

## Hemodialysis access monitoring and surveillance, how and why?

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### TABLE OF CONTENTS

1. Abstract
2. Introduction
3. Clinical monitoring
4. Surveillance techniques
  - 4.1. Direct access flow measurement
  - 4.2. Duplex ultrasound
  - 4.3. Venous pressure monitoring
  - 4.4. Measurement of access recirculation
5. Do monitoring and surveillance impact outcomes?
6. What should a clinician do?
7. References

## 1. ABSTRACT

Hemodialysis access is the ‘life line’ for patients on renal replacement therapy. Vascular access failure and complications are the second leading cause for hospitalization of patients on hemodialysis. The concept of access monitoring is based on the basic tenet that identification of patients at risk of developing future access failure, coupled with elective intervention will decrease the incidence of hemodialysis access failure and improve patient outcomes. Clinical monitoring and surveillance techniques are very effective in detecting hemodialysis access lesions. However, the studies analyzing the impact of monitoring and surveillance have yielded a variety of controversial results, which is likely the result of the differences in methodology and use of a variety of parameters. Despite the controversy surrounding the value of monitoring and surveillance, the ‘Conditions of Coverage’ for dialysis providers mandate monitoring with appropriate and timely referrals to achieve and sustain vascular access. This review discusses pros and cons of various monitoring and surveillance techniques and suggests a strategy based on current literature.

## 2. INTRODUCTION

Hemodialysis access is the ‘life line’ for patients on dialysis and is the most important component in determining the success or failure of dialysis therapy. Despite this recognition, vascular access failure and complications are the second leading cause for hospitalization accounting for more than 20% of hospitalizations in hemodialysis patients resulting in over \$1.5 billion expenditure in United States annually (1). Additional costs are incurred from missed treatments and placement of temporary dialysis catheters with significant inconvenience, pain and infection risks when vascular access fails. Failure to detect access dysfunction that can lead to its failure has consequences of increased morbidity and mortality (2-3). Thus, vascular access complications continue to be one of the most difficult obstacles in optimal care of patients on dialysis.

The concept of access monitoring is based on the basic tenet that identification of patients at risk of developing future access failure, coupled with elective intervention (such as correction of stenotic lesions), will decrease the incidence of hemodialysis access failure and improve patient outcomes. The updated 2006 KDOQI Clinical Practice Guidelines for vascular access defined the

terms of monitoring and surveillance of vascular access. Monitoring refers to examination and evaluation of the vascular access by means of physical examination and other data obtained routinely in the course of hemodialysis. Surveillance refers to periodic evaluation of vascular access by utilizing tests that involve special instruments. A number of studies have indeed demonstrated the ability of access monitoring and intervention program to decrease the incidence of thrombosis and prolong access life (4) and to decrease the need for emergent interventions (5-6). Although there is consensus that monitoring the access is useful in detecting stenosis (7-11). Several studies have reported that use of these monitoring/surveillance techniques may not assist in prediction of thrombosis or alter the outcome (12-14). Based on the promising results of the earlier studies, KDOQI (Kidney Disease Outcomes Quality Initiative) guidelines have recommended prospective periodic monitoring and surveillance of fistula and grafts for early recognition of access dysfunction followed by referral for diagnostic evaluation and treatment of dysfunction (15). In 2008, Centers for Medicaid and Medicare Services issued an ESRD Interpretive Guidance Update stating that 'the dialysis facility must have an ongoing program for vascular access monitoring and surveillance for early detection of failure and to allow timely referral of patients for intervention when indications of significant stenosis are present (16). Although angiography remains the gold standard for diagnosing inflow and outflow stenotic lesions, clinical monitoring and methods of surveillance use efficient techniques to detect access abnormalities to plan proper intervention. Clinical monitoring and surveillance techniques suggested by 2006 K/DOQI guidelines include physical examination, measurement of access recirculation, measurement of static venous pressure and dynamic venous pressure, intra-access flow and vascular access imaging. In this article we will discuss the methods of monitoring and surveillance, as well as the evidence regarding pros and cons of such techniques.

