Best Practices in Hemodialysis

Access Flow • Dialysis Adequacy • Cardiac Function

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Acknowledgments

Twenty years ago, Transonic® pioneered two measurement technologies for use during a hemodialysis session. Transit-time ultrasound technology, pioneered by Transonic founder Cornelis Drost, is used to verify true delivered blood from the dialysis pump. Ultrasound dilution technology, developed by Nikolai Krivitski, Ph.D., D.Sc., is employed to measure vascular access flow, recirculation, and cardiac function. These on-the-spot measurements have since revolutionized vascular access management in end-stage renal disease (ESRD) patients as they undergo hemodialysis.

Development of these measurement modalities was supported, in part, by grants from the National Institutes of Health. We gratefully acknowledge their significant financial assistance.

The true innovators, though, are our end users: clinicians, such as Dr. Thomas Depner and Dr. Lawrence Spergel, who are dedicated to the improvement of care for their ESRD patients through the advancement of new methodologies. We and the larger nephrology community owe a debt of gratitude to these physicians and researchers whose ultimate goal is the removal of the prefix "end-stage" from all renal disease.

We are also indebted to Dr. Eric S. Chemla and Dr. Thomas Tucker for their contributions to this handbook.

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I. Introduction: Hemodialysis: Flow-based Best Practices

"The Transonic Flow-QC® Hemodialysis Monitor has benefited numerous dialysis-dependent patients by reducing and, in many cases, eliminating the agony of a clotted AV graft or fistula, thereby facilitating correction of access stenoses on an elective basis that prevents missed dialysis and the need for placing temporary catheters." Depner, T, MD, UC Davis

A. Why Flow-based Hemodialysis Assessment?

The effectiveness of hemodialysis depends on having sufficient flow moving through a vascular access to sustain hemodialysis. Before Transonic hemodialysis surveillance, direct measurement of vascular access flow did not exist. Clinicians were forced to rely on surrogate measurements such as the blood urea nitrogen (BUN) test to learn what percentage of recirculation was taking place through an access. Test results took time. They were not precise. Moreover, it is now recognized that any access recirculation is a late indicator of access dysfunction.

B. Aha Moment Sparks Genesis of the Hemodialysis Monitor

In 1991, Biomedical Engineer Nikolai Krivistki Ph.D., D.Sc., came to the United States from Russia. He had previously worked at the ICU and Hemodialysis Units of Moscow USSR Medical Academy's National Research Center for Surgery. During his first several months at Transonic Systems, he familiarized himself with Transonic products, especially its proprietary clamp-on tubing flowsensors and dedicated tubing flowmeter. Suddenly, he had an "Aha" moment. He envisioned how existing transit-time ultrasound technology could be combined with classical indicator dilution technology to provide a superior flow measurement. He termed his innovation "ultrasound indicator dilution" technology.

I. Hemodialysis Flow-based Best Practices cont.

B. Aha! Moment Sparks Genesis of the Hemodialysis Monitor cont.

As he considered real-life blood flow measurement problems reported by nephrologists such as Dr. Thomas Depner and Dr. Jeffrey Sands, Nikolai had another "aha" insight. He realized that vascular access flow could be measured directly with ultrasound dilution technology by simply reversing the dialysis blood lines and injecting saline into the venous line. The first patents of the"Krivitski Method" were filed in the fall of 1994. Indicator dilution measurements soon revolutionized hemodialysis by providing direct access flow measurements. The measurements took off quickly because it gave clinicians information they needed — about the adequacy of dialysis and what is the actual flow through a vascular access. Within a few short years, ultrasound indicator dilution technology was recognized in the Guidelines of the American Kidney Foundation as the gold standard, or the technology with which other measurement technologies should be compared.

Awards followed including, in 2000, the prestigious US Small Business Administration's Tibbets Award for Research and Innovation which was presented to Transonic at a White House breakfast ceremony. The new indicator dilution technology also spurred an avalanche of publications that reported on the value of access flow measurements in assessing hemodialysis effectiveness and predicting the advent of a stenosis within an access. Since then, the measurements made possible by Dr. Krivitski's insights have become the corner stone of many vascular access measurement programs.

C. Product Improvements

Transonic's first HD01 Hemodialysis Monitor was a tubing bypass flowmeter mounted on a computer. It was followed by a second-generation HD02 monitor. In 2006, a self-contained HD03 Hemodialysis Monitor was launched with Flow-QC® software and augmented by Administrator software that provided the capability to trend patients' measurements over time. The HD03 provides vascular access surveillance, dialysis adequacy and cardiac function tests. With these tests, fistulograms or interventions to ensure assess patency and cardiovascular health can be scheduled proactively rather than become emergent procedures. Early interventions with minimally invasive restorative flow procedures reduce morbidity and costs. The clinic can continue to administer dialysis, collect and analyze data and reduce its dependence on outside services.

I. Hemodialysis Flow-based Best Practices cont.

D. Vascular Access Patency, Dialysis Adequacy & Cardiac Function

Vascular Access Patency

Access flow is the quintessential vital sign for an AV Access. Insufficient flow causes underdialysis. Still lower flow invites thrombosis. Too much flow can lead to cardiac problems with associated morbidities. Transonic vascular acccess surveillance measures access flow directly for an immediate snapshot of access function and detection of flow limiting problems wherever they might occur within a vascular access circuit. An access patency record is created by measuring vascular access flow routinely and trending the results over several months. A drop in access flow may signal formation of a stenosis in time for proactive minimally invasive intervention.

Dialysis Adequacy

The Hemodialysis Monitor is also used to optimize dialysis delivery by measuring delivered pump blood flow and recirculation, each of which can compromise delivery of a KT/V prescription. By measuring true delivered blood flow through dialysis tubing with transit-time ultrasound technology and then comparing the actual delivered blood flow to the pump's reading, any flow limiting cause can be identified and corrected on the spot. With ultrasound dilution technology and a single infusion of saline, the Hemodialysis Monitor also detects and quantifies access recirculation.

The Monitor can help to optimize dialysis through central venous catheters (CVCs). Measurements are used to establish a maximum dialysis pump setting before recirculation occurs. Known flow and recirculation values can be used to adjust the length of dialysis, identify flow restrictions and failing CVCs, and determine the best connections between a CVC and blood lines.

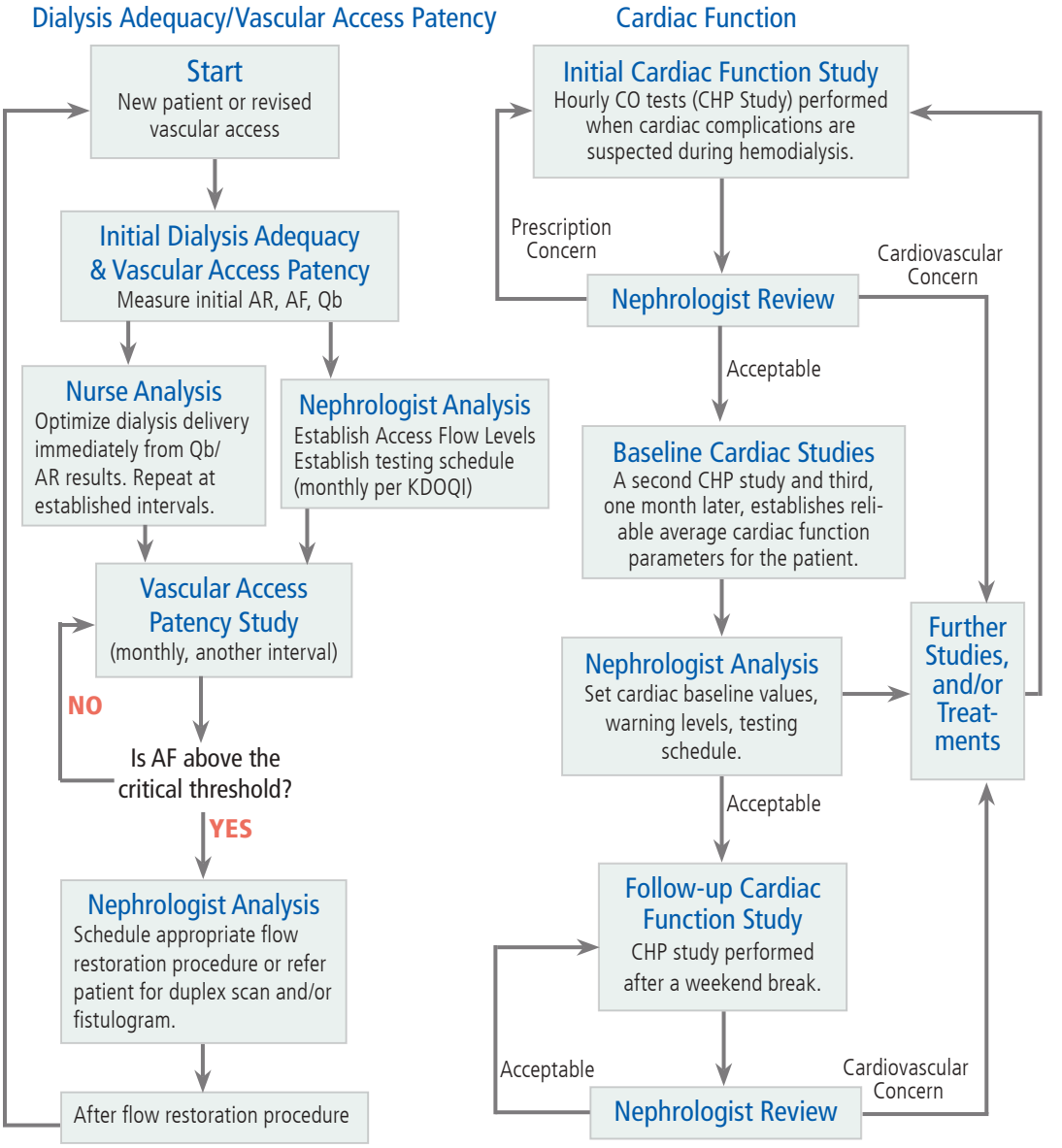
Cardiac Function Testing

Moreover, the Hemodialysis Monitor provides a way to measure and integrate cardiac function tests into a hemodialysis clinic's dialysis protocol in order to forestall the devastating effects of cardiovascular disease, the leading cause of death in hemodialysis patients.

A comprehensive monitoring protocol for dialysis adequacy, vascular access patency and cardiac function, on the next page, provides a framework for the information presented in the remainder of the handbook.

I. Hemodialysis Flow-based Best Practices cont.

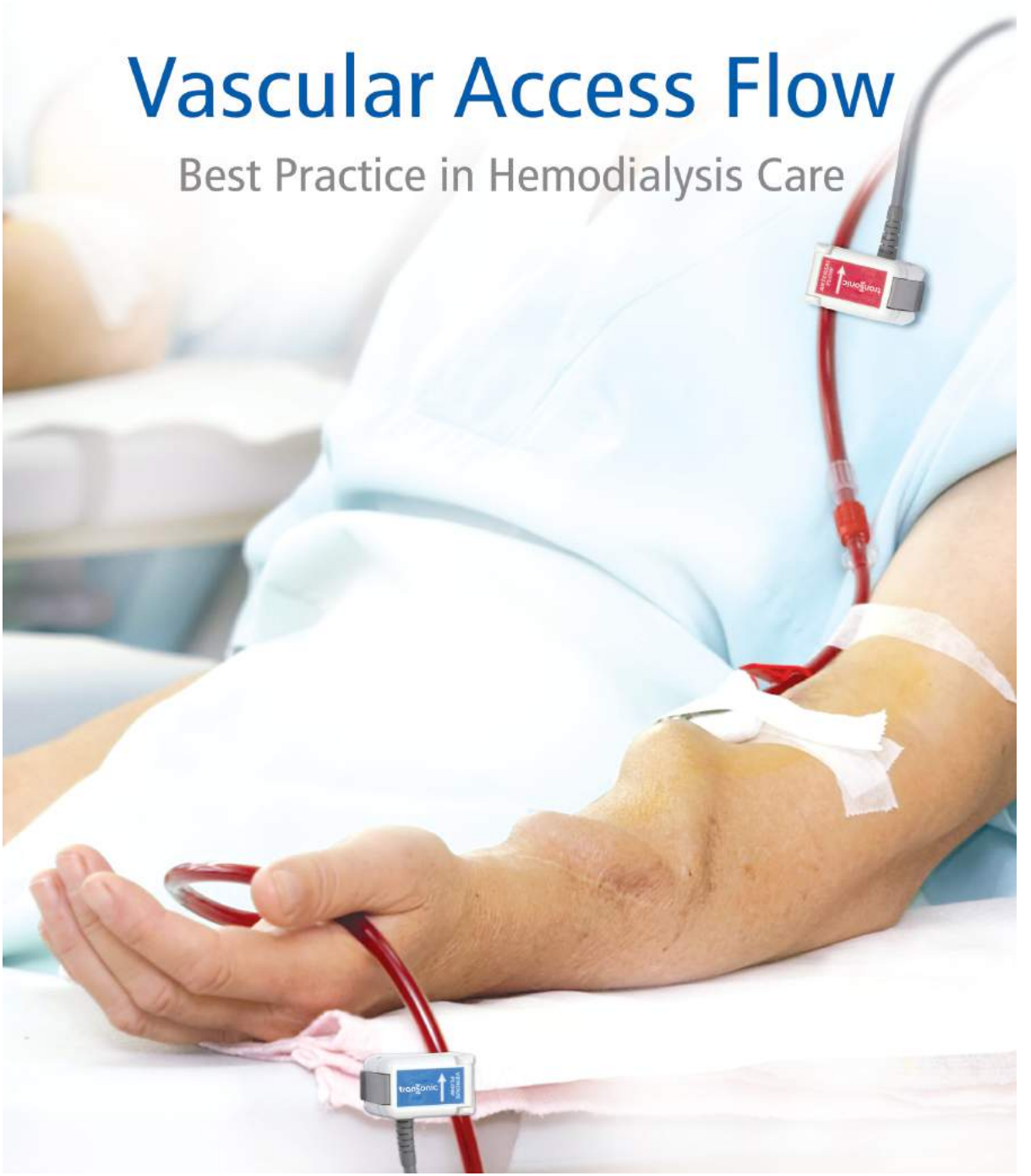
E. Flow-QC® Protocol for Comprehensive Hemodialysis Management



A Flow-based Access Management Protocol includes an initial dialysis adequacy study, followed by periodic access patency surveillance and a cardiac function assessment.

Vascular Access Flow

Best Practice in Hemodialysis Care



II. Flow-based Vascular Access Management

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II. Flow-based Vascular Access Surveillance

"A hemodynamically significant stenosis is the substrate for thrombosis by reducing flow, increasing turbulence, and increasing platelet activation and residence time against the vessel wall." KDOQI Guidelines 2006[1]

A. Hemodialysis Vascular Access Surveillance

A hemodialysis patient's vascular access is his or her lifeline. If it fails, underdialysis can occur that can lead to costly hospitalizations[1]. The National Kidney Foundation's Kidney Disease Outcome Quality Initiative (KDOQI) Guidelines, the European Renal Association-European Dialysis and Transplant Association's (ERA-EDTA) European Best Practice Guidelines on Haemodialysis, the Australian CARI and Canadian Guidelines all advise proactive vascular access management.[1-4] KDOQI Guidelines recommend surveillance at least once a month to diagnose any asymptomatic, but hemodynamically significant stenoses, to prevent their progression to a functionally significant stenosis, a substrate for thrombosis. KDOQI Guidelines advise that "these monthly measurements should be…tabulated and tracked within each dialysis center as part of a Quality Assurance/ Continuous Quality Improvement program" and evaluated to look for trends toward decreases in flow in order to proactively identify access stenoses for expeditious referral for corrective procedures.[1]

Transonic® hemodialysis surveillance tracks a patient's vascular access flow over time (Fig. 2.1, page 8). If access flow decreases below a critical threshold, fistulograms or interventions can be scheduled proactively to delay access failure. Such early intervention with minimally invasive restorative flow procedures reduces morbidity and costs.[6] The clinic can continue to administer dialysis, collect and analyze data, and reduce its dependence on outside services for costly studies and lab tests.

II. Flow-based Vascular Access Surveillance cont.

As a corner stone for a comprehensive Vascular Access Management Program Transonic Flow-QC® Hemodialysis Surveillance inform clinicians of the following:[5]

- Measures actual function in AV grafts and fistulas in order to identify failing accesses and avert underdialysis and/or thrombosis;
- Indicates effectiveness of interventions through post-intervention surveillance, or limb ischemia;
- Excludes access dysfunction quickly as cause of underdialysis;
- Identifies a mid-access obstruction;
- Identifies high-flow versus low flow accesses to select ideal treatment plan for correction (flow-restricting versus re-vascularization procedure);
- Permits access surveillance to be performed by the clinic's staff who then can alert nephrologist to possible onset of access dysfunction;
- Implements KDOQI Guidelines;
- Implements Best Practices for patient care with gold standard reference method.

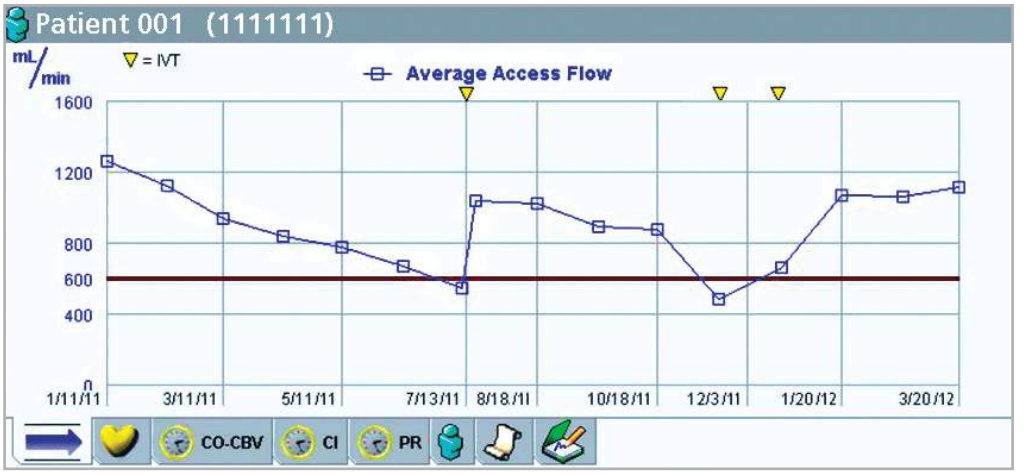


Fig. 2.1: Access Flow Trend: This flow history of a patient's AV access shows that the onset of stenoses were identified by decreases in flow below 600 mL/min. Interventions, indicated by the inverted arrows, resulted in immediate increases in access flow.

