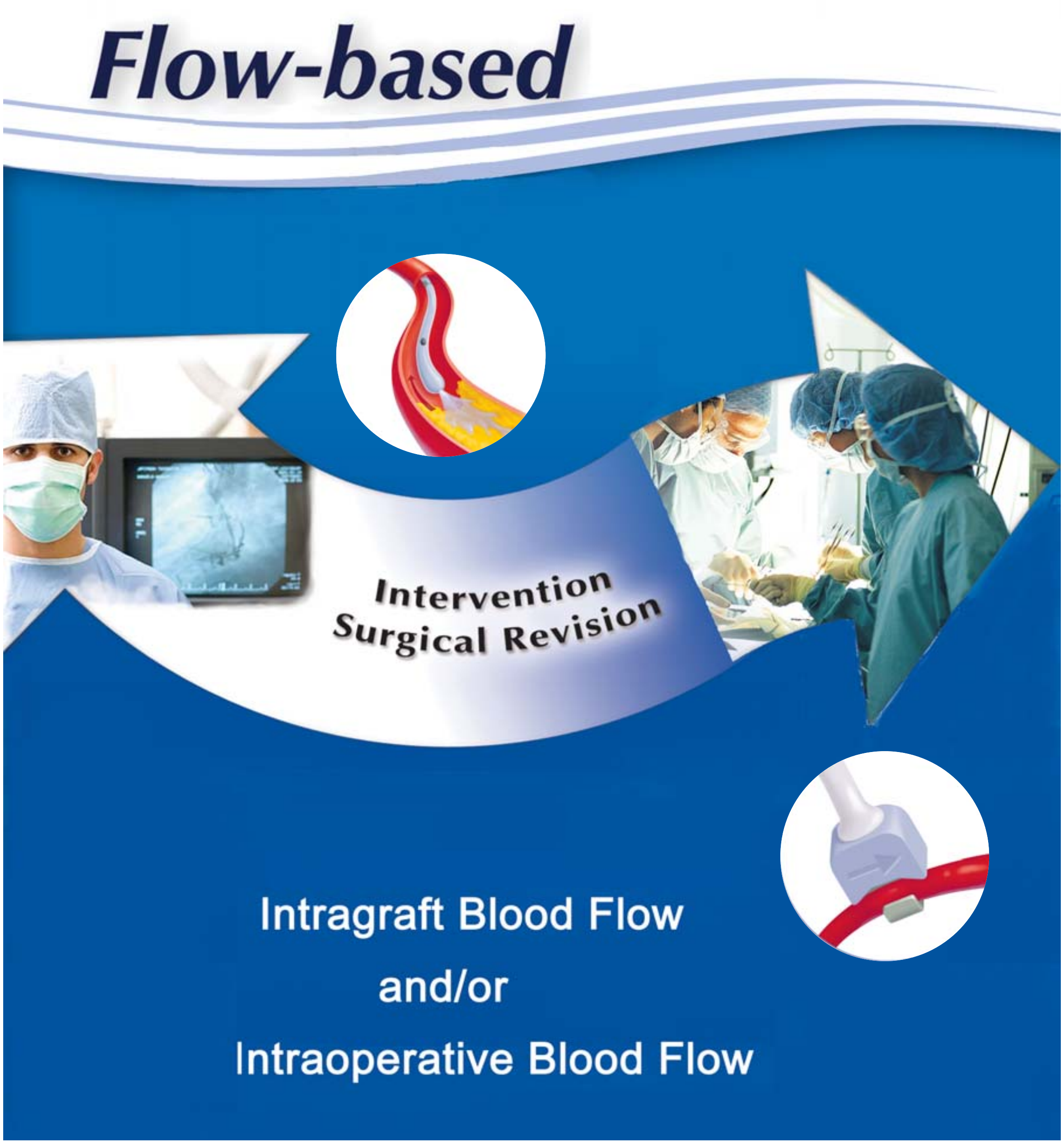

Flow-based
Intervention
Surgical Revision
Intragraft Blood Flow
and/or
Intraoperative Blood Flow

Flow-based AV Access Intervention and/or Surgical Revision

Routine Transonic Flow-QC® surveillance during hemodialysis trends declining vascular access flows to detect the presence of hemodynamically significant stenoses or to identify high flows that threaten cardiac overload.[1-3] When a significant stenosis has been identified, various techniques including an endovascular intervention or a surgical revision are used to restore access flow to an acceptable level for hemodialysis delivery. This chapter presents the use of flow measurement with these two well established treatment modalities.[4]

1. Flow-guided Percutaneous Transluminal Angioplasty (PTA)

When AV fistulas or grafts fall below a critical threshold, percutaneous transluminal angioplasty (PTA) is the front line treatment for repairing the access.[5,6,7,8] Elective rather than emergent, less invasive than surgery, angioplasty conserves the current access site and preserves future access sites. During angioplasty, on-the-spot intragraft flow measurements with the Transonic® ReoCath™ Flow Catheter and Endovascular Flowmeter (HVT100) guides interventional radiologists as they attempt to restore access patency.

2. Flow-based Access Revision Surgery

Surgery is also used to revise challenging AV accesses and restore flow. A number of surgical protocols are used to adjust access flows that can be either too low or too high. Transonic intraoperative flow measurements inform the surgeon and assist in intraoperative decision making during these procedures.

A. Measuring Intragraft Blood Flow during Angioplasty

After apparently successful angioplasties, access blood flow fails to normalize in one third of patients.[13-14] Vesely attributes these poor outcomes to the presence of an arterial inflow stenosis, failure to identify multiple lesions within the access, elastic recoil immediately following the angioplasty and/or poor cardiac output. On-the-spot measurements of intragraft blood flows during the angioplasty procedure (Fig. 3.1) informs the interventionalist about the entire vascular circuit.[15-16]

McCarley et al reported that, when surveillance was combined with expedient angioplasty, the rate of graft thrombosis decreased almost fourfold, overall costs dropped by approximately 50% and catheter use decreased dramatically.[11] During angioplasty, intragraft flow measurements provide quantitative data at three points of the intervention: at its outset; during the intervention, and/or at its conclusion.

