Current Vascular Access Surveillance Techniques

a report by
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The initial blood flow and pressure characteristics of a hemodialysis access site are established at the time when it is created by the access surgeon. The size of the artery and vein, starting arterial and venous blood flow and pressure, and the physical construction of the access will all influence the initial access flow and intra-access pressure. The patient's cardiac output, which may vary significantly, is always a factor that influences any given measurement of access flow or intra-access pressure. Determining access flow and pressure parameters when the access is created or immediately following an access revision is important information to include in an access surveillance system since it establishes the baseline needed for prospective trend analysis. A patient with a starting access flow of 950ml/minute that decreases by 30% to 630ml/minute will require a different surveillance response than a patient with a starting access flow of 1,500ml/minute that decreases by 30% to 1,020ml/minute. When a stenosis develops at any point in the access or downstream of the access site in the venous return, access flow and intra-access pressure will change. The challenge with any access surveillance is the accurate measurement and interpretation of changes to access flow and intra-access pressure.

The value of routine use of any surveillance technique for detecting anatomic stenosis alone without concomitant functional assessment by measurement of access flow, venous pressure, recirculation, or other physiologic parameters has not been established. Physical examination (inspection, palpation, and auscultation) of the vascular access to detect physical signs that suggest the presence of dysfunction should always be undertaken conjointly with any surveillance methodology.

Surveillance Using Intra-access Pressure Measurements

Direct Measurement of Static Venous Pressure

Static intra-access pressure measurements are made at the start of dialysis by measuring the arterial access pressure (AAP) and venous access pressure (VAP) at the access needles before the patient is connected to the dialysis machine. Access Alert (Medisystems) facilitates intra-access pressure measurements by providing sterile filters that connect directly to the access needles to prevent contamination. Intra-access venous and arterial pressures are read from a hand-held analog manometer. The venous access pressure ratio (VAPR) is calculated by dividing the venous access pressure by the patient's mean blood pressure. Results are entered in the patient's dialysis record.

Intra-access pressures can also be measured by using the pressure transducers of the dialysis machine. With the blood pump and ultrafiltration turned off, pressure in the venous line and the arterial pre-blood pump pressure are recorded. The venous and arterial intra-access pressures are calculated using an equation that corrects for the difference in height between the pressure transducers on the machine and the level of the patient's access site (0.76 • Δ height added to the machine transducer reading).

Table 1 shows the interpretation of static pressure measurements for grafts. Venous outlet stenosis can be detected with the VAPR. The higher the degree of stenosis at the outlet, the greater the VAPR. Strictures between the area of arterial and venous needle canalizations cannot be detected by measuring VAP alone.[1] Detection of these lesions requires the simultaneous measurement of pressures from both the arterial and venous needles. A central stenosis that has led to the development of a collateral circulation may have normal pressures.

Accesses can be classified into the categories listed in *Table 1* using the equivalent access pressure ratios from the arterial or venous needles; the criteria must be met on each of two consecutive weeks to have a high likelihood of a 50% diameter lesion.

Patients who develop a progressive and reproducible increase in venous or arterial segment >0.25 above their previous baseline irrespective of access type are also likely to have a hemodynamically significant lesion. Intra-access strictures are usually characterized by the development of a difference between the arterial and venous pressure ratios >0.5 in grafts or >0.3 in native fistulae.

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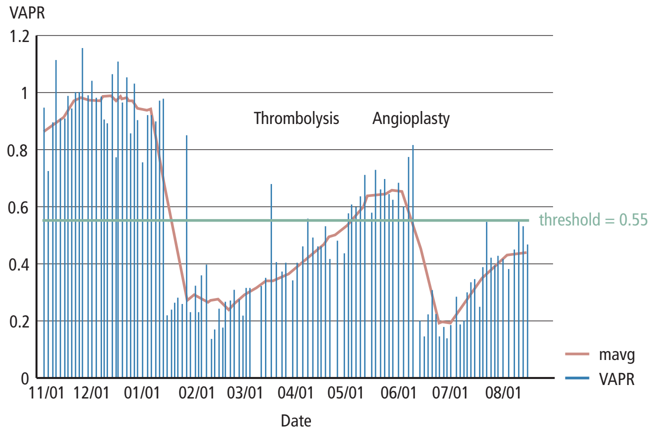
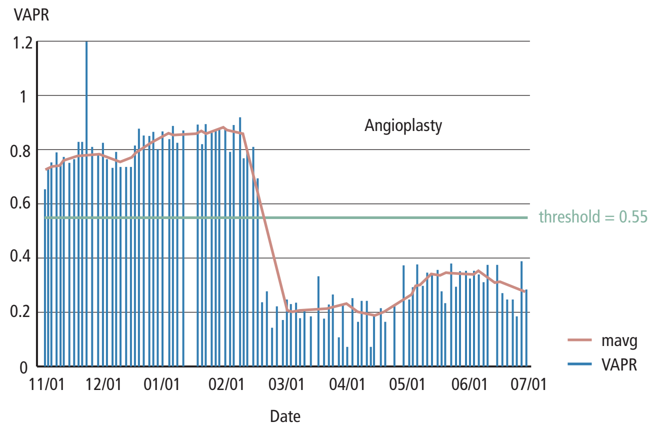
Figure 1a: Venous Access Pressure Ratio (VAPR) Data Using the Vasc-Alert System for a Patient That Was Allowed to Clot