### 3. CLINICAL MONITORING

Physical examination of the vascular access should be done routinely to evaluate for signs of stenosis, which include persistent swelling of the arm, presence of collateral veins, prolonged bleeding after needle withdrawal, and changed characteristics of pulse or thrill in the outflow vein. In combination with hemodialysis adequacy ( $URR/Kt/V$ ) and other information obtained from the dialysis session, physical examination may detect up to 80- 90% of stenotic lesions in AVF in experienced hands. Asif *et al* showed that physical examination can accurately detect and localize stenoses in a great majority of arteriovenous fistula when performed correctly by an experienced nephrologist (17). Similarly, one study showed that the accuracy of physical examination for the diagnosis of AVF stenosis was 88%, with sensitivity and specificity of 96% and 76%, respectively, while the accuracy, sensitivity and specificity of intra-access pressure (IAP) were 71%, 60% and 88%, respectively (18). Signs and symptoms of access dysfunction that are assessed in clinical monitoring are related to both inflow and outflow stenotic lesions (Tables 1 & 2). It is important to mention

that juxta-anastomotic venous outflow stenotic lesions are hard to differentiate from inflow arterial stenotic lesions, and both, inflow and outflow lesions, have shared signs and symptoms. All aspects of physical examination, inspection, palpation, and auscultation need to be applied in evaluation of access function and utilized in conjunction with other surveillance techniques.

### 4. SURVEILLANCE TECHNIQUES

Direct access flow monitoring, duplex ultrasound and direct or derived static venous dialysis pressure measurement are the most common methods of surveillance.

#### 4.1. Direct access flow measurement

Access flow monitoring is the preferred and most recommended method of surveillance for stenotic lesions. Access flow ( $Q_a$ ) can be measured by using ultrasound dilution, conductivity dialysance, duplex ultrasound, thermal dilution, magnetic resonance angiography, Crit-line (optodilution by ultrafiltration and direct transcutaneous measurement), glucose pump infusion technique, urea dilution and differential conductivity. These different methods have been shown to be effective in detecting stenotic lesions.

The principle of all indicator dilution techniques is based on the introduction of a change in the dialyzed blood by infusing a substance (saline) or creating a physical change (temperature), which is detected by sensors and is used to calculate  $Q_a$ . The indicator is infused prior to the venous needle after reversal of dialysis lines, at which time the total flow in the AVG/AVF equals both access flow and dialysis machine pump flow. The portion of the indicator that enters the arterial needle is in reversed ratio to  $Q_a$ .

In ultrasound dilution, ultrasound sensors measure the difference in protein concentration and produce dilution curves, after the infusion of saline. It is based on different ultrasound velocity in saline and blood. As the ultrasound velocity is slower in saline compared with blood, a bolus of infused saline after reversal of dialysis lines is detected by the ultrasound transducer (20). These dilution curves are then used to measure  $Q_a$ . The need for the presence of an ultrasound technologist, ultrasound dilution machine, and maintenance program are significant limitations of this technique.

In thermal dilution the rate of increase in temperature is measured by a sensor after infusion of cold saline via the cannulation needles with reversed lines. The degree of change in temperature is used to measure the access flow. This technique has similar limitations as ultrasound dilution. However, thermal dilution test can be performed by a dialysis nurse. One does not need an ultrasound technician or ultrasound machine to perform this test. The sensors are located on the HD machine. Main limitation of this technique is that it is available only on certain machines and validation of results is limited.

In conductivity dialysance measurement an on-line clearance monitor automated for measurements of conductivity dialysance is used to measure  $Q_a$ . (21-22).

## Hemodialysis access monitor

**Table 1.** Signs and symptoms of inflow stenotic lesions

A	Decreased access flow
B	Decreased hemodialysis adequacy (URR/Kt/V) in the absence of other causative factors
C	Systolic accentuation of bruit on auscultation over the site of AV anastomosis in AVF and AA in AVG
D	Poor filling and pulsations of the outflow vein distal to the site of manual occlusion of AVF with other signs of decreased access flow (normally expected to augment upon compression)
E	High negative arterial pressure during hemodialysis (below -200 mm Hg with 15 gauge needles and a blood flow of 400ml/min (6, 19)
F	Difficult cannulation

**Table 2.** Signs and symptoms of outflow stenotic lesions

A	Decreased access flow
B	Decreased hemodialysis adequacy (URR/Kt/V) without change in dialysis prescription
C	Systolic accentuation of bruit over the outflow vein in AVF and venous anastomosis in AVG
D	Increased pulsation of AVG and the outflow vein distal to the stenotic area in AVF
E	Swelling of the distal limb and site of hemodialysis access because of increased venous pressure
F	Development of collateral veins
G	Prolonged bleeding after cannulation of both AVF and AVG in the absence of excessive/or change in anticoagulation
H	Drawing blood clots from AVG/AVF after cannulation
I	High venous pressure during hemodialysis (more than 125 mmHg with the use of 15 gauge needles and blood flow of 200 mL/min on three successive measurements (19)
J	High negative arterial pressure during hemodialysis with juxta anastomotic lesions (below -200 mm Hg with 15 gauge needles and a blood flow of 400ml/min) (19)
K	Difficult cannulation and infiltration
L	Poorly collapsible AVF with arm elevation

The real-time dialysance of sodium is measured, which can be considered equivalent to the dialysance of urea. This technique utilizes an increase in sodium concentration of the dialysate going into the dialyzer as an indicator. This technique can be done by any trained dialysis technician, is less expensive and correlates highly with ultrasound dilution technique.