At the Intervention's Outset

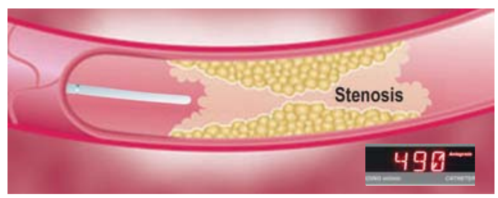


Fig. 3.1: ReoCath™ antegrade flow catheter measuring intragraft flow before angioplasty.

At the procedure's outset, an intragraft flow measurement confirms, first of all, that the procedure is indeed necessary and blood flows are lower than 600 ml/min K/DOQI-recommended threshold. Studies have demonstrated that when a static pressure ratio is used for access surveillance, a high flow access can be erroneously targeted for an intervention.[17] It has also been shown that angiographic findings alone do not correlate with blood flow.[18,19] Vesely addresses this failure of angiography by advising that the intervention should not performed unless clinical or hemodynamic abnormalities correlate with angiographic findings.[5]

A flow measurement at the beginning of the intervention also provides a flow baseline from which a target flow goal for the procedure can be set. In essence, each individual then serves as his or her own control as the goal of the intervention is improve flow through the access. Intragraft blood flow measurements at the onset of angioplasty both confirm the need for the intervention and provide a baseline from which flow should improve.

Flow-based AV Access Intervention *cont.*

During the Intervention

As the intervention proceeds, intragraft ReoCath™ flow measurements provide objective functional data to guide the interventionalist to achieve the target flow goal (see Section C, "How the ReoCath™ System Works," page 57).

Since Fistula First has mandated increased use of native fistula in lieu of prosthetic grafts, the interventionalist can no longer assume that the cause for declining vascular access flow is a single venous outflow stenosis common in grafts, and correcting it endovascularly will solve the access flow problem. The 2006 K/DOQI Update states, "Inflow stenosis is more common than previously believed. ...Access inflow stenosis occurs in one third of patients referred to interventional facilities with clinical evidence of venous stenosis or thrombosis.".[7,18,19] Vesely concurs, "Arterial anastomotic stenoses are the single most important flow determinant of the entire vascular access."[5]

When a Reocath™ intragraft flow measurement demonstrates that the flow target has been attained, the intervention can be safely concluded. However, if, after angioplasty, flow remains below expected levels, the interventionalist is immediately alerted that another problem within the circuit exists that needs to be addressed.

At the Intervention's Conclusion

Although improvement in blood flow following angioplasty should be obvious, Beathard warns, "Elasticity of venous stenotic lesions appears to be a much more serious problem than has been previously recognized ... Recoil of an elastic lesion can be easily missed."[7] To this end, a followup intragraft flow measurement several minutes after completion of the intervention will confirm continuing good flow and the absence of elastic recoil (Fig. 3.2). Conversely, it will alert the interventionalist if recoil has occurred. Flows can then be documented for the patient record and compared with vascular access flows obtained during subsequent access surveillance in the hemodialysis unit with the Flow-QC® Monitor.

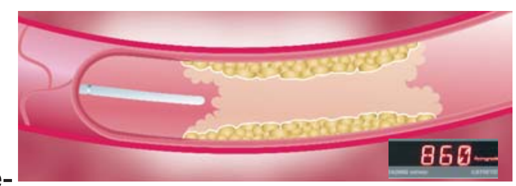


Fig. 3.2: ReoCath™ antegrade flow catheter measuring intragraft flow after angioplasty.

1. Angioplasty Success

Angioplasty success is defined as a significant improvement in access blood flow.[18,20]

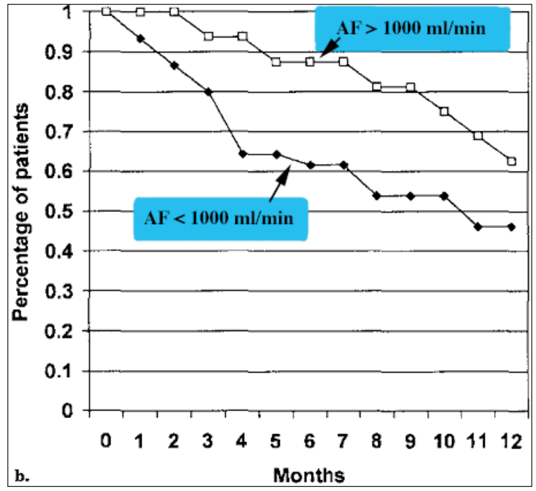


Fig. 3.3: Murray B et al: "Access Flow after Angioplasty Predicts Subsequent Arteriovenous Graft Survival"[17]

It has been suggested that post-PTA access flow should ideally return to or be higher than former optimum access flow levels, the literature reports the average flow increase to be about 300 ml/min. Krivitski reports that patients whose blood flow increased more than 300 ml/min during angioplasty also showed significant increases in flow measured during subsequent hemodialysis. In his review of 17 studies, the post angioplasty weighted mean flow increase was 309 ml/min for AV grafts and 329 ml/min for AV fistulas respectively.[22] Murray and colleagues also have reported that blood flow achieved after angioplasty is predictive of subsequent graft patency (Fig. 3.3) and asserts that grafts with post-angioplasty access flows of less than 1L/min are more likely to require repeat intervention, to exhibit thrombosis within the first six months, and have a lower one-year survival compared with those with access blood flow rates greater than 1L/min.[20]

K/DOQI defines successful angioplasty as one where the residual stenosis is less than 30% of the diameter of the access. Ahya et al dispute this anatomic measure, "Visual assessment of the lesion following angioplasty fails to predict the hemodynamic success of the procedure."[13] A Murray study in which flow actually decreased after angioplasty in four grafts also supports the conclusion that anatomic assessment by angiography does not correlate with flow. Although residual stenoses were visualized in the grafts, none was greater than 30% of the diameter of the access.[21] Beathard calls for total elimination of the stenosis and cites a Lilly study of 330 cases in which the median primary patency for a graft was longer (6.9 months) when there was no residual stenosis than if there was any degree of residual stenosis (4.6 months).[7,8]

2. How the ReoCath™ System Works

The ReoCath™ Flow Catheter System consists of single-use antegrade and retrograde catheters, a ReoCath™ extension cable and the Transonic® HVT100 Flowmeter (Fig. 3.4). The 6 French antegrade and retrograde flow catheters each have an external injection port connected to a central lumen (Figs. 3.5, 3.6) through which room temperature saline is released into the access during angioplasty.