II. Flow-based Vascular Access Surveillance cont.

B. Ultrasound Dilution Technology — The Gold Standard

1. Vascular Access Flow Methodology

The Transonic® Hemodialysis Monitor marries two gold standard technologies: ultrasonic transit time and indicator dilution[9-11]. Transonic transit-time ultrasound flow measurements through sterile tubing is the gold standard for blood flow verification. Transonic ultrasound dilution access flow surveillance, the "Krivitski Method®," is the gold standard technology for access flow measurements in dialysis patients. The Krivitski Method calls for the temporary reversal of arterial and venous blood lines at their respective needle connections to create mixing conditions conducive for an indicator dilution flow measurement when a bolus of isotonic saline is injected into the blood circuit (Fig. 2.2). Classic dilution equations are used to calculate vascular access flow.[10-12]

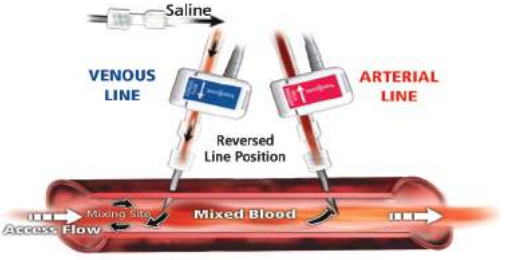


Fig. 2.2: "Krivitski Method"is the temporary reversal of blood lines at needle connections to create proper indicator dilution mixing conditions. When dialysis lines are reversed to induce recirculation, vascular access flow (Q_a) can be calculated.[10]

2. Vascular Access Flow Measurements

Access flow measurements can be performed in either prosthetic grafts or fistulas created with an end-to-side anastomosis (Fig. 2.2).[11-13] The dialyzer removes blood from the venous side of the access and returns the blood to the arterial side to create the mixing conditions needed for an indicator dilution measurement of access flow (Fig. 2.3).

When saline is introduced into the venous line, it dilutes the blood's protein concentration and reduces ultrasound velocity. This diluted blood is first detected by the flow/dilution sensor clipped onto the venous blood line and the Monitor's software generates a venous dilution curve. The diluted blood from the venous line then enters the access and

mixes with incoming access flow. Upon reaching the arterial needle, a portion of mixed blood is removed from the access by the dialyzer. This mixed (diluted) blood is detected by the arterial flow/dilution sensor and the Hemodialysis Monitor's software generates an arterial dilution curve. Access flow is calculated from the ratio of the area under the venous curve to the area under the arterial curve (Fig. 2.4). The use of two sensors effectively eliminates multiple factors, such as viscosity that can influence ultrasound velocity.

Fig. 2.3: Hemodynamics of access flow measurement with lines reversed by Krivitski Method. Line reversal creates an artificial recirculation loop with a mixing site at the arterial side of the access.

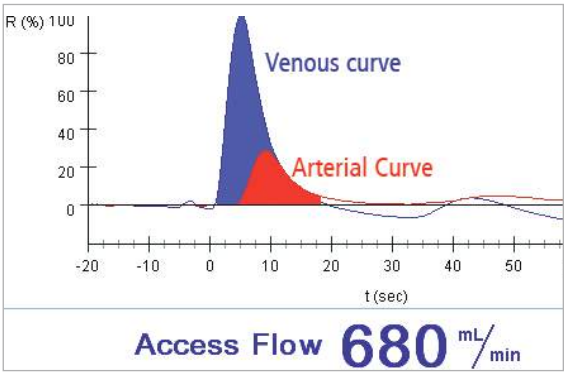


Fig. 2.4: Result showing flow/dilution curves and access flow measurement of 680 mL/min flow.

Tips for Adequate Saline Mixing in Fistulas

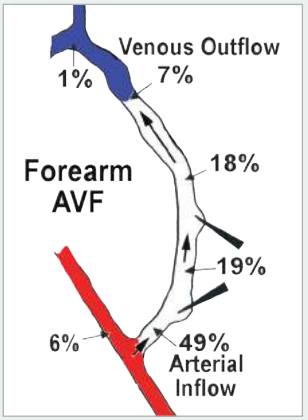
1. If delivered blood flow is 200-300 mL/min, any needle orientation (toward or away from incoming access flow) produces adequate mixing for up to 2 liters of flow.
2. In fistulas with a large aneurysm, or in upper arm fistulas with >2 L/min of flow, the arterial needle should be positioned so that it faces incoming access flow.
3. When measuring access flow with a needle in a collateral or branch of the vein, you may see the message "Check Line Reversal and Needle Placement." Confirm the message by repeating the measurement. If the message reappears, occlude the collateral fistula branch downstream from the needle for 2-3 minutes and remeasure access flow.

II. Flow-based Vascular Access Surveillance cont.

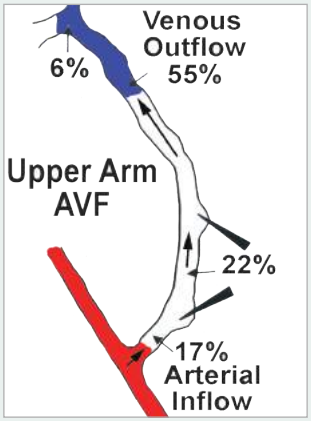
Transonic® Vascular Access Surveillance

Transonic vascular access surveillance detects hemodynamically significant stenoses at all sites within an access circuit (arterial inflow, between the dialysis needles, venous outflow) in both AV fistulas and prosthetic grafts. While other technologies can detect venous outflow stenoses, the site where most stenoses form in prosthetic grafts, they do not detect stenoses at all sites within the circuit.

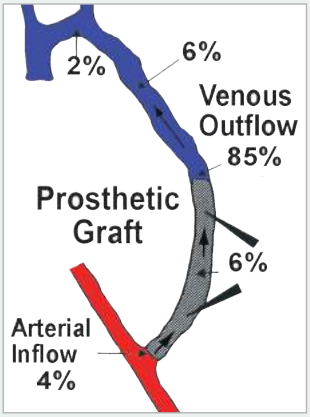
In prosthetic grafts, most stenosis occur at the venous outlet. This is not the case in fistulas where a significant number of stenoses may also occur at the arterial inlet and/or between the needles. This makes the Transonic Monitor's capability to measure flow to detect stenoses anywhere in the circuit unique. KDOQI Guidelines acknowledge that inflow stenoses are more common than previously believed and occur in up to one-third of patients with clinical symptoms of venous stenosis or thrombosis.[1,20-21]



Arterial inflow	49%
Between Needles	19%
Venous Outflow	18%



Arterial inflow	17%
Between Needles	22%
Venous Outflow	55%



Arterial inflow	4%
Between Needle	6%
Venous Outflow	85%

Stenosis Sites in AV Fistulas and Grafts: The figures above show the sites of most frequent stenoses for AV fistulas and prosthetic grafts. Note that in forearm fistulas, 49% of stenoses are inflow stenosis. Adapted from Turmel-Rodrigues *et al*, Nephrol Dial Transplant 2000; 15: 2029-2036.[22]

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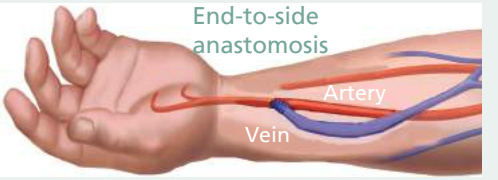
II. Flow-based Vascular Access Surveillance cont.

Access Flow Measurement in Fistulas with Side-to-Side Anastomosis "Proximal Branch Flow" as Access Flow Surrogate[13]

End-to-Side Anastomosis

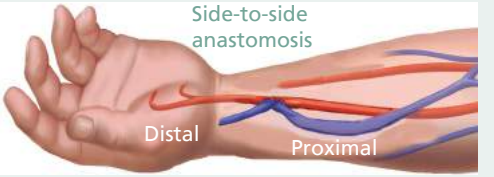
When a AV fistula is constructed with an end-to-side anastomosis, access flow is measured with the blood lines reversed as previously described.



Fistula created with end-to-side anastomosis connecting the arterial inflow and venous outflow conduits.

Side-to-Side Anastomosis

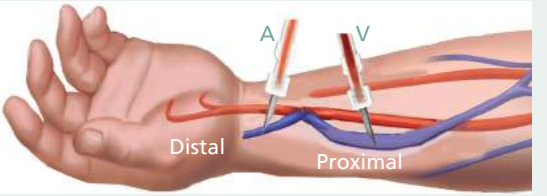
However, when a fistula is created with a side-to-side anastomosis, the flow pattern becomes more complex.[13] The venous limb of the fistula now has two branches: a "proximal" branch oriented towards the shoulder and a "distal" branch oriented towards the hand. Blood flow is usually greater in the proximal branch.



Fistula created with side-to-side anastomosis showing proximal and distal branches of venous outflow limb of the fistula.

Access Flow Measurement

AV fistulas created with a side-to-side anastomosis may have the hemodialysis needles placed so that blood is withdrawn from the distal branch of the venous limb by the arterial needle and is returned to the proximal branch of the venous limb through the venous needle.



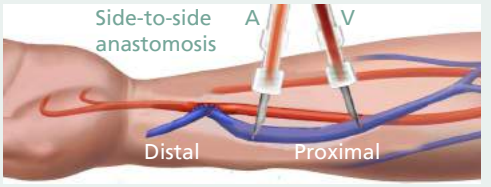
Fistula created with side-to-side anastomosis with the needles placed in the proximal and distal limbs of the fistula's venous outflow for normal dialysis. Unsuitable for access flow measurement.

This configuration positions the dialysis needles on opposing venous limbs of the arterial-venous anastomosis and is, therefore, unsuitable for Krivitski Method access flow measurements.

Access Flow Measurement in Fistulas with Side-to-Side Anastomosis "Proximal Branch Flow" as Access Flow Surrogate cont.

Repositioning the Needles

Therefore, to measure access flow in fistulas with a side-to-side anastomoses with the Krivistki Method, the arterial needle must be repositioned into the proximal branch. The arterial needle should face the flow if the distance between needle tips is less then 2-3 cm, or if there is a large aneurysm at the needle. With both needles now in the proximal branch of the venous limb, the blood lines can be reversed as usual and access flow measured. Access flow should be recorded as "Proximal Branch Flow." Proximal branch flow serves, in essence, as a surrogate for total access flow.



Needle reposition into the proximal branch to measure "proximal" branch flow.

The access should be considered at risk when:

- Proximal branch flow drops by 25% over a four-month period indicating changes in the vascular resistance at the fistula anastomosis or the proximal branch.
- Access Flow falls below 500 mL/min. Since proximal branch flow is less than or equal to access flow, access flow may still be above 500 mL/min when proximal branch flow registers 500 mL/min. For example, if proximal branch flow is 80% of access flow, access flow would actually be 625 mL/min. This means that proximal branch flow surveillance may signal a premature need for a fistulogram.

Summary

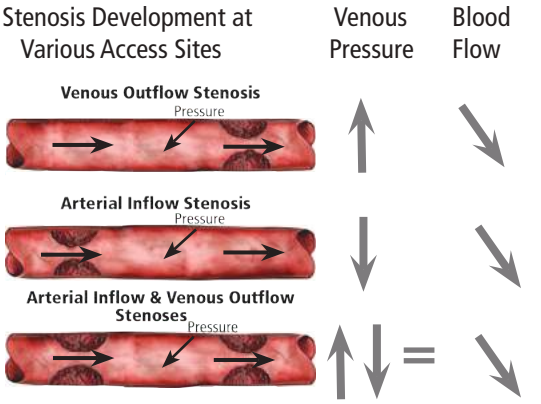
The assumption "access flow is equal to proximal branch flow" is a safe assumption. Proximal branch underestimation of flow will not cause a misdiagnosis of a failing access. It may, however, prompt premature fistulography for a deteriorating access.

Reference: Transonic Technical Note DL-4-tn "Measuring Flow in AV Fistulae," Krivitski, NM, 2005.[13]

II. Flow-based Vascular Access Surveillance cont.

3. Venous Pressures Do Not Correlate with Flow Measurements[7-8]

The top graphic demonstrates increased resistance caused by a stenosis located past the venous pressure measurement site. Venous pressure increases; flow decreases. With an inflow stenosis, before the point where pressure is measured (middle graphic), venous pressure decreases. If multiple stenoses occur (bottom), one before the pressure measurement site, and another after, the two pressure components can cancel one another out, and result in no change in venous pressure. However, stenoses that decrease access flow can form at all sites within an access.



Venous Pressure Monitoring Does Not Accurately Predict Access Failure in Children

Chand DH, Poe SA, Strife CF, Pediatr Nephrol. 2002; 17(9): 765-9.

BACKGROUND

Access failure is a significant cause of morbidity and mortality in hemodialysis patients. Routine monitoring of arteriovenous (AV) fistulas and grafts could increase access longevity. Dynamic venous pressure monitoring is a surveillance test advocated to detect early signs of vascular thrombosis.

METHOD

- Venous pressure measurements were reviewed in children undergoing hemodialysis with an AV fistula or graft, obtained per DOQI recommendations;
- Venous pressure means from before an antecedent thrombosis served as baseline venous pressures.
- Two paired t-tests compared mean baseline pressure measurements with mean pressures per individual immediately preceding each thrombosis episode.

RESULTS

- 335 venous pressures were collected in ten pediatric patients.
- 18 thromboses occurred in five patients, in whom a total of 241 venous pressures were measured.
- Venous pressures did not correlate with thrombotic events (P=0.4284).
- No correlation was found between specific thrombotic events with mean patient-specific venous pressures.

CONCLUSION

Dynamic venous pressure monitoring is not an adequate predictor of access thrombosis in pediatric patients.

II. Flow-based Vascular Access Surveillance cont.

Static Venous Pressure Does Not Correlate with Access Flow

Spergel LM, Holland JE, Fadem SZ, McAllister CJ, Peacock EJ, "Static Venous Pressure Ratio Does Not Correlate with Access Blood Flow," Kid Int 2004; 66(4): 1512-1516. (Transonic Reference # HD382A)

INTRODUCTION

Measurement of AV graft static venous pressure has been championed as a non-invasive screening test for venous stenosis. It is listed in the KDOQI Guidelines as the second surveillance method of choice following access flow measurement. The attraction of static venous pressure as a surveillance tool is that:
1) it can be performed during the dialysis session
2) does not require any other equipment other than a dialysis machine with a digital pressure display.

OBJECTIVE

The purpose of this prospective multi-center study was to investigate the relationship between Static Venous Pressure Ratio (SIAVPR) and vascular access flow, and to investigate the premise that KDOQI-designated abnormal SIAVPR thresholds are indicative of low flow.

STUDY

- Included 242 patients (146 prosthetic grafts, 96 arteriovenous fistulas).
- SIAVPR and flow were simultaneously measured monthly.
- Total of 1161 measurement sessions were conducted during the 8-month study period.
- Each patient has an average of 4.8 measurements.

RESULTS

- The study showed that SIAVPR at any threshold cannot discriminate between an access with clinically significant stenosis and a well-functioning access with high flows.
- A mathematical formula presented demonstrates that SIAVPR only indicates the relative relation of outflow resistance to resistances and is unrelated to Qa.

CONCLUSION

Although SIAVPR may detect outflow stenosis, it is as likely to wrongly target a well functioning access for referral. Therefore, an absolute SIAVPR at any level should not be used as a surrogate for low flow or access dysfunction.

TAKE HOME

This paper categorically reputes the validity of using venous pressure monitoring to predict thrombosis.

II. Flow-based Vascular Access Surveillance cont.

C. Vascular Access Surveillance Program

KDOQI, European, Australian and Canadian Guidelines advise that periodic access flow surveillance is an effective tool for predicting hemodynamically significant stenoses and declining access health.[1-4] To establish a surveillance program, the nephrologist sets a:

Access Flow Trending Threshold: Flow at which the access is at higher risk for failure.

Critical Access Flow Threshold: Flows at or below which indicate a significant stenosis and require immediate verification and follow up.

KDOQI Guidelines recommend monthly surveillance to diagnose the onset of stenosis.[1] For native fistulas, the threshold for the critical flow threshold is >500 mL/min (Fig. 2.5). European Guidelines set the flow threshold of >300 mL/min in forearm fistulas as an indication for preemptive intervention.[2] For vascular access prosthetic grafts, both KDOQI and European Guidelines set the Critical Flow Threshold at >600 mL/min (Fig. 2.6) or access flow of less than 1000 mL/min if flow drops 25% (European Guidelines: 20%) or more over four months.

Nephrologists should also consider a patient's history when setting flow thresholds to ensure that the level is set high enough to permit proactive action before access failure.

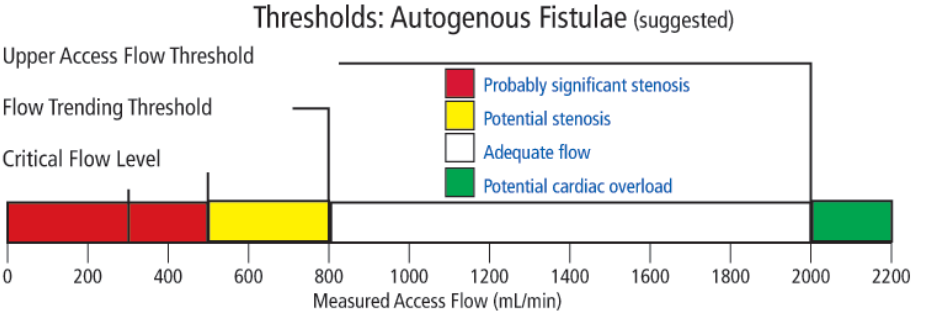


Fig. 2.5: Access Flow Level Guidelines for Fistulas, Adult Patients: KDOQI sets a Critical Level at 500 mL/min. European Guidelines recommend >300 mL/min. The Flow Trending Threshold is 800 mL/min, and the potential for cardiac overload exists at flows of over 2000 mL/min. Actual flow levels should be customized for each patient by the nephrologist.

