flow drop after aneurysm clipping, or residual flow during temporary clipping, and has the potential to predict post-operative complications in bypass or carotid endarterectomy surgeries.

6 Amin-Hanjani S, Alaraj A, Charbel FT, "Flow replacement bypass for aneurysms: decision-making using intraoperative blood flow measurements." Acta Neurochir (Wien) 2010;152(6):1021-32 (Transonic Reference # 7940AH) *There are two categories of challenges in decision-making for revascularization of complex aneurysms: choice of a bypass and verification of bypass success. Direct intraoperative measurement of flow deficit in aneurysm surgery requiring parent vessel sacrifice can guide the choice of flow replacement graft and confirm the subsequent adequacy of bypass flow.*

7 Kirk HJ, Rao PJ, Seow K, Fuller J, Chandran N, Khurana VG, "Intraoperative Transit-time Flowmetry Reduces the Risk of Ischemic Neurological Deficits in Neurosurgery," Br J Neurosurg 2009; 23(1): 40-7. (Transonic Reference # 7744AH) *Transit-time ultrasound flowmetry provides immediate feedback regarding vessel patency and clip-related arterial compromise and local vasospasm. It was found to have a broad utility in intra-cranial surgery including AVMs, fistulae disconnections and tumor excisions. Transit-time ultrasound flowmetry was found to be was safe, rapidly performed, easy to interpret and generally reliable. Its use contributes significantly to the safety of patients.*

8 Lee M, Guzman R, Bell-Stephens T, Steinberg GK, "Intraoperative Blood Flow Analysis of Direct Revascularization Procedures in Patients with Moyamoya Disease," J Cereb Blood Flow Metab 2011; 31(1): 262-74. (Transonic Reference: # 7969AH) This landmark moyamoya study is the largest single center study for direct revascularization for Moyomoya published. The authors conclude that surgery is the mainstay for treatment of moyamoya disease; direct revascularization surgery promotes clinical benefits more promptly, with low morbidity; revascularization results in a four-fivefold increase in blood flow through the anastomosis; STA diameter and flow is the main determinants of blood flow augmentation.

9 Nossek E, Chalif DJ, Dehdashti AR, "How I Do It: Occipital Artery to Posterior Inferior Cerebellar Artery Bypass," Acta Neurochir (Wien) 2014; 156(5): 971-5. (Transonic Reference # 10077AH) *An occipital artery to posterior inferior cerebellar artery (OA-PICA) bypass option should remain as a treatment modality in the armamentarium of neurovascular surgeons. Check the flow in the distal PICA while the proximal PICA is clamped and compare to the baseline PICA flow.*

10 Durand A, Penchet G, Thines L," Intra-operative monitoring by imaging and electrophysiological techniques during giant intracranial aneurysm surgery," Neurochirurgie. 2016; 62(1): 14-9. (Transonic Reference # 11175AH)
"Precise measurement of flow with a flowmeter is also a valuable tool to certify that brain perfusion is preserved in the main distal arteries after occluding a GIA. Its use is also strongly recommended if a bypass procedure is added to the microsurgical treatment of a GIA in order to certify that the target flow is obtained in the bypass before occluding the parent artery carrying the aneurysm. The risk of secondary occlusion of superficial temporal artery to middle cerebral artery bypass could also be predicted by measuring the cut flow index perioperatively. It is defined as the ratio between the final bypass flow and the primary flow obtained at the sectioned end of the donor artery ("cut flow"). An index inferior to 0.5 seems to be a strong indicator of bypass dysfunction with a high risk of secondary thrombosis (50%)."

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