Fig 3.4: HVT100 Endovascular Flowmeter measures intragraft blood flow in the arteriovenous (AV) vascular access to provide quantitative informa-tion about access functionality during angioplasty.

Each catheter has two temperature sensors (thermistors). When room temperature saline is injected into the access, a thermister located close to the proximal end of the catheter records the temperature of the injected saline solution. The second thermister located close to the distal tip of the catheter records the thermodilution within the access.

The catheter connects to the HVT100 Endovascular Flowmeter via a two meter extension cable. The flowmeter automatically calculates and displays intra-graft

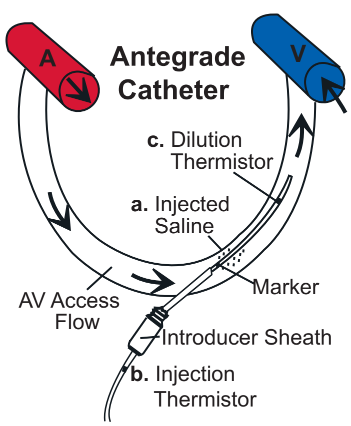


Fig. 3.5: Antegrade catheter (6 F, 35 cm length) is inserted in the same direction as blood flow. Saline is released proximal to the catheter tip and then is measured downstream by the dilution thermister.

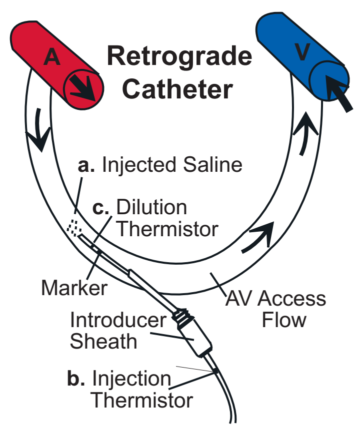


Fig. 3.6: Retrograde catheter (6 F, 48 cm length) is inserted against the direction of blood flow. Saline is released at the catheter tip and is then is measured downstream by the dilution thermister.

3. Intragraft Measurement Protocol

With the ReoCath™ Flow Catheter system, the interventional radiologist introduces a 10cc bolus of room temperature, isotonic saline into the access while performing the endovascular procedure (see Procedure, page 59). The system calculates intragraft blood flow from the change in temperature of the injected saline. The Flow Measurement Protocol (Flow Charts 3.1, 3.2, pages 60-61) recommends that these intragraft flows be measured before and after balloon insertion. By comparing the post-angioplasty value to the pre-angioplasty baseline flow value, the interventional radiologist has immediate feedback on the procedure's success. If intragraft blood flow has not increased to satisfactory levels, the balloon can be re-inserted until flow is optimized.

Principle of Operation

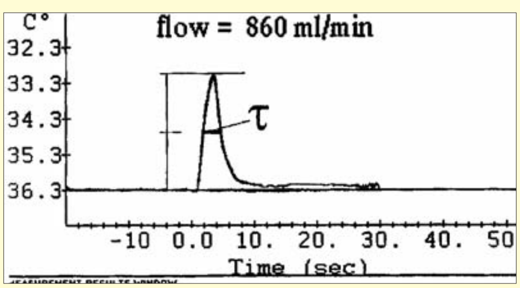
For flow measurements within the AV vascular access, the HVT100 Endovascular Flowmeter and ReoCath™ Flow Catheter use classical dilution-based equations adapted to the unique hemodynamic conditions that exist within the access. Intra-access blood flow measurements are based upon the following equation:

$$Q = k\,(Tb - Ti)\,V/S - 0.5\,V/\tau$$

Where:

Q = intra-access blood flow;
k = a coefficient related to the thermal properties of blood, saline = 1.08
Tb = temperature of the blood prior to injection;
Ti = temperature of injected saline;
V = volume of injected saline (10ml);
S = the area under the temperature-time dilution curve resulting from the mixing of blood and injected saline;
τ = width of the dilution curve at 50% height (Figure).

The expression ($0.5V/\tau$) is an average expected increase in blood flow as a result of the saline injection.



Thermal dilution curve generated by the change in temperature between the isotonic saline injected into the AV access and the diluted temperature registered by the catheter thermistor within the access.