II. Flow-based Vascular Access Surveillance cont.

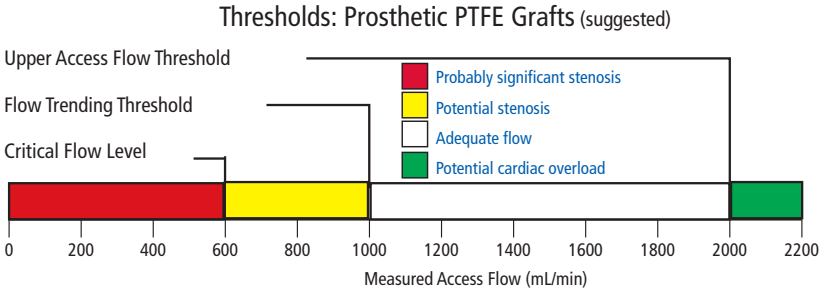


Fig. 2.6: PTFE Grafts Access Flow Level Guidelines, Adult Patients: KDOQI and European guidelines set the Critical Level at > 600 mL/min for prosthetic grafts. The Flow Trending Threshold is 1000 mL/min, and the potential for cardiac overload exists at flows of over 2000 mL/min. Actual flow levels should be tailored for each patient by the nephrologist.

Upper Access Flow Threshold: A third threshold to be observed is the Upper Access Flow Threshold. It is generally accepted that in both fistulas and grafts, 2000 mL/min is a valid upper access flow threshold. Above 2000 mL/min, the patient may be at risk for cardiomegaly or other conditions resulting from cardiac overload. Cardiac output measurements are recommended when, in the absence of recirculation, access flow levels are above this upper threshold.

1. Chronological Trending of Measurements

Once an access flow surveillance schedule has been established, each patient's data should be examined within the context of the patient's chronological history. When a patient's access flow is below the Critical Flow Threshold, Flow-QC software automatically alerts the clinician. Patients who fall into the high risk or critical categories defined by the threshold of critical access flow should be brought to the nephrologist's attention.

2. Minimizing Access Flow Surveillance Errors

KDOQI Guidelines address multiple issues that should be considered as an access surveillance program is implemented. In addition, published data[15-18] suggest the application of some simple rules during access flow data analysis. The following recommendations are advised to improve outcome quality:

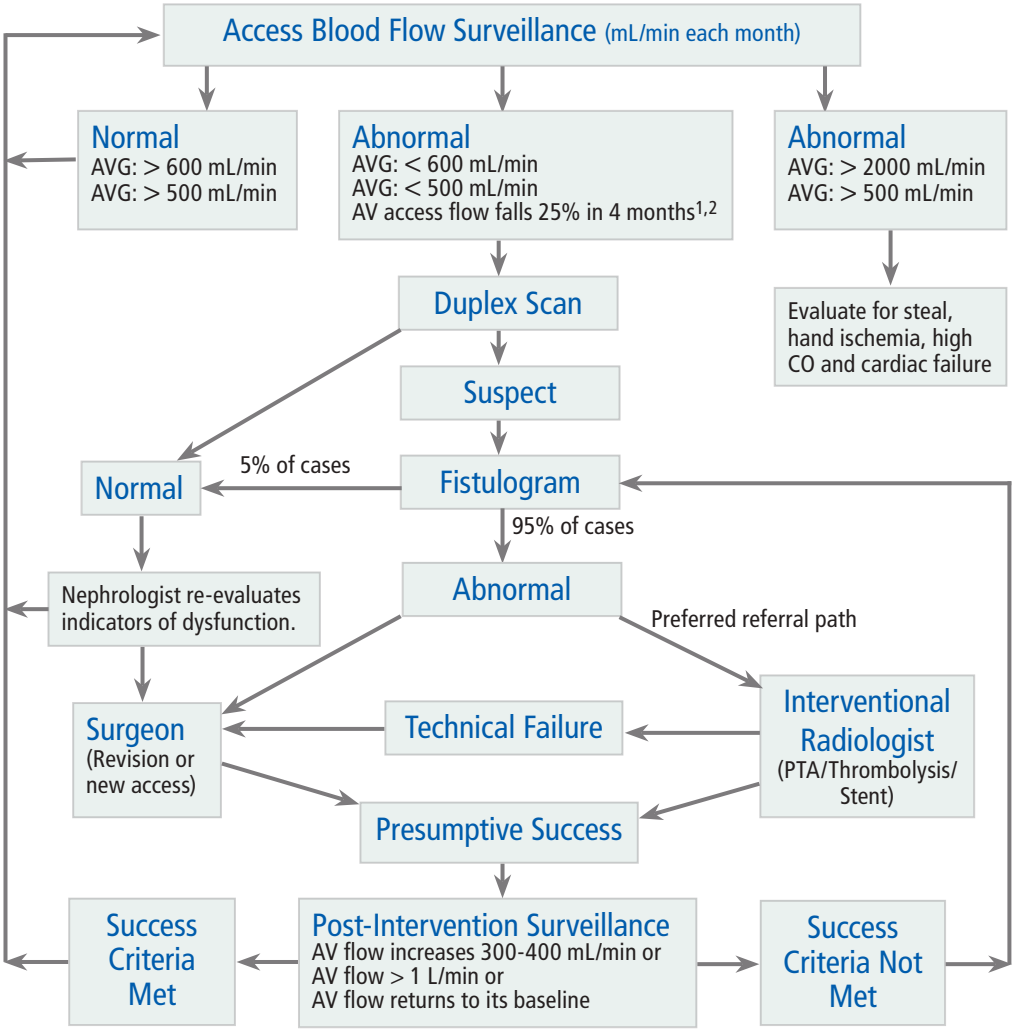
II. Flow-based Vascular Access Surveillance cont.

- For AV grafts, use both KDOQI-recommended thresholds: absolute threshold of 600 mL/min; dynamic threshold of a 25% decrease within 4 months. Using both these thresholds should decrease false-positive rates. The dynamic threshold may be more predictive of stenosis. Using only one threshold may not be as effective and may lead to a misleading message about the effectiveness of flow surveillance.[18]
- It is recommended that access flow measurements be performed during the first hour and one-half to two hours of a dialysis session. However, this approach may not always avoid hypotensive episodes or other abnormal situations. If a 20-30% decrease in flow is observed, it may be the result of significant stenosis, or a decrease in systemic pressure. If a significant decrease in mean arterial pressure (MAP) is observed, the patient's previous access flows and MAPs should be reviewed.[16-17] Before the patient is referred for angiography, the access flow measurement should be repeated at the patient's next session to confirm that the decrease also exists when the patient's MAP is normal.
- Flow measurements should be performed at least once a month in AV grafts to avoid thrombosis events.[18]
- For native fistulas, outcomes could possibly improve by decreasing the absolute threshold to 500 mL/min[18-21] or as low as 300 mL/min in forearm fistulas as recommended by 2007 ERA-EDTA guidelines.[2] This threshold takes into account the observation that fistulas generally have longer life spans with lower flows, and that the initial access flows at distal locations (anatomical snuffbox) are generally lower.

"The [HD03] allows you to proactively manage your patients as part of a multi-discipinary vascular access care program to reduce complications and costs of end-stage renal disease." *Duda, CR et al, Nephrology News & Issues, 2000; 14(5).*

II. Flow-based Vascular Access Surveillance cont.

D. Transonic® Vascular Access Surveillance Protocol



1 If AVG flow falls by 25% in four months, and flow i< 1000mL/min, refer for fistulogram per KDOQI Guidelines.
2 Lower access flow may result if a patient's BP is significantly lower than his or her BP history. Therefore, compare current BP with BP history and/or confirm measurement results by repeating measurement before referring for fistulogram.

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II. Flow-based Vascular Access Surveillance cont.

The impact of access blood flow surveillance on reduction of thrombosis in native arteriovenous fistula: a randomized clinical trial. A Randomized Clinical Trial

Aragoncilla I *et al,* J Vasc Access. 2015 Sept 18

INTRODUCTION

Although all vascular access (VA) clinical guidelines recommend monitoring and surveillance protocols to prevent vascular access thrombosis, randomized clinical trials (RCT) have failed to consistently demonstrate the benefits of flow-based surveillance. Therefore, the value of surveillance remains controversial.

OBJECTIVE

To present a 3-year follow-up multicenter, prospective, open-label, controlled RCT, to evaluate the usefulness of QA measurement using Doppler ultrasound (DU) and ultrasound dilution method (UDM), in a prevalent hemodialysis population with native arteriovenous fistula (AVF).

METHODS

- Classic monitoring and surveillance were applied to all patients.
  - Experimental group (n = 98)
  - Control group (n = 98)
- DU and UDM were performed in the experimental group every three months.
- When flow was ≤ 500 mL/min, there is a 25% decrease in QA or a hemodynamically significant stenosis the patient was referred for fistulography, surgery or close clinical surveillance observation.
- Thrombosis rate, assisted primary patency rate, primary patency rate and secondary patency rate were measured.

RESULTS

- Significant reduction in thrombosis rate after one year.
  - Experimental (QA) group (0.022 thrombosis/patient/year)
  - Control group (0.099 thrombosis/patient/year)
- Assisted primary patency was significantly higher in the QA group compared to the control group.
- In the QA group, the numbers undergoing angioplasty and surgery were higher but with no significant difference in non-assisted primary patency rate.
- There was no significant improvement in the secondary patency rate in the QA group.

CONCLUSION

QA surveillance that combines Doppler Ultrasound and Indicator Dilution methods shows a reduction in thrombosis rate and an increased assisted primary patency rate in AVF after one-year.

E. Multi-disciplinary Vascular Access Care Program (pages 22-23)[23]

Multi-disciplinary vascular access care programs to proactively address access-related morbidity among hemodialysis patients. These programs are designed to improve all vascular access-related outcomes, prolong vascular access life, and reduce hospitalization costs associated with the vascular access.[6] Benefits include improved quality care and satisfaction outcomes, cost-effectiveness, optimizing seamless care delivery, and empowering the nephrologist in the delivery of vascular access care.

Duda *et al's* 2000 Process Implementation Model on the following pages presents the process and timetable for implementation and core competencies. An Assessment Phase evaluates the current access care and baseline data. This is accompanied by a thorough and ongoing Educational Phase to develop vascular access core competency among all team members. The heart of a vascular access care program is a fully integrated and proven Access Surveillance Program and referral process. The objectives of these protocols are to:

- detect and intervene when significant access stenosis is suspected to prevent access thrombosis;
- prolong access life;
- prevent inadequate dialysis;
- reduce access-related morbidity and hospitalizations;
- decrease the number of missed dialysis treatments.

Other components of the program include the Diagnosis Phase to identify patients at risk for vascular access stenosis or other causes of access dysfunction to determine whether an intervention should be radiologic or surgical. During the Intervention Phase the patient actually undergoes a procedure to correct the diagnosed complication. Finally, Documentation of vascular access care program indicators is essential for the success of the continuing quality improvement (CQI) process. CQI recommends monthly analysis of data and benchmarking of vascular access performance criteria.

This and other multi-disciplinary access management programs that implement KDOQI guidelines, prolong access life, prevent inadequate dialysis and reduce access-related morbidity and hospitalizations.

II. Flow-based Vascular Access Surveillance cont.

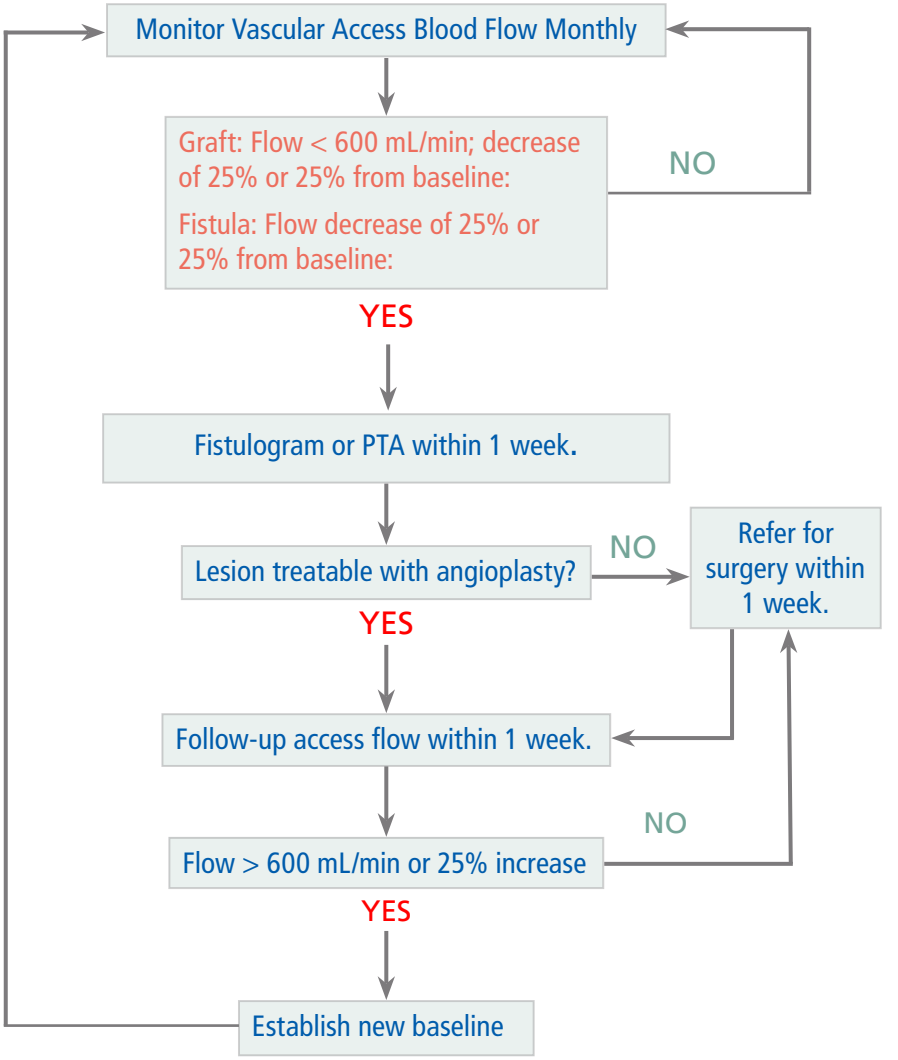
Vascular Access Care Program (VACP)		
PHASE	PROGRAM	DEFINITION
ASSESSMENT PHASE	Assessment	Evaluation of the current access care delivered by a multi-disciplinary team in a Dialysis Facility and the collection of vascular access baseline data for subsequent comparison.
EDUCATION PHASE	Education	Thorough and ongoing process to develop VA care core competency of all team members.
SURVEILLANCE PHASE	Surveillance	Prospective VA surveillance techniques performed on each patient monthly and following any access intervention.
DIAGNOSIS PHASE	Diagnosis	Identify patients at risk for vascular access by completing a fistulogram or other diagnostic test to identify stenosis or other cause of access dysfunction. Provides information necessary to determine whether an intervention should be radiological or surgical.
RADIOLOGIC OR SURGICAL INTERVENTION	Intervention	The phase when the patient actually undergoes a procedure to correct the diagnosed access complication.
DOCUMENTATION OF VACP INDICATORS		The VACP documentation requirements and process.
CQI TO ACHIEVE OUTCOMES AND BEST DEMONSTRATED PRACTICES	CQI	The GAMBRO Continuous Improvement Process (CIP) which enables monthly analysis of data and benchmarking of VA performance criteria.

II. Flow-based Vascular Access Surveillance cont.

Process Implementation Model[23]		
Purpose	Core Components	Time Line
Standardizes assessment criteria and provides VA benchmarks for the continuous improvement process (CIP).	1. Assess clinic staff and patient for vascular access care behavior and knowledge 2. Assess each patient's access each treatment	1st Month & Ongoing
Assure that all members of the VA Care team are knowledge-able and capable of providing VA care.	1. Access Care Basics and Techniques 2. How to apply VACP in my Center 3. Access evaluation techniques to assess potential stenosis 4. When to refer for diagnosis	1st Month & Ongoing
Detects access dysfunction early and to permit sufficient lead time for a planned access intervention as well as assess the "success" of any completed access intervention (radiological or surgical).	1. Identifies patients at risk with access problems 2. Defines access intervention required	1st Month & Ongoing
Provides a clear "road map" for any subsequent access intervention.	1. Identifies patients at risk with access problems 2. Defines access intervention required	1st Month & Ongoing
Intervention is planned and delivered specifically to correct a diagnosed access problem.	1. per Radiology 2. per Surgery	Ongoing per diagnosis
Facilitates the tracking of each patient's VA history and ensures center-specific and national data are collected, monitored and trended.	1. Access status for each patient each treatment 2. Access Clinical Indicators for each patient each treatment	Ongoing per intervention & flow
Evaluates each Centers own standards of care against the national goals and benchmarks to promote each Center's CIP to achieve best-demonstrated practices in VA care.	1. Trend and analyze VACP Clinical Indicators each month 2. Maintain and monitor center-specific VA care improvement.	Ongoing per monthly CQI meeting process

II. Flow-based Vascular Access Surveillance cont.

F. Vascular Access Blood Flow Monitoring (VABFM) Protocol



II. Flow-based Vascular Access Surveillance cont.

Vascular Access Blood Flow Monitoring Reduces Access Morbidity and Costs

Vanderbilt University Medical Center, Dialysis Clinics, Inc., and Renal Care Group, Inc.
McCarley PB *et al*, Kidney Int 2001; 60:1164-72.

BACKGROUND

Vascular access morbidity results in poor patient outcomes and accounts for a significant proportion (estimated at 25%) of total annual Medicare end-stage renal disease (ESRD) expenditures.

OBJECTIVE

To compare the clinical outcomes and financial impact of access blood flow monitoring with the Transonic Hemodialysis Monitor to detect access malfunction by investigating the effect of vascular access blood flow monitoring (VABFM) on thrombosis-related events, compared to the those of dynamic venous pressure monitoring (DVPM), and no monitoring for vascular access stenosis.

STUDY

Access-related information for 132 chronic hemodialysis patients was collected by three patient-care technicians over a three-phase study (Phase I, eleven months no monitoring, Phase II, twelve months DVPM, Phase III, ten months VABFM). During Phase II of the study, dynamic venous pressure at a pump flow of 200 mL/min in the first five minutes of dialysis was monitored. In Phase III, VABFM followed the protocol shown on the previous page. When VABFM and DVPM indicated potential vascular access failure, the patient was referred for a fistulogram, with percutaneous angioplasty (PTA) or surgery following within one week.

