Optimizing Function and Treatment of Hemodialysis Grafts and Fistulae

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ABSTRACT

We are entering a new era for the management of hemodialysis grafts and fistulae. The hallmark of this new era will be the use of quantitative, hemodynamic parameters to optimize vascular access function and improve the results of our endovascular interventions. The implementation of vascular access surveillance programs has not only decreased the incidence of vascular access thrombosis, but also has provided new insights into the hemodynamic performance of grafts and fistulae. The measurement and analysis of intra-access blood flow has proven useful for the early detection of developing stenosis, and also provides a quantitative method to assess the results of our endovascular interventions. In the future, the use of quantitative hemodynamic measurements will play an increasingly important role in our evaluation and treatment of hemodialysis grafts and fistulae.

KEYWORDS: Hemodialysis, vascular access, blood flow, angioplasty

Objectives: Upon completion of this article, the reader should be able to (1) outline the importance of a vascular access surveillance program, (2) describe the different parameters that are used to determine the success of vascular access-related interventions, and (3) identify the blood flow values that are associated with normal and abnormal hemodialysis grafts and fistulae.

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Numerous scientific studies have demonstrated that periodic assessment of vascular access function can provide early detection of developing stenoses.¹⁻⁴ Early detection combined with early treatment of hemodynamically significant stenoses can reduce the incidence of thrombosis.⁵⁻⁸ This is the premise of vascular access surveillance. Implementation of a vascular access surveillance program is the single most effective strategy for optimizing the performance and longevity of hemodialysis grafts and fistulae. Vascular access surveillance is performed in the hemodialysis treatment center while the patient is connected to the hemodialysis machine.

However, because this is a covert activity, the majority of radiologists remain unaware of this critically important task.

Quantitative measurements of intra-access blood pressure or intra-access blood flow have proven to be sensitive predictors of impending thrombosis and are commonly used as surveillance methods.^{4,7,9-11} The measurement and analysis of intra-access blood flow has provided new insights into the hemodynamic performance of vascular access conduits. As interventionalists we have focused our attention on the graft (or fistula) and the native outflow veins, the most frequent sites for

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obstructing stenoses. But we have neglected the other important components of the vascular access circuit—the cardiac pump and the native arteries that provide blood flow to the vascular access. Recent studies have revealed that these components can be critical determinants of vascular access function.^{12,13} Therefore, we must consider the entire vascular access circuit in our evaluation and treatment of the dysfunctional hemodialysis graft or fistula.

The recent availability of catheter-based technology to measure intra-access blood flow provides a simple and useful method to assess the function of the entire vascular access circuit. The ability to measure blood flow during endovascular procedures also provides a quantifiable method to determine the success of our interventions. Continued clinical research may prove that these intraprocedural measurements of blood flow are predictive of the long-term patency following our treatment procedures. Quantitative measurements of hemodynamic performance are ideal parameters for evidence-based practice and might become the gold standard for assessing the outcomes of our endovascular interventions.

Quantification of vascular access function has many applications and benefits. This article will review the concepts and research supporting the importance and usefulness of this new method to evaluate a vascular access. This article will also attempt to elucidate the complex issues surrounding our determination of the success of vascular access-related interventions.

VASCULAR ACCESS SURVEILLANCE

The long-term patency that can be expected following angioplasty of a dysfunctional, but patent hemodialysis graft is considerably better than the results obtained following treatment of a thrombosed graft. The expected 6- and 12-month primary patency rates following angioplasty of a patent hemodialysis graft are ~60 and 40%, respectively.¹⁴ However, following an endovascular thrombectomy and angioplasty procedure the expected 3-month primary patency rate is only 40%.¹⁴

With this information in mind, the best approach to prolong patency is to identify and repair the dysfunctional vascular access before thrombosis occurs. The fundamental tenet of vascular access surveillance is that routine, periodic monitoring of grafts and fistulae will lead to the early detection of developing venous stenoses. Early detection combined with expeditious treatment of hemodynamically significant lesions will decrease the incidence of vascular access thrombosis. Decreasing the incidence of thrombosis will thereby prolong the patency of the vascular access.

