

## **GUIDELINE 4. DETECTION OF ACCESS DYSFUNCTION: MONITORING, SURVEILLANCE, AND DIAGNOSTIC TESTING**

Prospective surveillance of fistulae and grafts for hemodynamically significant stenosis, when combined with correction of the anatomic stenosis, may improve patency rates and may decrease the incidence of thrombosis.

The Work Group recommends an organized monitoring/surveillance approach with regular assessment of clinical parameters of the AV access and HD adequacy. Data from the clinical assessment and HD adequacy measurements should be collected and maintained for each patient's access and made available to all staff. The data should be tabulated and tracked within each HD center as part of a Quality Assurance (QA)/CQI program.

### **4.1 Physical examination (monitoring):**

Physical examination should be used to detect dysfunction in fistulae and grafts at least monthly by a qualified individual. (B)

### **4.2 Surveillance of grafts:**

Techniques, not mutually exclusive, that may be used in surveillance for stenosis in grafts include:

#### **4.2.1 Preferred:**

**4.2.1.1** Intra-access flow by using 1 of several methods that are outlined in [Table 7](#) using sequential measurements with trend analysis. (A)

**4.2.1.2** Directly measured or derived static venous dialysis pressure by 1 of several methods. (A) (Protocol provided in [Table 8](#) for using transducers on HD machines to measure directly; criteria in [Table 9](#) for derived methods.)

**4.2.1.3** Duplex ultrasound. (A)

#### **4.2.2 Acceptable:**

**4.2.2.1** Physical findings of persistent swelling of the arm, presence of collateral veins,

prolonged bleeding after needle withdrawal, or altered characteristics of pulse or thrill in a graft. (B)

#### **4.2.3 Unacceptable:**

**4.2.3.1** Unstandardized dynamic venous pressures (DVPs) should not be used. (A)

### **4.3 Surveillance in fistulae:**

Techniques, not mutually exclusive, that may be used in surveillance for stenosis in AVFs include:

#### **4.3.1 Preferred:**

**4.3.1.1** Direct flow measurements. (A)

**4.3.1.2** Physical findings of persistent swelling of the arm, presence of collateral veins, prolonged bleeding after needle withdrawal, or altered characteristics of pulse or thrill in the outflow vein. (B)

**4.3.1.3** Duplex ultrasound. (A)

#### **4.3.2 Acceptable:**

**4.3.2.1** Recirculation using a non-urea-based dilutional method. (B)

**4.3.2.2** Static pressures (B), direct or derived. (B)

### **4.4 When to refer for evaluation (diagnosis) and treatment:**

**4.4.1** One should not respond to a single isolated abnormal value. With all techniques, prospective trend analysis of the test parameter has greater power to detect dysfunction than isolated values alone. (A)

**4.4.2** Persistent abnormalities in any of the monitoring or surveillance parameters should prompt referral for access imaging. (A)

**4.4.3** An access flow rate less than 600 mL/min in grafts and less than 400 to 500 mL/min in fistulae. (A)

**4.4.4** A venous segment static pressure (mean pressures) ratio greater than 0.5 in grafts or fistulae. (A)

**Table 7. Flow Methods in Dialysis Access**

Duplex Doppler Ultrasound (Quantitative color velocity imaging): [DDU]
Magnetic Resonance Angiography: [MRA]
Variable Flow Doppler Ultrasound (Specs USA): [VFDU]
Ultrasound dilution (Transonics): [UDT]
Crit-Line III (optodilution by ultrafiltration; HemaMetrics): [OABF]
CritLine III direct transcutaneous (HemaMetrics): [TQA]
Glucose pump infusion technique [GPT]
Urea dilution [UreaD]
Differential Conductivity (GAMBRO): [HDM]
In Line Dialysance (Fresenius): [DD]

#### 4.4.5 An arterial segment static pressure ratio greater than 0.75 in grafts. (A)

##### RATIONALE

###### Definitions

The following terms will apply to HD vascular access

*Monitoring*—the examination and evaluation of the vascular access by means of physical examination to detect physical signs that suggest the presence of dysfunction.

*Surveillance*—the periodic evaluation of the vascular access by using tests that may involve special instrumentation and for which an abnormal test result suggests the presence of dysfunction.

*Diagnostic testing*—specialized testing that is prompted by some abnormality or other medical indication and that is undertaken to diagnose the cause of the vascular access dysfunction.

###### Purpose of Access Surveillance

Vascular access function and patency are essential for optimal management of HD patients. Low BFRs and loss of patency limit HD delivery, extend treatment times, and, in too many cases, result in underdialysis that leads to increased morbidity and mortality.<sup>248</sup> Between 1991 and 2001, the incidence of vascular access events in patients undergoing HD increased by 22%.<sup>249</sup> In long-term AV accesses, especially grafts, thrombosis is the leading cause of loss of vascular access patency. Thrombosis increases health care spending<sup>7,250</sup> and adversely affects QOL,<sup>162,250-253</sup> and vascular access-related complications account for 15% to 20% of hospitaliza-

tions among patients with CKD stage 5 undergoing HD.<sup>7,12,252</sup> Prevention of access dysfunction by maintaining adequate flow and preventing thrombosis translates into a policy of “Dialysis Dose Protection.” (See the KDOQI HD Adequacy Guidelines.) It is not feasible for any one individual to manage all aspects of access care. Multidisciplinary teams should be formed at each HD center,<sup>254-256</sup> with a VAT coordinator, if possible. Whatever the team’s size and composition, its most important function is to work proactively to ensure the patient is receiving an adequate dialysis dose by maintaining access function and patency.

*The basic tenet for vascular access monitoring and surveillance is that stenoses develop over variable intervals in the great majority of vascular accesses and, if detected and corrected, underdialysis can be minimized or avoided (dialysis dose protection) and the rate of thrombosis can be reduced.* Whether prospective monitoring and surveillance can prolong access survival currently is unproven. However, it fosters the ability to salvage vascular access sites through planning, coordination of effort, and elective corrective intervention, rather than urgent procedures or replacement.<sup>257</sup> A number of monitoring and surveillance methods are available: sequential access flow, sequential dynamic or static pressures, recirculation measurements, and physical examination.

Failure to detect access dysfunction has consequences on morbidity and mortality.<sup>248,249</sup> In a recent study of 721 randomly selected patients from all 22 long-term HD units in northeast Ohio, barriers found to significantly ( $P < 0.001$ ) and independently relate to inadequate dialysis dose delivery were patient noncompliance, low

**Table 8. Static Intra-Access Pressure (IAP) Surveillance**

a)	Establish a baseline when the access has matured and shortly after the access is first used. Trend analysis is more useful than any single measurement.
b)	Assure that the zero setting on the pressure transducers of the dialysis delivery system being used has been calibrated to be accurate within $\pm 5$ mm Hg.
c)	Measure the mean arterial blood pressure (MAP) in the arm contralateral to the access.
d)	Enter the appropriate output or display screen where venous and arterial pressures can be visualized (this varies for each dialysis delivery system). If a gauge is used to display pressures, the pressure can be read from the gauge.
e)	Stop the blood pump and cross clamp the venous line just proximal to the venous drip chamber with a hemostat (this avoids having to stop ultrafiltration for the brief period needed for the measurement). On the arterial line, no hemostat is needed since the occlusive roller pump serves as a clamp.
f)	Wait 30 seconds until the venous pressure is stable, then record the arterial and venous intra-access pressure (IAP) values. The arterial segment pressure can only be obtained if a pre-pump drip chamber is available and the dialysis system is capable of measuring absolute pressures greater than 40 mm Hg.
g)	Unclamp the venous return line and restore the blood pump to its previous value.
h)	Determine the height correction, $\Delta h$ between the access and the drip chamber(s) either by direct measurement (A) or using a formula (B) based on the difference in height between the top of the drip chamber and the top of the arm rest of the dialysis chair ( $\Delta$ ). Both measurements need to be in cm. Height corrections are not needed if the measurements in step 6 are done with access level with the drip chamber <ul style="list-style-type: none"> <li>▪ Measure the height from the venous or arterial needle to the top of the blood in the venous drip chamber. The offset in Hg = height (cm) <math>\times</math> 0.76</li> <li>▪ Use the formula, offset in mm Hg = <math>3.6 + 0.35 \times \Delta</math>.</li> </ul>
i)	The same correction values can be used for both if the 2 drip chambers are at the same height. If the drip chambers are not at equal heights, the arterial and venous height offsets must be determined individually. In a given patient with a given access the height offsets need to be measured only once and then used until the access location is altered by construction of a new access.
j)	Calculate the normalized arterial and venous segment static IAP ratio(s), $P_{IA}/MAP$ Arterial ratio = (arterial IAP + arterial height correction)/MAP Venous ratio = (venous IAP + venous height correction)/MAP

