Reduce Intraoperative Stroke Risk with Volume Flow Measurements

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

transonic
THE MEASURE OF BETTER RESULTS.
Charbel Flowprobes® Provide On-the-Spot Quantitative 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

“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-Hanjani, MD, FACS

“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.”

N Nakayama, MD

Transonic Systems Inc. is a global manufacturer of innovative biomedical measurement equipment. Founded in 1983, Transonic sells “gold standard” transit-time ultrasound flowmeters and monitors for surgical, hemodialysis, pediatric critical care, perfusion, interventional radiology and research applications. In addition, Transonic provides pressure and pressure volume systems, laser Doppler flowmeters and telemetry systems.
Charbel Intracranial Micro-Flowprobes®

Cerebrovascular surgery seeks to preserve blood flow in intracranial vessels or augment flow to cerebral territories during:

- **Aneurysm Obliteration Surgery:** Quantitative flow data guides clip placement for full preservation of flow in parent vessels and distal branches.
- **Arteriovenous Malformation (AVM) Resection Surgery:** Flow data guide surgical resection by clarifying ICG-VA visualization; discriminating between deep small arterial feeders and venous drainages, and identifying transit arteries and residual nidus.
- **Spinal Dural Arteriovenous Fistula (SDAVF) Surgery:** Flowmetry assesses the value and direction of flow thereby aiding fistula localization and confirming its disconnection.
- **Revascularization (EC-IC Bypass) Surgery for Occlusive Disease:** Flow measurement quantifies an increase in cerebral flow after revascularization.

Intraoperative volume flow measurements assure the integrity of cerebral flows or alert the surgeon to dangerous flow deficits while decreasing the need for disruptive intraoperative angiography. Measurements also provide documentation of flow for the patient’s record.

### Intracranial Flowprobe

- **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.

<p>| INTRACRANIAL PROBE SPECIFICATIONS |</p>
<table>
<thead>
<tr>
<th>PROBE</th>
<th>CATALOG #</th>
<th>VESSEL SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>size</td>
<td>x = N, D; k = R, B</td>
<td>outer diameter mm</td>
</tr>
<tr>
<td>1.5 mm</td>
<td>HQx 15 Mk</td>
<td>1.0 - 1.5</td>
</tr>
<tr>
<td>2 mm</td>
<td>HQx 2 Mk</td>
<td>1.5 - 2.7</td>
</tr>
<tr>
<td>3 mm</td>
<td>HQx 3 Mk</td>
<td>2.5 - 3.7</td>
</tr>
</tbody>
</table>

- **Fig. 2:** Charbel Micro-Flowprobes® are available in 1.5, 2 and 3 mm sizes.

-MB-Series Flowprobes ship pre-sterilized for use where Creutzfeldt-Jakobs disease transmission is a concern. -MR-Series Flowprobes are reusable (up to 16 sterilization cycles).
Charbel Extracranial Micro-Flowprobes®

A shorter bayonet handle MB-S and MB-R Micro Flowprobes are designed to be used under the microscope for extracranial vessels such as the superficial temporal artery during STA-MCA bypass surgery.

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<tr>
<td>4 mm</td>
</tr>
<tr>
<td>6 mm</td>
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</tbody>
</table>

Fig. 1: Comparison of Flowprobe bodies of intracranial Flowprobes (top) and extracranial Flowprobes.

Fig. 2: -MB-S & -MR-S-Series Micro-Flowprobes (3 mm, 4 mm, 6 mm) feature a shorter bayonet handle and larger flowsensing body to be used during on extracranial vessels during EC-IC bypass surgery.

Fig. 3: Comparison of bayonet handles of the -MB-Series Charbel Micro-Flowprobes® for intracranial vessels and the -MB-S & -MR-S-Series Micro-Flowprobes for extracranial vessels during EC-IC bypass surgery.

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Medical Note

Intraoperative Blood Flow Measurement during Aneurysm Clipping Surgery

Courtesy of F.T. Charbel, M.D., F.A.C.S.

Charbel Micro-Flowprobes® measure blood flow in major cerebral vessels. The Flowprobes use ultrasonic transit-time principles to directly measure volume blood flow, not velocity. Measurements detect low flow states that might result in intraoperative strokes.

**Measurements Steps:**

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

3. **Apply Flowprobe**
   Determine the optimal position for applying the Probe on the vessel. Select a site wide enough to accommodate the Probe's acoustic reflector without compromising perforating arteries coming off the vessel. Apply the Probe so that the entire vessel lies within the ultrasonic sensing window of the Probe and aligns with the Probe body.
   