Unfortunately, because of the cost of surveillance and the lack of reimbursement for these programs, the majority of hemodialysis units in the United States

have not yet implemented vascular access surveillance programs.

According to the recommendations of the National Kidney Foundation's Kidney Disease Outcomes Quality Initiative (K/DOQI) guidelines, hemodialysis grafts and fistulae should be monitored routinely with weekly physical examinations and undergo monthly surveillance using a quantitative assessment of vascular access function.¹⁴ A variety of different surveillance methods have been used, including measurements of venous pressure, recirculation, dialysis efficiency (Kt/V), and intra-access blood flow. However, as stated in the K/DOQI guidelines, monthly measurement of static venous pressure or intra-access blood flow are the two most useful methods for the detection of developing stenoses.¹⁴

Venous Pressure Measurements

In a landmark series of clinical investigations and ensuing publications, the team of Sullivan and Besarab^{15–17} described the hemodynamic relationship between the location and severity of a stenosis, and the change in pressure within a hemodialysis graft. As the severity of an outflow stenosis increases, the pressure within the graft will increase. This relationship is the basis for the use of static venous pressure measurements as a vascular access surveillance method. The standardized technique for performing static venous pressure measurements is described in detail in the K/DOQI guidelines.¹⁴ Of note, this surveillance method has not been validated in native arteriovenous fistulae.

A static venous pressure is a meticulous measurement of intragraft pressure when the blood pump in the hemodialysis machine is turned off. It is important to understand that intragraft pressure is variable and directly related to the patient's systemic blood pressure. To correct for this variability in blood pressure, the intragraft venous pressure is refined by normalizing the value to the patient's blood pressure. The normalized pressure ratio is determined by dividing the static venous pressure (VP0) by the patient's mean arterial pressure (MAP).

Within a normal, stenosis-free hemodialysis graft there is a substantial loss of blood pressure between the brachial artery and the venous anastomosis.¹⁷ The decrease in arterial pressure is immediate; the blood pressure within the brachial artery is reduced by 40% across the arterial anastomosis. The arterial inflow pressure is progressively reduced an additional 20% from the arterial anastomosis to the venous anastomosis. This loss of energy occurs in the absence of any anatomic lesion and is thought to be due to compliance mismatch and tissue vibration induced by turbulent blood flow. The normalized pressure ratio will vary according to the specific location from which the measurement is

obtained. As reported by Sullivan and Besarab,¹⁷ when measured in the arterial limb of a graft, a normalized pressure ratio >0.50 represents a significant stenosis. When the intragraft pressure is measured in the venous limb, a normalized pressure ratio >0.33 is considered abnormal.

Static venous pressure measurements are obtained in the hemodialysis treatment center when the patient is connected to the hemodialysis machine. It is important to understand that an intragraft pressure measurement reflects the vascular resistance that is downstream from the venous needle, the usual measurement point. Given that the majority of stenoses are located at the venous anastomosis or within the native veins, this method is effective in assessing the hemodynamic significance of these lesions. However, stenoses that are located proximal to measurement point, such as native arterial stenoses or midgraft stenoses, will often go undetected using this method. Furthermore, normalized pressure ratios are not useful for the assessment of multiple stenoses that are located in series along the vascular access circuit.

Intra-Access Blood Flow Measurements

Several clinical studies have demonstrated that the arterial inflow resistance, not the venous outflow resistance, is the most significant component of total graft resistance.^{17–19} Given that the arterial inflow component is not assessed using static venous pressure measurements, a more useful surveillance method would be one that reflects the total resistance of the entire vascular access circuit. Comparative studies of different surveillance methods have shown that periodic measurement of intra-access blood flow is the most sensitive and specific method for the detection of access-related stenoses.^{4,7,9,10}