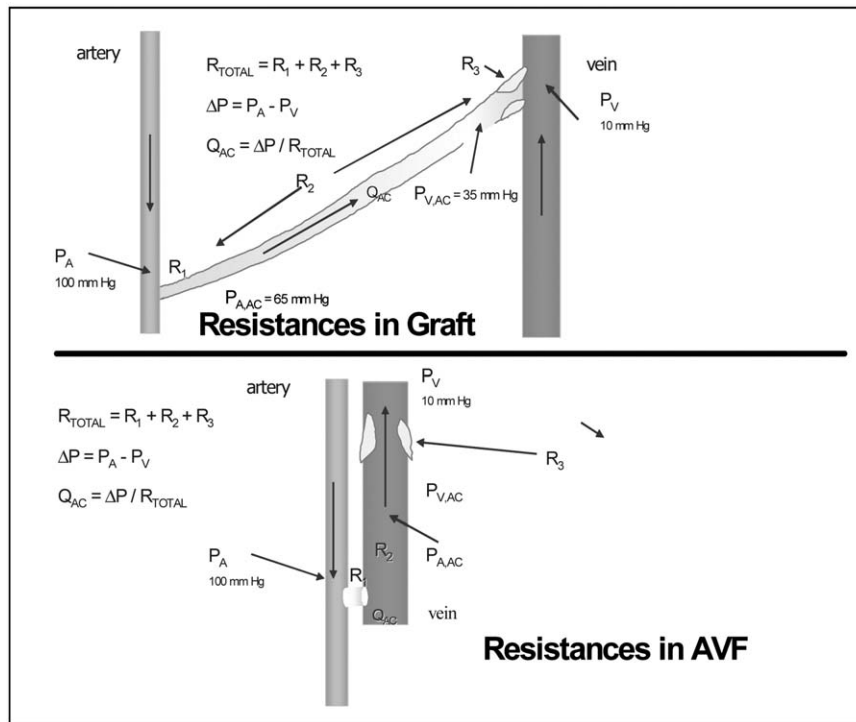
dialysis prescription, catheter use, and access thrombosis.<sup>253</sup> Every 0.1 decrease in  $Kt/V$  was independently and significantly ( $P < 0.05$ ) associated with 11% more hospitalizations, 12% more hospital days, and a \$940 increase in Medicare inpatient expenditures. Vascular access-related complications accounted for 24% of all hospital admissions.<sup>258</sup> The reader is referred to the KDOQI HD Adequacy Guidelines for additional

information on the importance of achieving the prescribed dialysis dose with regard to mortality.

Asymptomatic, but hemodynamically significant, stenoses usually are detected through a systematic monitoring and surveillance program. Detection of such stenoses is important to prevent progression to a functionally significant stenosis, currently defined as a decrease of greater than 50% of normal vessel diameter, accompa-

**Table 9. Criteria for Intervention**

Degree of Stenosis	Access Pressure Ratio					
	Graft			Fistula		
	Arterial Segment	Venous Segment		Arterial Segment	Venous Segment	
<50% of diameter	0.35-0.74			0.13-0.43		0.08-0.34
>50% of diameter						
Venous outlet	>0.75	or	>0.5	>0.43	or	>0.35
Intra-access	$\geq 0.65$	and	<0.5	>0.43	and	$\leq 0.35$
Arterial inflow	<0.3		Clinical findings	<0.13 + clinical findings		Clinical findings



**Fig 3. Pressure profiles in grafts (top) and fistulae (bottom).** Symbols: P, pressure;  $\Delta P$ , change in pressure; R, resistance;  $Q_{AC}$ , access flow; A, arterial; V, venous. Figure adapted from Sullivan K, Besarab A: *Strategies for maintaining dialysis access patency. Chapter 11. In Cope C (ed): Current Techniques in Interventional Radiology (ed 2). Philadelphia, PA, Current Medicine, 1995, pp 125-131.*

nied by hemodynamic or clinical abnormality, such as abnormal recirculation values, elevated venous pressures, decreased blood flow, swollen extremity, unexplained reduction in  $Kt/V$ , or elevated negative arterial prepump pressures, that prevent increasing to acceptable blood flow.<sup>259</sup> This definition evolves from an analysis of hemodynamics and clinical correlation.

### *Normal Hemodynamics*

Access flow and pressure are related in a permanent AV access through the relationship:

$$Q_A = \Delta P / R$$

The driving force for access flow,  $Q_A$ , is the pressure gradient,  $\Delta P$ , between the artery and central veins. This driving force tends to be the same for both fistulae and grafts. Within the constraints imposed by the arterial anastomotic site, the ultimate access flow in mature accesses tends to be similar in fistulae and grafts.<sup>260,261</sup> What differs is the rate of maturation. Grafts

reach their maximum flow rate in a matter of days to weeks, as opposed to fistulae, which may require weeks to months to mature.<sup>71,138,262-264</sup>

This difference in achieving maximum flow may explain the difference in the incidence of immediate steal between the 2 access types, with the fistulae permitting more time for adaptation to occur.

The pressure profile differs in the 2 access types. As shown in Fig 3, the pressure decrease profile in a graft progressively decreases along the length of the graft. At both anastomoses, there are pressure gradients, even in the absence of stenosis (illustrated as the luminal incursions). Within the body of the graft, there is a 20- to 30-mm  $\Delta P$  that is the effective driving force.<sup>265-267</sup>

Conversely, in a fistula, the preponderance of the arterial pressure is dissipated within the first few centimeters of the access; pressures in the "arterial segment" are only approximately 20% of those in the feeding artery.<sup>265-267</sup> Fig 4 shows the difference in profiles.

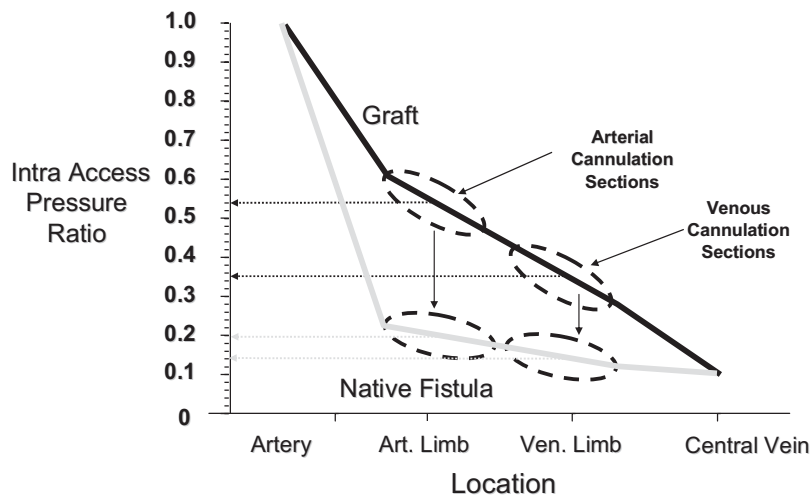


Fig 4. IAPs within normal grafts and fistulae. Reprinted with permission: Besarab A, Frinak S, Aslam M: Pressure measurements in the surveillance of vascular accesses. In Gray R (ed): *A Multidisciplinary Approach for Hemodialysis Access*. Philadelphia, PA, Lippincott Williams & Wilkins, 2002, Chapter 21, pp 137-150.

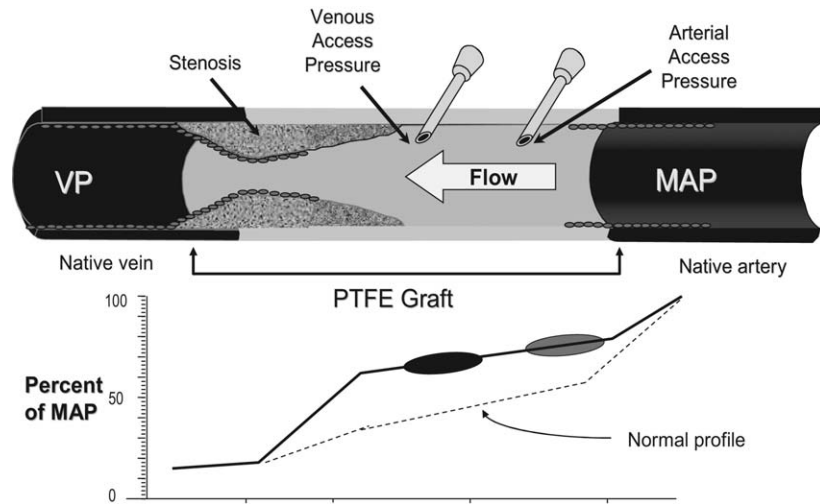
The IAP ratio refers to the actual pressure at the site of measurement divided by the mean arterial blood pressure (MAP). The effective  $\Delta P$  in the fistula generally is only 8 to 10 mm Hg, frequently 25%, and seldom more than half those noted in grafts. Despite these differences in pressure profiles, access flow in grafts and fistulae are approximately equal at 6 months<sup>267</sup> because the overall  $\Delta P$  is the same. However, fistulae—unlike grafts—have an intact endothelial lining that allows them to actively dilate and remodel over extended periods. As a result, progressive flow increases are limited only by cardiac factors. Fistulae also differ from grafts in having side branches that reduce resistance to flow (parallel circuits). However, multiple accessory veins can limit the development of the major superficial vein needed for cannulation (see CPGs 1 and 2). Ligation of accessories or spontaneous occlusion of side branches within a fistula results in an access that hemodynamically mimics the profile of a graft.