RESULTS

Phase	Graft Thrombosis	PTA Procedures	Hospital days	Missed Dialysis treatments	Catheter Use	Cost Savings
I. No Monitoring	0.71	0.09	1.8	0.98	0.29	Phase III (Transonic): 49% less than Phase I (no monitoring); 54% less than Phase II (dynamic VP).
II. Dynamic Venous Pressure	0.67	0.32	1.6	0.86	0.17	
III. Transonic® HD Surveillance	0.16	0.54	0.4	0.26	0.07	

Graft thrombosis, PTA, access-related hospital days, missed dialysis treatments and catheter use rates are per patient/per year.

COST SAVINGS

As a result of reduced vascular access morbidity, related costs fell 49% from Phase I with no monitoring to Phase III with VABFM and were 54% less in Phase III than in Phase II, effecting a total savings of $158,550.

CONCLUSION

"Vascular access blood flow monitoring along with preventative interventions should be the standard of care in chronic hemodialysis patients."

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G. Pediatric Vascular Access Monitoring

A 2006 report of the United States Renal Data Systems (USRDS) reported that hemodialysis was the most frequently used renal replacement therapy in 2004 with 1,346 incident pediatric cases.[31] Even though an arteriovenous fistula is the preferred access that meets the criteria of delivering a flow rate needed for the dialysis prescription, has a long use life and a low rate of complications, and the Centers for Medicare and Medicaid Services (CMS) sponsored Fistula First Initiative aimed to increase fistula use in the adult population, the most common access in children remains a central venous catheter (CVC). Nationally, only 12.3% of pediatric patients have an AVF and 8.5% have an AVG. Chand *et al*[31] reported that, from his experience in northern Ohio where AVF rates in pediatric patients are more than 80%, higher AVF rates can be established through a multi-disciplinary team approach that involves pediatric nephrologists, experienced hemodialysis nurses, vascular surgeons, interventional radiologists and recreational therapist/child life specialists.

Patients range from neonatal to teenagers. Therefore, the blood tubing used to dialyze these patients comes in many sizes and configurations. To overcome the challenge of small tubing sizes for young children, Transonic recommends the use of standard sensors on Transonic Clear Advantage Tubing sets inserted between the smaller blood lines and needle lines. The Monitor's software normalizes access flow in children by correcting the raw access flow data for body surface area and reporting mL/min/1.73m^2.

Hemodialysis Studies in Pediatric Patients

Goldstein and colleagues from Texas Children's Hospital report that ultrasound dilution (UD) is a valid measurement of access flow in children.[25-28] "When the uncorrected flow value reported by UD is corrected for patient body surface area, UD is predictive for the presence or absence of severe AV graft stenosis, regardless of patient size. In 2001, Texas Children's Hospital instituted a rapid referral policy (within 48 hours) for AVF or AVG angioplasty using monthly Flow-QC surveillance to access vascular access flow. Children with a corrected vascular access flow of less than 650 mL/min per 1.73m^2 were referred for balloon angioplasty. The practice led to a 90% reduction on vascular access thrombosis rates and a 40% reduction in vascular access management costs, compared with the institution's previous venography surveillance protocol. Moreover, it also led to fewer missed school days, less separation from family and peers, and fewer invasive procedures.[25]

In 2015, Ashoor and colleagues published a study (see sidebar on next page) that reports their experience monitoring AV accesses by ultrasound dilution technology in pediatric patients at Boston's Children Hospital.[28] They report that their AV access thrombosis rates fell from 13.5 per 100 patient-months on HD during the baseline period to 3.5 per 100 patient-months on HD during the screening period; secondary complications declined from four events per 100 patient-months during baseline period to 2.5 events per 100 patient-months during surveillance period; mean blood flow rate by UD measurement was lower in AV accesses that went on to thrombose compared to those without thrombosis (1,203 mL/min/1.73 m^2 vs. 1,683 mL/min/1.73 m^2) and median flow rate increased from 730 mL/min to 1,180 mL/min following angioplasty. They concluded that noninvasive UD screening is very sensitive in detecting hemodynamically significant stenosis and can decrease AV access thrombosis rates.

Optimizing Central Venous Catheter (CVC) Measurements

Most pediatric ESRD patients (78.9%) are dialyzed via a CVC. Its usage rate is 89% for children less than thirteen years of age and 64% for those in the 13-19 age group.[31] The primary advantage of a CVC is that it can be used immediately and the access doesn't require cannulation. It is painless to the patient and requires little planning prior to placement. It also can be easily removed when it is used as a "transitional" access for future transplant or peritoneal dialysis. However, it is the least desirable type of vascular access because they are prone to infection, have high failure and replacement rates and can permanently damage vessels.

In patients with a CVC, the Transonic Flow-QC Monitor can measure Dialysis Adequacy by measuring Delivered Blood Flow and Recirculation. Optimum blood pump speed to customize dialysis prescription can be determined by Delivered Blood Flow. Catheter dysfunction is identified by the presence of high percentage of Recirculation (see pages 47-48).

II. Flow-based Vascular Access Surveillance cont.

AV Access Monitoring by Ultrasound Dilution in a Pediatric Hemodialysis Unit[28]

Ashoor IF, Hughson EA, Somers MJ, Blood Purif. 2015;39(1-3):93-8. Boston Children's Hospital, Boston, MA

BACKGROUND

Maintenance of an arteriovenous (AV) access for dialysis delivery in children and adolescents becomes all the more important because of the small size of their vessels.

OBJECTIVES

Primary: To evaluate the impact of UD monitoring on AV access-related morbidity, especially access thrombosis and to evaluate secondary morbidity outcomes including access-related hospitalizations, and need for new access creation or temporary dialysis catheter placement.

Secondary: To evaluate UD monitoring to screen for hemodynamically significant AV stenosis by:

- Differentiating between patent AV accesses and those at true risk to thrombose.
- Detecting improvements in blood flow to restore patency after interventional procedures.
- To determine UD's sensitivity & specificity for detecting stenoses vis á vis fistulagrams.

METHOD

HD patients with AV accesses were monitored using UD technology. Its effectiveness was assessed by comparing UD results to fistulograms and its impact on AV-related morbidity.

PERIOD	# OF PATIENTS	TIME ON HD	# MEASUREMENTS	ACCESS AGE (at monitoring onset)	MONITORING LENGTH
Baseline	14 (5 AVF & 9 AVG)	24 months	—	—	—
Intervention	16 (7 AVF & 9 AVG)	8 months	164	12 months	5 months

RESULTS

- AV access thrombosis rates fell from 13.5 per 100 patient-months on HD during the baseline period to 3.5 per 100 patient-months on HD during the screening period ($p < 0.04$).
- Secondary complications (hospitalizations, new access creation, temporary dialysis catheter placement) declined from 4 events per 100 patient-months during baseline period and to 2.5 events per 100 patient-months during surveillance period.
- Mean blood flow rate by UD measurement was lower in AV accesses that went on to thrombose compared to those without thrombosis (1,203 mL/min/1.73 m^2 vs. 1,683 mL/min/1.73 m^2, $p < 0.001$).
- Following angioplasty, median flow rate increased from 730 mL/min to 1,180 mL/min.
- When compared to fistulograms, UD surveillance was 94% sensitive and 77% specific in detecting hemodynamically significant stenosis, with positive and negative predictive values of 83% and 91% respectively.

CONCLUSION

Noninvasive UD screening is very sensitive in detecting hemodynamically significant stenosis and can decrease AV access thrombosis rates.

II. Flow-based Vascular Access Surveillance cont.

Ultrasound Dilution Evaluation of Pediatric Hemodialysis Access[25]

Goldstein SL, Allsteadt A, Kidney International 2001; 59: 2357-2360.

OBJECTIVE

To evaluate the accuracy of indicator dilution flow measurements in pediatric hemodialysis patients.

STUDY

- 13 pediatric HD patients with permanent vascular accesses (9 AVG and 4 AVF), received a total of 73 indicator dilution access flow measurements over 3 months.
- All patients had received hemodialysis for at least two months at Texas Children's Hospital.
- Access flow measurements were corrected for body size by normalizing the measurement to mL/min/1.73m^2. This conversion factor equates the pediatric access flow with those of adults.

RESULTS

- Patients with AVG with corrected access flows less than 700 mL/min/1.73m^2 had severe stenosis demonstrated on venogram, whereas patients with corrected access flows of greater than 700 mL/min/1.73m^2 did not have severe stenosis.
- Accesses showing stenosis on venography, performed every six months on well-functioning accesses and every six to twelve weeks on problem accesses, had significantly reduced corrected access flows than those accesses without stenosis.
- There was no evidence of stenosis in the fistulas studied by venogram, due to the small number of patients with AV fistulas and the low rate of thrombosis in fistulas.
- Kt/V and delivered pump flow measurements did not vary with access flow during the study. Ultrasound indicator dilution and chemical recirculation techniques failed to show greater than five-percent recirculation in any access, therefore failing to indicate stenosis.

CONCLUSION

- Study supports monthly ultrasound dilution measurements to prevent access thrombosis in children receiving hemodialysis.
- Ultrasound indicator dilution (UD) is a valid indicator of access flow in children. "When the uncorrected flow value reported by UD is corrected for patient body surface area, UD is predictive for the presence or absence of severe AV graft stenosis, regardless of patient size." There was no evidence of stenosis in the fistulas studied by venogram, due to the small number of patients with AV fistulas and the low rate of thrombosis in fistulas.
- Recirculation measurements and dialysis adequacy parameters are late indicators of stenosis in pediatric patients.
- Corrected access flow of less than 700 mL/min/1.73m^2 was highly predictive of stenosis in pediatric hemodialysis patients.

II. Flow-based Vascular Access Surveillance cont.

Reducing Vascular Access Morbidity: A Comparative Trial of Two Vascular Access Monitoring Strategies

Lok CE *et al,* Nephrol Dial Transplant 2003 Jun;18(6):1174-80.

INTRODUCTION

Thrombosis is the primary cause of access failure in PTFE grafts and arteriovenous fistulas (AVFs) and can lead to significant patient and access morbidity and mortality. Detecting lesions early and intervening with angioplasty or surgical revision is the primary intervention. This 3-year prospective study compares Duplex ultrasonography (Duplex US) and saline ultrasound dilution technique (UD) in a large urban dialysis center.

OBJECTIVE

To compare the efficacy of Duplex US and UD, each followed by radiological or surgical intervention to monitor grafts and fistulas, in order to detect access malfunction and prevent vascular access thrombosis. A secondary goal was to determine patient and access characteristics that predict access thrombosis.

METHODS

- Year 1: Duplex US was used to monitor all AVG every 6 months or more frequently for accesses that appeared at risk for stenosis or thrombosis. The nursing staff assessed AVFs at each dialysis session. Those that demonstrated evidence of stenosis by two of three criteria (abnormal physical exam, elevated venous pressures or abnormal monthly recirculation studies) were referred for a Duplex US exam. If the Duplex US found a severe stenosis, indicating a lesion of >50%, a referral for an angiogram was made.
- Year 2: Transition year to using Transonic UD to monitor vascular accesses.
- Year 3: Transonic UD became the primary monitoring strategy with 1516 flow studies performed.
- Transonic study protocol: monthly measurements for AVG; bimonthly for AVFs. At least two flow measurements were obtained in the first hour of dialysis, when the patient was haemodynamically stable with a systolic blood pressure >110 mmHg at a blood flow rate of 300 mL/min. Qa measurements were averaged. If a low or declining flow, (<650mL/min for grafts or < 500 mL/min for AVFs or a drop of >15% compared with the previous measurement), referral for an angiogram and angioplasty or surgical revision was made. If the lesion was not severe (<50%), routine Transonic monitoring was resumed.
- The primary end point of this study was the cumulative thrombosis rate at 14 and 30 days after access monitoring. Secondary end points were the cumulative procedure rates for angiograms, angioplasties and thrombolysis. Exploratory end points of interest included risk factors for thrombosis, the rate of access-related hospitalizations and the average length of stay of these hospitalizations.

RESULTS

Five hundred forty eight accesses in 401 patients; 303,656 access days at risk were analyzed,

Year	Modality	# of Accesses	Thrombosis Rate per 1000 access days	Angiography per 1000 access days	Angio-grams	Angio-plasty	Thrombo-lysis	Hospital-izations
Year 1	Duplex	344	1.01	2.74				
Year 3	UD	425	0.66	1.96	55% lower	13% lower	31% lower	down

CONCLUSION

- Low flow rates detected using Transonic monitoring were associated with increased thrombosis.
- Stenosis detected using Duplex ultrasonography was not a strong predictor of incipient thrombosis.

Are Hemodialysis Access Flow Measurements by Ultrasound Dilution the Standard of Care for Access Surveillance?

Garland JS, Moist LM, Lindsay RM, Advances in Renal Replacement Therapy 2002; 9(2) 91-98.

BACKGROUND

This publication reviews blood flow and other methods for access dysfunction screening, the techniques used to measure it and the predictability of access flow measurements in determining the presence of access stenosis and allowing successful intervention. Other technologies reviewed include differential conductivity, thermodilution (Frensenius), and hematocrit dilution (Critline). It also addresses the cost-effectiveness of such surveillance.

The authors first review the methods of screening for vascular access dysfunction in PTFE grafts and fistulae. Static and dynamic venous pressures are listed along with the advantages and disadvantages of dynamic venous pressures in PTFE grafts. They note that serial measurement of blood flow over time by one of many techniques is the preferred method of screening in PTFE grafts, whereas in AV fistulae, direct blood flow measurements are preferred for access surveillance.

Indicator dilution technology and the Krivitski Method® are reviewed. They cite the advantages of the ultrasound dilution technique as:

1) Easy to use;
2) Immediate answers;
3) Accurate;
4) Can measure delivered blood flow;
5) Can be integrated into the dialysis session.

They list the technology's disadvantages as its expense, fragility and the requirement of nursing or technician time to take the measurements.

CONCLUSION

The reviewers conclude that comparison of the various methods and their study support the conclusions that:

- Ultrasound indicator dilution is the current Gold Standard for measurement of vascular access recirculation and access flow;
- Ultrasound indicator dilution is the method of choice for monthly surveillance of vascular access grafts in adherence to NKF-K/DOQI guidelines
- Available evidence suggests that access flow measurements are the best tests currently available to screen for access dysfunction
- As preventative interventions (angioplasty and surgery) are successful, they should be regarded as the present standard of care;
- Monthly surveillance is a cost-effective strategy.

II. Flow-based Vascular Access Surveillance cont.

Comparison of Different Techniques of Hemodialysis Vascular Access Flow Evaluation

Lopot F, Nejedly B, Sulková S, Bláha, J, Int J Artif Org 2003; 12:1055-1063.

BACKGROUND

Study compares several different methods used to measure vascular access flow (QVA). Ultrasound dilution was used as the reference because of its high reproducibility at the same flow and at different flows.

STUDY

Reproducibility of each method was assessed by duplicate measurements:

1) at unchanged conditions;
2) at controlled change in the relevant measurement condition: flow (TD,UD); sensor position (TQA).

Accuracy of each method was assessed by comparing measurements of each method with reference Transonic ultrasound dilution method. Methods compared:

- UD: Ultrasound dilution (Transonic Systems Inc.)
- DD: Duplex Doppler
- TD: thermodilution: (BTM Fresenius, Europe)
- TQA: direct transcutaneous optodilutional QVA evaluation (Critline III TQA, Hemametrics)
- QABF: direct optodilutional QVA evaluation from jumpwise changes in ultrafiltration rate at both normal and reversed needle connection (Critline III, ABF-mode, Hemametrics)
- ORX: optodilutional RX measurement (Critline III, R-mode, Hemametrics)

RESULTS

Method	At Same Flow (n) (same sensor position)	At Different Flows (n) (different sensor position)	Correlation with UD/TD	Comment
UD	0.9702 (58)	0.9735 (24)		best reproducibility
TD	0.9197 (40)	0.8508 (168)	0.9545 (54)	viable alternative method
DD			0.8691 (27) (TD)	weaker correlation
TQA	0.9712 (85) (UD,TD)	0.7255 (22)	0.8077 (36)(UD)(TD)	sensor placement critical
QABF			0.6957 (26)	poor correlation
ORX	0.6430 (23)		0.702 (33)	worse reproducibility and correlation with UD; overestimates flow 25%

CONCLUSIONS

Ultrasound dilution (Krivitski Method): Very high reproducibility and the negligible impact of changes in blood flow on the accuracy of vascular access flow measurement justifies its current status as the reference method for vascular access flow evaluation.

II. Flow-based Vascular Access Surveillance cont.

H. Select Vascular Access Surveillance References

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II. Flow-based Vascular Access Surveillance cont.