There are several noninvasive techniques for measuring intra-access blood flow, including Doppler ultrasound, ultrasound dilution, hematocrit dilution, thermal dilution, and differential conductivity. The majority of these techniques are based upon the Fick principle in which blood flow is calculated by injecting a known indicator substance and measuring its concentration downstream with the addition of a time factor. Doppler ultrasound also can be used to measure the velocity of blood flow through a vascular access. If the cross-sectional diameter is known, the rate of blood flow can be calculated. However, there can be inaccuracies due to operator error, turbulent blood flow, and variability in the cross-sectional diameter of the vascular access, which interferes with the reliability of this measurement method.²⁰

The most widely used technique to measure blood flow in hemodialysis grafts and fistulae is the ultrasound dilution method using the Transonic HD01 system

(Transonic, Inc., Ithaca, NY). Using this system, the measurement of intra-access blood flow is performed while the patient is connected to the hemodialysis machine. The measurements are typically obtained during the first hour of a hemodialysis treatment so that the blood flow values are minimally affected by the decrease in cardiac output that often occurs during prolonged hemodialysis treatment. To perform the blood flow measurement the hemodialysis machine is stopped and the arterial and venous blood lines are reversed from their normal position. Photometric flow sensors, which are connected to an electronic flow meter, are clipped onto the reversed arterial and venous blood lines. The hemodialysis blood pump is restarted at a fixed blood flow, usually 200 mL/min, and a saline bolus (5 mL) is injected into the reversed venous blood line. The saline mixes with the blood flowing through the access and is detected by the sensor on the arterial line. The data are collected in a laptop computer and blood flow values are automatically calculated and recorded. Two blood flow measurements are typically obtained. If the values differ by more than 10%, a third measurement should be performed.

In a clinical validation study using the ultrasound dilution technique, the error of duplicate measurements in the same patient was $5.0 \pm 3.8\%$.²¹

Blood Flow in Hemodialysis Grafts and Fistulae

The routine measurement of intra-access blood flow has provided new insights into the hemodynamics of vascular access. Intra-access blood flow is significantly higher than many of us would have imagined.

Prior to the creation of a vascular access the blood flow in the brachial artery is ~ 50 to 150 mL/min.^{22,23} This dramatically increases to 800 to 2000 mL/min following placement of a vascular access. In a well-functioning forearm loop graft, with a brachial artery anastomosis, the blood flow should exceed 1000 mL/min. In a forearm straight graft, with a radial artery anastomosis, the average blood flow should exceed 800 mL/min. Blood flow in a polytetrafluoroethylene (PTFE) hemodialysis graft is maximal within 2 to 4 weeks after construction and will then variably decrease over time because of the progressive development of stenoses.^{24,25} Blood flow in a native fistula will increase over the first 3 to 6 months after construction. Although there is substantial variability, the typical blood flow through a mature fistula is 700 to 900 mL/min.

A baseline measurement of intra-access blood flow should be obtained and recorded when the access is first used for hemodialysis. This baseline value represents the patient's "normal" blood flow and will be used to determine the success of future endovascular interventions. As recommended by the K/DOQI guidelines,

hemodialysis patients should undergo an intra-access blood flow measurement once a month.¹⁴ Both the magnitude and the rate of decrease in blood flow over time are predictive of impending thrombosis. However, trend analysis of sequential blood flow values is more predictive of thrombosis than is a single blood flow measurement.⁶

As also recommended by the K/DOQI guidelines, a patient should be referred for a diagnostic fistulogram if the intra-access flow is less than 600 mL/min or if the blood flow is less than 1000 mL/min and has decreased by more than 25% over a 4-month period.¹⁴ However, it may be prudent to modify this recommendation for certain patients. This would include patients who have a baseline blood flow that is lower than normal or for patients who have undergone multiple interventions and have persistent, untreatable problems.

Benefits of a Surveillance Program

There are several important benefits of a vascular access surveillance program. A poorly functioning access decreases the efficiency of hemodialysis treatment and thereby adversely affects the patient's quality of life. Early detection and pre-emptive treatment of developing stenoses can improve the hemodynamic performance of the vascular access and optimize the efficiency of hemodialysis treatment.