Following thrombolysis, VAPR values remain low for about one month then show a relatively rapid increase that exceeds 0.55 in four months. This rapidly increasing trend in VAPR values is typical following access thrombosis.

Figure 1b: Venous Access Pressure Ratio (VAPR) Data Using the Vasc-Alert System for a Patient That Underwent Angioplasty Before Clotting



VAPR values remained low during the four-month period following angioplasty.

Vasc-Alert® System

The Vasc-Alert® computer algorithm identifies persistent VAPR elevations that may signify that an access requires additional evaluation. This algorithm calculates VAPR from the venous drip chamber (VDP), measurements by the dialysis machine, and blood pump flow data that are routinely collected during dialysis and determine persistent increases of VAPR. The program extracts the most recent hematocrit (an index of viscosity effects) and individual treatment data from the dialysis database, and VAPR is calculated each time blood pressure is measured during dialysis. Data from the last 60 minutes of dialysis is excluded to eliminate the effect of ultrafiltration on hematocrit, blood pressure, and changes in systemic and vascular access resistances. The algorithm calculates mean VAPR for each dialysis session. Readings are considered abnormal if the VAPR exceeds 0.55 during three consecutive treatments. The dialysis treatment is never interrupted to take a reading.

The Vasc-Alert system also obtains the machine pre-pump arterial pressure recorded during dialysis. The ratio of the absolute value of the pre-pump arterial pressure divided by machine blood flow is calculated. An arterial pressure ratio (APR) greater than 0.6 in grafts and 0.65 in fistulae during three consecutive treatments indicates that the patient has an obstruction in the arterial inflow. *Figure 1a* and *Figure 1b* show VAPR data from Vasc-Alert example reports where VAPR values are plotted for each dialysis treatment; following thrombolysis or angioplasty, VAPR values are reduced below the threshold level of 0.55. The data in *Figure 1a* are typical for a patient who has undergone thrombolysis; VAPR values are again above threshold in approximately four months.

Table 1: Interpretation of Static Pressure Measurements for Grafts

Access type	Graft		Graft
	Arterial access pressure ratio		Venous access pressure ratio
Normal	0.35–0.74		0.15–0.49
Stenosis			
Venous outlet	>0.75	or	>0.5
Intra-access	>0.75	and	<0.5
Arterial inflow	<0.3		Clinical findings

Dynamic Pressure Surveillance

The system was initially developed for surveillance of dialysis patients using 16 gauge needles. Blood flow on the dialysis machine is set between 200 and 225ml/minute for the first 30 minutes of treatment and the VDP measured by the dialysis machine is recorded. Patients exceeding a VDP of 150mmHg were considered abnormal and referred for an access intervention. It should be noted that up to 80% of the pressure that is recorded may be the result of the pressure drop through the dialysis needle. The method was not consistently adapted for larger bore needles (15G and 14G) as high-efficiency dialysis promulgated, and criteria for intervention were not standardized. As a result, dynamic venous pressure surveillance alone is no longer recommended by the National Kidney Foundation Kidney Disease Outcomes Quality Initiative (NKF KDOQI) guidelines.

Surveillance Using Access Flow

The NKF KDOQI guidelines for surveillance using access flow recommend that access flow measured by ultrasound dilution, conductance dilution, thermal dilution, Doppler, or other technique should be performed at least monthly. Flow measurements should be made during the first 1.5 hours of treatment to minimize errors caused by a decrease in cardiac output due to ultrafiltration. The flow measurement should be the mean value calculated from three separate measurements.

AV graft and AV fistula intervention criteria:

- Access flow less than 600ml/minute in graft, the patient should be referred for fistulogram.
- Access flow less than 1,000ml/minute that has decreased by more than 25% over four months should be referred for fistulogram.