It is immediately apparent that 2 anatomic factors determine access function: (1) quality and (2) physical dimensions of the artery and vein. The major determinant of  $Q_A$  in a given patient will be determined by the capacity of the artery to dilate and its general “health.” In general, arteries at more distal sites have less capacity to deliver flow than more proximal sites, ie, radial < brachial < axillary < femoral. Arteries that are calcified or affected by atherosclerosis will result in lower flow accesses whether supplying a fistula or a graft. If the artery is healthy,

flow capacity will be determined by the characteristics of the vein used in access construction. Too small a vein will limit the flow in both a fistula and graft. Unfortunately, arterial disease is not uncommon; access inflow stenosis occurs in one third of the patients referred to interventional facilities with clinical evidence of venous stenosis or thrombosis.<sup>268</sup> This is much greater than has been traditionally reported.<sup>10,24,105,108,269</sup> Thus, it is very important to assess the access by using physical examination early after its construction. Because flow and pressure measurements are not performed routinely until the access is cannulated, initial assessment of the access depends on the physical examination, which can detect many problems in a fistula.

#### ***Effect of Stenosis on Hemodynamics: Access Flow, IAP, Access Recirculation, and Physical Examination***

In grafts, the majority of stenoses develop in the venous outflow, frequently right at or within several centimeters of the venous anastomosis.<sup>10,24,105,108</sup> Lesions within the graft also occur, and most accesses have more than 1 lesion at any 1 time.<sup>10,266,267,269</sup> The pathophysiological state of graft failure arises from neointimal hyperplasia. In a fistula, there may be ischemic effects, as well as injury resulting from recurrent cannulation and subsequent fibrosis. Stenoses in a fistula tend to occur at the surgical swing sites (including the arterial anastomosis) or the puncture zone of the vein. The outcome is the same in both fistulae and grafts: a reduction in access

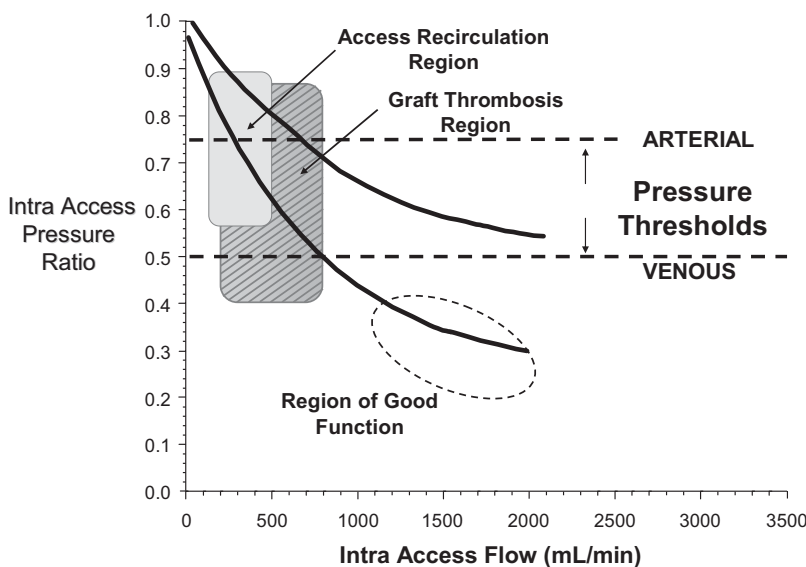


**Fig 5. Effect of venous outlet stenosis on pressure profile. Reproduced with permission from Medisystems Inc.**

flow rate. However, the effect on IAP differs according to access type and site of stenosis. As illustrated in Fig 5, an outlet stenosis in a graft will increase the pressure at all locations upstream from the stenosis. Conversely, an inflow lesion will decrease all pressures downstream of the stenosis. An intragraft stenosis between the needles will decrease flow while increasing pressure upstream and decreasing pressure downstream of the lesion.

In a fistula, pressure profiles depend on the location of the lesion and the presence or absence of collateral or accessory veins. Arterial inflow lesions that develop after acceptable maturation

are detected more easily by using  $Q_A$ , the inability to deliver blood flow to the dialyzer, reductions in adequacy, and recirculation measurements<sup>270,271</sup> than by IAP measurements. Intra-access pressure ( $P_{IA}$ ) with inflow lesions tends to remain unchanged or decrease as  $Q_A$  decreases over time.<sup>272</sup> An outflow lesion will produce a pressure profile similar to that seen in grafts; the magnitude of the pressure elevation is dictated by the number of venous tributaries. Not uncommonly, in upper-arm fistulae, there is spontaneous or deliberate occlusion of side branches (as with transposition); an outflow lesion then produces a pressure profile very similar to that of grafts.



**Fig 6. Effect of graft venous outlet stenosis. Reprinted with permission: Besarab A: Blood Purif 2006;24:77-89 (DOI: 10.1159/000089442). S. Karger AG, Basel.**

For a given graft access, the access flow pressure profile resulting from venous outflow stenosis is illustrated in Fig 6.

An initially well-functioning graft with an access flow approaching 2 L/min (usually in the upper arm) will manifest decreasing flow as both the arterial and venous pressure slowly increase with the development of outflow tract stenosis. Hemodynamic simulations indicate that flow decreases by less than 20% until the stenosis process produces a 40% to 50% decrease in luminal diameter. Thereafter, flow decreases rapidly as the degree of stenosis increases to 80%.<sup>273</sup> Because the intimal hyperplasia process progresses with time, its detection requires sequential measurements of flow or pressure or both to detect a threshold at which action should be taken. Note that the graft thrombosis region by flow shown in the hatched area is reached long before a graft would show recirculation and therefore affect the delivered dose of dialysis. Access recirculation in grafts is a late manifestation of stenosis and a poor predictor of imminent thrombosis; it occurs in less than 20% of cases.<sup>271</sup> For this reason, the Work Group no longer recommends recirculation measurements in grafts. Conversely, because fistulae typically can maintain patency at much lower flows than grafts, recirculation occurs much more frequently; 1 study reported that about one third of fistulae had a significant recirculation fraction by using an ultrasound dilution technique.<sup>271</sup> When recirculation was measured by using the Fresenius Body Thermal Monitor (BTM), the device was able to detect fistulae requiring revision with a sensitivity of 81.8% and specificity of 98.6%, although the BTM method does not differentiate between access and cardiopulmonary recirculation.<sup>274</sup>

The main issue for most HD clinics is which surveillance test best meets their needs. The following discussion summarizes the methods available and the reason for the ordering of the test by the Work Group in CPGs 4.2 and 4.3.

### ***Physical Examination (Look, Touch, Listen)***

Physical examination can be used as a monitoring tool to exclude low flows associated with impending graft failures.<sup>275,276</sup> There are 3 components to the access examination: inspection (look), palpation (touch), and auscultation (listen).<sup>276</sup> The Work Group is convinced that the

basic skills have been largely abandoned in favor of technology and need to be taught to all individuals who perform HD procedures.<sup>277</sup> Simple inspection can reveal the presence of aneurysms. A fistula that does not at least partially collapse with arm elevation is likely to have an outflow stenosis. This logic applies to the case in which a tourniquet does not appear necessary for optimal cannulation. Strictures can be palpated and the intensity and character of the bruits can suggest the location of stenosis. Downstream stenosis also produces an overall dilation of the vein, giving it “aneurysmal” proportions.

In grafts, one can determine the direction of flow in a loop configuration and avoid inadvertent recirculation by erroneous needle insertion. In a patent graft in which blood flow is less than the blood pump flow setting, the presence of recirculation can be detected easily by occluding the graft between the needles and looking at the arterial and venous pressures. A strong pulse too often is misinterpreted as being evidence of good flow, rather than the opposite. A pulse suggests lower flows.<sup>278</sup> In a newly thrombosed graft, the arterial pulse often is transmitted into the proximal end of the graft, leading to erroneous cannulation, which could be avoided easily by simply using a stethoscope to confirm absence of flow. A bruit over an access system and its draining veins that is only systolic is always abnormal; it should be continuous. An intensification of bruit suggests a stricture or stenosis.<sup>278</sup> Palpable thrill at the arterial, middle, and venous segments of the graft predicts flows greater than 450 mL/min.<sup>278</sup> A palpable thrill in the axilla correlates with a flow of at least 500 mL/min.<sup>279</sup> The character of pulse and thrill correlates with postintervention outcome for stenosis.<sup>280</sup> The interested reader is referred to additional literature for further enjoyment and enlightenment.<sup>271</sup>

Of note, a preliminary study has shown that sounds acquired by using electronic stethoscopes that were then digitized and analyzed on a personal computer could be used to characterize stenoses.<sup>281</sup> Stenotic vessel changes were found to be associated with changes in acoustic amplitude and/or spectral energy distribution. Acoustic parameters correlated well ( $r = 0.98$ ;  $P < 0.0001$ ) with change in degree of stenosis, suggesting that stenosis severity may be predicted from these parameters. Furthermore, acoustic

parameters appeared to be sensitive to modest diameter changes of 20%. These results suggest that, in the future, readily available computerized analysis of vascular sounds may be useful in vessel patency surveillance.