   Bend the Probe’s flexible neck segment as needed. 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 lumen and provide ultrasound coupling. Do not irrigate continuously because the Flowprobe will also measure saline flow. The Signal Quality Indicator (bucket display) on the Flowmeter indicates acoustic contact. If acoustic contact falls below an acceptable value, an acoustic error message will be displayed.

4. **Measure Baseline Flows**
   Before clipping the aneurysm, measure baseline flows in all vessels at risk. Measure baseline flows 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**
   After applying the Flowprobe, wait 10-15 seconds for mean readings to stabilize. Then press the PRINT button on the Flowmeter or take a snapshot on AureFlo® to document the phasic flow patterns for the case record. If the Flowmeter 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 back side). Temporary clipping can also produce hyperemia which can cause flows to be 20-30 % higher than baseline.

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**RIGHT SUPERIOR CEREBELLAR ANEURYSM with Flowprobe** placed on superior cerebellar artery (SCA) to measure restoration of flow after clipping the aneurysm.
Intraoperative Blood Flow Measurement during Aneurysm Clipping Surgery

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).

Flow Measurement Protocol

- **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 Measurement Summary**
- 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 Flowprobe around the vessel. Listen to FlowSound® to hear volume flow.
- When readings stabilize, flow data can be captured by recording or taking a snapshot on the Aureflo®, or by pressing PRINT on a HT300-Series Flowmeter. If the HT300-Series 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**
- 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-based SCA Aneurysm Clipping

Courtesy: F.T. Charbel, M.D., F.A.C.S., Professor and Head, Neurosurgery, University of Illinois at Chicago, USA

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 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.

Integrity of Flow Checked after aneurysm clipping
SCA flow dropped to 2-4 cc/min. PCA flow was recorded as 55-60 cc/min.

Correction
The SCA was found to be partially incorporated in the clip. Following repositioning of the clip, SCA and PCA flows returned almost to baseline levels.
Intraoperative Blood Flow Measurement during Aneurysm Clipping Surgery Cont.

<table>
<thead>
<tr>
<th>TECHNICAL RECOMMENDATIONS: ANEURYSM SURGERY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANEURYSM SITE</strong></td>
</tr>
</tbody>
</table>
| Carotid Ophthalmic A (Opth) | M1 | 2.0 | 80-110 | Usually large aneurysms with no proximal control.
| | A1 | 2.0 | 40-60 | Flow must be preserved in the ICA and M1 and A1 outlet vessels. |
| | ICA | 3.0 | 120-170 | |
| Posterior Communicating A (PCom) | M1 | 2.0 | 80-110 | Usually large aneurysms with no proximal control.
| | A1 | 2.0 | 40-60 | Flow must be preserved in the ICA and M1 and A1 outlet vessels. |
| | ICA | 3.0 | 120-170 | |
| Anterior Choroidal A (ACh) | M1 | 2.0 | 80-110 | Flow in the anterior choroidal is particularly important. The 1.5 mm probe is good for this vessel. |
| | A1 | 2.0 | 40-60 | |
| | ICA | 3.0 | 120-170 | |
| | AChA | 1.5 | 20-60 | |
| Carotid Bifurcation (ICA) | M1 | 2.0 | 80-110 | The technical challenge is to preserve flow in the M1 and A1 outlet vessels. Flow in the ICA (3 mm) can be checked also. |
| | A1 | 2.0 | 40-60 | |
| Anterior Communicating A (ACom) | A1 (ipsilateral) | 2.0 | 40-60 | High risk. The technical challenge is to preserve flow in the A2 outlet vessels. No change in both A2s indicates flow is fully preserved. One A1 usually predominates and feeds both vessels. |
| | A1 (contralateral) | 2.0 | 40-60 | |
| | A2 (both) | 1.5 | 40-50 | |
| Middle Cerebral A (MCA) | M2 (outlet) | 2.0 | 50-80 | This is a straightforward, relatively low stress case for the surgeon. One of the easiest places to put the probe. |
| Post. Inferior Cerebellar A (PICA) | VA | 3.0 | 100-200 | Check flow in proximal or distal VA and PICA. |
| | PICA | 2.0 | 10-15 | |
| Superior Cerebellar A (SCA) | SCA (ipsilateral) | 1.5 | 18-20 | Check flow in ipsilateral SCA and PCA (Posterior Cerebral Artery). |
| | PCA | 2.0 | 26-30 | |
| | P2 (ipsilateral) | 2.0 | 26-30 | |
| Basilar Tip A (BA) | SCA | 1.5 | 18-20 | The perforators will still need to be inspected. |
| | PCom (prelude to sacrifice) | | | |

* Expected Flow rates courtesy of F.T. Charbel M.D., F.A.C.S
Medical Note

Intraoperative Blood Flow Measurement during Arterial EC-IC Bypass Surgery

Courtesy of FT Charbel, M.D., F.A.C.S.