Another important benefit of a surveillance program is a reduction in the total cost of maintaining the vascular access. Although frequent angioplasty often is necessary to maintain patency, the cost of an angioplasty is less than the cost of a thrombectomy procedure. Preservation of vascular access patency leads to substantial savings by reducing the cost of hospitalization, decreasing the need for temporary hemodialysis catheters, and decreasing the number of missed hemodialysis treatments. A recent study demonstrated a 48% reduction in the annual cost of vascular access services as a result of a surveillance program.²⁶

Numerous clinical studies have demonstrated that early detection and treatment of significant stenoses can prevent thrombosis. The decrease in the vascular access thrombosis rate can be dramatic. McCarley et al²⁶ reported a decrease in the incidence of graft thrombosis from 0.71 per patient per year to 0.16 per patient per year following the implementation of a graft surveillance program. Besarab et al¹⁶ reported a similar decrease in the graft thrombosis rate from 0.58 to 0.19 thromboses per patient per year. Surveillance also works for arteriovenous fistulae; Schwab et al²⁷ reported a decrease in the fistula thrombosis rate, from 0.16 to 0.07 per patient per year, using intra-access blood flow monitoring.

Several studies have reported that the prevention of graft thrombosis will increase the overall lifespan of the vascular access.^{16,28-30} Besarab et al¹⁶ reported an

increase in average graft age from 1.97 to 2.98 years following the implementation of a vascular access surveillance program. However, more recent studies do not substantiate this improvement in access longevity. Although early detection and treatment of stenoses can decrease the incidence of thrombosis, there may be no improvement in the long-term survival of the vascular access.³¹⁻³³ It also has been suggested that preemptive angioplasty might adversely affect survival of the vascular access. A stable stenosis might be stimulated by early angioplasty, thereby leading to rapid and more severe restenosis.³²

In summary, the implementation of a vascular access surveillance program can decrease the incidence of thrombosis and thereby minimize the complications that result from vascular access occlusion. The nephrologist and the other members of the hemodialysis treatment center have a critical responsibility for maintaining an effective graft surveillance program. To optimize vascular access function it is imperative that our nephrology colleagues routinely monitor vascular access function and refer appropriate patients for endovascular treatment before thrombosis occurs.

QUANTIFICATION OF VASCULAR ACCESS FUNCTION

Determining the End point of Endovascular Interventions

The Society of Interventional Radiology Standards of Practice Committee has defined a variety of different end points for vascular access-related interventions.^{34,35} Many of these end points are also incorporated into the National Kidney Foundation's K/DOQI Clinical Practice Guidelines for Vascular Access.¹⁴ Furthermore, a multidisciplinary consensus document on this topic was published recently and included contributors from the Society of Interventional Radiology and the Society of Vascular Surgery.³⁶

An end point is used to define the successful completion of a procedure. However, the definition of a successful procedure can be viewed from several different perspectives. For example, the end point for clinical success is alleviation of the patient's symptoms. Hemodynamic success is restoration of normal blood pressure throughout the treated vascular segment. For the treatment of stenoses, the end point for anatomic success is less than 30% residual diameter reduction. These clinical, hemodynamic, and anatomic end points serve as the determinants of a success endovascular intervention.

However, our clinical experience has demonstrated that these commonly used end points are unreliable for predicting the long-term patency of a hemodialysis graft or fistula. Although we use end points

to define immediate success, there is no postprocedural end point that correlates with long-term patency. Our inability to predict the long-term outcome of our endovascular procedures continues to frustrate both the physician and patient.

As mentioned above, the Standards of Practice documents define end points, and the methods to measure those end points, which should be used to determine the success of our interventions. However, there are multiple factors that might confound our ability to use these standardized end points accurately and uniformly and thereby predict the outcomes of our procedures. A discussion of each specific end point might be useful to understand better the factors that affect our ability to quantify accurately the results of our interventions.

Anatomic Success

The determination of anatomic success is based on the measurement of the degree of residual stenosis following an endovascular intervention.³⁵ Although this may seem simple, the methods by which these measurements are performed are fraught with problems.