### Access Flow

Access flow can be measured by using a number of techniques, as summarized in Table 7. Doppler ultrasound (DU)<sup>282-287</sup> and MRA<sup>46,54,288-290</sup> are direct techniques for assessing flow in vascular accesses. Duplex Doppler ultrasound (DDU) requires an accurate measurement of the cross-sectional diameter of the access. The method is operator dependent and subject to error caused by variation in cross-sectional area and the angle of insonation.<sup>291,292</sup> Because turbulence in the access can limit the accuracy of the measurements, flow measurements can be made in the feeding artery (usually the brachial) or distal part of the access.<sup>272</sup> The difference between the flow in the artery and the access usually is less than 10%. Despite these operator-related and equipment-related limitations, *sequential* measurements have been used extensively to detect and refer patients for interventions or predict the risk for thrombosis. In addition to flow measurements, both DDU and MRA provide anatomic assessment and direct evidence for the presence, location, and severity of access stenosis. However, the current cost of these methods, as well as the inability to make measurements during HD, limits their use. Research and development are needed to simplify procedures and reduce costs.

Indirect methods use an indicator dilution technique; the major techniques include ultrasound dilution (UDT),<sup>272,293</sup> a timed ultrafiltration method<sup>294</sup>; transcutaneous access flow rate

(TQA), a method that can be performed during or independently of HD<sup>295,296</sup>; glucose infusion<sup>297,298</sup>; differential conductivity<sup>299,300</sup>; and, finally, ionic dialysance.<sup>301,302</sup> All the methods described, except for TQA, variable flow DU, and glucose infusion, require measurements with the blood tubing initially in the normal position and then reversed to induce access recirculation.

With UDT, access flow is measured from the induced recirculation when the needles are reversed. The software calculates the area under the curves (AUC) as a measure of recirculation.

$$Q_A = Q_{BP} (1/R - 1)$$

where  $Q_{BP}$  is blood pump flow and  $R$  is degree of recirculation induced. The UDT method is the only one that independently measures actual flow in the tubings, rather than accepting the readings on the HD system for the roller pump.

Pitfalls in measurement have been identified and recently reviewed.<sup>303</sup> Accurate calibration of the blood pump is essential with most methods, but frequently is not performed regularly. The indicator injection also must not affect flow in the access itself. The technique must separate access recirculation from cardiopulmonary recirculation that is unavailable with high-efficiency dialysis. Finally, access flow is a function of the ratio of systemic to access resistance, and measurements should be conducted within the first 90 minutes of dialysis to minimize effects of hypotension. Table 10 summarizes the recommendations for access flow surveillance. All methods require some modification/interruption of the dialysis treatment, except perhaps ionic dialysance.

**Table 10. Access Flow Protocol Surveillance**

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Access flow measured by ultrasound dilution, conductance dilution, thermal dilution, Doppler or other technique should be performed monthly. The assessment of flow should be performed during the first 1.5 hr of the treatment to eliminate error caused by decreases in cardiac output or blood pressure related to ultrafiltration/hypotension. The mean value of 2 separate determinations (within 10% of each other) performed at a single treatment should be considered the access flow.

#### Graft

If access flow is <600 mL/min in a graft, the patient should be referred for fistulogram.

If access flow 1,000 mL/min that has decreased by more than 25% over 4 mo, the patient should be referred for fistulogram.

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With ionic dialysance, alteration of the proportioning ratio of dialysate to water alters the dialysis sodium concentration, as well as blood sodium level. The resulting change in blood sodium level, as well as the change in dialysate conductivity, serves as the indicator for calculating  $Q_A$ .

$$Q_A = [(D \cdot Dr)/(D - Dr)] \cdot [1/(\text{blood water fraction})]$$

where  $D$  is the dialysance in the normal blood tubing position and  $Dr$  is the value with the tubing reversed. As with UDT, ultrafiltration should be minimized and recirculation must be absent in the normal blood tubing configuration. At flow rates less than 1,000 mL/min, the method consistently underestimates access flow compared with UDT.<sup>301,302</sup>

With the timed ultrafiltration method, a difference in hematocrit (Hct) is the indicator

$$Q_A = Qf H_0 (\Delta H_r - \Delta H_n)$$

where  $Qf$  is ultrafiltration rate,  $H_0$  is initial Hct, and  $\Delta H$  is change in Hct induced by ultrafiltration with the tubing in reversed ( $r$ ) and normal ( $n$ ) positions. The method correlates well with UDT.

The TQA method has not been extensively used.

The variable-flow DU method<sup>304-306</sup> measures velocity between the 2 dialysis needles at varying dialyzer blood flows. Using a conservation of volume approach, a computer algorithm solves for access flow without the need to measure the cross-sectional diameter of the access.<sup>306</sup> The method's accuracy is best at flows less than 1,000 mL/min.

The easy availability of urea as a marker has led some to use it as an indicator substance to calculate recirculation and therefore derive flow. Such measurements underestimate flow compared with conductivity.<sup>307</sup> Although  $Q_A$  can be estimated by using the urea method, the sensitivity and specificity of a low value is a poor predictor of access outcome and may lead to cost-ineffective investigations.<sup>307</sup>

Variation in access flow during dialysis<sup>308</sup> can result from changes with cardiac output,<sup>309-311</sup> MAP,<sup>309,310</sup> and changes in blood volume.<sup>311</sup> Access flow can increase by up to 11% or decrease by up to 30% from initial values by the end of dialysis, potentially impairing the ability

of  $Q_A$  to predict impending vascular access failure.<sup>312</sup> Access resistance remains stable during treatments and could be a more useful measure of vascular access performance as part of an access surveillance program. For all these reasons, it is recommended that measurements be made early in the HD treatment.

### Access Pressure

Measurements of pressure from the HD circuit were not originally designed to assess access (dys)function, either directly or indirectly. Rather, they were used to calculate the mean transmembrane pressure so that the appropriate ultrafiltration rate could be achieved. Volumetric control systems made these measurements unnecessary. Pressure measurements were retained to provide safety. During HD, blood is drawn out of the vascular access through the arterial needle by the blood pump on the HD machine.

Prepump pressures are now used to determine whether the prescribed dialyzer blood flow can be delivered without generating excessive negative pressures. At high negative pressures, the collapse of the pump segment reduces the true flow and true flow may differ from "displayed" flow by up to 15%.<sup>313,314</sup> The degree of collapse is affected, in turn, by differences among manufacturer tubing sets.<sup>315</sup> These considerations are important in evaluating the relationship of flow to access pressure. Excessively negative pressures can result in hemolysis.<sup>316</sup> Differences in blood tubing performance are of obvious importance to manufacturers, leading to improvements. The newer generations available may show little differences with the improved blood flow delivered during dialysis, benefiting all patients.

When blood passes through the dialyzer, the blood traverses the venous drip chamber and returns to the patient's vascular access through the venous needle. The pressure required to infuse blood back into the access is recorded as the venous drip chamber pressure (VDP) or DVP. The original purpose of VDP was to detect infiltration or malpositioning of the needle because partial occlusion of the needle orifice or infiltration would quickly increase and sound an alarm. There still is no "alarm" for detecting accidental withdrawal of the needle outside the body; exsanguinations have occurred.

One of the components of the VDP is the actual IAP ( $P_{IA}$ ). As shown in Fig 4, the IAP ( $P_{IA}$ ) in a graft is usually less than 50% of MAP. Most of this pressure decrease occurs at the arterial anastomosis, unless there is intragraft stenosis. When outflow stenosis develops (eg, because of neointimal hyperplasia at or downstream from the graft-vein anastomosis),  $P_{IA}$  increases and flow decreases. When  $P_{IA}$  increases to greater than 50% of MAP ( $P_{IA}/MAP$  greater than 0.50), graft flow commonly has decreased into the thrombosis-prone range of 600 to 800 mL/min (Fig 6), and the presence of stenosis is likely. If a stenosis develops in the body of a graft between the areas used for arterial and venous limb cannulation,  $P_{IA}$  at the venous needle remains normal or can even decrease despite increasing stenosis.<sup>270,271</sup> Stenosis at the arterial anastomosis of both grafts and fistulae causes  $P_{IA}$  to decrease. Conversely, a high basal  $P_{IA}$  can be observed with a healthy artery in the absence of stenosis when the flow delivered is in excess of the venous system's initial capacity. Because of these pressure confounders, there is little correlation between a single measurement of flow and  $P_{IA}/MAP$ .<sup>317</sup> Serial measurements of pressure in each patient are more valuable than isolated measurements of either  $P_{IA}$  or  $P_{IA}/MAP$  ratio. This is illustrated in Fig 7. Note that the arterial pressure ratio is approximately 0.2 units higher than the venous ratio and the baseline initial value for both ratios is lower than usual because of the use of a 4- to 6-cm taper at the arterial anastomosis that limits inflow to prevent steal.

In fistulae, blood entering the venous system returns through multiple collateral veins. As a consequence,  $P_{IA}/MAP$  in a fistula is, on average, less than in a graft and may not increase with outlet stenosis. The test, therefore, theoretically is less valuable as a surveillance tool for stenosis in fistulae. However, most elbow-level fistulae do not have or lose collaterals and often behave hemodynamically like grafts. In both fistula types, elevation of  $P_{IA}/MAP$  indicates the development of a stenosis in the venous outflow from the access and is associated with an increased probability of access failure or need for revision to provide adequate blood flow for HD.<sup>10,265,266,317</sup>

Like access flow, measurement of  $P_{IA}$  has evolved.