**Introduction**
When an arterial extracranial-intracranial (EC-IC) bypass is selected to augment flow during surgery for occlusive cerebrovascular disease, the Charbel Micro-Flowprobe® assesses the patency and adequacy of flow before, during and after construction of the bypass. Transonic Flow-QC® either confirms that the bypass is working well, or prompts a revision if a technical error is suspected. Measurements are also taken periodically during closure of the skin incision to make sure the bypass has not kinked or twisted (See Case Report on page 3).

**Arterial Bypass**
For an arterial bypass (Fig. 1), baseline flows are first measured in the extracranial and intracranial vessels. After the extracranial artery is cut, free flow of the artery is measured by allowing the cut distal end to bleed freely for 15-20 seconds (Fig. 2). This free flow represents the amount of flow at zero resistance or the “carrying capacity” of the bypass, the maximum flow that the artery can deliver.

Once the bypass is constructed, post-anastomotic flow is measured (Fig. 3) in the donor artery. The Cut Flow Index (CFI) is calculated by dividing the Post-Bypass Flow by the Free Flow. 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 with no clinical justification such as a poor quality recipient vessel, the surgeon should reexamine the bypass for technical problems, and revise if necessary.

**Reference**

**Measurements Steps:**

**Extracranial Donor Artery**
1. Choose the appropriate size Probe to measure baseline flow in the extracranial donor artery. Record flow on the EC-IC Bypass Record.

<table>
<thead>
<tr>
<th>Probe Size</th>
<th>Vessel Range, Outer Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>2.5 - 3.7 mm</td>
</tr>
<tr>
<td>4 mm</td>
<td>3.3 - 4.7 mm</td>
</tr>
<tr>
<td>6 mm</td>
<td>4.4 - 6.6 mm</td>
</tr>
</tbody>
</table>

2. After cutting the extracranial artery, measure the free flow in the donor (Fig. 2) to determine the flow or “carrying” capacity of the bypass. Record flow on the EC-IC Bypass Record.
3. After the bypass has been anastomosed to the recipient vessel, measure post-bypass flow in the donor (Fig. 3) and compare with free flow. Record flow on the EC-IC Bypass Record.
4. If post-bypass flow in the donor artery is substantially less (<50%) than free flow, reexamine the anastomosis and redo, if necessary.

**Intracranial Recipient Artery**
1. Choose an appropriate size Flowprobe and measure and record baseline flow in the intracranial recipient artery.

<table>
<thead>
<tr>
<th>Probe Size</th>
<th>Vessel Range, Outer Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 mm</td>
<td>1.0 - 1.5 mm</td>
</tr>
<tr>
<td>2 mm</td>
<td>1.5 - 2.7 mm</td>
</tr>
<tr>
<td>3 mm</td>
<td>2.5 - 3.7 mm</td>
</tr>
</tbody>
</table>

2. After the bypass has been constructed, measure flow in the recipient vessel and compare to pre-bypass (bypass) flow. Record flow on the EC-IC Bypass Record.
3. If post-bypass flow in the recipient artery is considerably less than pre-bypass flow, reexamine the bypass and redo, if necessary and press the PRINT button on the Flowmeter to document the phasic flow patterns for the case record. If the HT300-Series Flowmeter displays a negative flow, press the INVERT button to change the polarity before printing the waveform.

**Flow Record**

<table>
<thead>
<tr>
<th>Date</th>
<th>Type of Bypass</th>
<th>Reason for Bypass</th>
<th>Surgeon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extracranial Donor</td>
<td>Probe Size</td>
<td>BP Mean</td>
<td>Pre-Bypass Flow ml/min</td>
</tr>
<tr>
<td>Intracranial Recipient Artery</td>
<td>Probe Size</td>
<td>BP Mean</td>
<td>Pre-Bypass Flow ml/min</td>
</tr>
</tbody>
</table>

**Measurement Protocol**

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

Select Flowprobe Size for Donor Extracranial Artery

Measure *in situ* baseline flow in donor extracranial artery

Cut donor extracranial artery

Measure and record free (cut) flow in donor artery

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

Measure and record post-bypass flow in donor artery

Calculate Cut Flow Index (CFI)

\[
CFI = \frac{\text{Post Bypass Flow}}{\text{Cut “Free” Flow}}
\]

CFI < 0.5

Examine bypass for kinks etc.; Analyze recipient bed.