A single access flow (QA) threshold for angiography in all patients is too simplistic, in the authors' opinion. The optimal threshold might vary by patient subgroup and the best function ever attained by the access, hence the need to establish the best function parameters for the access and following trends.

Indicator Dilution Methods

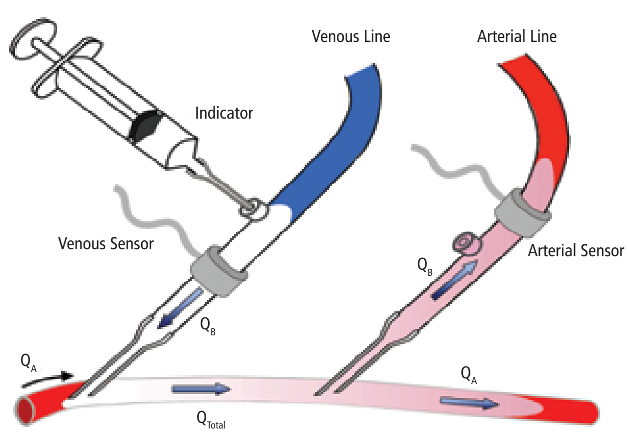
All indicator dilution methods are similar in that a substance is introduced into or a physical change is made in the circulating blood that is then detected by a sensor. Data from the sensor are used to calculate access flow. To make an access flow measurement the bloodlines are normally reversed (see *Figure 2*). Note that the arterial bloodline withdraws blood downstream from the venous return from the machine.

The indicator is injected above the venous sensor. All of the indicator bolus travels past the venous sensor and enters the arterial end of the access. The total flow through the access (Q_{Total}) is now equal to the initial Q_A plus the blood pump flow (Q_B). When the bolus arrives at the arterial needle a portion of the indicator enters the arterial line and the remaining portion travels into the venous return to the heart. The higher the access flow, the smaller the portion of indicator that enters the arterial line. *Figure 3* shows the signals obtained from the arterial and venous sensors.

Since the machine Q_B is known, access flow can be calculated by determining the area under the venous and arterial dilution curves. The ratio R = arterial area/venous area is then used in the equation $Q_A = Q_B(1/R - 1)$ to determine the access flow.

The indicator dilution method, which utilizes the reversal of arterial venous lines, was developed for ultrasound dilution by Transonics®. Ultrasound velocity is slower in saline (1,533m/second) compared with blood (1,580m/second); this allows a bolus of saline traveling through a bloodline to be detected by the ultrasound transducer. Ionic dialysance or conductivity dialysance developed by Fresenius uses an increase in the sodium concentration of the dialysate going into the dialyzer as an indicator. The Fresenius blood temperature monitor (BTM) is based on thermal dilution for access flow measurements. The Critline III system from HemaMetrics is similar to the Transonic system, but it uses an optical detector to determine the hematocrit in the arterial blood line. Instead of using a bolus of saline the sensor detects a change in hematocrit induced by increasing the dialysis machine ultrafiltration rate. The Critline III TQA system from HemaMetrics does not require reversal of the bloodlines; instead, it uses a transcutaneous optical flow sensor. The transcutaneous optical sensor is placed on the skin directly over the access approximately 25mm downstream of the venous access needle.

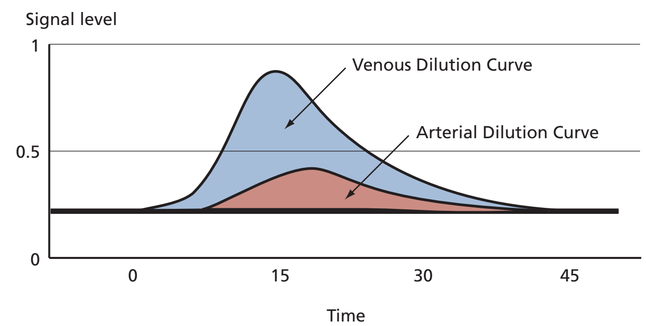
Figure 2: Diagram of the System Used for Access Flow Measurements with the Arterial and Venous Lines Reversed



$Q_{Total} = Q_A$ (Access flow) + Q_B (Blood flow)

The indicator is injected upstream from the venous sensor. Following injection, the bolus travels past the venous sensor and enters the arterial end of the access. The total flow through the access is now the access flow Q_A plus the blood pump flow Q_B. When the bolus arrives at the arterial needle a portion of the indicator enters the arterial line and the remaining portion travels into the venous return. If the access flow is high, only a small portion of indicator will enter the arterial line; as access flow decreases there is less dilution of the indicator in the access and a larger portion of it is detected at the arterial sensor.