**Direct measurement of static pressure.** Pressures in the access can be measured directly at the site of cannulation in the "arterial" and "venous" segments of the graft or fistula by using a pressure-measuring device. Although one can use a sophisticated electronic method (separate transducers placed in line with the dialysis tubing)<sup>265-267</sup> as originally reported, a much simpler technique uses a device consisting of a hydrophobic Luer-Lok connector that connects a standard dialysis needle to an aneroid manometer.<sup>318</sup>

IAPs also can be measured by using the pressure transducers of the dialysis machine. Under conditions of no blood flow and no ultrafiltration, the only difference between the pressure measured by an independent transducer and the machine transducer is that resulting from the height differential between the location of the machine transducers and the access. The two pressures

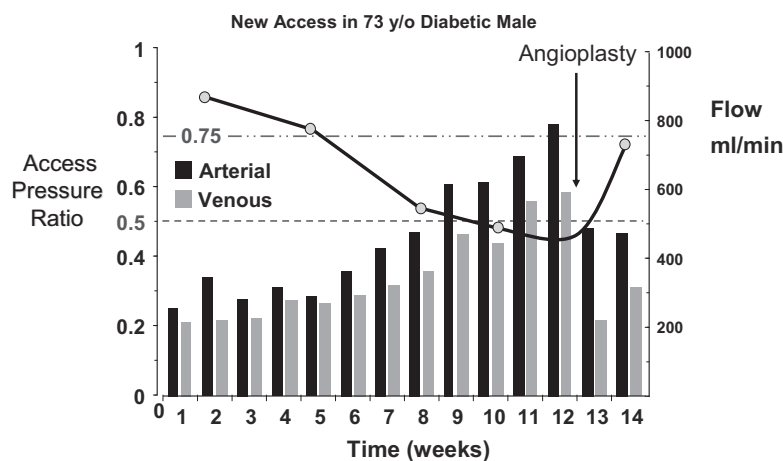


Fig 7. Relationship of IAP ratio to access flow. Reprinted with permission: Besarab A: Blood Purif 2006;24:77-89 (DOI: 10.1159/000089442). S. Karger AG, Basel.

can be equated by either moving the access to the level of the venous drip chamber or moving the drip chamber to the level of the access. Alternatively, the height difference,  $\Delta h$ , can be measured and the additional pressure ( $0.76 \cdot \Delta h$ ) can be added to the machine transducer reading.<sup>319</sup>

Table 8 provides the sequence of steps for measuring static pressure. It is important that the pressure transducers be calibrated accurately.

**Interpretation.** Venous outlet stenosis can be detected with venous  $P_{IA}$  alone. Trend analysis is more useful than any single measurement. The greater the degree of stenosis at the outlet, the greater the venous pressure ratio. Strictures between the area of arterial and needle cannulation cannot be detected by measuring venous ( $P_{IA}$ ) pressure alone.<sup>271</sup> Detection of these lesions requires simultaneous measurement of pressures from both the arterial and venous needles. Central stenoses that have collateral circulation may have “normal” pressures, but these usually present with significant ipsilateral edema. Accesses can be classified into the categories listed in Table 9. Using the equivalent  $P_{IA}$  ratios from the arterial or venous needles, the criteria must be met on each of 2 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 greater than 0.25 units more than their previous baseline, irrespective of access type, also are likely to have a hemodynamically significant lesion. Intra-access strictures usually are characterized by the development of a difference between the arterial and venous pressure ratios greater than 0.5 in grafts or greater than 0.3 in native fistulae. Because fistulae can remain patent at much lower flows than grafts, sequential measurement of conductance (ie, a blood pump/absolute value of prepump pressure), particularly at maximum prepump pressure permitted by the system, can detect fistula dysfunction and stenosis.<sup>320,321</sup>

Although measuring static pressure as described in Table 8 is straightforward, it is tedious, time consuming, and not “user friendly.” Staff frequently bypass crucial steps, leading to poor-quality data being collected and recorded. This has led to a reevaluation of statistical methods to use the information within the dynamic pressure.

**VDP or DVP and extraction of equivalent  $P_{IA}$ .** DVP (also referred to as VDP under conditions of blood flow) is measured routinely during HD in the presence of extracorporeal blood flow. These pressures can be read off the dialysis machine or stored electronically with the blood pump running. One of the components of DVP is the actual IAP ( $P_{IA}$ ) because the pressure needed to return blood into the access is the sum of that needed to overcome the needle resistance and IAP. DVP/VDP has been used to detect venous outlet problems,<sup>322</sup> but measurements are meaningful only if obtained at the beginning of dialysis and usually with low BFRs (50 to 225 mL/min) because at high BFRs, much of the resistance to flow is from the needle, and not the vascular access.

Measurement of DVP is less sensitive and specific than direct measurements of access flow rates or static pressure measurements. The reason for “poorer” performance results from many factors, including the lack of consistency about which flow should be the standard, varying in studies from 50 to 425 mL/min<sup>322-325</sup>; differences in needle design (wall thickness, actual length); and effects of viscosity affected chiefly by Hct. In addition, use of DVP as a method also requires that studies be performed to standardize the critical value as a function of needle gauge, length, and inner diameter (wall thickness). Consistency requires that a uniform flow value to test at be determined.

**Indirect methods for determining  $P_{IA}$ .** Most HD systems can store the blood pump values associated with DVP. A computerized algorithm has been developed that uses an empirical formula to calculate an equivalent  $P_{IA}$  from the DVP made during treatment. During a given treatment, many measurements at different flows can be made along with the simultaneous MAP, and an average equivalent  $P_{IA}$ /MAP can be calculated. The average values can be trended with each treatment and examined for an upward trend. When the ratio exceeds 0.55, the access has a greater risk for clotting.<sup>326</sup> This technique has been commercialized, providing monthly reports and trend analysis. Its ability to predict thrombosis is equal to that of direct measurement of  $P_{IA}$ . In the evolution of the IAP ratio to detect stenosis, the discriminator value has progressively increased from 0.4 using the ratio of

systolic pressures, 0.45 using the ratio of mean pressures measured directly, 0.5 using transducers on the machine, and finally 0.55 when deriving  $P_{IA}$  from the dynamic pressure.

### ***Recirculation: Method, Limits, Evaluation, and Follow-Up***

Recirculation is the return of dialyzed blood to the dialyzer without equilibration with the systemic arterial circulation. The technique is not recommended as a surveillance tests in grafts. However, up to one third of dysfunctional fistulae will show an increase in recirculation that may be manifested as a decrease in urea reduction ratio (URR) or  $Kt/V$ , but this occurs late.

Access recirculation in a properly cannulated access is a sign of low access blood flow<sup>192</sup> and a marker for the presence of vascular access stenosis, particularly in fistulae. Such stenoses can be corrected, preventing underdialysis and decreasing the risk for access thrombosis.<sup>327</sup> Access recirculation can be measured accurately by using UDT<sup>328</sup> or conductivity.<sup>299</sup> A  $K^+$ -dilution method is more reliable than the 2-needle urea-based method and compared with UDT, has 100% sensitivity, 95% specificity, 91% positive predictive value, and 100% negative predictive value.<sup>329</sup> In analogy to access flow measurement, glucose infusion also has been used to measure recirculation.<sup>330</sup>

The amount of recirculation occurring with reversed needles usually is substantial ( $>20\%$ ), as confirmed when the tubings are deliberately reversed for access flow measurements. However, even with ideal sample timing and proper cannulation, laboratory variability in urea-based measurement methods will produce variability in calculated recirculation.<sup>331</sup> Therefore, individual recirculation values less than 10% by using urea-based methods may be clinically unimportant. The Work Group believes that they do not prompt further evaluation. Values greater than 10% by using urea-based recirculation measurement methods require investigation.

New loop grafts are at particular risk for reversed needle placement because of a lack of familiarity with the access anatomy. When possible, an access diagram that depicts the arterial and venous limbs should be obtained from the surgeon who constructed the access to aid in proper cannulation. If not available, the anatomy

can be deduced by *temporarily* occluding the graft at its midportion. The portion retaining a pulse is the arterial limb.