CFI > 0.5

Patent Bypass

Measure post-bypass flows at proximal and distal recipient artery sites to document surgical success.
Background
In 2004, University of Illinois at Chicago cerebrovascular surgeons F.T. Charbel and S. Amin-Hanjani introduced the concept of a Cut Flow Index to evaluate the quality of an extracranial to intracranial (EC-IC) bypass used to augment flow during cerebral ischemia.¹

EC-IC Bypass Surgery
A surgical team headed by Dr. Sepideh Hanjani undertook extracranial to intracranial (EC-IC) bypass surgery to create a bypass from the superficial temporal artery (STA) to the middle cerebral artery (MCA).

Cut Flow Measured
Per their standard protocol, they measured the Cut Flow of the intended bypass conduit, the STA, with a Transonic® Flowprobe. STA Cut Flow measured 82 mL/min indicating that the STA had a good carrying capacity for use as a bypass.

Bypass Flow Measured
The bypass was created with the STA and bypass flow was measured. It measured 80 mL/min. The surgeons were pleased with an excellent Cut Flow Index of 0.98. After repeated measurements and stable flows, wound closure commenced.

Last Flow Check before Wound Closure
Just before placing the last few skin stitches, the surgeon again rechecked the STA bypass flow. To the surgical team’s surprise, the flow had dropped to less than 20 mL/min.

Embolus Removed/Flow Measured/Flow Restored
The wound was reopened and the surgeon discovered an embolus at the anastomosis. The embolus had presumably formed in the STA during the surgery and had dislodged after removal of the muscle retractors and had travelled into the anastomotic site. The microscope was quickly returned into the field and Dr. Hanjani made a small cut in the recipient artery at a branching site distal to the anastomosis. The incision allowed the thrombus to escape. Subsequent intraoperative flow measurements corroborated restoration of flow in the bypass to the pre-embolus level.

<table>
<thead>
<tr>
<th>STA Bypass</th>
<th>STA Bypass at wound closure</th>
<th>STA Bypass after embolus release</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 mL/min</td>
<td>20 mL/min</td>
<td>80 mL/min</td>
</tr>
<tr>
<td>Cut Flow Index: 0.98</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reference

Flow Measurement Summary
Measure vessels and choose correct size Flowprobe. Add saline/cerebrospinal fluid as needed to obtain good ultrasonic contact. When the flow reading is stable, press PRINT on a HT300-Series Flowmeter or take a snapshot on the AureFlo® to document flow for the patient’s record.

Equipment: Flowmeters

Intracranial and Extracranial Flowprobes

**INTRACRANIAL FLOWPROBES**
- Flexible neck
- Reflector
- Probe body

**EXTRACRANIAL FLOWPROBES**
- Flexible neck
- Reflector
- Probe body

**Fig. 4:** The AureFlo® system continuously measures, displays, records and documents absolute volume flow.

**Fig. 5:** HT353-Series Single-channel Optima Flowmeter can be used with Transonic Charbel Micro-Flowprobes®.

**Fig. 6:** -MB Series & -MR-Series Charbel Micro-Flowprobes® are 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.

**Fig. 7:** Comparison of Flowprobe bodies of intracranial Flowprobes (top) and extracranial Flowprobes (bottom).

**Fig. 8:** -MB-S & -MR-S-Series Micro-Flowprobes (3 mm, 4 mm, 6 mm) feature a shorter bayonet handle and larger flowsensing body to be used during on extracranial vessels during EC-IC bypass surgery.

**References**


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Medical Note

Intraoperative Blood Flow Measurement during STA-M4/MCA Bypass Surgery for Moyamoya Revascularization

Introduction
One strategy 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 M4 middle cerebral artery branch. The bypass is designed to augment flow in the intracranial territories (Fig. 1).

During surgery, the Charbel Micro-Flowprobe® is used to measure direct volume blood flow in the STA bypass and small target M4/MCA 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
Measure mean arterial pressure (MAP), end-tidal CO₂ and temperature. Record values on an Bypass Flow Record.