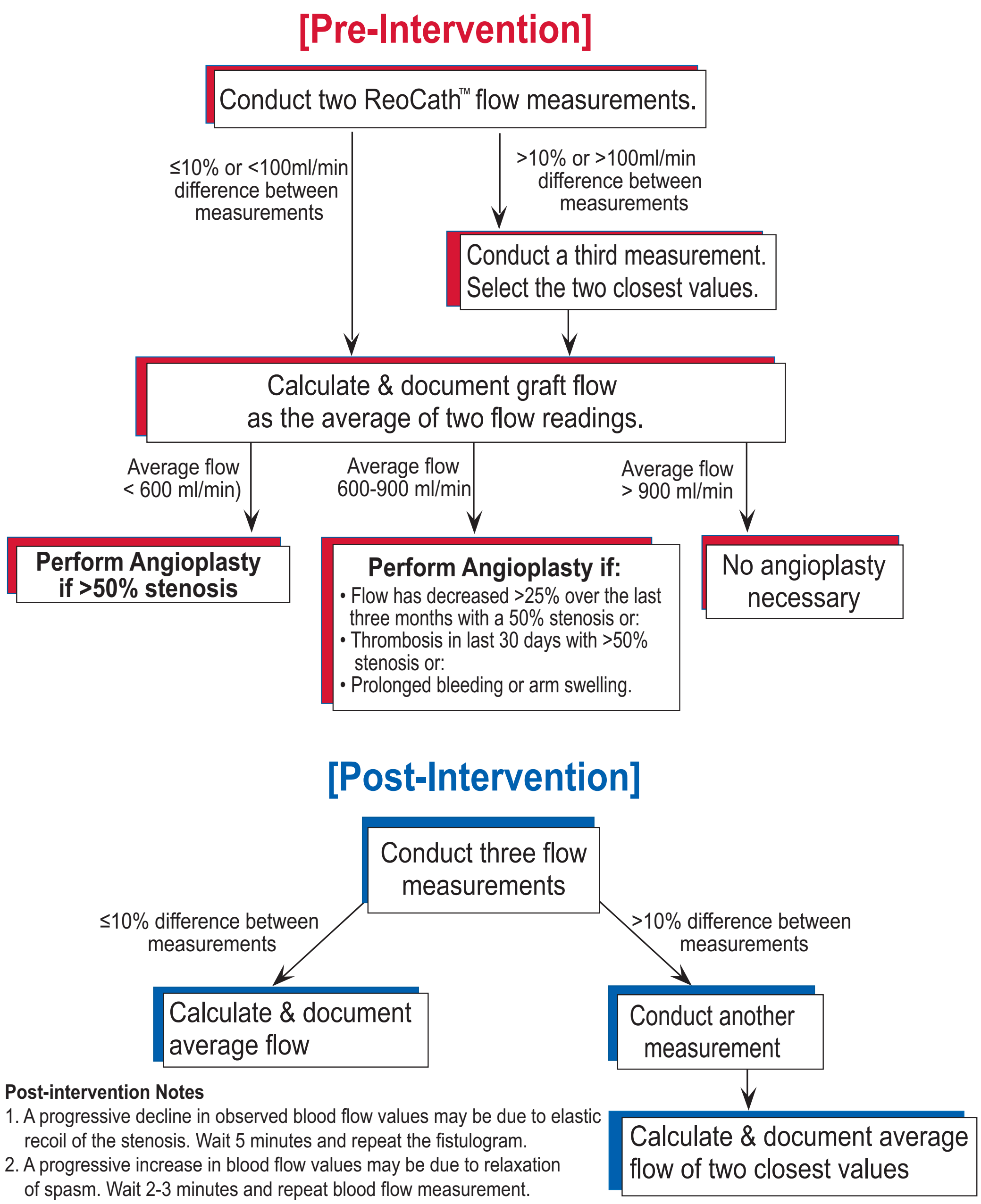
INTRA-GRAFT FLOW MEASUREMENTS PROCEDURE

1. Connect HVT100 Endovascular Flowmeter to grounded power receptacle.
2. Select either an Antegrade or Retrograde sterile ReoCath™ Flow Catheter, open pouch and pass the connector to the non-sterile field.
3. Remove the distal cap, curve retainer, and tag from catheter.
4. Have someone outside the sterile field attach the connector of the catheter to the extension cable. Connect extension cable to the HVT100 Endovascular Flowmeter.

   Note: The system will not identify the type of catheter (antegrade or retrograde) until it is inserted into the introducer sheath.
5. Open stopcock on the ReoCath™ Flow Catheter and prime the catheter with isotonic saline. Close the stopcock.
6. Insert the catheter through the 6F or larger introducer sheath until the marker band is visible outside the sheath.
7. Press the start button on the front of the Flowmeter.
8. The meter will display "Wait". The catheter indicator light will display which catheter type is connected, either antegrade or retrograde.
9. After 15-20 seconds, the Flowmeter will display "Ready". Open the catheter stopcock and inject about 10 ml of room temperature saline (20-25ºC) as a 2-3 second bolus in a smooth, continuous motion. (Small deviations in the injection volume do not affect measurement accuracy.)
10. Close the stopcock.
11. The Flowmeter display will change to "PROC. 21" and countdown to "PROC. 00" and will then change to "CALC. 10" (at this point the Flowmeter has begun to calculate flow) The countdown will continue to "CALC 00". *Note: at some point during the CALC. process, the display may pause momentarily (this is normal).*
12. The Flowmeter will display blood flow in ml/min. If there was a problem with the injection, the display will instead read "REPEAT". Please return to Step 7.
14. Repeat Steps 7-11 once or twice to ensure measurement reproducibility.
15. Remove the catheter from the introducer sheath and keep it in the sterile field for possible additional measurements later in the procedure.
16. After use, dispose of the catheter according to standard infection control procedures.
17. The extension cable and meter can be cleaned with alcohol wipes.

Note: Catheters can be used repeatedly during the same procedure.