### ***Comparison of Surveillance Methods***

#### ***Accuracy and Reproducibility***

Only 1 study has directly compared many of the available flow techniques with regard to reproducibility.<sup>332</sup> Reproducibility is assessed by using duplicate measurement at unchanged conditions, whereas accuracy is determined under controlled change in a relevant measurement condition (2 different blood flows for ultrasound, changed sensor position in TQA). An accurate method produces the same result. In most studies using some form of dilution or concentration of an indicator, UDT is taken as the reference method for comparison because it most accurately separates cardiopulmonary from access recirculation and independently measures blood flow to the dialyzer. Ultrasonic flow is approximately 10% to 15% less than indicated by the blood roller pump, the magnitude correlating inversely with negative arterial blood tubing pressure.<sup>333</sup> It shows very high reproducibility, for measurement at the same extra corporeal blood flow,  $Q_B$  (correlation coefficient of duplicate measurement,  $r = 0.97$ ;  $n = 58$ ) and measurement at 2 different  $Q_B$  ( $r = 0.97$ ;  $n = 24$ ), justifying its current status of a reference method in  $Q_A$  evaluation.<sup>334</sup> The coefficient of variation usually is less than 8%.<sup>327</sup> Slightly lower reproducibility is found with thermal dilution (TD) or Fresenius BTM at the same  $Q_B$  ( $r = 0.92$ ;  $n = 40$ ) and 2 different  $Q_B$  ( $r = 0.851$ ;  $n = 168$ ); this inaccuracy can be overcome by increasing the number of measurements with averaging. Use of the simple Krivitski formula,  $Q_A = Q_{BP} (1/R - 1)$  in TD (which measures total recirculation, ie, sum of access recirculation and cardiopulmonary recirculation) brings about underestimation of  $Q_A$ , which progressively increases from  $Q_A$  of about 600 mL/min upward. High correlation of TD versus UDT ( $r = 0.95$ ;  $n = 54$ ) makes TD a viable clinical alternative in  $Q_A$  evaluation. Consistently different  $Q_A$  values obtained at 2 different  $Q_B$ s should prompt closer investigation of anatomic conditions of the access. Good correlation ( $r = 0.87$ ;  $n = 27$ ) also is found between  $Q_A$  measured by using DDU and UDT.<sup>332,335</sup>

The direct TQA method showed very high reproducibility ( $r = 0.97$ ;  $n = 85$ ); however, only for unchanged sensor position. Correlation of  $Q_A$  measured at 2 different sensor positions was much worse ( $r = 0.73$ ;  $n = 22$ ). Correspondence of TQA with UDT was satisfactory ( $r = 0.81$ ;  $n = 36$ ). Skilled and experienced operators are a must with this method. Similar results were found by others who reported, for triplicate measurements, coefficients of variation of 7.5% for differential conductivity by hemodynamic monitoring (HDM), 9.1% for UDT, and 17.4% for optodilution by ultrafiltration (OABF).<sup>336</sup> Repeatability data (variation among temporally separated measurements) showed values of 10.6% for HDM, 13.0% for UDT, and 25.2% for OABF. Fewer comparisons have been made with the other methods. Glucose pump test (GPT) flow measurements correlate well with UDT measurements and have acceptable replicability.<sup>298</sup>

Ionic dialysance or conductivity dialysance, as it frequently is referred to, is being used increasingly by clinicians to measure access flow in both the United States and Europe, particularly with Fresenius dialysis delivery systems, in which the methodology is built into the machines as on-line clearance. Major refinements have been made to increase the replicability and accuracy of this method at lower BFRs, but preliminary reports comparing the measurements with UDT have not yet been formally published.

#### *Detection of Stenosis or Predicting Thrombosis*

As important as accuracy of a method is, the goal of any surveillance method is to detect access stenosis in a timely way so that appropriate correction can be undertaken before thrombosis. 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.

Table 11 summarizes the available studies in which the presence and degree of stenosis was confirmed by using angiography. As reflected by data in the table, DDU is most accurate because it can directly visualize the degree of stenosis. When DDU is used to measure flow, rather than identify anatomic stenosis, sensitivity and specificity decrease. A quick survey of the table clearly

shows that none of the tests consistently achieves a sensitivity of 90% and specificity greater than 80%.

Because of the accuracy of DDU in detecting the presence of a 50% (by diameter) stenosis,<sup>337</sup> it has been used in some studies as the reference method, rather than angiography, to avoid invasive procedures. As shown in Table 12, UDT has good accuracy, whereas physical examination has high specificity, but poor sensitivity.

Table 13 shows that DDU and UDT are equivalent in predicting thrombosis.

Data are still limited for some of the newer surveillance tests. Table 14 summarizes the observations. There is excellent correlation between flow measurements by means of GPT and UDT ( $r > 0.9$ ).<sup>298</sup> GPT also has been validated recently as a surveillance technique in grafts. Using DDU to assess for the presence of stenosis, GPT picked up severe stenosis in 14 of 112 grafts (100% sensitivity) and performed better than UDT (86% sensitivity).<sup>297</sup> Specificity was less than 60% for both tests. Diagnostic efficiency (percentage of grafts with agreement between test result and factual situation) was 90% and 80% ( $P = 0.056$ ) for GPT and UDT, respectively. MRA also can provide anatomic<sup>338</sup> and  $Q_A$  measurements, but it is prohibitively expensive. Intravascular ultrasounds (IVUSs) can be used to evaluate abnormalities in fistulae<sup>297</sup> and may find abnormalities not seen with angiography. However, it is too expensive for routine use, but may be a valuable adjunct in evaluating the efficacy or completeness of the intervention on the access.

An important issue in fistulae is the assessment of such abnormalities as aneurysms and extreme tortuosity in “well-functioning” fistulae. DU is a very valuable technique, particularly in fistulae; in addition to measuring flow and identifying stenosis directly, it can detect other abnormalities in presumably well-functioning accesses.<sup>345</sup> Pseudoaneurysms do not decrease access flow;  $Q_A$  is significantly greater than the mean (1,204 mL/min) in fistulae with aneurysms, calcifications, and tortuous vessels and, of course, less in those with stenosis. No correlation is noted between  $Q_A$  or the presence of stenosis with fistula age. Some degree of stenosis was detected in 64% of fistulae, with 57% of stenoses located in the anastomotic region; 22%, in the vein junction; 19%, at 1 or both ends of the

**Table 11. Diagnostic Accuracy of Tests Used for Access Surveillance in the HD Population: Angiogram for Stenosis vs. Other Test**

Author, Year	N	Type of Access		Applicability	Test 1 <sup>a</sup>	Threshold Value for Stenosis			Results		Quality
		AVF	AVG			Sens	Spec	AUC	CI		
Bosman 1997 <sup>340</sup>	42 (70 grafts)	0%	100%	↑↑	UDT	ND	-	-	0.72 <sup>b</sup>	(0.66, 0.78)	●
Tessitore 2003 <sup>338</sup>	127	100%	0%	↑↑	UDT	750 mL/min	84%	91%	0.91	(0.88, 0.94)	●
Schwarz 2003 <sup>337</sup>	66	100%	0%	↑↑	UDT	465 mL/min	68%	89%	0.79	(0.66, 0.91)	○
Schwarz 2003 <sup>337</sup>	66	100%	0%	↑↑	DDU	390 mL/min	76%	78%	0.80	(0.65, 0.94)	○
Gadallah 1998 <sup>342</sup>	56	34%	66%	↑↑	DDU	<sup>c</sup>	100%	100%			○
Robbin 1998 <sup>341</sup>	41	100%	0%	↑↑	DDU	<sup>d</sup>	92%	50% <sup>e</sup>			○
Bosman 1997 <sup>340</sup>	42 (70 grafts)	0%	100%	↑↑	Venous pressure	ND			0.83 <sup>c</sup>	(0.78, 0.88)	●
Laissy 1999 <sup>288</sup>	19	100%	0%	↑↑	MRA	<sup>f</sup>	92%	86%			○
Planken 2003 <sup>338</sup>	15	53%	47%	↑	MRA	<sup>f</sup>	100%	0%	0.74		○
							100%	20%	0.81		

AUC=area under curve; AVF=arterio-venous fistula; AVG=arterio-venous graft; CI=confidence interval; DDU=duplex Doppler ultrasound; MRA=magnetic resonance angiography; ND=no data; PSV=peak systolic velocity; Sens=sensitivity; Spec=specificity; UDT=ultrasound dilution technique.

- a. This test is compared to the "reference standard", angiogram
- b. Based on number of grafts
- c. Access stenosis defined by > 50% narrowing or reduction of luminal diameter of vessel
- d. Access stenosis defined by PSV ratio > 2.0 or > 50% stenosis
- e. Derived specificity calculated based on data provided
- f. Access stenosis defined by 50% vessel stenosis or 40% stenosis with turbulent flow

**Table 12. Comparison of Diagnostic Tests for Access Surveillance and Monitoring in the HD Population: Duplex Doppler Ultrasound As Reference**

Author, Year	N	Type of Access AVF	AVG	Applicability	Test 1 <sup>a</sup>	Threshold Value for Stenosis	Results	Quality
May 1997 <sup>285</sup>	170 (220 accesses)	22%	78%	↑↑↑	UDT <sup>b</sup>	ND	r = 0.79 P = 0.0001	●
Malik 2002 <sup>124</sup>	193 (258 exams)	72%	28%	↑↑	Physical exam	ND	Sensitivity = 36% Specificity = 93%	○

AVF=arterio-venous fistula; AVG=arterio-venous graft; ND=no data; r=correlation coefficient; UDT=ultrasound dilution technique.

a. This test is compared to the "reference standard", duplex US.

b. Access stenosis defined by doubling of systolic velocity in vessel narrowed more than 50%

**Table 13. Comparison of Diagnostic Tests to Predict Thrombosis in Chronic Hemodialysis Patients**

Author, Year	Study Design	N	Type of Access AVF	AVG	Follow-up (maximum)	Applicability	Test 1	Test 2	Prediction Difference	Quality
Lok 2003 <sup>343</sup>	Prospective with historical control	401	63%	37%	ND	↑↑	DDU <sup>a</sup>	UDT <sup>a</sup>	NS <sup>b</sup>	○
May 1997 <sup>285</sup>	Prospective, uncontrolled	170 (220 accesses)	0%	100%	ND	↑↑	DDU	UDT	+ <sup>c</sup>	○

AVF=arterio-venous fistula; AVG=arterio-venous graft; DDU=duplex Doppler ultrasound; ND=no data; NS=not significant; PTA=percutaneous transluminal balloon angioplasty; UDT=ultrasound dilution technique.