Pre-anastomosis: Intracranial Recipient Artery
1. Measure the diameter of the intracranial recipient artery (M4/MCA) and choose an appropriately sized Charbel Micro-Flowprobe® to measure recipient vessel flow.

<table>
<thead>
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</table>

2. Measure recipient vessel (M4/MCA) flow.
3. Record flow and flow direction on EC-IC Bypass Record.

Extracranial Donor Artery
4. Dissect the extracranial STA artery free, and skeletonize a segment for application of the Flowprobe.
5. Measure the diameter of the extracranial donor artery (STA) and choose the appropriately sized Flowprobe to measure STA baseline flow.

<table>
<thead>
<tr>
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Post-anastomotic Flow Measurements
6. After construction of the STA-MCA bypass, measure post--anastomotic flows in the intracranial and extracranial arteries sequentially in the following order:
   1) distal M4/MCA (Fig. 3);
   2) proximal M4/MCA;
   3) distal STA;
   4) proximal STA.
7. If post-bypass flow in the recipient artery (sum of absolute values of distal and proximal M4/MCA flow) is not significantly above the pre-bypass flow, reexamine the anastomosis and the bypass for kinks or twists and redo, if necessary. Apply a vasodilator (papaverine) when there has been some vasospasm due to manipulation of the vessel and/or flow measurements seem to be low or absent.
8. Record flow rates and flow directions, MAP, end-tidal CO₂, and occlusion time on the EC-IC Bypass Record.

Fig. 2: 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 the anastomosis and as the Flowprobe is applied to the vessel.

Fig. 3: Measuring blood flow in recipient M4/MCA artery after anastomosis to STA bypass.

References
When construction of an arterial extracranial to intracranial (EC-IC) bypass is impossible due to atherosclerosis, twisting or a poor section of the temporal artery, the cerebrovascular surgeon may elect to harvest a vein to use as an EC-IC bypass (Fig. 1) in order to preserve or augment intracranial flow. Transonic’s quick intraoperative flow measurements provide valuable on-the-spot feedback during the surgery as the surgeon identifies and defines specific hemodynamic requirements for the bypass and formulates an ongoing operative strategy for the case.

**Venous Bypass**

Since the proximal end of the vein graft is anastomosed to a carotid artery, one concern with this type of bypass is that it will produce too much flow for the recipient vasculature. Free flow is, therefore, measured in the graft once it has been anastomosed to the carotid artery to determine the maximum flow capacity for the graft and to match the graft hemodynamically to the recipient arterial vasculature. Baseline flows are also measured in the intracranial recipient vessel before anastomosis.

After the graft has been anastomosed intracranially to the recipient cerebral artery, post-anastomotic flows are measured in the graft and recipient artery and compared with baseline flows.

**Flow Measurement Steps**

**Extracranial Donor Venous Graft**

1. Choose the appropriate size probe to measure baseline flow in the extracranial venous graft. Record flow on the EC-IC Bypass Record (Fig. 4).

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>3 mm</td>
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</tr>
<tr>
<td>4 mm</td>
<td>3.2 - 5.3 mm</td>
</tr>
<tr>
<td>6 mm</td>
<td>4.5 - 7.5 mm</td>
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</table>

2. After anastomosing the venous graft proximally to the carotid artery, measure the free flow or “carrying capacity” of the graft. Record flow on the EC-IC Bypass Record (Fig. 3).

*Continued on next page.*
3. After the bypass has been anastomosed to the recipient vessel, measure post-bypass flow in the donor graft. Record flow on the EC-IC Bypass Record (Fig. 3). Compare the flow hemodynamically with flow in the recipient artery and with free flow.

4. If post-bypass flow in the donor artery is substantially less (<50%) than free flow, reexamine the anastomosis and redo, if necessary.

Intracranial Recipient Artery

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

<table>
<thead>
<tr>
<th>Probe Size</th>
<th>Vessel Range, Outer Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 mm</td>
<td>1.0 - 1.5 mm</td>
</tr>
<tr>
<td>2 mm</td>
<td>1.5 - 2.7 mm</td>
</tr>
<tr>
<td>3 mm</td>
<td>2.5 - 3.7 mm</td>
</tr>
</tbody>
</table>

2. After the bypass has been constructed, measure flows in the recipient vessel and compare with graft flows. Record flows on the EC-IC Bypass Record.