ReoCath™ Flow Measurement Protocol for PTFE Grafts

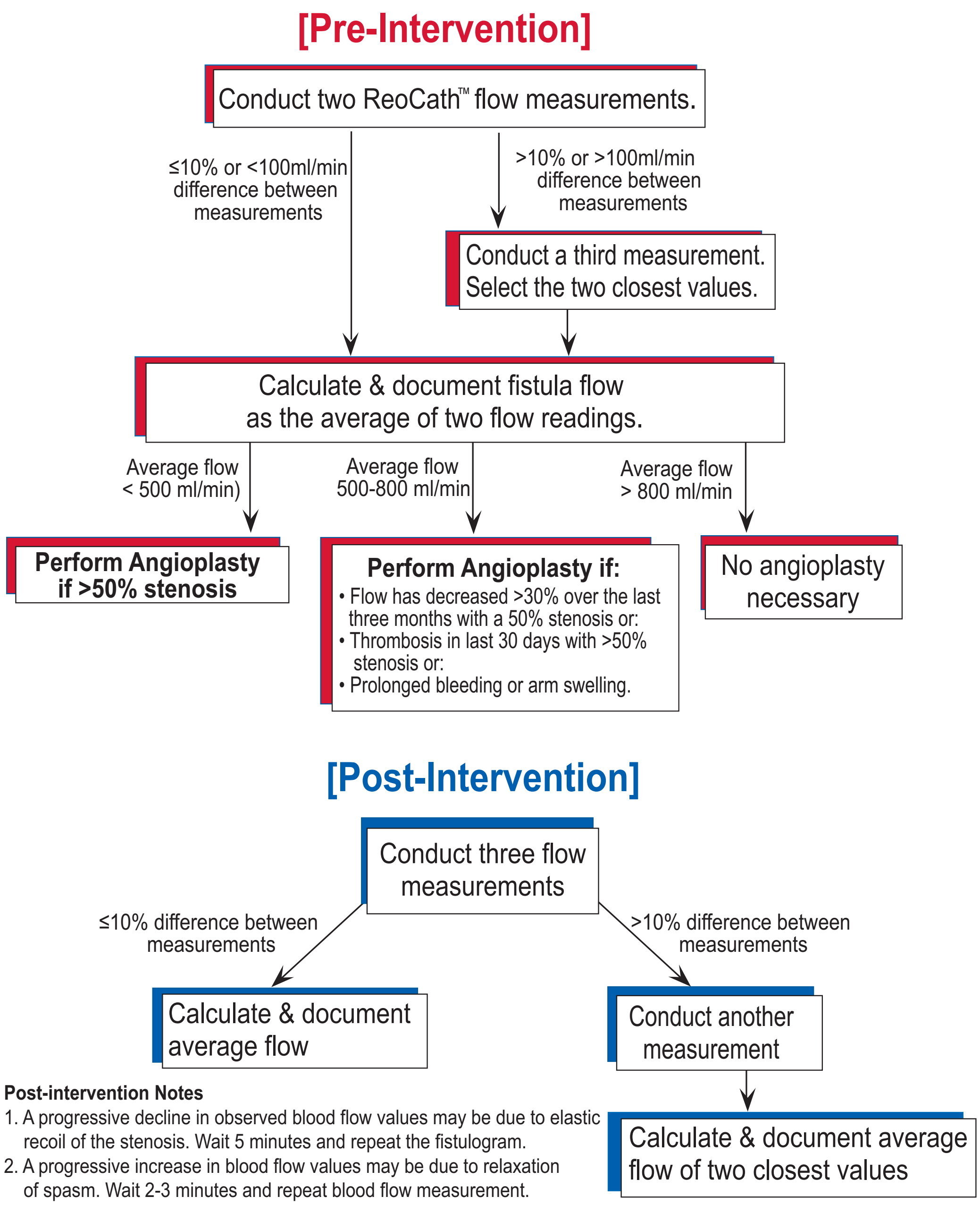


Post-intervention Notes

1. A progressive decline in observed blood flow values may be due to elastic recoil of the stenosis. Wait 5 minutes and repeat the fistulogram.
2. A progressive increase in blood flow values may be due to relaxation of spasm. Wait 2-3 minutes and repeat blood flow measurement.

Flow Chart 3.1: Protocol for Flow-guided intra-graft blood measurement in PTFE grafts

ReoCath™ Flow Measurement Protocol for Fistulas



Post-intervention Notes

1. A progressive decline in observed blood flow values may be due to elastic recoil of the stenosis. Wait 5 minutes and repeat the fistulogram.
2. A progressive increase in blood flow values may be due to relaxation of spasm. Wait 2-3 minutes and repeat blood flow measurement.

Flow Chart 3.2: Protocol for Flow-guided intra-graft blood measurement in AV fistulas.

4. Validation Studies

Transonic ReoCath™ Flow Catheter technology has been rigorously validated on the bench, *in vivo* and in clinical studies.[15,16]

4.1. Bench Test

In the bench test model, catheter flow was meas-ured 397 times while water flow in a graft model was varied from 150 - 1,700 ml/min. Measure-ments between the ReoCath™ Flow Catheter system and the Transonic® HT109 Volume Tubing Flowmeter demonstrated excellent correlation (r = .98). More than 60% of the ReoCath™ measurements were within 5% of true flow as measured by the flowmeter and 95% of the measurements were within 15% of the true flow.

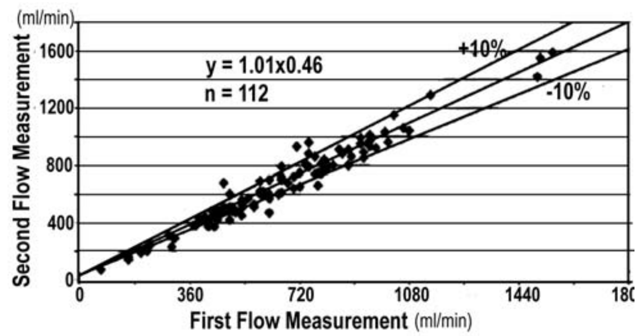


Fig. 3.7: Reproducibility of sequential blood flow meas-ure-ments made by the Reocath™ Flow Catheter system during the clinical validation study of 24 patients.

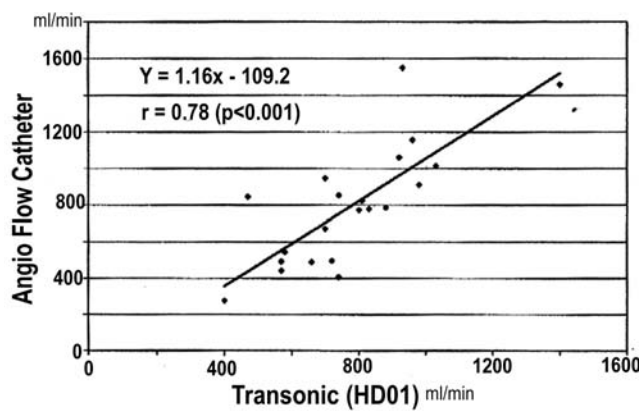


Fig. 3.8: Correlation of post-angioplasty blood flow measure-ments (HD01 Hemodialysis Monitor) with those obtained with the ReoCath™ Flow Catheter system.

4.2. *In Vivo* Testing

In vivo testing in two adult ewes followed. Eleven intragraft blood flow measurements, obtained with the ReoCath™ Flow Catheter system, were compared to values measured with a Transonic perivascular volume flow-probe. Again, the two measurement methodologies demonstrated excellent correlation (r = .99).