H. Select Vascular Access Surveillance References cont.

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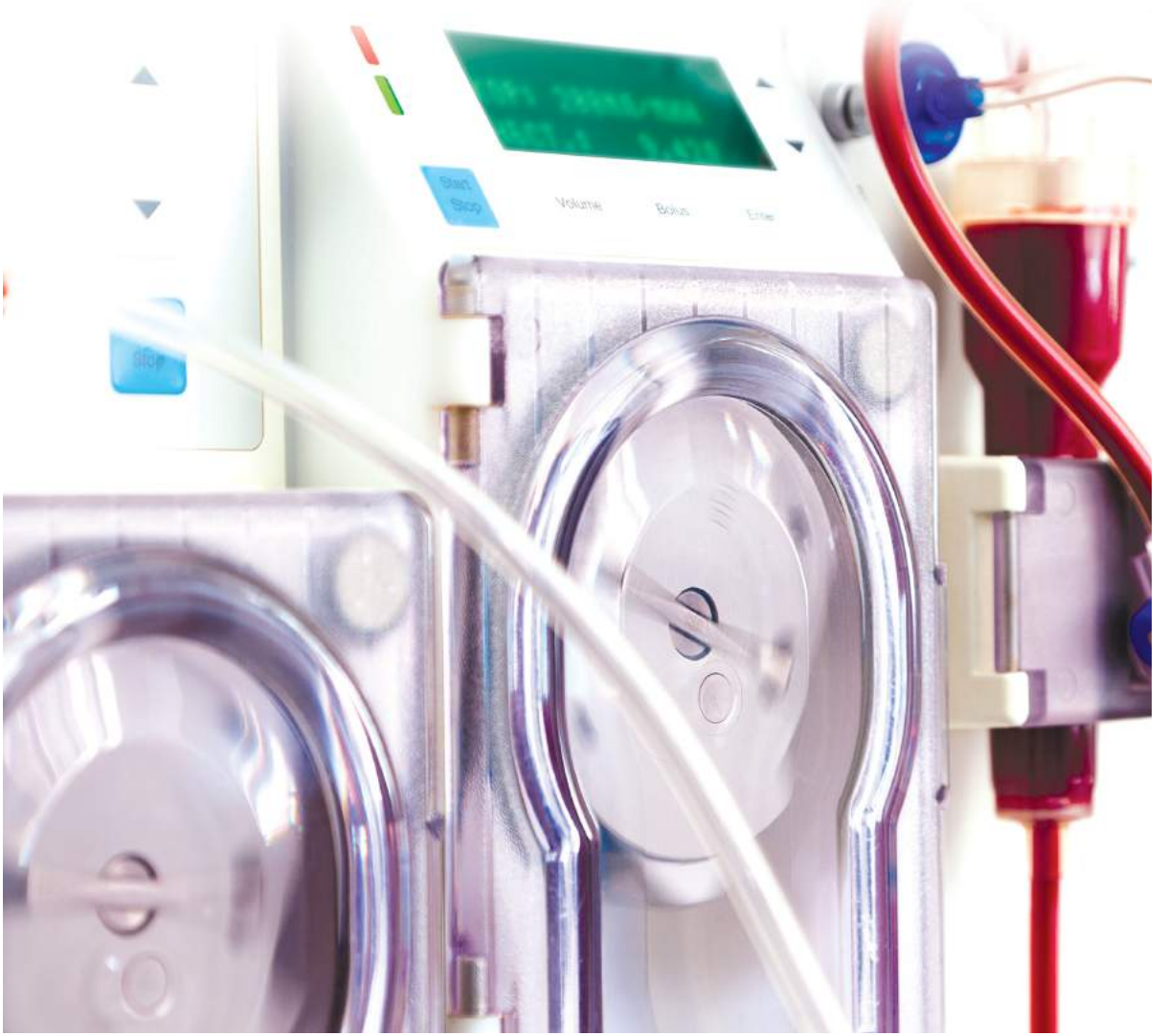
Dialysis Adequecy

Best Practice in Hemodialysis Care



III. Flow-based Dialysis Adequacy cont.

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III. Flow-based Dialysis Adequacy

"Any access recirculation is abnormal. Recirculation … should have prompt investigation of its cause. … If access recirculation values exceed 20%, correct placement of needles should be confirmed before conducting further studies."
http://www.kidney.org/professional/KDOQI/guideline–upHD–VA/index.htm

A. Hemodialysis Adequacy

The Transonic Hemodialysis Monitor is used to optimize efficient dialysis delivery through measurement of delivered pump blood flow and recirculation. Use of these measurements guarantee efficient and effect hemodialysis by:

- Testing the calibration of the blood pump;
- Verifying true delivered blood flow;
- Comparing delivered blood flow to pump setting to identify flow disparity and avoid underdialysis. If disparity is significant, measurements assist in determining cause (blood pump calibration versus inflow restriction/excessive pre-pump negative arterial pressure);
- Detecting and quantifying access recirculation in AV access, catheters;
- Identifying inadvertent reversal of dialysis lines to prevent recirculation and/or underdialysis;
- Determining proper needle placement;
- Identifying sources of large negative arterial blood line pressure (and its resulting underdialysis);
- Determining the most appropriate blood pump setting for a low flow access when it is not feasible to increase access flow;
- Using delivered flow and recirculation measurements to maximize catheter function.

III. Flow-based Dialysis Adequacy cont.

A. Hemodialysis Adequacy cont.

When a patient begins hemodialysis, a baseline Dialysis Adequacy Flow Study confirms dialysis delivery and can be used to set vascular access parameters. During an initial dialysis adequacy analysis, delivered blood flow, recirculation and vascular access flow are evaluated in relation to their "normal" dialysis conditions. Delivered blood flow is expected to be within 10% of the dialysis pump setting. In a healthy access, zero percent recirculation is the norm. A sufficient access flow rate is necessary to maintain access patency. The mechanical shear force of flow delays stenosis and thrombosis by working against the body's clotting mechanisms.

1. True Delivered Blood Flow Verified by Transit-Time Ultrasound[1]

Effective dialysis depends on delivery of the dialysis prescription through functional blood lines into a patent vascular access. Underdialysis is often caused by poor delivered blood flow. By comparing the flow reading of Transonic actual delivered blood flow through the dialysis lines, connected to either a graft, fistula or catheter, with the dialysis pump setting, dialysis delivery problems can be quickly identified and resolved.

To measure true delivered blood flow, matched Flow/dilution Sensors clip onto the arterial and venous dialysis lines during hemodialysis (Fig. 3.1) Each sensor emits an ultrasound beam that transects the tubing and blood in upstream and downstream directions. When the ultrasound beam travels in the direction of flow, the transit time it takes to traverse the distance through the tubing and blood is decreased by a flow-dependent amount. When the beam travels in the opposite direction, against the flow in the tubing, the beam's transit time is increased by a flow-dependent amount. By subtracting the integrated upstream and downstream transit times, volume flow is calculated.[1] The Hemodialysis Monitor continuously displays this delivered blood flow.

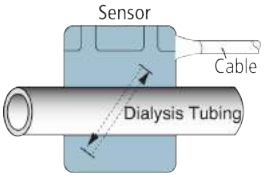


Fig. 3.1: Blood line inserted into the groove of the flow/dilution sensor body.

Prescribed delivered blood flow can be verified by comparing the reading of delivered blood flow on the Hemodialysis Monitor to the setting on the dialysis machine. At high blood pump settings, it is

A. Hemodialysis Adequacy cont.

not uncommon to see a difference between the two due to the size of the access needles (Fig. 3.2). Larger diameter needles (15G) deliver flow more efficiently than smaller diameter needles (16G). Under-delivery of prescribed blood flow may also be caused by the site of needle placement in the access. The arterial needle tip may be too close to the vessel wall.

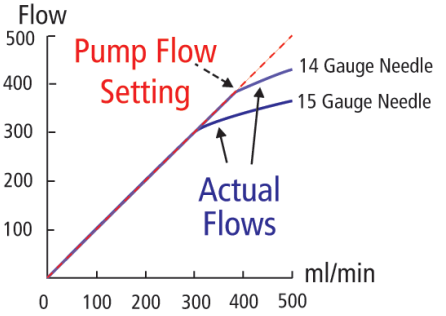


Fig. 3.2: Discrepancy between delivered blood flow and the pump setting can be caused by: negative pressure effects of the roller pump; access condition; needle size and placement; kinked or occluded tubing; calibration of dialysis machine or sensors.

If the arterial needle does not face the incoming access flow (needle is down rather than up), it may also be difficult to achieve high delivered blood flow. Other access factors may also limit delivery of prescribed delivered blood flow. They include:

Discrepancy between Delivered Blood Flow and Pump Setting[2-6]

To diagnose large delivered blood flow differences between the pump and the monitor, turn the pump speed to 200 mL/min. At this speed, pump errors due to high negative pressures are negligible and the Monitor's delivered blood flow reading should correspond to the dialysis pump setting. If the readings agree at this setting, the deviations at the high pump settings were due to one of the factors described above.

Delivered Blood Flow Disparity at Pump Speed 200 mL/min

If delivered blood flow readings do not agree with the monitor's at a pump setting of 200 mL/min, check the tubing selection on the monitor to ensure that it matches the dialysis tubing being used. Ultrasound dilution sensors are sensitive and accuracy decreases if the sensor is not calibrated for the specific tubing being used. In general, the accuracy of a Transonic Delivered Blood Flow reading is ± 6%. Other possible causes for pump and hemodialysis monitor blood flow discrepancies could be:

- the dialysis machine is not in calibration
- the arterial needle tip is too close to the vessel wall.

III. Flow-based Dialysis Adequacy cont.

Flow/Dilution Sensor Set-up

1. Open the door of the first paired Flow/dilution Sensor.
2. Place the tubing segment to be inserted next to the Flow/dilution Sensor.
   The arrow on the Sensor must point in the direction of flow.
3. Open a 70% isopropyl alcohol wipe (prep pad).
4. Wipe the entire circumference of the tubing segment which will be inserted into the Flow/dilution Sensor.
5. Immediately insert tubing segment into the Flow/dilution Sensor
6. Close the Tubing Sensor door.
7. Repeat the same [Wipe, Insert, Close Door] sequence for the second paired Flow/dilution Sensor and tubing segment.
8. Verify Signal Strength indicator on the upper left of the Hemodialysis Monitor screen is green when the Monitor has been turned on. This means that the paired Flow/dilution Sensors have adequate contact with the tubing. If the Signal Strength indicator is not green, repeat the [Wipe-Insert-Close door] sequence to achieve proper contact.

Open and closed arterial Flow/dilution Sensor on tubing.

Note: If you are using Flow-QC® tubing, place the arterial sensor in the center of the arterial Flow-QC segment and the venous sensor in the center of the venous Flow-QC segment.

III. Flow-based Dialysis Adequacy cont.

2. Access Recirculation

Measurement of Access Recirculation (Flow Chart, page 49) is the next step in the Flow-QC® Hemodialysis Adequacy Flow Study. Most patients have zero percent access recirculation.[7] If recirculation is reported, confirm the measurement by a second recirculation measurement. If the second measurement reports zero percent recirculation, a third measurement is advised as the deciding "vote." In some cases where there is borderline recirculation (< 5%), it is recommended that pump flow be increased to confirm recirculation.

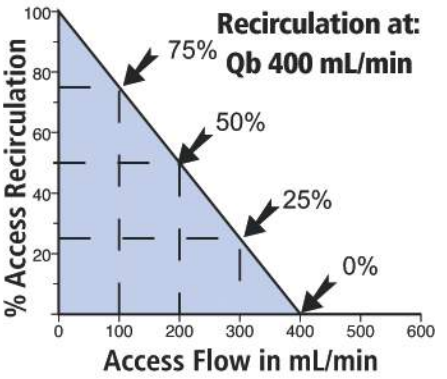


Fig. 3.3: Recirculation (theoretical): When delivered blood flow (Qb) is 400 mL/min, access recirculation theoretically appears at an access flow of 399 mL/min or anything below the delivered blood flow. If measured access flow is 300 mL/min, there is theoretically 25% recirculation; at 200 mL/min measured access flow, 50% recirculation; at 100 mL/min measured access flow, 75% recirculation.

A theoretical model (Fig. 3.3) demonstrates that at a blood flow of 400 mL/min, access recirculation is likely to begin appearing. When access flow is 300 mL/min and blood flow is 400 mL/min, 100 mL/min must be drawn from the venous return to make up the deficit at the arterial needle. Recirculation then equals 100/400 mL/min or 25%. If repeat measurements confirm the presence of recirculation, two possibilities exist:

Zero Percent Recirculation (0% Access Recirculation (AR))

As a late indicator of a failing access, recirculation generally occurs when access flow (AF) is less than dialysis pump flow (Qb). Because Transonic ultrasound dilution technology is able to separate actual peripheral vascular access recirculation from cardiopulmonary recirculation, measurement of zero percent access recirculation has become the new recirculation standard.[7-9] Modalities which cannot separate cardiopulmonary recirculation from access recirculation will indicate false positive recirculation.

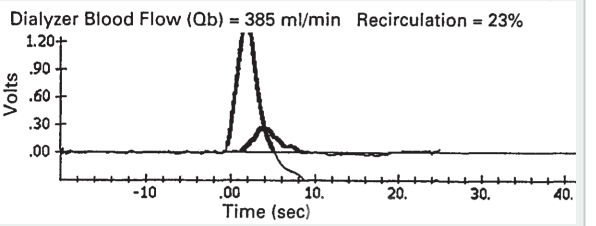
III. Flow-based Dialysis Adequacy cont.

Identifying a New Reality: Zero Vascular Access Recirculation Using Ultrasound Dilution

MacDonald JT *et al*, ANNA J 1996; 23(6): 603-8.)

Background

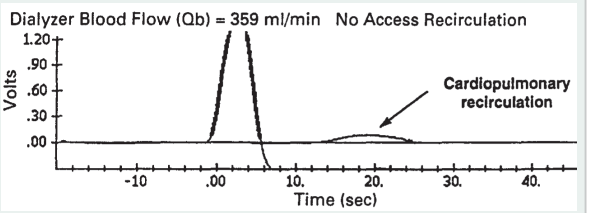
Access recirculation occurs when a portion of the blood returning from the dialyzer recirculates though the arterial line rather than passing through the venous circuit. Underdialysis occurs when recirculation is present. Recirculation is now considered a late indicator of access dysfunction. Because traditional methods such as blood urea nitrogen (BUN) sampling can not separate recirculation of dialyzed blood through the access from recirculation through the cardiopulmonary system (cardiopulmonary recirculation or CPR), recirculation is often overestimated.



When recirculation is present, the saline indicator passes through the arterial sensor and produces dilution curves.

Objective

Access recirculation was studied to better understand the rate of true access recirculation caused by close needle position *(in vitro)* or by low vascular access flow *(in vivo)*.



A flattened arterial dilution curve in the first ten seconds following saline injection confirms the zero percent recirculation.

Study

- Testing of needle position *in vitro*: The distance between insertion of the arterial and venous needles was varied from 1.5 cm to 12 cm in a laminar access flow model. Dialyzer blood flow and recirculation were measured.
- 74 patients were tested for access recirculation with the Hemodialysis Monitor.

Results

- Recirculation only occurred when access flow was smaller than or close to pump flow regardless of needle position.
- Two of 74 patients had recirculation with access flows less than pump flows; a second group had no recirculation with high access flows; a third group (7) had no access recirculation, but low access flows which required further investigation (two had stenoses between the needles).

Conclusions

- Ultrasound dilution monitor provides a rapid, simple and noninvasive method of measuring access flow and recirculation during hemodialysis which eliminates the false positives of BUN measurements.
- Data reveal that the prevalence of recirculation measured by ultrasound dilution is significantly less than that found by other methodologies.
- Zero recirculation is a reality, due to ultrasound dilution's ability to separate CPR from access recirculation.

III. Flow-based Dialysis Adequacy cont.

2. Access Recirculation cont.

To measure vascular access recirculation, Flow/dilution Sensors monitor the blood's ultrasound velocity (1560 - 1590 m/sec). The greater the protein concentration in the blood, the faster ultrasound will travel. When a bolus of isotonic saline (velocity in blood is 1533 m/sec) is injected into the blood, the blood protein concentration is diluted. Flow/dilution Sensors detect the reduced ultrasound velocity.[9]

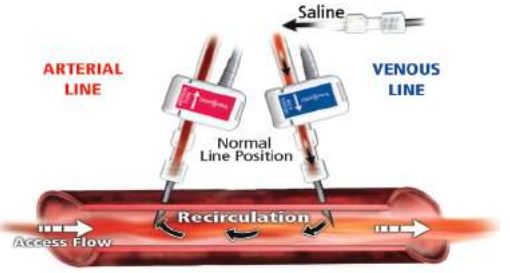


Fig. 3.4: Recirculation Measurement. Saline is introduced into the venous sensor with the dialysis lines in normal position. Access recirculation (back flow) through the vascular access into the arterial needle is measured.

When recirculation occurs, the saline indicator returns immediately to the arterial line (Fig. 3.4) where the diluted blood is detected by the arterial sensor. The Monitor's software converts the data into conventional dilution curves (Fig. 3.5). The first blue curve indicates the saline dilution as blood flows through the venous sensor. The second red curve represents saline dilution as flow passes through the arterial sensor. Recirculation is calculated as a ratio of the area under the arterial curve to the area under the venous curve.

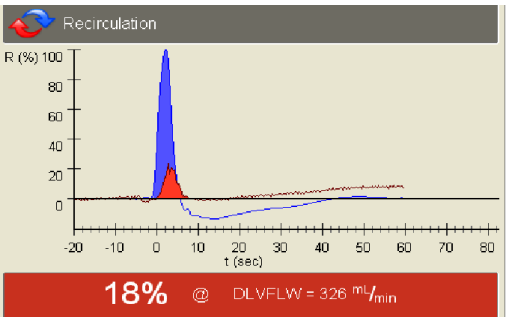


Fig. 3.5: A blue venous (upper) dilution curve followed by a red (lower)arterial curve. The ratio of the areas under the curves indicates 18% recirculation.

True Recirculation — Access at Risk

When recirculation is not accounted for by blood line reversal, the patient's access may be at risk for thrombosis because recirculation is a late predictor of access dysfunction.

III. Flow-based Dialysis Adequacy cont.

2. Access Recirculation cont.

Venous Stenosis

When a venous stenosis occurs, and access flow does not meet pump demands, some newly dialyzed blood from the venous line recirculates immediately back into the arterial line to compensate for a flow deficit at the arterial needle (Fig. 3.6).

Stenosis Between Needles

Although access recirculation generally occurs when access flow is less than dialysis pump flow, an important exception exists when a stenosis occurs between the dialysis needles (Fig. 3.7). Because the stenosis limits flow through the access, the pump simply bypasses the stenosis (the area of greatest hemodynamic resistance) altogether and zero recirculation is reported.

Inadvertent Reversal of Blood Lines

If hemodialysis surveillance detects vascular access recirculation but the recirculation disappears after the blood lines are reversed, the hemodialysis lines have been inadvertently reversed. At times blood lines are inadvertently reversed with respect to conventional dialysis line orientation. To determine if this is the case, examine whether the venous needle is placed upstream from the arterial needle with respect to the direction of the access flow. Then repeat the recirculation measurement after intentionally cross-connecting the arterial line to the venous needle and vice-versa. If the result is zero percent recirculation, or if the recirculation measurement is less than the first for the same delivered blood flow, the lines have been inadvertently reversed and the second blood line orientation is correct. Document this correct orientation on the patient's record to prevent recurrence of inadvertent blood line reversal.

Fig. 3.6: Access recirculation caused by venous stenosis. Some dialyzed blood recirculates back from the venous needle to the arterial needle.

Fig. 3.7: When 0% recirculation occurs although access flow is less than delivered blood flow, a mid-graft stenosis limits access flow. Pump flow (Qb) bypasses the stenosis.

III. Flow-based Dialysis Adequacy cont.

B. Hemodialysis Adequacy in Central Venous Catheters (CVCs)

Even though CVCs are prone to thrombosis and infection, 75% of hemodialysis patients receive a CVC either to initiate hemodialysis or for permanent hemodialysis delivery. KDOQI Guidelines define CVC dysfunction as failure to attain and maintain blood flow sufficient to perform hemodialysis without significantly lengthening hemodialysis treatment. The Guidelines recommend CVC blood flow be maintained at more than 300 mL/min to ensure adequate hemodialysis.