Angiographic measurements can be made using film-screen angiography or digital subtraction angiography. The degree of stenosis can be measured by hand directly on the radiographic film, with or without the aid of an external ruler, or using the calibrated software in the digital imaging system. However, stenoses can be eccentric and the angiographic assessment of a lesion is often dependent on which orthogonal views have been obtained, and which image is selected for measuring the degree of stenosis.

The SIR Standards of Practice document states that when measuring the degree of stenosis, the reference vessel should be a "normal" segment of vessel that is upstream from the lesion.³⁵ However, it can be difficult to select a normal reference vessel because the upstream vessel might be irregular or aneurysmal. Furthermore, many practicing interventionalists do not actually measure the treated lesion after an intervention; they simply estimate the degree of stenosis. There can be significant intra- and interobserver variability when using a simple visual estimate of the degree of stenosis.

It is well accepted that a stenosis causing > 50% diameter reduction is considered to be a hemodynamically significant lesion. This value is based on the physiology of a "critical arterial stenosis"³⁷. A 50% reduction in luminal diameter corresponds to a 75% reduction in cross-sectional area, the critical point at which blood flow begins to decrease dramatically. Following an endovascular intervention the standard definition of anatomic success is a residual stenosis with less than 30% diameter reduction. Although there are well-recognized, physiological concepts that support the use of a 50%

stenosis as the definition of a hemodynamically significant lesion, there is no such scientific basis for the use of < 30% residual stenosis to define a successful treatment. In fact, this value of 30% was reached by a consensus committee with representatives from interventional radiology and vascular surgery. Despite my best efforts, I have been unable to determine an explanation for the choice of this 30% value. This well-accepted, standard end point (< 30% residual stenosis) has no hemodynamic or physiologic meaning. Therefore, it is not surprising that the use of this parameter as a determinant of success is not predictive of the long-term patency of a hemodialysis graft or fistula. This poor correlation between the degree of residual stenosis and subsequent patency was substantiated by Clark et al,³⁸ who reported their analysis of 96 interventions performed in native arteriovenous fistulae. Following angioplasty, 24 lesions had > 30% residual stenosis and by definition had failed treatment. However, there was no difference in the long-term patency of this group when compared with patients with lesions having < 30% residual stenosis on final fistulography.

The use of < 30% residual stenosis as a criterion to determine the success of an endovascular intervention has no physiologic basis. Several recent studies have demonstrated that radiologic (anatomic) criteria, such as the degree of stenosis and the percent change in stenosis, do not correlate with intra-access blood flow measurements.^{39–41} The eccentricity of stenoses, the multiplicity of stenoses in an individual patient, and the effect of untreated lesions (> 30% stenosis), all are likely factors that are responsible for our inability to directly correlate the intragraft blood flow values with the characteristics of a stenosis.

What should be done with lesions that are > 30% stenosis but < 50% stenosis? According to the K/DOQI guidelines and the SIR standards, these lesions should not be treated. However, it is likely that these lesions do have a hemodynamic effect on blood flow through a hemodialysis graft and therefore these lesions might be appropriate for treatment. The assessment of intragraft blood flow during angioplasty procedures might provide additional information regarding the hemodynamic importance of lesions that are > 30% but < 50% stenosis.

Another related and interesting topic is the determination of technical success for our endovascular interventions. Should technical success be based on anatomic criteria, the measurement of which is both subjective and fraught with error? Or should it be based on the restoration of normal intragraft blood flow, a hemodynamic parameter that is less subjective and more reflective of vascular access performance? This is an interesting subject that will become more important as the use of blood flow measurements becomes more widespread. It is hoped that continued clinical

investigation will provide scientific support for the use of hemodynamic end points, not anatomic end points.

Hemodynamic Success

The K/DOQI guidelines describe several techniques that can be used to assess the hemodynamic performance of a hemodialysis graft or fistulae.¹⁴ However, the majority of these techniques are performed while the patient is connected to the hemodialysis machine. This section discusses three techniques that can be performed in the angiography suite to assess the hemodynamic success of endovascular interventions. These include (1) transstenotic pressure measurements, (2) physical examination, and (3) intra-access blood flow.