+ Statistically significant beneficial effect of treatment compared to control (or intervention 1 vs. intervention 2)

a. Coupled with angiogram and PTA or surgery for those with access stenosis defined by doubling of systolic velocity in vessel narrowed more than 50%, or UDT flow < 650 mL/min for AVG or < 500 mL/min for AVF or 15% decrease from previous measurement

b. NS both AVG and AVF

c. UDT, but not DDU, predicts thrombosis in multivariate analysis

**Table 14. Comparison of Newer Tests to Established Tests for Stenosis Detection**

Author, Year	N	Type of Access AVF	AVG	Applica- bility	Test 1 <sup>a</sup>	Test 2	Results	P-Value or 95% CI	Quality
Arbab-Zadeh 2002 <sup>344</sup>	22	100%	0%	↑↑	Angiogram <sup>b</sup>	IVUS	Author's conclusion: IVUS feasible		●
Smits 2002 <sup>46</sup>	18	39%	61%	↑	Angiogram <sup>b</sup>	MRA	Mean difference in maximum stenosis between tests	Observer 1: 3.2% (-26.7%, 33.1%)	●
								Observer 2: 4.1% (-23.8%, 32.1%)	
							Mean interobserver difference	MRA: 3.2% (-28.8%, 35.2%) DSA: 3.6% (-9.4%, 16.7%)	
Planken 2003 <sup>338</sup>	15	53%	47%	↑	Angiogram <sup>b</sup>	MRA	Interobserver agreement on access stenosis	DSA: k = 0.69 MRA: k = 0.81	●
								r = 0.901	
Ram 2003 <sup>298</sup>	33	24%	76%	↑	UDT	GPT		<0.001	●

AVF=arterio-venous fistula, AVG=arterio-venous graft; DSA=digital subtraction angiography; GPT=glucose pump infusion technique; IVUS=intravascular ultrasound; k=kappa statistic for interobserver agreement; MRA=magnetic resonance angiography; PSV=peak systolic velocity; r=correlation coefficient; UDT=ultrasound dilution techniques; CI=confidence intervals

a. This test represents "gold standard" unless otherwise specified

b. Access stenosis defined by > 50% narrowing or reduction of luminal diameter of vessel

aneurysm; and 2%, in the remaining region of the efferent vein.<sup>345</sup> Chronic venous occlusion with collateral veins was detected in 6% of fistulae.<sup>345</sup> Aneurysms were observed in 54% of fistulae with a mean diameter of 12.4 mm, with 96% of them located at puncture sites. Ten patients had a small thrombus in an aneurysm and at puncture sites. Thus, although a high level of abnormalities is present in well-functioning mature fistulae, the abnormalities are not sufficient to affect the functioning of the HD fistula and, in most cases, need only observation. More advanced lesions require therapy (see CPG 5).

DDU is a particularly useful modality to determine reasons for maturation failure of fistulae 4 to 12 weeks after construction,<sup>346</sup> even if preoperative vein mapping had shown adequate vein size ( $\geq 3$  mm) and outflow. Using the criteria of peak systolic velocity ratio (SVR) of 2:1 or greater to detect a 50% or greater stenosis involving arterial inflow, and venous outflow and an SVR of 3:1 or greater to detect a 50% or greater anastomotic stenosis, DDU of 54 native fistulae (23 brachiocephalic, 14 radiocephalic, and 17 basilic vein transpositions) found that 20% were occluded and 26% were normal. The remainder showed a variety of lesions: 16 fistulae (42%), venous outflow; 13 fistulae (34%), anastomotic; and 2 fistulae (5%), inflow stenoses. In 7 fistulae (18%), branch steal with reduced flow was found. Sensitivity, specificity, and accuracy of DDU in detecting stenoses of 50% or greater were 93%, 94%, and 97% compared with fistulography, respectively. Because many of these fistulae cannot be studied by using other surveillance techniques, routine DDU surveillance of primary fistulae should be considered to identify and refer for correction of flow-limiting stenoses that may compromise the long-term patency and use of the fistula.

Inflow stenosis is more common than previously believed (ie,  $<5\%$  of cases). An inflow stenosis is defined as stenosis within the arterial system, artery-graft anastomosis (graft cases), artery-vein anastomosis (fistula cases), or juxta-anastomotic region (the first 2 cm downstream from the arterial anastomosis) with a 50% or greater reduction in luminal diameter judged by comparison with either the adjacent vessel or graft. Such stenosis was found in nearly a third of 223 cases referred to an interventional facility

serving several centers.<sup>268</sup> All referred accesses had a coexisting stenosis on the venous side. The frequency of inflow stenosis was less in grafts (29% of cases) than fistulae (40 of 101; 40%). Of these, 22 (54%) had a coexisting lesion on the venous side. Access inflow stenosis thus is much greater than traditionally reported in cases referred to interventional facilities with clinical evidence of venous stenosis or thrombosis.

Attempts to combine the various surveillance techniques have been performed. One study found no difference in the ability to detect stenoses in grafts from using  $Q_A$  by UDT compared with static venous pressure ratios.<sup>340</sup> However, DVPs were of little use. Use of a  $P_{IA}$  compared with  $Q_A$  also was examined in 125 grafts followed up for 80.5 patient-years.<sup>347</sup> Standardized monitoring of either  $P_{IA}$ ,  $Q_A$ , or the combination of both, followed by subsequent corrective intervention, decreased the thrombosis rate in grafts compared with a historical control rate.<sup>348</sup> Rates in 2 separate parts of the study for thrombosis not preceded by a positive test result were 0.24 and 0.32 episodes/patient-year at risk compared with a historical rate greater than 0.7, respectively. The surveillance strategies were equally effective in decreasing thrombosis rates, and access survival curves were not significantly different between subgroups.<sup>347</sup> Again, DVP alone was not useful because either  $Q_A$  or  $P_{IA}$  turned positive before the dynamic pressure limit ( $>150$  mm Hg at 200 mL/min) was reached. Unlike these 2 studies showing limited to no utility of DVP alone, another study was able to find some utility for DVP measurements for grafts.<sup>349</sup> Stenosis greater than 50% by diameter on fistulography or a thrombotic event was defined as a “vascular access impairment episode,” whereas stenosis less than 50% or the absence of a thrombotic event was defined as “no vascular access impairment episode.” By combined dynamic pressure readings and flow surveillance (DVP  $>120$  mm Hg;  $Q_A < 500$  mL/min in fistulae and  $< 650$  mL/min in grafts or a decrease in  $Q_A > 25\%$  compared with the highest previously measured value were considered positive), improved sensitivity over flow alone for fistulae, but not grafts, was observed.<sup>268</sup> Sensitivity and specificity of the combined surveillance protocol for fistulae were 73.3% and 91%; in grafts, they were 68.8% and 87.5%, respectively. The rate of thrombotic

events was less in patients with fistulae who underwent early repair, but in grafts, the addition of DVP did not decrease the thrombosis rate any further than surveillance based on  $Q_A$  alone. Finally, when UDT, DDU flow, DVP, and pre-pump pressure were examined as predictors of thrombosis in 172 grafts, DVP used alone was not predictive.<sup>285</sup>

In summary, available data suggest that the utility of DVP at flows of 150 to 225 mL/min to predict stenosis or thrombosis is limited or absent in grafts. Studies are needed to determine whether the method retains any utility in fistulae. Conversely, flow measurements, DDU assessment for stenosis, and static pressure measurements (direct or indirect by using computers) can detect hemodynamically significant stenosis in grafts and fistulae. Although the location of stenosis in fistulae (inflow) favors  $Q_A$  over  $P_{IA}$ , no direct comparisons have been made by using DDU anatomic imaging or contrast angiography to determine the accuracy of the techniques in this access type. If the prescribed Kt/V is not delivered in a patient who is using a fistula, measurement of access flow should be performed by using a recommended method (Table 7).

The Work Group believes there is insufficient evidence to suggest 1 surveillance technique from those listed in the guidelines as “preferred or acceptable” because the choice at a particular site is affected by many variables; chief among these are access type, technology, effect of operator, and cost (usually labor). Although DDU studies are predictive of access stenosis and the likelihood for failure,<sup>350</sup> frequency of measurement is limited by expense. In addition, interobserver variability in measurement of DDU flow in some instances can reduce the reliability of DDU flow measurement.<sup>351</sup> Variation in the internal software used for calculating DDU flow measurements by different manufacturers also is a factor preventing standardization. Magnetic resonance flow is accurate, but expensive. Both DDU flow and magnetic resonance are difficult to perform during HD sessions.