4.3. Clinical Study

In a prospective clinical study, intragraft measurements in 25 patients with the ReoCath™ Flow Catheter system were compared to pre- and post-angiography measurements with the Transonic HD01 Hemodialysis Monitor.[22] All patients had PTFE loop grafts, 20 of which were located in the forearm and five were in the upper arm. Fistulograms identified 40 hemodynamically significant stenoses in 24 patients. In each of those patients, angioplasty was performed. Prior to the balloon insertion the ReoCath™ Flow Catheter was inserted through a vascular sheath so that the side holes in the catheter were within the graft, but had not entered its stenotic segment. For each measurement, 10 ml of sterile room temperature, isotonic saline was injected into the catheter's injection port over 3-4 seconds. Two consecutive intragraft blood flow measurements were taken and the results averaged. If the two measurements differed by more than 10%, a third measurement was taken. Sequential measurements were highly reproducible (Fig. 3.7). Measurements were performed both before and immediately after angioplasty.

On an average of 11.9 days before angioplasty, the mean vascular access blood flow measured by the HD01 Monitor in the 24 subjects was 463±154 ml/min. When intragraft flow was measured just prior to balloon insertion with the ReoCath™ Flow Catheter system, the mean flow was 495±180 ml/min. Post-angioplasty correlation between the ReoCath™ flows and HD01 flow measurements were 779±331 ml/min and 781±221 ml/min respectively (Fig. 3.8). The mean increase in vascular access blood flow following angioplasty measured by the ReoCath™ system was 324±267 ml/min and 319±256 ml/min measured by the HD01 Monitor 4.9 days (average) following angioplasty.

4.4. Conclusion

The ReoCath™ system provides a quantitative flow assessment of the entire vascular circuit: its arterial inflow segment, mid-access segment and venous outflow segment.[15-16] This data alerts the interventional radiologist to lesions wherever they are located within the circuit to ensure success of the intervention and avert an immediate return of the patient to the radiology suite or to surgery for another intervention.[23-24]

B. Flow-based AV Access Revision Surgery

Creation of AV fistulas or grafts produces unique cardiovascular hemodynamics. Oxygenated arterial blood usually flows through an intricate high resistance system of arterioles and capillaries before it reaches the venous system. When an AV access is created and arterial blood flows through the access, it immediately encounters a low resistance vein. This makes AV accesses (prosthetic grafts, in particular) susceptible to myointimal hyperplasia that can eventually lead to stenosis, thrombosis and access failure.

A well functioning access remains free of complications and provides sufficient flow to deliver the prescribed dialysis prescription. When access flow is inadequate, options include: repairing it endovascularly, and/or surgically revising the access, or a creating a new access at another site. When surgery is chosen, intraoperative flow measurements during the revision provide quantitative flow data to help the procedure attain its desired conclusion.

> *"Accurate flow measurements can be of great assistance during vascular reconstructive surgery. The primary aim with these intraoperative measurements is to obtain information on the immediate result of the reconstruction, where a technical failure may jeopardize an otherwise successful operation."*[25]

1. Low Access Flow

If an access fails or a patient develops acute upper arm or extremity ischemia, the vascular surgeon must repair the access or establish another access rather than resort to use of a catheter for long-term dialysis. During these surgeries, intraoperative flow measurements help guide the revision to a successful outcome.

When the more common AV access sites are exhausted, vascular surgeons may turn to creative complex bypasses in order to establish a viable AV access for administration of hemodialysis.[28-30]

Examples of complex expanded polytetrafluoroethylene (ePTFE) bypass grafts reported in the literature include: a necklace bypass (axillary artery to contralateral axillary vein); contralateral internal jugular vein (brachial artery to the internal jugular vein); femorofemoral crossover or "Bikini Bypass" (femoral artery to contralateral femoral vein); axillary artery to popliteal vein (axillary artery to superficial femoropopliteal vein): femoral artery to right atrium.[28-30]

When the ESRD patient returns to hemodialysis, ongoing quantitative surveillance of a revised access can then be resumed with ultrasound dilution monitoring of graft inflow rate, recirculation, access flow and cardiac output described in Chapter II of the handbook.

The following two case studies demonstrate the use of intraoperative flow measurements as a surgeon revises problematic accesses with creative solutions.

1.1: Case Study

Brachiocephalic Fistula with Cephalic Arch Stenosis: Correction by Cephalic Vein Ligation and Anastomosis to the Axillary Vein

A 58-year-old male patient, on dialysis for the past 25 years, has had three transplants that had ultimately failed. He had a very high rate of panel reactive antibodies (PRA) which made him unsuitable for another transplant.

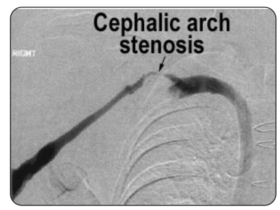


Fig. 3.9: Fistulogram showing cephalic arch stenosis.

Attempts at peritoneal dialysis (PD) ended in peritonitis. He was being dialyzed through a precious 12-year-old right brachiocephalic arteriovenous fistula (AVF). The patient was well aware of his disease and very cooperative.

Cephalic Arch Stenosis

During the previous year, his vascular access flow measurements, as measured by the Transonic Flow-QC® Hemodialysis Monitor, dropped. He was referred for a fistulogram that revealed a right cephalic arch stenosis (Fig. 3.9). The stenosis was successfully dilated three times, but, the intervals between the dilations and the next access flow decrease was only eight weeks.

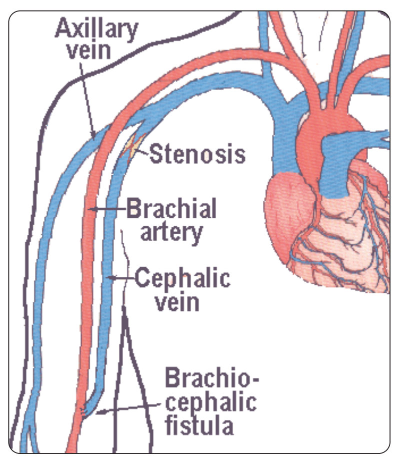


Fig. 3.10: Right brachiocephalic fistula with cephalic arch stenosis.