3. Evaluate the hemodynamic match between the donor flows and recipient vessel flows.

**Measurement Tips**

- Select a Flowprobe size so that the vessel will fill at least 75% of the lumen of the Flowprobe. Use sterile saline or cerebrospinal fluid to obtain good ultrasonic contact between the Flowprobe and vessel.
- Bend the Flowprobe’s flexible segment to best position the Flowprobe around the vessel. Listen to FlowSound® to hear volume flow.
- When flow readings are stable, flow data can be captured by recording or taking a snapshot on the Aureflo®, or by pressing PRINT on a HT300-Series Flowmeter. If the HT300-Series flow reading is negative on the LED, press INVERT to reverse the polarity of the flow reading from negative to positive before printing out the waveform.

<table>
<thead>
<tr>
<th>Flow Record</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EC-IC Bypass</strong></td>
</tr>
<tr>
<td><strong>Patient Label</strong> (optional) Of Name/Age/Sex</td>
</tr>
<tr>
<td><strong>Date</strong></td>
</tr>
<tr>
<td>Extracranial Donor</td>
</tr>
<tr>
<td>Intracranial Recipient Artery</td>
</tr>
</tbody>
</table>

**Comments/Observations/History**

---

**Protocol: Flow Measurements during Venous EC-IC Bypass**

**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.
  - Measure post-bypass flows at proximal and distal recipient artery sites to document surgical success.

- M4 flows increased
  - Good bypass.
  - Flows increased significantly
  - Aggressive post-op management indicated to avoid complications.

---

**Fig. 3:** Example of a Flow Record to record flow readings during EC-IC Bypass.
Flowprobe Selection Guide

### Perivascular Flowprobe Series & Available Sizes

<table>
<thead>
<tr>
<th>Suffix</th>
<th>Description</th>
<th>Sizes (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-FMC</td>
<td>Coronary (J-reflector, extended neck)</td>
<td>1.5, 2, 3, 4</td>
</tr>
<tr>
<td>-FMV</td>
<td>Vascular (J-reflector, standard handle)</td>
<td>1.5, 2, 3, 4, 6, 8, 10, 12, 14</td>
</tr>
<tr>
<td>-FME</td>
<td>Carotid (L-reflector, standard handle)</td>
<td>4, 6, 8, 10</td>
</tr>
<tr>
<td>-FTV</td>
<td>OptiMax® (J-reflector, hands-free butterfly wings)</td>
<td>4, 6, 8, 10, 12</td>
</tr>
<tr>
<td>-FTE</td>
<td>OptiMax® (L-reflector, hands-free butterfly wings)</td>
<td>4, 6, 8, 10, 12</td>
</tr>
<tr>
<td>-MU</td>
<td>Microvascular (L-reflector, standard handle)</td>
<td>0.7, 1, 1.5, 2, 3</td>
</tr>
<tr>
<td>-AU</td>
<td>Cardiac Output Confidence Flowprobe® (C-shaped design, no handle)</td>
<td>4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36</td>
</tr>
<tr>
<td>-MB</td>
<td>Intracranial Charbel Micro-Flowprobe® (L-reflector, long bayonet handle)</td>
<td>1.5, 2, 3</td>
</tr>
<tr>
<td>-MR</td>
<td>Extracranial EC-IC Bypass: Micro-Flowprobe (L-reflector, short bayonet handle): -MB-S: single use; -MR-S: resposable</td>
<td>3, 4, 6</td>
</tr>
<tr>
<td>-FSB</td>
<td>Basic (L-reflector with sliding cover, no handle)</td>
<td>1.5, 2, 3, 4, 6, 8, 10, 12, 14</td>
</tr>
<tr>
<td>-P</td>
<td>Port Access (J-reflector, long port-access handle)</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>-FD</td>
<td>Port Access (J-reflector, long port-access handle)</td>
<td>1.5, 2, 3, 4</td>
</tr>
</tbody>
</table>

### Recommended Sizes and/or Flowprobe Series for Specific Vessels or Applications

#### Cardiac Surgery

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Probe Size (mm)</th>
<th>Probe Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>CABG: On or Off Pump</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial conduits</td>
<td>1.5, 2, 3, 4</td>
<td>-FMC</td>
</tr>
<tr>
<td>Saphenous vein</td>
<td>2, 3, 4</td>
<td>-FMV</td>
</tr>
<tr>
<td>Port access - coronary arteries</td>
<td>1.5, 2, 3, 4</td>
<td>-FD</td>
</tr>
<tr>
<td>Cardiac Output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ascending aorta</td>
<td>28, 32, 36</td>
<td>-AU</td>
</tr>
<tr>
<td>Pulmonary artery</td>
<td>24, 28, 32</td>
<td>-AU</td>
</tr>
<tr>
<td>Pediatric heart</td>
<td>4, 6, 8, 10, 12, 14, 16, 20</td>
<td>-AU</td>
</tr>
</tbody>
</table>