The optodilutional Delta-H method, using the Crit-Line III monitor utilizes an optical detector to measure arterial blood hematocrit (23-25). It is based on the reverse relationship between hematocrit and blood volume. In this technique, hematocrit changes induced by increasing ultrafiltration are continuously measured by an optical sensor placed between the arterial line and the dialyzer. In this technique:  $Q_a = (UF_{max} - UF_{min}) \times Hct (rev\ max) / (Hct \Delta rev - Hct \Delta norm)$ . Where  $Q_a$  is access flow;  $UF_{max}$  is maximum ultrafiltration;  $UF_{min}$  is minimum ultrafiltration;  $Hct (rev\ max)$  is the maximum hematocrit with reversed hemodialysis lines;  $Hct \Delta rev$  is the change in arterial hematocrit with reversed lines;  $Hct \Delta norm$  is arterial hematocrit change without reversal of dialysis lines.

The Critline III TQA system from HemaMetrics uses a transcutaneous optical flow sensor, placed directly distal to the venous access needle and does not require reversal of dialysis lines (25).

In the glucose pump infusion technique venous blood glucose concentration is measured before and after constant glucose infusion into the arterial needle. The

infusion concentration and the pre and post venous blood glucose concentrations are then used to calculate  $Q_a$ .

### 4.2. Duplex ultrasound

This technique with color-flow ultrasound provides flow measurement, in addition to structural findings (20, 26). It is highly sensitive and specific in detecting stenotic lesions; however, it is also expensive and requires trained ultrasound professional. Accuracy of Doppler Ultrasound is extremely close to angiography in diagnosis of stenosis of vascular accesses, with sensitivity of 92% to 100% and specificity of 94% to 97% (27-29)

### 4.3. Venous pressure monitoring

Dynamic venous pressure is measured by the dialysis machine pressure transducer at the beginning of hemodialysis using a 15 gauge needle with a blood flow of 200 mL/min. The finding of venous pressure above 125-150 mmHg on 3 consecutive dialysis sessions is abnormal (10). Static venous pressure is measured by a manometer connected to the access needle before starting the dialysis pump. This pressure is normalized to systemic pressure and is normally less than 0.4. According to the 2006 K/DOQI guidelines, patients with a venous segment static pressure ratio of above 0.5 in AVG and AVF, or arterial segment static pressure ratio of above 0.75 in AVG should be referred for further evaluation (30). It is less informative in AVF than in AVG and is not considered an optimal screening test for both AVF and AVG.

### 4.4. Measurement of access recirculation

Access recirculation can be measured by non-urea based dilutional methods by utilizing the thermodilution technique or other bolus techniques (6). The percentage of the dialyzed extracorporeal blood that returns to the access arterial inflow without systemic equilibration determines the amount of recirculation. The thermodilution technique is based on thermal dilution for access flow measurements and utilizes a blood temperature monitor (BTM) (31). The temperature of arterial and venous blood is measured by two sensors without direct contact with the blood. A thermal bolus is generated by changing the dialysate temperature by 2.5- 3 Celsius degrees for 3-5 minutes without injection of cold saline and the percentage of both access and cardiopulmonary recirculation is measured. The pitfall of this technique is the difficulty in separating the access recirculation from the cardiopulmonary recirculation if sensors with long response time are used. This can be avoided by using sensors with short response time.

## 5. DO MONITORING AND SURVEILLANCE IMPACT OUTCOMES?

The primary aim of a monitoring or surveillance program is to reduce adverse vascular events by improving the ability to intervene in a timely fashion. The studies analyzing the impact of monitoring and surveillance have yielded a variety of controversial results. In a study done by McCarley et al, a total of 132 chronic hemodialysis patients were followed prospectively for three consecutive study phases- 11 months of no monitoring (phase I), 12 months