Transonic Flow-QC and CVC Hemodialysis Dose Delivery

Delivery of the prescribed dose of dialysis closely correlates to the amount of blood cycled through the dialyzer and therefore, to the rate of delivered blood flow. The use of catheters for dialysis delivery has two potential pitfalls that can be avoided through Flow-QC Monitoring:

1. A tissue flap and/or fibrin sheath blocking the lumen of the catheter's arterial entry port, impeding flow and causing a severe drop in dialysis dose delivery. This can be identified and often corrected via the Flow-QC Delivered Blood Flow Test.
2. The close proximity of the catheter's arterial entry and venous return ports make recirculation likely. If there is, for instance, 10% recirculation, the amount of blood cycled through the dialyzer is effectively 10% less and underdialysis can occur. This is monitored and can be corrected via the Flow-QC Recirculation Test.

Flow-QC Delivered Blood Flow Test

During hemodialysis, the nurse compares the Transonic Delivered Flow reading with the dialysis pump setting. The test takes less than a minute and can be performed in normal or reversed line configuration. If the disparity is more than 10%, kinked tubing, a tissue flap and/or fibrin sheath may be causing possible inflow obstruction and reduced dose delivery. Check the tubing for kinks and/or reverse the dialysis lines. Again compare Transonic Delivered Flow with the machine pump setting. If the two are now within 10%, dialysis may be continued with the lines in this configuration. If a large discrepancy between the two readings persists, central venous catheter failure may be indicated and the nephrologist should be alerted.

III. Flow-based Dialysis Adequacy cont.

B. Hemodialysis Adequacy in Central Venous Catheters Cont.

Flow-QC Recirculation Test

A Transonic recirculation measurement can be performed with lines in either normal or reversed configuration. By knowing the percent of recirculation:

- The nurse can adjust dialysis delivery parameters (time, pump setting etc.) to compensate for recirculation and deliver the prescribed dose of dialysis to the patient.
- Dialysis lines may be reversed. Correction might also correct high recirculation.

The nurse should report unusual delivered blood flow and recirculation readings to the patient care team or nephrologist to ensure optimum short- and long-term management of the patient's hemodialysis treatment.

Case Example:

Flow-QC Hemodialysis Adequacy Test Detects Hemolysis Risk

ESRD Patient

75-year-old woman with Central Venous Catheter: Blood Lines: normal line position; Pump Setting: 300 mL/min; Delivered Blood Flow: 190 mL/min; Recirculation: 0%.

A 35% disparity between pump setting (300 mL/min) and delivered blood flow (190 mL/min) indicated a significant risk of hemolysis.

Response

Lines were checked to see that they were not kinked. Blood lines were then reversed and the pump was reset to 300 mL/min. Delivered blood flow and recirculation were again measured.

- Delivered Flow: 290 mL/min
- Flow-QC Recirculation: 2-3%

Results

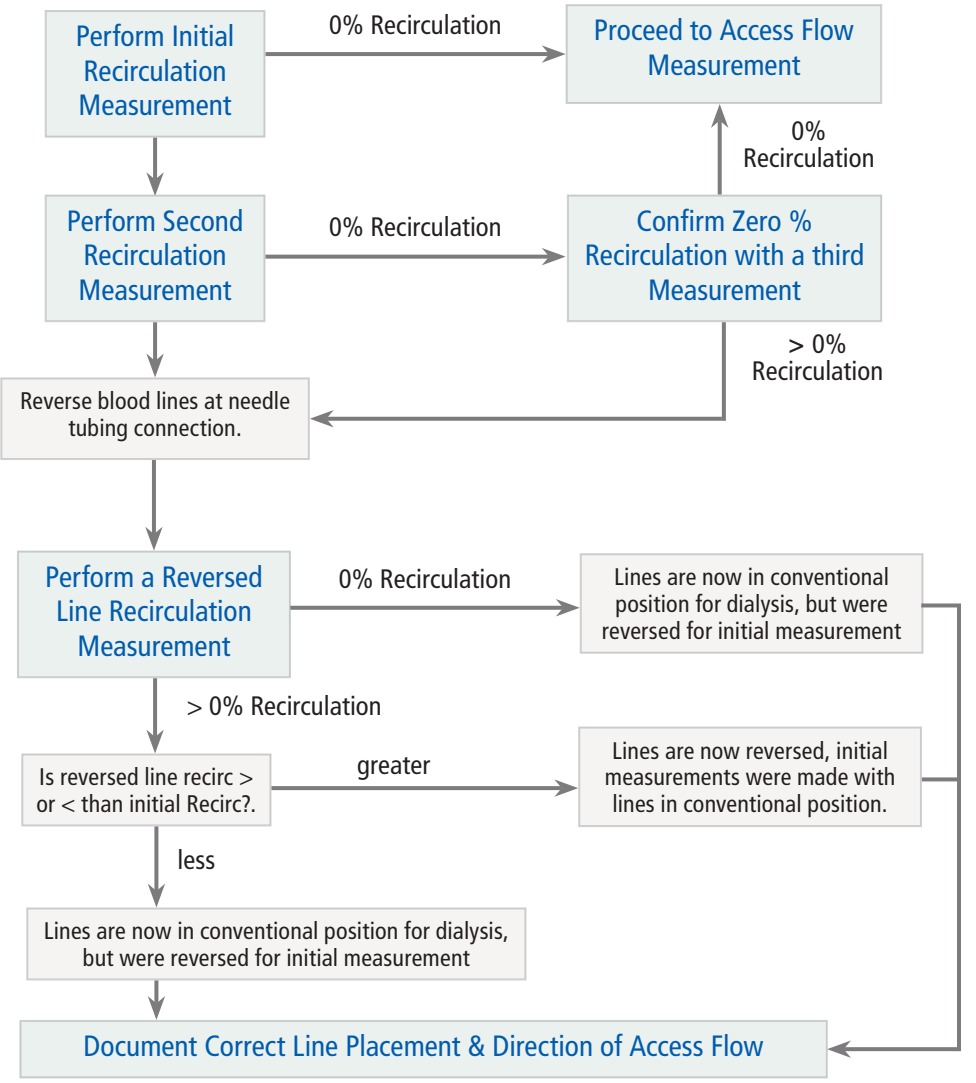
The patient received better treatment with the lines in a reversed position and the pump delivering 290 mL/min.

Take Home

CVC patient treatment can be optimized with Flow-QC Delivered Flow and Recirculation measurements.

III. Flow-based Dialysis Adequacy cont.

C. Flow-QC® Recirculation Protocol



When 0% recirculation is confirmed, proceed directly to an access flow measurement.
When recirculation is present, a series of steps is presented to identify the cause.

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III. Flow-based Dialysis Adquacy cont.

D. Select Hemodialysis Adequacy References

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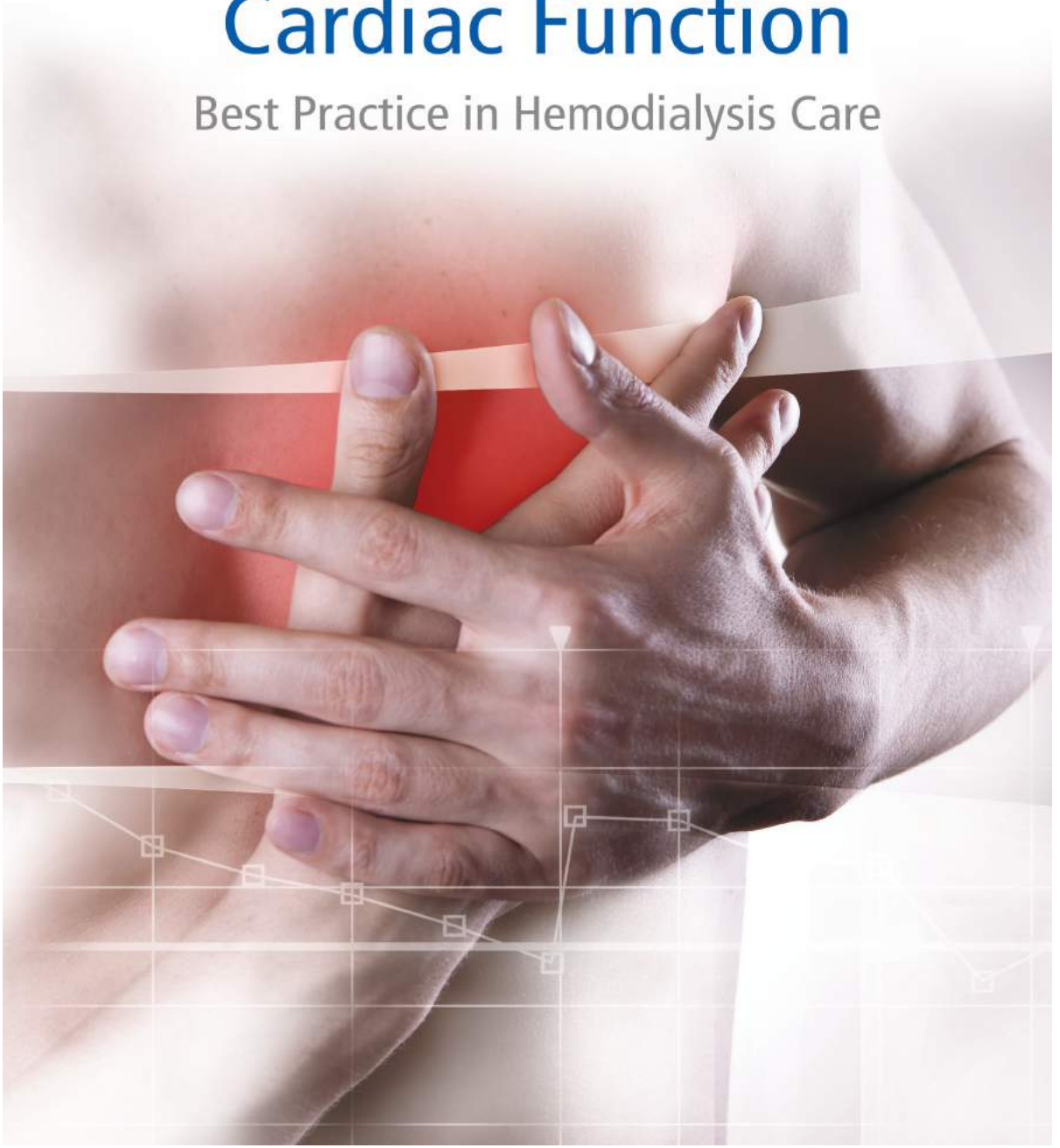
Cardiac Function

Best Practice in Hemodialysis Care



IV. Cardiac Function Assessment cont.

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IV. Cardiac Function Assessment during Hemodialysis

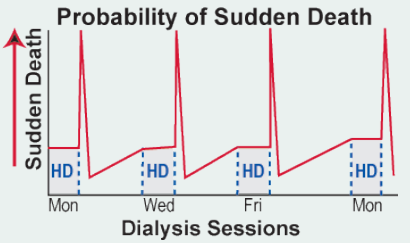
A. Cardiovascular Disease — An ESRD Epidemic

Cardiovascular disease (CVD) is the leading cause of morbidity and mortality in patients with End-Stage Renal Disease (ESRD).[2-3] It accounts for half of the deaths and one-third of hospitalizations of dialysis patients.[4]

"In addition, cardiovascular collapse is a major cause of complications during hemodialysis treatments."[5] Congestive heart failure (CHF) in ESRD patients results from cardiac overload, anemia, severe hypertension and cardiac dysfunction. CVD mortality rates are approximately 30 times that of the general population,[4] and in adolescents, CVD mortality rates are over 1,000 times that of their age-related peers.[28] These alarming statistics force nephrologists to assume a greater awareness of the cardiovascular systems of their patients. Proactive cardiovascular management of dialysis patients is now a major challenge in hemodialysis care.

Patients who do not feel well at the end of a dialysis session are subject to an unidentified decrease in Cardiac Index (CI) to critical ICU levels of <2 L/min/m^2.

As an AV fistula steals flow from an already limited systemic circulation, low CI can become a major contributor to decreased myocardial perfusion leading to sudden death.



"35% of deaths occurred in the first 12-hour interval ... 27% of these deaths occurred during dialysis and 33% occurred in the first hour after the dialysis treatment."[6]

IV. Cardiac Function Assessment cont.

1. Hemodialysis — A Stress Test for Cardiac Function

"Hemodynamic stability is threatened and often severely compromised by hemodialysis largely because of the obligate fluid removal during a short time span."[7]

Thomas Depner, MD, underscores the importance of testing cardiac function during hemodialysis.[7,8] He notes that the rapid removal of large volumes of fluid during hemodialysis severely tests the limits of a patient's cardiac function. Just as a treadmill stress test tests a heart's response to exercise, cardiac output measurements during hemodialysis monitor a heart's response to fluid removal during the dialysis treatment. Because cardiovascular parameters can change dramatically during dialysis, multiple cardiac measurements are advised during a dialysis session in order to assess a patient's clinical condition.[8]

2. Cardiac Output and Access Flow

Although extensively documented in the literature, the AV access is also often overlooked as a source of cardiac dysfunction. By bypassing the customary arteriole/capillary beds and establishing a direct high flow connection between the arterial and venous systems, an AV access creates a drop in peripheral arterial resistance which significantly affects blood flow. In order to maintain blood pressure and improve cardiac output, the body compensates for this precipitous drop in resistance by increasing heart rate and stroke volume.[3,9,10] This phenomena was first observed in World War II soldiers with trauma-induced arteriovenous fistulas.[3]. Iwashima *et al* reported an 15% increase in cardiac output by the seventh day after arteriovenous fistula creation[10]. This increased cardiac workload can lead to an increase in size of the left ventricle (left ventricular hypertrophy)[9,10].

"An Easily Overlooked Diagnosis"

In 1995, Engelberts and Tordoir *et al* (Maastricht University, the Netherlands) reported a case where excessive shunting in a hemodialysis access fistula led to high-output cardiac failure. They termed it "an easily overlooked diagnosis." Following surgical closure of the fistula, the patient's condition improved, and signs of congestive heart failure subsided."[7] In 1998, PR Young Jr. *et al* (Bowman Gray School of Medicine, Wake Forest University) reported two renal transplant patients who developed high-output cardiac failure from brachiocephalic fistulas. Successful transplantation, coupled with fistula ligation, resolved the

cardiac complications.[8] Additional reports[30-32] cemented the relationship between high volume AV access flows and cardiac complications.

Access Flow - Cardiac Output (AF/CO) Ratio

MacRae *et al* (University of Calgary, Canada) reported the high output cardiac failure associated with high flow AVFs (> 1.5 L/min), particularly in men with upper arm fistulas and previous access surgeries.[2,4,5] In her 2006 comprehensive review, *"The Cardiovascular Effects of Arteriovenous Fistulas in Chronic Kidney Disease: A Cause for Concern?"*, MacRae documents the evidence, to date, on the subject.[2] She emphasizes that the ratio between access flow and cardiac output is an important clinical indicator and notes that the average flow in an upper arm fistula is 1.13 to 1.72 L/min. In the same study 15% of patients were found to have flows of over 2 L/min. Access flow that exceeds 25% of cardiac output indicates a potential cardiac problem. In most cases, high output cardiac failure was associated with a access flow to cardiac output ratio of more than 40 percent.[10] MacRae recommends that hemodialysis patents be screened for potential high output cardiac failure using a Qa/CO ration and patients with a Qa/CO ratio of more than 30 percent undergo further testing.[10]

> *"A high flow AV access can produce life-threatening cardiac complications. The volume flow level that will induce high-output failure or extremity ischemia will vary with each patient, based on co-morbidities, especially the degree of cardiac disease and peripheral arterial disease. For patients at risk based on such pre-existing conditions, which can be a majority of patients in a given hemodialysis population, the widespread consensus (evidence-based) is that patients with access flows of 2L or higher should be tested and followed for these complications--and have a flow-reduction procedure performed at the earliest signs of cardiac complications or extremity ischemia.*
>
> *Unfortunately, with the high prevalence of cardiac disease in the HD population, an insidious and silent access flow as a major cause or contributor to a potentially deadly cardiac complication, is often overlooked. Therefore, it is critically important for the practitioner to be aware of the relationship between access flow and cardiac failure, since many of these high-flow patients will have morbidity and mortality that otherwise could have been avoided."*[39]
>
> Lawrence Spergel MD, FACS, founding father and clinical director of the Fistula First Breakthrough Initiative

Italian Study Sets 2L/min AVF Flow Cut-off Value

In 2008, Basile *et al* (Miulli General Hospital, Acquaviva delle Fonti, Italy) published a study of 96 patients with AV fistulas and cardiac failure.[24] The study showed that upper arm AVFs are associated with an increased risk of high output cardiac failure. It was the first published study with a high predictive power for AV fistula flows greater or equal to 2.0 L/min to result in high-output cardiac failure. In this landmark study, both AV access flow and cardiac output were measured using the Transonic Hemodialysis Monitor.