#### Transplant Surgery

<table>
<thead>
<tr>
<th>Organ</th>
<th>Probe Size (mm)</th>
<th>Probe Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hepatic artery</td>
<td>4, 6, 8</td>
<td>-FMV, -AU</td>
</tr>
<tr>
<td>Portal vein</td>
<td>10, 12, 14</td>
<td>-FMV, -AU</td>
</tr>
<tr>
<td>Kidney</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renal artery</td>
<td>4, 6</td>
<td>-FMV, -FSB</td>
</tr>
<tr>
<td>Renal vein</td>
<td>10</td>
<td>-FMV, -FSB</td>
</tr>
<tr>
<td>External iliac artery</td>
<td>6, 8</td>
<td>-FMV, -FSB</td>
</tr>
<tr>
<td>Hypogastric artery</td>
<td>4, 6</td>
<td>-FMV, -FSB</td>
</tr>
</tbody>
</table>

#### Pancreas

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Probe Size (mm)</th>
<th>Probe Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common iliac artery</td>
<td>8</td>
<td>-FMV</td>
</tr>
</tbody>
</table>

#### Cerebrovascular Surgery

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Probe Size (mm)</th>
<th>Probe Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aneurysm Clipping</td>
<td>1.5, 2, 3</td>
<td>-MB, -MR</td>
</tr>
<tr>
<td>EC-IC Bypass</td>
<td>3, 4, 6</td>
<td>-MB-S, MR-S</td>
</tr>
<tr>
<td>Intracranial</td>
<td>1.5, 2, 3</td>
<td>-MB, -MR</td>
</tr>
<tr>
<td>AVM, Tumor Resection, Dural Fistula</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outflows</td>
<td>variable</td>
<td>-MB, -MR</td>
</tr>
</tbody>
</table>

#### Vascular Surgery

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Probe Size (mm)</th>
<th>Probe Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carotid Endarterectomy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common carotid artery</td>
<td>8, 10</td>
<td>-FTE, -FME, -FSB</td>
</tr>
<tr>
<td>External carotid artery</td>
<td>6</td>
<td>-FTE, -FME, -FSB</td>
</tr>
<tr>
<td>Internal carotid artery</td>
<td>6</td>
<td>-FTE, -FME, -FSB</td>
</tr>
<tr>
<td>AV Fistulas &amp; Grafts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radial artery</td>
<td>2, 3</td>
<td>-FMV, -FSB</td>
</tr>
<tr>
<td>Brachial artery</td>
<td>3, 4, 6</td>
<td>-FMV, -FTV, -FSB</td>
</tr>
<tr>
<td>Graft venous outflow</td>
<td>4, 6</td>
<td>-FMV, -FTV, -FSB</td>
</tr>
</tbody>
</table>

#### Abdominal

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Probe Size (mm)</th>
<th>Probe Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renal bypass</td>
<td>4, 6</td>
<td>-FMV, -FTV, -FSB</td>
</tr>
<tr>
<td>Aorta</td>
<td>16, 20</td>
<td>-AU, -FSB</td>
</tr>
<tr>
<td>Common iliac</td>
<td>10, 12</td>
<td>-FMV, -AU, -FSB</td>
</tr>
<tr>
<td>Portocaval shunt</td>
<td>10, 12, 14</td>
<td>-FMV, -AU, -FSB</td>
</tr>
<tr>
<td>Splenorenal shunt</td>
<td>10, 12, 14</td>
<td>-FMV, -FTV, -AU, -FSB</td>
</tr>
</tbody>
</table>

#### Lower Extremity Bypass

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Probe Size (mm)</th>
<th>Probe Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profunda femoris</td>
<td>8</td>
<td>-FMV, -FTV, -AU, -FSB</td>
</tr>
<tr>
<td>Common femoral</td>
<td>8, 10</td>
<td>-FMV, -FTV, -AU, -FSB</td>
</tr>
<tr>
<td>Popliteal</td>
<td>4, 6</td>
<td>-FMV, -FTV, -FSB</td>
</tr>
<tr>
<td>Tibial</td>
<td>3, 4</td>
<td>-FMV, -FTV, -FSB</td>
</tr>
</tbody>
</table>

#### Microvascular Surgery

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Probe Size (mm)</th>
<th>Probe Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reattachments/Flaps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microvessels in hand, wrist</td>
<td>0.7, 1, 1.5, 2, 3</td>
<td>-MU</td>
</tr>
</tbody>
</table>

[Visit www.transonic.com for more information.]
Transonic® Flowmeters
Versatile Systems to Optimize Flow

Choose the Flowmeter That Best Fits Your Needs

Establishing adequate blood flow is a prime objective of any cardiovascular procedure. But without definitive measurements, one really doesn’t know exact flow. Transonic’s Flowmeters give you this information.