Clinically, the fistula was pulsatile with no thrill or bruit. Dialysis was painful and inefficient with very high venous pressures, low pump speed and poor inflow (200-250 ml/min). It was decided to correct the problem surgically through creation of a new arch, by ligating the cephalic vein, just proximal to the stenosis, mobilizing it and swinging it over to anastomose with the axillary vein.

continued on next page

2. High Access Flow

2.1: Cardiac Overload

The unique hemodynamics produced by AV fistula creation may cause AV fistulas to mature to flow levels (greater than 2L/min) that can over work the heart and lead to congestive heart failure. When AV access flows exceed 2 liters per minute, cardiac output measurements with the Flow-QC® Hemodialysis Monitor and Central Hemodynamic Profiling inform whether the heart is indeed stressed (see pages 44-48).

Banding

When cardiac overload occurs, the traditional approach has been to band or lengthen the fistula to increase resistance and reduce cardiac overload. When the surgeon chooses to "band" a fistula, Intraoperative flow measurements confirm that "banding" has reduced flow to an acceptable level.[31-32]

Inflow Reduction

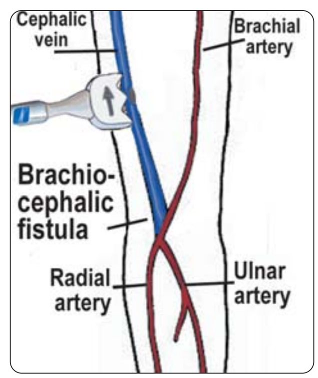


Fig. 3.14: Fistula flow is measured.

Banding of a fistula, however, can be counterproductive. Although fistula flow is reduced and less stress is placed on the heart, the reduction in blood flow within the access might accelerate stenosis and subsequent thrombosis. Recognition of this danger has led to the use of alternative methods to reduce flow through an high access bypass. A 2007 study by Chemla and colleagues reports anastomotic distalization to reduce inflow in the vascular access to treat high cardiac output in hemodialysis patients.[33]

The access inflow reduction procedure described in the study, calls for the fistula anastomosis to be exposed, dissected and tied off. The brachial artery is then reconstructed with either an end-to end anastomosis or a patch. The radial artery is then dissected at the wrist and a 6 mm expanded polytetrafluoroethylene (ePTFE) graft is implanted between the radial artery and the cephalic vein and bypass outflow is then measured (Figs. 3.14, 3.15).

The anastomotic distalization decreased access mean flow significantly with a resultant decrease in cardiac output and resolution of symptoms (Table 3.3).

INFLOW REDUCTION SURGERY (n = 17)	MEAN FLOW ML/MIN	CARDIAC OUTPUT L/MIN
PRE-SURGERY	3135 ± 692	8 ± 3.1
POST-SURGERY	1025 ± 551	5.6 ± 1.7

Table 3.3: Mean blood flow and cardiac output in 17 patients pre- and post-inflow reduction surgery.

> *"Flow reduction using intraoperative access flow monitoring is an effective and durable technique allowing for the correction of distal ischemia and cardiac insufficiency in patients with a high-flow autogenous access."*[34]

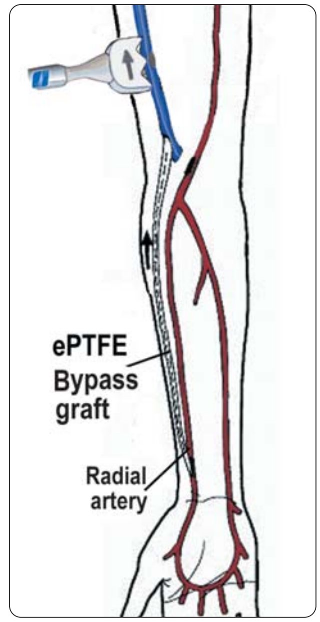


Fig. 3.15: Following construction of a bypass graft from the radial artery to the cephalic vein, outflow is measured.

2.2: Measurement Steps during Intraoperative Fistula Banding or Inflow Reduction Surgery

1) Establish Flow Goal

Before surgery, an AV access flow goal is established, with consideration to the type and location of the access, patient size, weight, gender, medical and access flow histories.

2) Measure Flow before Revision

Measure flow through the AV access before the AV access revision per protocols on pages 11 and 12.

3) Measure Flow after Revision and Compare Flows

Measure access outflows after revision. Compare and document the before and after flows. Evaluate the flow measurement after repair or revision against the desired AV access flow target.

3. Ischemic Steal Syndrome

Ischemic steal syndrome (ISS) following hemodialysis is a devastating complication that occurs when an AV access that shunts arterial inflow into the low-pressure venous circuation "steals" arterial flow from lower arm and hand perfusion. While some level of "steal' is an almost universal "physiologic" result of vascular access creation, it is usually asymptomatic. However, ischemic steal syndrome develops in 1.6 - 8% of patients whose inherent compensatory mechanisms such as collateral circulation and vasodilatation cannot meet metabolic demands.

Ischemic steal syndrome challenges the clinician to relieve distal ischemia while maintaining a functional hemodialysis access. Traditional approaches include banding or lengthening the fistula to increase fistula resistance, but the resulting decrease in blood flow may also lead to access stenosis or thrombosis.

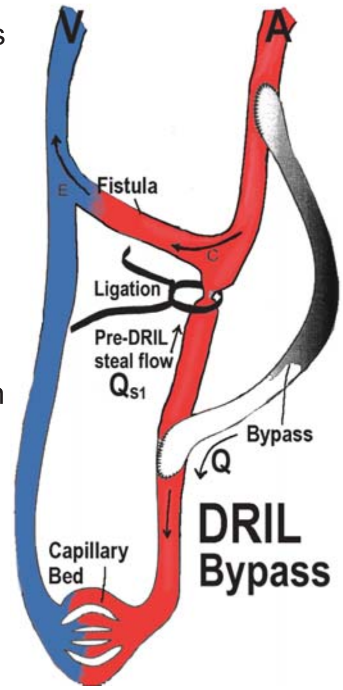


Fig. 3.16: DRIL includes distal artery ligation and bypass construction to an extremity.