Studies/Reviews Highlight High AVF - CO Link

In the 2013 October issue of Clinical Transplant, Schier *et al* (Innsbruck University, Austria) reported the results of a 2005-2010 retrospective study of kidney-transplant recipients. Twenty-five percent of the recipients (29 of 113) needed an AV fistula closure, mostly due to cardiac failure symptoms.[25] Stern *et al* from UNC Kidney Center's Division of Nephrology and Hypertension, in Chapel Hill, NC describes how an increase in preload can lead to increased cardiac output when a large proportion of arterial blood is shunted from the left-sided circulation to the right-sided circulation via the fistula. Patients may present with the usual signs of high-output heart failure including tachycardia, elevated pulse pressure, hyperkinetic precordium, and jugular venous distension. The nephrologist is then faced with the dilemma of preventing progression of heart failure at the expense of losing a vascular access. The authors conclude that treatment should be directed at correcting the underlying problem by surgical banding or ligation of the fistula.[26]

In her 2012 Seminars in Nephrology article, *"High-output Heart Failure: How to Define It, When to Treat It, and How to Treat It,"* Wasse *et al* (Emory University) succinctly outlines the problem.[27] Dr. Wasse describes the mechanisms by which a dialysis AV access may promote the development of high-output cardiac failure, the risk factors for and diagnosis of high-output heart failure, and recommends management strategies for patients with high-output heart failure. The literature addressing the various types of cardiac complications (congestive heart failure, left ventricular hypertrophy, coronary artery disease, right ventricular dysfunction, valvular heart disease, aortic stenosis) of AV fistulas in patients with end-stage renal disease has been most recently reviewed by Dr. Alkhouli and colleagues in their 2015 publication in Nefologia (see excerpt at top of next page).[28]

IV. Cardiac Function Assessment cont.

Excerpt: Cardiac Complications of Arteriovenous Fistulas in Patients with End-stage Renal Disease

Alkhouli M et al,, Nefrologia. 2015 May-Jun;35(3):234-45[28]

"Despite their association with a lower mortality, AVFs have significant effects on cardiac functions predominantly related to the increase in preload and cardiac output (CO). Patients with end stage renal disease (ESRD) requiring dialysis almost invariably have volume overload due to water and salt retention. They also have pressure load due to arterial sclerosis and hypertension, and increased CO secondary to chronic anemia. In addition, many hemodialysis patients have significant pre-existing myocardial, valvular or coronary heart disease. It is, therefore, often difficult to tease out the exact contribution of an AVF to cardiac dysfunction in hemodialysis patients. Nevertheless, worsening in cardiac functions soon after AVF creation has been observed favoring a causative effect of the AVF on certain cardiac functions. Current literature suggests that the creation of AVF can cause or exacerbate the following conditions: congestive heart failure, left ventricular hypertrophy, pulmonary hypertension, right ventricular dysfunction, coronary artery disease, and valvular dysfunction."

3. Proactive Cardiac Function Monitoring during Hemodialysis

It is therefore incumbent upon the nephrologist to order periodic cardiac function tests, and track the results along with its associated vascular access flow rates. While access flow remains fairly constant during a hemodialysis treatment, cardiac output decreases an average of 20% during the treatment causing less blood flow to be available to sustain the body's vital functions. A healthy body will respond to this by increasing peripheral resistance to sustain the blood supply to the heart and brain. Other considerations include:

- The site of a vascular access affects average flow values. Upper arm sites typically have higher flows than lower arm sites.
- Patients with initial high flow fistulas are at greater risk for cardiovascular problems. A fistula may "over-mature" and present a flow over 2 L/min.
- Autologous fistulas tend to remain sufficiently patent to sustain dialysis at lower flows than do prosthetic grafts.
- A straight upper arm prosthetic graft may initially exhibit an overly high flow. Graft flow tends to decrease over time, so banding a prosthetic graft is not advised. Access flow and cardiac function of these patients should be monitored monthly to ensure that access flow drops before cardiac complications arise.

"The ability to monitor cardiac output is one of the important cornerstones of hemodynamic assessment ...in particular in patients with pre-existing cardiovascular comorbidities." Tucker T *et al,* [11]

IV. Cardiac Function Assessment cont.

The Cardiovascular Effects of Arteriovenous Fistulas in Chronic Kidney Disease: A Cause for Concern

MacRae JM *et al,* Seminar in Dialysis 2006; 19:349-352.

Immediate hemodynamic effects of AVF creation	Increase in Cardiac Output (10-20%). Increase in sympathetic nervous system activity (increasing contractility). Increase in Stroke Volume and Heart Rate. Decrease in Peripheral Resistance.
Hemodynamic changes within one week of AVF creation	Increase in Circulating Blood Volume resulting in increased left atrial, inferior vena cava, and left ventricle end-diastolic volume (LVEDV). Increase in Neuro-hormones: vasodilator atrial natriuretic peptide (ANP) and brain natriuretic peptide (BNP) implying atrial and ventricular filling pressure are increased. Decrease in plasma renin and aldosterone levels. Decrease in Systemic vascular resistance and systolic/diastolic blood pressure.
Consequences of long-term AVF creation	**Left Ventricular Hypertrophy (LVH):** An adaptive response to increased cardiac workload caused by volume or pressure overload.
	High-Output Cardiac Failure High-flow AVF patients have a greater risk of developing CHF and greater increase in LVEDV. AVFs in HD patients may contribute to the development of heart failure. Left ventricle enlargement at the start of HD is very common and progressive left ventricle dilation with hypertrophy continues over time. Most of the left ventricle growth occurs during the first year of dialysis.
	Exacerbation of Coronary Ischemia AVF placement is associated with increased myocardial O_2 demand that may not be met, especially in patients with established coronary artery disease (CAD) or left ventricle hypertrophy (LVH). Increased O_2 consumption may have clinical manifestations in dialysis patients who have had CABG. A decrease in coronary perfusion that occurred with the onset of HD was demonstrated by the reduction in graft flow and reversible hypokinesis of the anterior left ventricle wall. High-flow AVFs with associated high cardiac output may increase O_2 demand.
	Central Vein Stenosis The endothelium plays an active role in vascular remodeling by secreting vasoactive substances and growth factors in response to alterations in flow and shear stress. Increased blood flow due to AVF creation alters the shear stress on the endothelium and promotes production of substances like transforming growth factor (TGF)-ß and NO which dilate the vessel lumen. A majority of central vein stenosis occurs at the junction of the cephalic and subclavian veins. There was a high correlation between the location of a central vein stenosis and ipsilateral AVF. It suggests that altered flow hemodynamics due to a fistula may result in endothelial damage and vascular remodeling, leading to stenosis.

CONCLUSIONS

- AVFs are superior to catheters and grafts due to fewer thrombogenic and infectious complications.
- A thorough cardiac assessment should be performed in patients with CAD prior to placing an AVF.
- Regular careful evaluations are necessary in patients with cardiac disease and AVFs.
- Patients with high flow fistulas (flow greater than 2L/min) and increasing LVEDV are recommended to have a flow reduction procedure on their AVF.
- Patients with preexisting severe ischemic heart disease should avoid AVF placement if the underlying ischemia cannot be treated.

The Quality of Cardiovascular Disease Care for Adolescents with Kidney Disease: A Midwest Pediatric Nephrology Consortium Study.

Hooper DK *et al*, Pediatr Nephrol 2013; 28(6): 939-49.[29]

Background

Cardiovascular disease (CVD) is the leading cause of increased mortality for adolescents with advanced kidney disease. Many patients have CVD mortality rates 1,000 times that of their age-matched peers and will die prematurely in early adulthood. Guidelines call for screening for cardiovascular risk factors in this population of patients.

Objective

To ascertain if the quality of preventive cardiovascular care may impact long-term outcomes for these patients.

Methods

- Records of 196 consecutive adolescents from seven American and one Canadian pediatric centers with pre-dialysis chronic kidney disease, on dialysis or with a kidney transplant, who transferred to adult-focused providers were reviewed.
- Cardiovascular risk assessment and therapy within and across centers were compared.
- Predictors of care were assessed using multilevel models.

Results

- Overall, 58% of five recommended cardiovascular risk assessments (family history of CVD, smoking status, lipid profile, physical activity, echocardiography for patients with a history of hypertension) were documented.
- Documented most frequently was smoking status (74%); an echocardiogram in patients with a history of hypertension (70%); family CVD history (53%); fasting lipid profiles and physical activity (47%) respectively.
- Overall, 58% of five recommended cardiovascular risk assessments (family history of CVD, smoking status, lipid profile, physical activity, echocardiography for patients with a history of hypertension) were documented.
- Only 20 of the 196 total patients (10%) received 100% of all indicated cardiovascular risk factor assessments.
- Recommended therapy for six modifiable cardiovascular risk factors was documented 57% of the time.
- Transfer after 2006 and kidney transplant status were also associated with increased cardiovascular risk assessment.

Conclusions

- Adolescents with kidney disease receive suboptimal preventive cardiovascular care, that may contribute to their high risk of future cardiovascular mortality.
- A opportunity exists to improve outcomes for children with kidney disease by improving the reliability of preventive care that may include formal transition programs.

B. Cardiac Function Assessment

1. Methodology

Cardiac output is the volume of blood being pumped by the heart in one minute. An average resting cardiac output is 5.6 L/min for a human male and 4.9 L/min for a female.[1]

"It is astonishing that no one has arrived at the following obvious method by which the amount of blood ejected by the ventricle of the heart with each systole may be determined directly..." Adolf Fick, 1870.

Adolf Fick introduced a method to measure an animal's cardiac output (CO) from arterial and venous blood oxygen measurements. His principle later formed the foundation of Stewart's indicator-dilution technology. In 1928, Stewart's equation was modified by Hamilton who described the bell-shape of a classic dilution curve (Fig. 4.1).

A variety of indicators has been used with this time-tested technology. All require that three criteria be met. They are:

1) Injection Phase: a known indicator is introduced into the circulatory system.
2) Mixing/dilution Phase: the indicator mixes with the blood.
3) Detection Phase: The indicator concentration is measured downstream from its introduction.

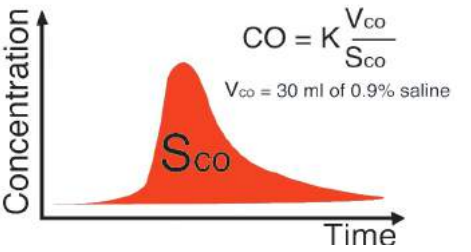


Fig. 4.1: Time concentration curve showing saline indicator dilution curve. CO is inversely related to the average dilution indicator concentration and the total time of indicator passage or CO is the amount of indicator injected/area of the dilution curve.

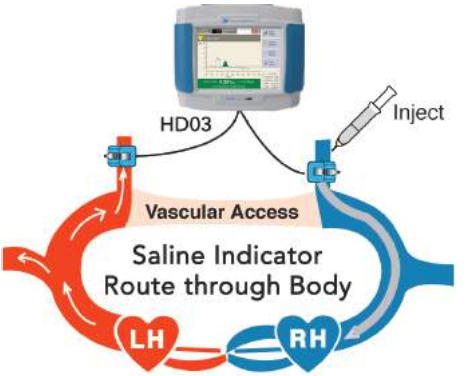


Fig. 4.2: Saline Indicator Route: Body temperature saline is injected into the venous line, travels through the heart and lungs and returns via the arterial system where a flow/dilution sensor records the diluted concentration.

Ultrasound dilution methodology, pioneered by Nikolai Krivistki PhD, DSc, uses body temperature saline, an innocuous indicator, that is injected into a patient's peripheral vascular access during the dialysis treatment. Injected into the venous blood line, the indicator travels through the heart and lungs and returns via the arterial system where a Flow/dilution Sensor records the diluted blood concentration (Fig. 4.2). Classic Stewart-Hamilton equations are used to calculate cardiac function and central hemodynamic parameters including Cardiac Output (CO), Cardiac Index (CI), Peripheral Resistance (PR) and Central Blood Volume (CBV).

2. Flow-QC® Cardiac Function Assessment

Transonic Flow-QC® Cardiac Function Monitoring with ultrasound indicator dilution technology provides a way to integrate cardiac function studies into a hemodialysis clinic's treatment protocol in order to forestall the devastating consequences of CVD.

Transonic Flow-QC cardiac function measurements help diagnose cardiac overload in ESRD patients.[1,11] When access flows measured during the dialysis session are unusually high (>2 L/min), cardiac overload can be suspected. A follow-up Flow-QC cardiac output measurement will verify whether the heart is stressed.

Cardiac output measurements during hemodialysis combined with access flow identifies:

a) Prolonged high access flow to cardiac output ratio that stresses the heart and can result in cardiomegaly and heart failure.

b) Dangerously low cardiac index that places patients at high risk for cardiovascular complications and failure.

c) Dramatic decreases of cardiac index during hemodialysis due to inaccurate dry weight estimation and/or inadequate medication.

d) Dangerous decrease in central blood volume during hemodialysis that may portend hypotensive episodes.

IV. Cardiac Function Assessment cont.

3. Flow-QC® Cardiac Function Parameters

Cardiac Output and calculated parameters are related to age and gender, and depend on a patient's clinical status such as the presence of diabetes or cardiac diseases and may change dramatically during a hemodialysis session.

Cardiac Output (CO)

Normal Range[1]: 5 - 8 L/min;
The volume of blood (in liters) ejected by the heart in one minute, is a fundamental measure of human hemodynamic performance. Typical values for hemodialysis patients range from 4 to 8 L/min with the determination of "normal CO" depending on a patient's body size."

Cardiac Index (CI)

Normal Range[1]: 2.2 - 4.5 L/min/m^2
Cardiac output divided by estimated Body Surface Area (BSA). A primary criterion of cardiac adequacy, CI is useful in comparing patients of different sizes. Cardiac Indexes from 6 - 8 L/min/m^2 may indicate high access flow. A low CI (< 2 L/min/m^2) at the beginning of a hemodialysis session indicates significant deterioration of cardiac function. A decrease in CI during the hemodialysis session indicates potential cardiac problems, inadequate dry weight estimation, and/or inadequate medication prescription.

Peripheral Resistance (PR)

Normal Range[1]: 9.6 - 18.8 mmHg x min/L (770 - 1500 dyne x sec/cm^5)
The average resistance to systemic blood flow is approximated as Mean Arterial Pressure divided by Cardiac Output. Patients diagnosed with diabetes may have substantially higher PR. Since CO generally decreases during hemodialysis and pressure is maintained, PR will increase during hemodialysis for most patients. Dr. Depner suggests that patients whose PR does not increase may have fluid overload. A Depner study correlated a higher initial PR, lower initial CO, and failure of PR to increase during hemodialysis with an increased 1-year mortality risk [8]

Central Blood Volume (CBV)

Normal values range from 0.8 - 1.6 L
The volume of blood in the heart, lungs, and great vessels. Central Blood Volume Index (CBVI) CBVI is CBV divided by the patient's weight (typical range, 11 - 17 mL/kg). CBV maintenance may be a factor in blood pressure regulation. CBV decreases during hemodialysis are similar to CO, and probably precede CO. When CBV is depleted, hypotensive episodes may occur. Monitoring CBV during ultrafiltration may indicate how fast a patient can be dialyzed without hypovolemic collapse.

IV. Cardiac Function Assessment cont.

Flow-QC® Cardiac Function Parameters				
PARAMETER	**TYPICAL RANGE**	**ABNORMAL RANGE**	**CLINICAL RELEVANCE**	**INTERPRETATION & RECOMMENDATIONS**
Access Flow (AF)	500 - 1600 mL/min	< 500 mL/min > 1600 mL/min for naive fistula	Heart compensates AF > 30% of CO CI < 2.2	Consider reducing AF by banding or other surgical procedure to avoid prolonged heart overload Body tissues are not adequately perfused due to A-V fistulae stealing. Repair or consider closure of fistula.
Cardiac Index (CI) (AF)	2.5 - 4.2 L/min/m^2	CI > 5 L/min/m^2	Usually indicates heart overload due to high access flow (see above).eqv Significant volume of accumulated liquid between dialysis sessions. May indicate low hematocrit	The reason for the increased CI should be identified and proper treatment implemented including: • A-V access intervention; • Change in dialysis prescription; • Change of erythropoietin prescription.
		CI < 2.0 L/min/m^2	Observed at the beginning of the HD session: indicates significant deterioration of CO function. Observed as a drop in CI during HD session: indicates potential cardiac conditions, inadequate dry weight estimation and/or medication prescription.	Refer to cardiologist for full study. The dry weight and medications should be examined and/or changed and central hemodynamic profiling (CHP) measurements repeated.
Central Blood Volume Index (CBVI)	11 - 17 ml/kg	< 10 ml/kg	Usually observed in obese patients where heart-lung system is relatively small compared to body weight.	Observation of CBVI decrease during or at the end of CHP may indicate patient is at risk for hypovolemic collapse. Dialysis prescription may be reconsidered
		> 20 ml/kg	High CBVI usually (especially if maintained during CHP) indicates extra fluid in lung circulation or left ventricular dilation	Perform follow-up studies.

* Parameters are given for research purposes. Some do not have well-established normal values.

[1]Darovic G.O.: Hemodynamic Monitoring *Invasive and Noninvasive Clinical Application*. WB Saunders Company, 1987.

transonic
THE MEASURE OF BETTER RESULTS.

IV. Cardiac Function Assessment cont.

4. Measuring Cardiac Function

Cardiac function measurements with a Transonic® HD03 Flow-QC® Hemodialysis Monitor require:

- Cardiac Output DTM inserted into the top rear of the HD03 Hemodialysis Monitor
- Flow-QC Clear Advantage® Tubing Set with a dedicated injection port for saline indicator injections into the venous blood line
- 30-mL syringes filled with saline warmed to body temperature.

Disposable Flow-QC® Clear Advantage Tubing Set

A Flow-QC Clear Advantage Tubing Set provides a safe injection port for a rapid 4 -7 second injection of a Cardiac Output saline bolus. The tubing set provides a consistent measurement environment. The ultrasonic and mechanical properties of these tubing sets are controlled to guarantee measurement accuracy, eliminate measurement variability from blood line brands, and reduce the need for periodic sensor calibration.

The Flow-QC Clear Advantage Tubing Set is placed in the hemodialysis circuit between the bloodline tubing and the venous and arterial needle tubing with the Flow/dilution Sensors positioned on the Flow-QC Clear Advantage Tubing. A bolus injection at another site, such as the bubble trap, would become too long and the software program may not be able to separate the timing of the first pass of the saline bolus from subsequent passes.

NORMAL CARDIAC FUNCTION VALUES (Hemodialysis Population)

Cardiac function depends on age, gender, and medical history (diabetes or cardiac disease). Cardiac parameters may fluctuate dramatically during a hemodialysis treatment. Flow-QC Surveillance measures:

CO	Cardiac Output	5 to 8 L/min (wgt & hgt dependent)
CI	Cardiac Index	2.2 to 4.5 L/min/m^2
CBV	Central Blood Volume	0.8 to 1.6 L (weight dependent)
CBVI	Central Blood Volume Index	11 - 17 ml/kg
PR	Peripheral Resistance	9.6 - 18.8 mmHg/L/min

IV. Cardiac Function Assessment cont.

To measure cardiac output and related parameters, fill a 30 mL syringe with 30 mL of saline warmed to body temperature. Insert Flow-QC® Clear Advantage® tubing segment into the hemodialysis circuit as shown (Fig. 4.3) and then prime tubing.

Attach the arterial & venous Flow-QC Clear Advantage tubing to the needle tubing (c) in normal line position with the flow/dilution sensors positioned in the middle of the Flow-QC Clear Advantage tubing lines and the arrows on the sensors each pointed in the direction of flow.