Moreover, you can choose the flowmeter that best fits your needs. They include:

- **Single-channel** Optima Flowmeters (key-activated or non key-activated)
- **Dual-channel** Optima Flowmeters (key-activated or non key-activated)
- An Optima Flowmeter integrated into the state-of-the art Aureflo
Optima Flowmeters®

Transonic Optima® Flowmeters provide immediate, quantitative flow measurements to ensure vessel and graft patency with unsurpassed accuracy and resolution.

The Optima Flowmeter complements a full line of Perivascular Flowprobes for vessels from 0.5 mm to 36 mm in diameter and our Tubing Flowsensors for tubing with 1/8 to 1 1/4 inch outer diameters.

Key-activated and Keyless Systems

- Key-activated HT354 single-channel and HT364 dual-channel Flowmeters for US and Canada placement. An Optima Key is required for each use.

The AureFlo®

AureFlo® display of recorded LIMA-LAD (systolic flow volume in red; diastolic in blue). Also displayed are mean flow in mL/min, pulsatility tracing and heart rate.

Case Portfolios: Record, Display, Create

- Recordings and snapshots can be labeled for identification before and after the procedure
- Select 8-second snapshots from recorded measurements for review or documentation
- Generous memory space allows storage of many cases
**Versatile Display**
- Touch-screen PC uploaded with FlowTrace® software
- Easy to read, high contrast display
- Display can be connected to an OR monitor

**Intuitive Operation**
- Quick and easy data entry
- Measure, capture, store and retrieve flow information

**Archive & Retrieve**
- Enhance operative notes and referral feedback
- Review case recordings remotely
- Print selected waveforms for reference, analyzing, teaching or documenting into the patient record

**Convenient & Portable**
- Small footprint, easy mobility
- Stable cart that securely holds Flowmeter, Monitor & printer
- Convenient writing surface and storage drawer

Why rely on guesswork and intuition, and wait until postoperative conditions determine surgical success? Make intraoperative flow measurements with a Transonic Flowmeter part of your routine to verify establishment of adequate blood flow before closing your patient.
Transonic®: The Flow Pioneer

Transonic, the recognized leader in clinical and research blood Flowmeters, is rooted in university research. The company was founded in 1983 by its current President Cornelis Drost and fellow collaborators at Cornell University’s College of Veterinary Medicine to commercialize the transit-time ultrasound flowmetry devices pioneered by the group.

From its initial animal research market niche, Transonic evolved into the market leader for innovative medical flow measurement instrumentation. Examples include:

- Transonic’s transit-time non-constrictive Perivascular Flowprobes, now the intraoperative quality assurance standard for beating-heart coronary bypass surgery.
- Its intraoperative bayonet-style Flowprobes help avert intraoperative stroke encountered during aneurysm clipping procedures, EC/IC bypass and other cerebrovascular procedures.
- Transonic’s Clamp-on Tubing Sensors are an integral component of ventricular assist devices, organ preservation units, ECMO and cardiopulmonary bypass circuits.

“Accurate flow measurements can be of great assistance during vascular reconstructive surgery. The primary aim with these intra-operative measurements is to obtain information on the immediate result of the reconstruction, where a technical failure may jeopardize an otherwise successful operation.”

A Lundell, MD, FACS

“Not a day goes by that these flow measurements don’t solve a problem for me.”

B. Mindich, MD

“...at the Medical Center here, we use the flowprobe as part of our routine monitoring the post-bypass patient. It gives us intraoperatively information about what’s transpiring with each individual graft. It’s not information that you could get any other way.”

E. Grossi, MD

Transonic Systems Inc. is a global manufacturer of innovative biomedical measurement equipment. Founded in 1983, Transonic sells “gold standard” transit-time ultrasound flowmeters and monitors for surgical, hemodialysis, pediatric critical care, perfusion, interventional radiology and research applications. In addition, Transonic provides pressure and pressure volume systems, laser Doppler flowmeters and telemetry systems.