3.1: Alternative Techniques to Relieve Ischemic Steal Syndrome

Distal revascularization-interval ligation (DRIL) technique has become an accepted alternative technique for managing ISS. The procedure eliminates the potential pathway for steal syndrome by ligating the artery distal to the AV fistula origin, and revascularizes the extremity through creation of a bypass (saphenous vein, PTFE graft) from above the AV fistula to below the AV fistula (Fig. 3.16).[35-50] However, because the DRIL technique calls for ligating the artery, it has not become universally accepted.

Wayne Gradman and colleagues from Los Angeles' Cedars Sinai Medical Center used mathematical models and intraoperative flow measurements to investigate several options for mitigating ischemic steal syndrome. He and other have proposed alternative procedures for alleviating ischemic steal syndrome.[48-50] These include:

Revision Using Distal Inflow (RUDI)[50]
The fistula is ligated at its origin and then re-established via a bypass from a more distal arterial source to the venous limb of the fistula.

Proximalization of Arterial Inflow (PAI)[50-53]
The fistula is ligated at its origin and then re-established via a bypass from a more distal arterial source to the venous limb of the fistula.

3.2: Flow Measurement Steps for Procedures to Relieve ISS

1) Expose Arterial Segment for Pre-Bypass Flow
Expose arterial inflow segment distal to the fistula origin. Select an optimum site (wide enough to accommodate the probe's acoustic reflector) for applying the probe, and clean the site of fat and excess tissue.

2) Select Flowprobe Sizes
Estimate the diameter of vessel with a gauge. Select a probe size so that the vessel diameter will fill 60% - 100% of the flowprobe window.

Site	Probe Size	Nonrestrictive Vessel Range
RADIAL	2 mm	1.5 - 2.7 mm
ARTERY	3 mm	2.5 - 7.7 mm

3) Apply Flowprobe and Measure Flow
Apply sterile Aquasonic Gel 100™ to the Flowprobe to provide ultrasound coupling between the probe body and probe reflector. Apply the Flowprobe to the site bending the probe's flexible neck segment, as necessary, so that the entire vessel lies within the flowprobe window and aligns with the probe body. Listen to the pitch of FlowSound™ as the Flowprobe is applied to the vessel. The higher the pitch, the greater the flow. Note if flow is going antegrade or retrograde. Retrograde flow indicates ISS.

Check the Signal Quality Indicator (bucket display) on the flowmeter's front panel for ultrasound acoustic contact. An acoustic error message will be displayed if ultrasound contact falls below an acceptable minimum.

4) Construct the Bypass

5) Measure and Evaluate Bypass Flow
With the Flowprobe positioned as under Step 3, measure bypass flow.

3.3: Case Study

ISS on a High Inflow Brachiocephalic Fistula: Management by Inflow Reduction Using a Bovine Bypass Graft from the Radial Artery[54-55]

Introduction

A female patient with a mature brachiocephalic fistula presented with ischemic steal syndrome (ISS) as she awaited a second nephrectomy. The fistula had not been cannulated. Surgery was undertaken to alleviate ISS symptoms before the nephrectomy.

Baseline Flow Measurement

Fistula (cephalic vein) flow was measured with a Transonic perivascular flowprobe (Fig. 3.17). Flow measured 1600 ml/min - 1700 ml/min confirming a mature fistula.

Fistula Anastomosis Ligation

The anastomosis was ligated and the brachial artery repaired (Fig. 3.18a).

Bypass Graft Construction

A bovine graft was constructed between the radial artery and the cephalic vein (Fig. 3.18b).

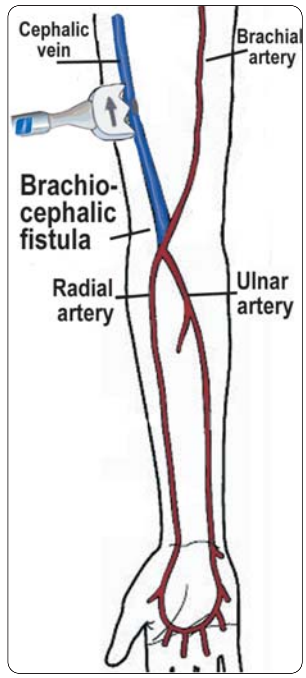


Fig. 3.17: Fistula flow is measured pre revision.

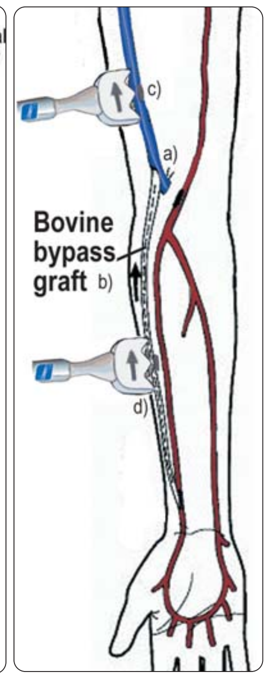


Fig. 3.18: After construction of a radial artery-cephalic vein graft, flow was remeasured.

Post-Bypass Flow Measurements

Cephalic vein flow after revascularization dropped to 600 ml/min (Fig. 3.18c). Bypass flow also measured approximately 600 ml/min (Fig. 3.18d).

Conclusion: After surgery, steal symptoms immediately began to improve as the brachial artery resumed full delivery of flow to the distal arm and hand circulation (Table. 3.4).

FLOW SUMMARY		
CONDUIT	BASELINE	POST REVASCULARIZATION
CEPHALIC VEIN	1600 -1700 ml/min	600 ml/min
BYPASS GRAFT		~600 ml/min

Table 3.4: Cephalic vein flow drop from 1600-1700 ml/min to 600 ml/min following inflow reduction surgery.

*Case study courtesy of **Eric S. Chemla, MD**, consultant surgeon and honorary senior lecturer, Renal Transplant and Vascular Surgery, St. George's Healthcare NHS Trust, London, UK*

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Transonic Systems' technological flow innovations include: intraoperative flowmetry using transit-time ultrasound, vascular access flow measurement during hemodialysis via blood line reversal, and catheter-based intragraft flowmetry during AV access intervention. Each of these technologies has spawned significant improvements in hemodialysis patient care.

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