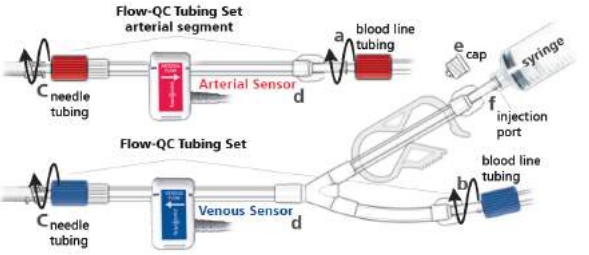


Fig. 4.3: The red-banded end of the arterial segment is connected to the male end of the arterial bloodline and the blue-banded branch of the Y end is connected to the male luer-lock connector on the venous bloodline.

With a Cardiac Output Data Transfer Module (DTM-CO) inserted in the HD03 Monitor, press the [Measure Patient] icon. Select the Flow-QC Tubing icon on the [Select Tubing] screen. Then press the Cardiac Output button to initiate the cardiac output measurement sequence. Enter parameters in the required fields and follow on-screen directions for the 6-7 second injection of 30 mL warmed saline. Measurement results including a CO dilution curve, calculated CO, CI and CBV values will display on the monitor.

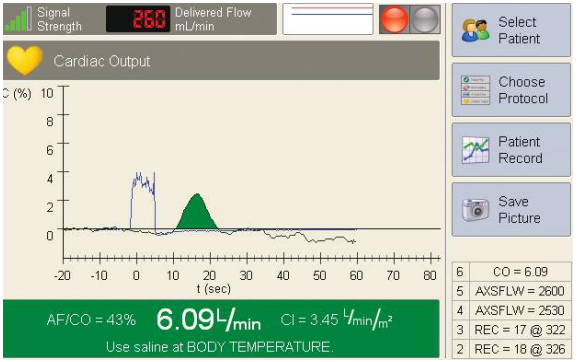


Fig. 4.4: Monitor display of measurement results.

Notes:

- If two measurements are within 15% of each other, a third measurement is not needed. If a Repeat Measurement message displays, repeat injection.
- CO can be measured in patients with access flow and no access recirculation. CO cannot be measured in patients with a CVC.

IV. Cardiac Function Assessment cont.

C. Central Hemodynamic Profiling (CHP)

Central Hemodynamic Profiling identifies low CI and offers the physician the opportunity to improve CI by adjusting dry weight medication and length of dialysis.[1,11]

Effective cardiac function management depends on a routine screening program such as Central Hemodynamic Profiling (Fig. 4.5) that identifies patients who leave hemodialysis sessions with dangerously low cardiac indices (CI ≤ 2.0), thereby increasing their risk for death, stroke or myocardial infarction. CHP is the periodic assessment of cardiac function during hemodialysis in order to track the heart's response to the stress of a dialysis treatment.

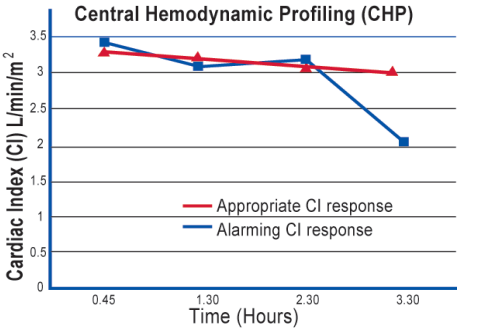


Fig. 4.5: Central Hemodynamic Profiling (CHP): four measurements taken during a single hemodialysis session shows Cardiac Index responses to the hemodialysis treatment. Acceptable CI results range between 2.5 - 4.2 L/min/m^2.[37,38]

A CHP study (Flow Chart, page 66) consists of hourly cardiac output measurements throughout the hemodialysis treatment. Transonic® Flow-QC Cardiac Output software automatically calculates Cardiac Index. If Cardiac Index drops below 2 L/min/m^2 during treatment, the hemodialysis prescription should be reviewed and adjusted immediately.

After adjustments are made, another CHP study should be performed during the next dialysis session. If this profile is stable and in the appropriate range, the patient's cardiac status can then be monitored as usual.

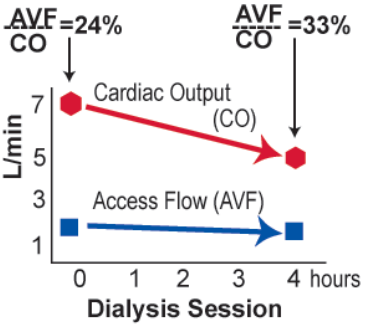


Fig. 4.6: One third of CO is redirected from the systemic circulation to the AV fistula placing patients at cardiac risk.

IV. Cardiac Function Assessment cont.

D. Cardiac Function Study Protocol

CHP identifies:

- Prolonged high levels of access flow (>1,600-2,000 mL/min) that can lead to cardiomegaly and high output cardiac failure identified by an access flow to cardiac output ratio (AVF/CO) exceeding 25-30% (Fig. 4.6).
- Cardiac Index of <2 L/min/m^2.
- Dramatic 20-30% drop in cardiac output during dialysis due to inaccurate dry weight estimation and/or medication that places patients at high risk for cardiovascular complications and sudden death following the session (Figs. 4.6-7).

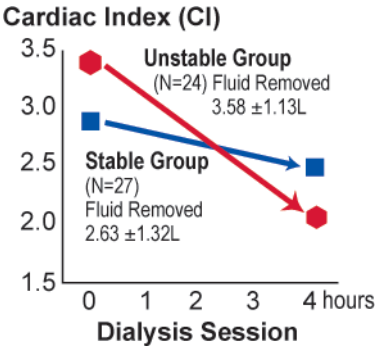


Fig. 4.7: Inadequate dry weight estimation increases the risk of cardiac failure.[1,11]

Flow-QC Cardiac Function Study Program

1. Initial Cardiac Stability Assessment

For new patients, patients who have had interventions, and patients with suspected cardiac complications. Transonic Flow-QC Protocol begins with a Tucker Central Hemodynamic Profiling (CHP) study consisting of hourly cardiac output measurements during the hemodialysis session. If a patient is stable (CI > 2.5), the measurements serve as the first data point for the patient's cardiac function baseline (see 2. below).

2. Three-part Baseline Cardiac Function Study

The Baseline Cardiac Function Study established reliable average cardiac function parameters for the patient and consists of:

1) The first baseline CHP study performed on a stable patient (see above).
2) A second CHP study performed shortly after the first. (One baseline study should following a two-day dialysis break, another, after a three-day break.)
3) A third CHP study one month later, after a weekend dialysis break, to confirm a patient's stability and serve as the third data point for the patient's cardiac function baseline.

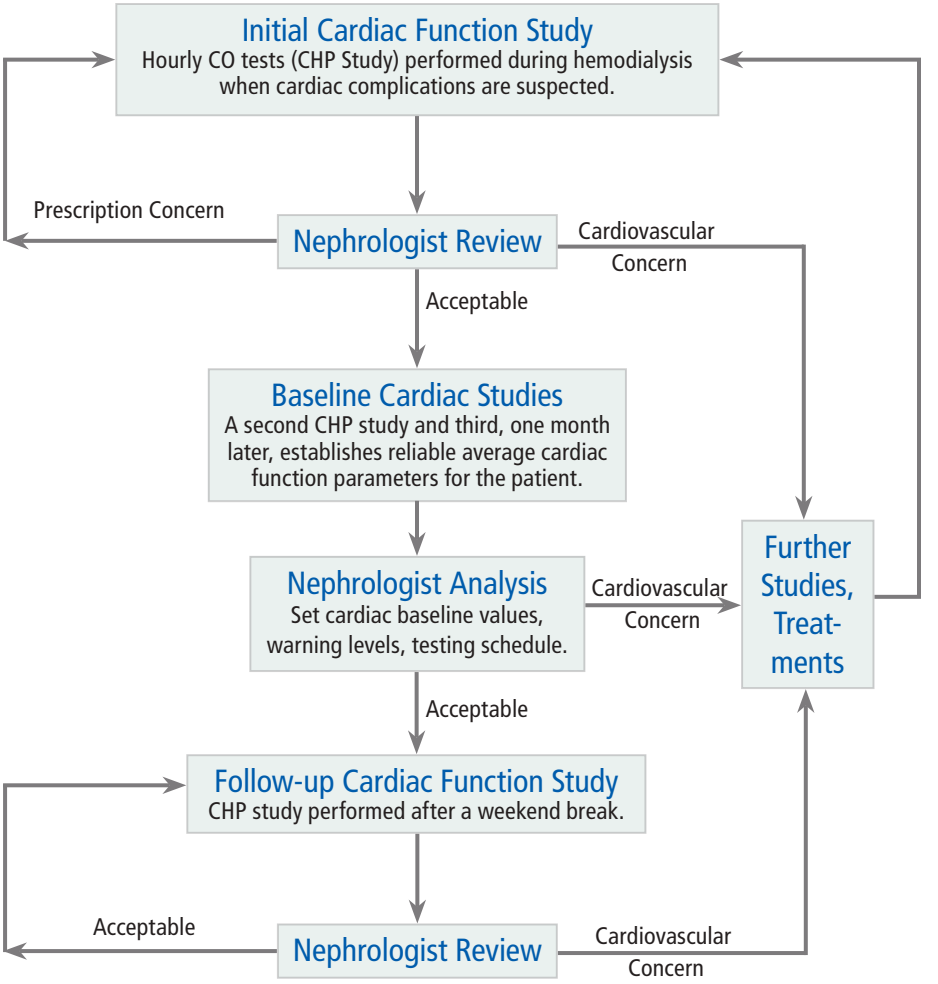
The nephrologist reviews the baseline study results, assesses the patient's status and prescribes a follow-up monitoring program.

3. Follow-up Cardiac Studies

Follow-up studies serve to monitor any progression of cardiovascular disease. A follow-up study consists of periodic CHP, preferably after a weekend break. The Flow-QC Protocol recommends quarterly testing for ESRD patients whose cardiovascular condition is stable and more frequent testing for patients with cardiovascular complications.

IV. Cardiac Function Assessment cont.

D. Cardiac Function Study Protocol cont.



E. Cardiac Function Case Studies

High Access Flow & Potential Cardiac Overload

A patient complaining of chest pains had 3630 mL/min AV fistula flow (Fig. 4.8) which prompted a CO measurement. CO was 10.8 L/min (Fig. 4.9). The vascular access was briefly occluded with a finger, and the patient's pulse rate dropped from 112 to 88 beats per min. An x-ray identified cardiomegaly. The vascular access was banded. Following banding, access flow measured 1700 mL/min and CO dropped to 7-8 L/min. The patient exhibited fewer post-dialysis hypotensive episodes, his dry weight decreased, his chest x-ray cleared and he reported significant improvement in his previous symptoms.

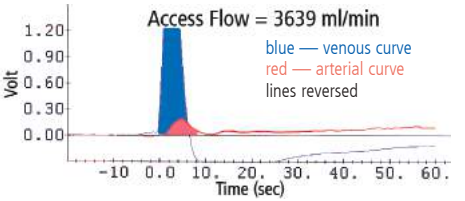


Fig. 4.8: Access flow measured over 3.6 L/min which prompted a CO measurement.

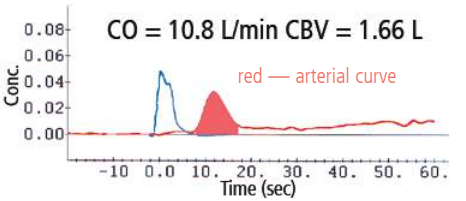


Fig. 4.9: A 10.8L/min CO measurement corroborated cardiac overload.

Deterioration of Cardiac Output & Cardiac Index during Hemodialysis

Flow-QC® Cardiac Function screening commenced 40 minutes into the hemodialysis session for a patient with ischemic heart disease. The first CO measurement was 4.3 L/min with a CI of 2.5 (Fig. 4.10). When the test was repeated two hours later, the patient's CO had dropped to 2.7 L/min and his CI was 1.6. The nephrologist was alerted, the patient's hemodialysis prescription was adjusted, and his cardiac condition was closely monitored.

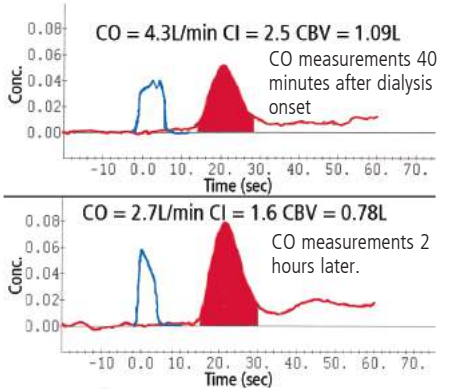


Fig. 4.10: Flow-QC® software screens showing deterioration of cardiac function during the course of the hemodialysis session.

Case studies courtesy of Dr. T.A. Depner, University of CA at Davis

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IV. Cardiac Function Assessment cont.

F. Cardiac Function Frequently Asked Questions

Q. I am seeing congestive heart failure (CHF) in patients with borderline cardiac function and excellent fistulas. We have done compression studies on these patients during a cardiac cath by measuring the ejection fractions, then compressing the fistula with a blood pressure cuff and remeasuring the ejection fraction. The ejection fraction increases and the patient becomes less symptomatic. There was a Transplant International article (France, 2008) stating that they are tying off fistulas in post-transplant patients to decrease left ventricular hypertrophy (LVH). Is anyone else seeing this?[39]

A. In fact, high-output cardiac failure and also pulmonary hypertension are well known complications of high-flow HD access. Although "high flow" is subjective, since every patient has a threshold of access flow that will induce such failure (as well as distal extremity ischemia), Fistula First uses a minimal threshold of 2 L/min flow to refer the patient for cardiac evaluation.

This is an often overlooked cause of LVH & CHF and any HD patient with a history of CHF or progressive LVH, should absolutely have access flow measured. When unrecognized, many of these patients with recurring CHF will die from their access-induced heart disease, since the cause was not recognized, and only gets worse.

The advent of accurate non-invasive measurement by ultrasound saline dilution has made it possible to measure access flow, which permitted a number of studies confirming the correlation between cardiac output and access flow. Access flow is usually approximately 20% of cardiac output. As access flow increases, so does cardiac output. The only reason that we do not see this problem in many patients, is because only a small proportion of patients have access flow approaching or greater than 2 L/min. Certainly, any patient developing LVH or CHF after starting HD should have the access flow measured. One reason I strongly urge use of access flow surveillance, is because it provides so much information. (Larry Spergel, MD, FACS)

Q. How accurate are Transonic CO measurements?

A. Transonic Cardiac Output measurements are the greater of 15% of true cardiac output, or ± 0.5 L/min.

Q. Why should the pump be set at 200 mL/min during CO measurements?

A. Injecting 30 ml of saline over 6 seconds increases the outflow rate of the venous blood line temporarily by 300 mL/min. Lowering the pump setting reduces the chance of pump stoppage during venous pressure elevation and also reduces the chance of the saline injection triggering recirculation.

F. Cardiac Function Frequently Asked Questions Cont.

Q. Why must there be 0% recirculation during a CO measurement?

A. For accurate Cardiac Output measurements, the full saline injection must reach the heart in a single bolus. The CO calculation is based on a bolus volume of 30 ml. If there is recirculation a part of the bolus will return back into the arterial bloodline and the lost saline would introduce a measurement error. Flow-QC® monitoring software will recognize recirculation during the CO measurement injection and will ask to repeat the measurement at a lower pump flow setting.

Q. Why do I need to enter the patient's height and body weight?

A. These values are used to calculate the patient's body surface area (BSA) from which Cardiac Index (CI) is derived. The Cardiac Output measurement protocol can be executed without these values, but the software would not calculate the CI and Central Blood Volume Index (CBVI). If pressures are not entered, the monitor's software will not calculate Peripheral Resistance (PR).

Q. Why must the saline be pre-warmed for the injection?

A. The transit-time of ultrasound changes with temperature. When CO is measured, the saline bolus travels through the cardiovascular circuit before returning to the arterial line flow/dilution sensor. Saline must be pre-warmed to body temperature so there will be no additional thermal changes to the saline indicator bolus as it passes through the body. A Transonic Fluid Bag Warmer is provided to warm and maintain the saline at a temperature of 33-38ºC. Never use a microwave to warm the saline!

Q. How should I inject the 30 mL?

A. The 30 ml injection is made into the injection port on the venous side of the Flow-QC tubing. It must be injected in one single pass fairly rapidly (4 to 7 seconds). Software automatically identifies and reports injection errors (direct recirculation, micro-bubble, incorrect saline temperature).

Q. Why do two consecutive CO measurements differ?

A. The repeatability of Transonic® indicator dilution technology is ± 4%. This means that two consecutive measurements may vary an average of 4% from their mean. Also, CO varies during the course of a respiratory cycle, over the course of the hemodialysis treatment, and with the patient's level of activity.

IV. Cardiac Function Assessment cont.

F. Cardiac Function Frequently Asked Questions Cont.

Q. Why aren't CO measurements possible with Central Venous Catheters?

A. Cardiac Output measurements require recording of a arterial dilution curve after introduction of an intravenous indicator (saline). If the indicator were to be injected through a central venous catheter, the indicator would not have the proper mixing conditions to dilute with the entire cardiac flow.

Q. How often should Cardiac Function parameters be measured?

A. Patient profiling is performed to establish and confirm the adequacy of medication dosages and the hemodialysis prescription. A patient's cardiovascular baseline consisting of monthly measurements over two consecutive months, can then be established by measuring Cardiac Output. This baseline should be established when a patient first enters into the Transonic® monitoring program and repeated when the patient returns from a hospitalization. After the baseline period, the nephrologist determines a measurement regimen for each patient including a prescribed testing interval (i.e., quarterly, monthly), whether an analysis of fluctuations in cardiovascular parameters induced by hemodialysis should continue, and the threshold at which changes in critical cardiac parameters should be brought to the attention of the nephrologist.

Q. What is an AF/CO ratio and will I get an AF/CO value every time I do an access flow measurement and CO measurement?

A. The AF/CO value is the percentage ratio of the patient's access flow to the patient's cardiac output. For example an AF/CO value of 22% would mean that 22% of the patient's cardiac output is being shunted through the patient's access. However, when access flow exceeds 25% of cardiac output, a potential cardiac problem may exist. The AF/CO ratio is calculated by the HD03 Flow-QC® Hemodialysis Monitor when access flow and cardiac output measurements are performed during the same hemodialysis session.

IV. Cardiac Function Assessment cont.

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IV. Cardiac Function Assessment cont.

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