TRANSSTENOTIC PRESSURE MEASUREMENTS

Transstenotic pressure measurements, more commonly called pullback pressure measurements, are often used to determine the success of endovascular procedures. Although pullback pressure measurements are a well-accepted technique for evaluating arterial stenoses, this technique has not been fully validated for the assessment of stenoses in hemodialysis grafts and fistulae. Importantly, the specific value of a transstenotic pressure gradient that characterizes a hemodynamically significant stenosis has not been defined. In an excellent clinical investigation of this technique, Funaki et al⁴² used a mean gradient of 10 mm Hg to define a significant stenosis and a successful treatment was defined as having < 3 mm Hg residual pressure gradient. Alternatively, Turmel-Rodrigues⁴³ suggests assessing stenoses based on the percentage of pressure change across the lesion. He defines a significant stenosis as causing a > 50% reduction in systolic pressure. Of note, Turmel-Rodrigues used systolic pressure values for calculating pressure gradients.

Following successful angioplasty (< 30% residual stenosis), Funaki et al⁴² measured pullback pressure gradients across 50 graft-related stenoses and found a > 10 mm Hg mean gradient in nine patients. After repeating the angioplasty procedure with a larger diameter balloon in these nine patients, the pressure gradient was reduced to < 3 mm Hg in six patients and was 5 mm Hg in three patients. The average patency for the six patients with a final pressure gradient < 3 mm Hg was 317 days, and 58 days for the three patients with a 5-mm Hg residual pressure gradient. Although this is a small study group, the results of Funaki et al suggest that pullback pressure measurements provide a quantifiable method to assess the success, and potentially predict the outcome, of an endovascular intervention.

However, the primary use of pullback pressure measurements is to assess focal stenoses, both before and after treatment. Importantly, the measurement of a transstenotic pressure gradient provides little insight

into the overall hemodynamic status of the vascular access. As previously described, the graft (or fistula) is only one segment of a larger vascular access circuit. As will be described, other methods can provide a more global assessment of the entire circuit.

PHYSICAL EXAMINATION

Several investigators have reported that a well-performed physical examination also can provide an accurate hemodynamic assessment of a hemodialysis graft or fistula.⁴⁴⁻⁴⁶ A recent study by Trerotola et al⁴⁶ reported that a physical examination of a hemodialysis graft was a more accurate predictor of long-term patency when compared with intra-access venous pressure measurements. These investigators reported that the presence of a thrill at the venous anastomosis can be used as an end point for a successful intervention and is predictive of long-term patency. Although an accurate physical examination requires an experienced examiner, this technique is underused and represents a valuable and inexpensive method that can be used to evaluate the success of endovascular interventions.

INTRA-ACCESS BLOOD FLOW

During the last 5 years, the measurement of intra-access blood flow has been recognized as a useful parameter to evaluate vascular access function. Measurement of intragraft blood flow also has provided a new method to assess the effectiveness of endovascular or surgical interventions.

Many hemodialysis treatment centers are routinely measuring intra-access blood flow as a vascular surveillance technique. Patients with low (< 600 mL/min) blood flow are referred to radiology for evaluation of the vascular access circuit. A diagnostic fistulogram is performed, stenoses are treated, and the patient returns to the hemodialysis treatment center. However, the effectiveness of the angioplasty procedure (the improvement in intragraft blood flow) is not known until follow-up blood flow measurements are obtained. This is often several days following the angioplasty procedure. Although the treated lesion can be assessed using radiologic (anatomic) criteria or transstenotic pressure measurements, the inability to determine the functional improvement, as measured by intragraft blood flow, at the time of the angioplasty procedure has proven to be problematic. For this reason a catheter-based system was developed to obtain measurements of intra-access blood flow during endovascular procedures.⁴⁷