Figure 3: Measuring the Indicator Passing Through the Circuit Over Time Produces the Arterial and Venous Dilution Curves



The area under each curve is used to calculate the ratio R = (arterial area)/(venous area). Access flow (Q_A) is then determined by the equation $Q_A = Q_B(1/R - 1)$, where Q_B is dialysis machine blood flow rate.

Saline is injected into the venous needle and the bolus is detected by the optical sensor.

Other Flow Technology

The variable pump flow (VPF) Doppler method measures access flow using a sensor that generates and records ultrasound. The sensor is placed between the arterial and venous access needles and the hemodialysis machine blood pump is set to a number of different flows. The Doppler signal is plotted for each blood pump setting and a regression line is used to calculate the access flow when the dialysis machine blood pump setting is zero.

> The usefulness of flow or pressure surveillance critically depends on the accuracy of the measurements themselves so that accurate confirmation of hemodynamic dysfunction is proven prior to correction of the stenosis.

The InGraft Velocimeter uses an ultrasound velocity sensor to detect the increased blood velocity though a stenosis. Measurements are made by inserting a catheter-mounted ultrasound velocity sensor through the venous dialysis needle, normally 6–10cm past the venous anastomosis; it is then slowly withdrawn. The sensor will measure an increase in flow velocity in the area where there is developing stenosis.

The glucose pump infusion technique for access flow measurement requires a constant glucose infusion into the arterial needle. A blood sample is taken from the venous needle before the start of the infusion (C_{a1}) and the other 11 seconds after the start of the infusion (C_{a2}). Since the concentration of the infusion solution is known (C_i) access flow can be calculated using the formula $Q_a=Q_i \cdot (C_i - C_{a2})/(C_{a2} - C_{a1})$

For all surveillance techniques, trend analysis is more useful than any single measurement. Trend analysis requires a computerized database for data storage and presentation of the individual patient data. The VAPR measurements in *Figure 1a* and *Figure 1b* demonstrate the advantage of having surveillance measurements from each dialysis treatment; it is very easy to determine the trend in the patient's data.

Perspective

Prevention of access dysfunction by maintaining adequate flow is the chief means of assuring delivery of the 'prescribed dialysis dose.' The basic tenet of vascular access monitoring and surveillance is that stenosis develops over variable intervals in the great majority of permanent accesses and, if detected and corrected, maturation of the access can be promoted, under-dialysis minimized or avoided, and thrombosis avoided or reduced. The usefulness of flow or pressure surveillance critically depends on the accuracy of the measurements themselves so that accurate confirmation of hemodynamic dysfunction is proven prior to correction of the stenosis. Unfortunately, both access flow and pressure vary in patients during and more importantly between dialysis sessions, hence the need for repeated measurements and trend analysis. The authors believe that prevention of thrombosis without prolongation of overall longevity is a worthy outcome. Improvement in survival can come only from better treatments of the lesions found. Pharmacological, cellular, and molecular engineering approaches are needed for preventing or producing regression of the lesion of neointimal hyperplasia.

Conclusions

The body of evidence suggests that detection of stenosis and prevention of thrombosis in permanent arteriovenous (AV) fistulae and grafts is valuable. When a test indicates the likely presence of a functionally significant stenosis, venography or fistulography should be used to definitively establish the presence and degree of the stenosis. Currently, there is agreement with the Society of Cardiovascular and Interventional Radiology (SCVIR) recommendations that in most cases angioplasty should be performed if the stenosis is greater than 50% by diameter. However, there have been no large-scale trials to determine whether correction only of 'hemodynamically' significant lesions (those associated with 'low' access flows or 'high' pressures or a change in access flow or pressure) is superior to correction of all stenosis greater than 50%.

> When a test indicates the likely presence of a functionally significant stenosis, venography or fistulography should be used to definitively establish the presence and degree of the stenosis.

Until such studies are conducted, the value of routine use of any technique for detecting anatomic stenosis alone without concomitant measurement of access flow, venous pressure, recirculation, or other physiologic parameter has not been established. Stenotic lesions should not be repaired merely because they are present. If such correction is performed, then intra-procedural studies of Q_A or intra-access pressure prior to and following percutaneous transluminal angioplasty (PTA) should be conducted to demonstrate a functional improvement with a 'successful' PTA. ■

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