of dynamic venous pressure monitoring (phase II) and 12 months of vascular access blood flow monitoring (phase III) (32). During the three study phases, graft thrombosis rate, hospital days, missed treatments and catheter use related to thrombosis events were all reduced during phase III compared to phase I and II. Percutaneous angioplasty procedures increased during phase II and III but the total cost of treatment for thrombosis related events for grafts and fistulas were reduced. In a randomized controlled study, Ram et al evaluated whether intervention based upon Qa (access flow, done monthly) or stenosis (duplex ultrasound, done quarterly) provide a benefit when added to intervention based upon clinical criteria alone (13). The preemptive PTA rate in the control group (0.22/patient per year) was two-thirds the rate in the flow-monitoring group (0.34/patient per year was referred for angiogram if Qa <650 ml/min or 20% decrease in Qa from baseline (13). Graft surveillance using access flow (Qa) increased the detection of stenosis, compared with standard surveillance (dynamic venous pressure and physical examination); however, intervention with angioplasty did not seem to improve the time to graft thrombosis or time to graft loss) and was the highest in the stenosis group (0.65/patient per year). The percentage of thrombosed grafts were similar in the control (47%) and flow-monitoring groups (53%) but were reduced in the stenosis group (29%,  $p=0.10$ ). However, two year graft survival was similar in the control, flow-monitoring and stenosis groups (62%, 60% and 64%, respectively) ( $p=0.89$ ). In another randomized, blinded, controlled trial of 112 patients with AVG, only the treatment group.

Intra-access pressure (IAP) has been promoted as a method of access surveillance. A number of studies have shown conflicting results (10-12). Schwab et al found that access replacement rates decreased by 73% after the implementation of dynamic venous pressure monitoring, and Besarab et al found a 76% reduction in access replacement rate with the use of static venous pressure monitoring. However, neither of these studies was randomized and both utilized historical control groups. Another study showed that intra-access pressure measurement is important in the detection of stenosis of vascular grafts and not in arteriovenous fistula (AVF) (33). Similarly, venous access pressure ratio test (VAPRT) improved sensitivity and specificity for detection of an arteriovenous graft dysfunction (34). However, static intra-access pressure measurement as a surveillance method failed to show correlation with access blood flow (35). Thus, standardized monitoring of either venous pressure (VP) or access flow (Qa) or the combination of both and subsequent corrective intervention can reduce thrombosis rate in vascular grafts. These surveillance strategies were shown to be equally effective in reducing thrombosis rates in another study (36).

Based on these studies, there remains a concern that interventions based on monitoring and surveillance may not be effective in maintaining access patency or prolonging its life. Randomized trial of prophylactic intervention of AV graft stenosis found no improvement in the primary patency rate except in a subset analysis of

“virgin” grafts (grafts with no previous surgical revision, angioplasty or thrombectomy) (37-38). A randomized study of 64 patients with elevated static venous pressure measured in upper extremity AV grafts, comparing intervention (prophylactic angiography and/or angioplasty) strategy and observation, failed to improve/prolong graft survival (13).

## 6. WHAT SHOULD A CLINICIAN DO?

Vascular access dysfunction remains a prevalent problem in hemodialysis. There is no uniformity in defining vascular access dysfunction by various researchers and numerous methods to describe anatomical and functional abnormalities have been proposed. Most methods of monitoring rely on clinical parameters which can be obtained by simple bedside examination; however, these methods are not routinely practiced in the dialysis clinics. Surveillance, on the other hand, requires use of technology and involves significant costs. Done properly and on a regular schedule, these methods have the potential to keep the access patent, avoid catheter use, decrease hospitalization and improve the quality of life for the dialysis patient. The controversial evidence regarding the predictive value of such research so far is a result of the differences in methodology and use of a variety of parameters. It has to be kept in mind that the methods useful in assessment of AV graft are not necessarily applicable to AV fistula. Moreover, inaccurate data has the risk of increasing the number of interventions without clinical benefit, and can cause harm because interventions have the potential to incite more aggressive vascular response and restenosis (39-40).

Despite the controversy regarding the value of monitoring and surveillance, the ‘Conditions of Coverage’ for dialysis providers mandate monitoring with appropriate and timely referrals to achieve and sustain vascular access. Further, evidence of periodic monitoring and surveillance of the vascular access should be documented and reviewed to take appropriate action. While monitoring is reimbursed in the dialysis composite payment in the United States, there is no separate funding for routine surveillance. In this era of restrictive payment systems, issues related to processes of monitoring and surveillance are important in determining the most cost-effective, convenient and highly accurate strategy of maintaining a vascular access. If done consistently, monitoring alone may provide clues to the majority of access problems. While surveillance may add only small benefits in this group of patients, it may be far more important where routine monitoring is not practiced.

Locally available expertise will remain the most important factor in determining the best approach for monitoring and surveillance of vascular access at a given center. In the absence of conclusive data, it will be important to pursue randomized research in this area to assess the impact of monitoring and surveillance on outcomes related not only to the longevity and performance of vascular access, but also to the reduction of morbidity, cost and improvement in quality of life.

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