The AngioFlow system (Angiodynamics, Queensbury, NY) consists of a digital flow meter and a single-use, 6-French endovascular catheter. The catheter has an external injection port connected to a central lumen that allows injection of saline. The injected saline exits the catheter through two radial side holes located 6 cm proximal to the rounded distal tip. The catheter

contains two temperature sensors (thermistors). One thermistor is located 1.5 cm from the distal tip of the catheter and is used to determine the thermodilution. The second thermistor is located in the proximal portion of the catheter, away from the blood stream, and is used to measure the temperature of the injected saline. The distal aspect of the catheter is curved to prevent contact between the distal thermistor and graft wall. The catheter is connected to the digital flow meter using a reusable extension cable (Fig. 1). The AngioFlow catheter is inserted into the graft or fistula and 10 mL of saline is rapidly injected through a side port in the catheter. The blood flow is measured and the digital readout appears on the flow meter. Using this system the blood flow in the vascular access can be accurately measured at any time during an endovascular procedure. For example, the postangioplasty blood flow value can be compared with the preangioplasty value to determine the improvement in blood flow and to establish a new baseline. Documentation of the new baseline blood flow value is beneficial as a comparison for future graft surveillance assessments.

Intra-access blood flow is variable and dependent on several factors, including the type and location of the access and the patient's blood pressure. Several investigators have demonstrated that there can be substantial variability in intra-access blood flow from one hemodialysis treatment to the next.^{48,49} This variability has been attributed to acute changes in intravascular fluid volume and blood pressure. There is no normal value for intra-access blood flow. For each patient the best estimate of normal blood flow is the baseline value that was measured when the access was first used. All blood flow

measurements should be compared with previous values that were obtained from that specific patient.

Successful treatment of a stenosis should return the intra-access blood flow to baseline level. Ahya et al³⁹ compared the postangioplasty blood flow value with the highest blood flow value ever measured in the graft and demonstrated that a successful intervention can return the blood flow to baseline. Interestingly, multiple investigators have compared the preangioplasty blood flow to the postangioplasty blood flow and reported that the average increase in blood flow is ~ 300 mL/min.^{30,39,40,47,50} It is surprising that numerous investigators have reported nearly identical changes in blood flow following endovascular interventions.

Clinical studies have also reported that 20 to 30% of patients continue to have persistently low (< 600 mL/min) blood flow following angioplasty.^{7,33,39} Persistently low blood flow following an apparently successful intervention may be due to (1) inconspicuous lesions that were not identified, (2) delayed elastic recoil of a treated stenosis, (3) unidentified arterial inflow stenoses, or (4) poor cardiac output. Even if the blood flow returns to normal, the duration of improved blood flow may be short lived. Spergel et al⁵¹ reported a mean duration of less than 30 days for maintaining blood flow > 600 mL/min following angioplasty. However, Smits et al⁷ reported that improved intra-access blood flow was sustained for 2.5 months following angioplasty.

Assessment of intragraft blood flow has provided evidence for a higher than expected incidence of arterial problems. A thorough evaluation of patients with persistently low blood flow might reveal significant arterial

Figure 1 Intraprocedural measurement of intra-access blood flow is performed using an AngioFlow catheter (arrow) connected to the digital flow meter (arrowhead).

pathology, primarily atherosclerotic stenoses within the proximal inflow arteries.⁵² With the growing numbers of elderly and diabetic hemodialysis patients, the presence of arterial stenoses is not surprising. As mentioned previously, the hemodynamics of the inflow arteries are substantially altered by the placement of the vascular access. Arterial stenoses that had been of little hemodynamic significance can become a substantial impediment to optimal blood flow following placement of a vascular access.

CONCLUSION

The implementation of a vascular access surveillance program is the single most effective strategy for optimizing the function and longevity of hemodialysis grafts and fistula. The increasing use of quantitative hemodynamic parameters can provide early detection of developing stenoses and also can provide an improved method to assess the results of our endovascular interventions. Continued clinical research might demonstrate that these hemodynamic measurements can be used to optimize vascular access function and thereby improve the longevity of hemodialysis grafts and fistulae.

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