Conversely, flow measurements performed by using UDT and other techniques can be done on-line during HD, thereby providing rapid feedback. The same applies for  $P_{IA}$ . Both access flow and IAP techniques have been validated in prospective observational studies.<sup>10,322,347,349,352,353</sup> Mea-

suring static venous pressures is the least expensive method of surveillance for stenosis.<sup>322,354</sup> Because of efficiency or cost, these methods are listed as preferred. In-line access flow measurements (DDU) are available and have been improved in terms of accuracy and replicability. However, there are no data yet on efficacy in detecting stenosis or effect on thrombosis rate.

The Work Group believes that recirculation is a relatively late predictor of access dysfunction and, if used, has a minor role in fistulae only. Non-urea-based recirculation measurements are very accurate, but require specialized devices.

Unexplained decreases in delivered dialysis dose, measured by using Kt/V or URR, frequently are associated with venous outflow stenoses.<sup>355</sup> However, many other factors influence Kt/V and URR, making them less sensitive and less specific for detecting access dysfunction. Inadequate delivery of dialysis dose is more likely to occur with a fistula than a graft.

In primary fistulae, inadequate flow through the access is the main functional defect predictive of thrombosis and access failure (defined as thrombosis or failure to provide adequate dialysis dose). Indirect measures of flow, such as dynamic and static venous dialysis pressure, may be less predictive of thrombosis and access failure in fistulae compared with grafts. However, measurement of recirculation becomes a more useful screening tool in fistulae compared with grafts because flow in fistulae, unlike grafts, can decrease to a level less than the prescribed blood pump flow (ie, <300 to 500 mL/min) while still maintaining access patency.<sup>192,270,271</sup> DDU may be useful in fistulae.<sup>346</sup> Comparative studies using HDM ( $Q_A$ ,  $P_{IA}$ ) and DDU need to be performed before firm recommendations can be made by the Work Group.

Regular assessment of physical findings (monitoring) may supplement and enhance an organized surveillance program to detect access dysfunction. Specific findings predictive of venous stenoses include edema of the access extremity, prolonged postvenipuncture bleeding (in the absence of excessive anticoagulation), failure of the vein to collapse with arm elevation, and changes in physical characteristics of the pulse or thrill in the graft.<sup>108,354</sup> Physical examination is a useful screening tool to exclude low flow (<450 mL/min) in grafts with impending fail-

**Table 15. Patient Education Basics**


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All patients should be taught how to:

- a. Compress a bleeding access;
- b. Wash skin over access with soap and water daily and before HD;
- c. Recognize signs and symptoms of infection;
- d. Select proper methods for exercising fistula arm with some resistance to venous flow;
- e. Palpate for thrill/pulse daily and after any episodes of hypotension, dizziness, or lightheadedness;
- f. Listen for bruit with ear opposite access if they cannot palpate for any reason.

All patients should know to:

- a. Avoid carrying heavy items draped over the access arm or wearing occlusive clothing;
  - b. Avoid sleeping on the access arm;
  - c. Insist that staff rotate cannulation sites each treatment;
  - d. Ensure that staff are using proper techniques in preparing skin prior to cannulation and wearing masks for all access connections;
  - e. Report any signs and symptoms of infection or absence of bruit/thrill to dialysis personnel immediately.
- 

ure.<sup>275,277,278</sup> In the context of proper needle position, an elevated negative arterial prepump pressure that prevents increasing the BFR to the prescribed level also is predictive of arterial inflow stenoses.

When a test indicates the likely presence of a stenosis, angiography should be used to definitively establish the presence and degree of stenosis. Currently, the Work Group is in agreement with the Society for Interventional Radiology, which recommends angioplasty if the stenosis is greater than 50% by diameter. Angioplasty by its very nature is a “disruptive” force on the vessel and can injure endothelium and underlying smooth muscle; each angioplasty can produce benefit or harm. However, there have been no large-scale trials to determine whether correction of only “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%. At the time of intervention, hemodynamic evaluation of each stenosis generally is not carried out.

Until such studies are conducted, the Work Group believes that the value of routine use of any technique for detecting anatomic stenosis alone—without concomitant measurement of access flow, venous pressure, recirculation, or other physiological parameters—has not been estab-

lished. Stenotic lesions should not be repaired merely because they are present. If such correction is performed, then intraprocedural studies of  $Q_A$  or  $P_{IA}$  before and after PTA should be conducted to show a functional improvement with a “successful” PTA.

#### ***The Patient as His or Her Own Surveyor and Protector***

The Work Group strongly advocates that all patients should be taught the “basics” of *how to take care of their vascular access*, including steps in personal hygiene, cleanliness, avoidance of scab picking, and so on, as discussed in [Table 15](#). In addition, patients should be taught where and how to detect a “pulse,” where and how to feel for a thrill, how to recognize infection, and—most importantly—when to notify a member of the dialysis staff of physician when the pulse or thrill is absent. Delay in recognizing loss of patency may influence the likelihood of restoring patency.

The patient must be taught the reason for avoiding “1-site-itis.” Topical anesthetics should be used judiciously if they help the patient comply with the policy of rotation of needle sites. To avoid aneurysm formation, the patient should insist on site rotation unless a buttonhole method is being used in a native fistula. With the large staff turnover ratios prevalent in HD units in the

United States, the patient must be diligent that staff uses the proper aseptic techniques whenever the access is palpated, inspected, or cannulated.

### ***Surveillance and Thrombosis***

#### *Nonrandomized Trials*

In dialysis AVGs, thrombotic events result primarily, but not solely, from progressive venous outflow stenosis.<sup>10,24,105,300,354,356-358</sup> Thrombotic events that cannot be resolved (ie, patency restored) are the leading cause of access loss. These stenoses are caused by intimal and fibromuscular hyperplasia in the venous outflow tract, typically at the graft venous anastomosis,<sup>359-362</sup> but can occur in the body of the graft, as well. The details of pathophysiology are beyond the limits of this discourse except to state that, to date, promising therapies in animal models have not yielded success in humans. Possible future therapeutic approaches have been summarized.<sup>363</sup>

As stenoses increase in severity, they produce a resistance to flow, increasing  $P_{IA}$  with an accompanying decrease in blood flow.<sup>266,318</sup> Cross-sectional studies using DDU or UDT showed a progressive increase in risk for access thrombosis during a follow-up interval of 1 to 6 months. The absolute value of the “critical or threshold”  $Q_A$  depends on the method used. Average access flow rates obtained by DDU are less (600 to 900 mL/min)<sup>252,335,364</sup> than those measured by using magnetic inductance (mean, 1,100 mL/min) or UDT (mean range, 900 to 1,200 mL/min).<sup>336</sup> Studies also showed that when access flow is measured repeatedly, trends of decreasing flow add predictive power for the detection of access stenosis or thrombosis.<sup>284-286,300,311,318,349,364-371</sup> Grafts with access blood flows less than 600 to 800 mL/min have a greater rate of access thrombosis than grafts with flow rates greater than 800 mL/min.<sup>268,284,286,300,311,318,372</sup> In addition to this absolute value, a decrease of 25% in access flow from a previous “stable” baseline greater than 1,000 mL/min has been suggested as a criterion for further diagnostic evaluation of grafts to detect the presence of at least one 50% (by diameter) stenosis within the access.<sup>285,364,369-371</sup> In general, the interval that is present to correct the lesion in grafts before the access thromboses varies inversely with the access flow, being less than 8

weeks at a flow less than 450 mL/min<sup>371</sup> and 3 months at flow rates of 600 to 800 mL/min.<sup>285</sup>

Although many centers refer patients directly for angiographic study without intermediate studies when a critical value is obtained, there may be a role for DDU anatomic scanning.<sup>282</sup> Because fistulae maintain patency at lower flows than grafts, criteria for intervention in fistulae are not as well established. Values of 400 to 650 mL/min have been proposed. Higher values increase sensitivity, but lose specificity. Some fistulae can maintain patency for years at flows less than 400 mL/min, but with high-efficiency/high-flux dialysis, the treatment time requires extension. Conversely, intervention with PTA almost invariably triggers a process of repeated need for PTA because the frequency of at least 1 abnormality in an access is so high. Optimal care of a particular patient requires individualization, and not rigid application of protocols.

Because the development and severity of stenosis evolve to varying degrees among patients over time, the likelihood of detecting a hemodynamically significant stenosis increases if the surveillance test is repeated frequently. Therefore, surveillance should be performed at intervals of 1 month or less—depending on the complexity and cost—to detect access dysfunction early and permit sufficient lead time for intervention. The Work Group concluded that trend analysis could be as important as any individual value for any monitoring technique. Because access pressure measurements do not require complex technology, their frequency should be greater than that for access flow measurements. For direct measurement of access pressure, a frequency of twice a month appears sufficient. With methods more likely to produce variation under real-world clinical practice conditions (such as those from the HD system transducers), measurements once every 1 to 2 weeks are needed to detect a trend. The Work Group believes that measurement of static pressures every 2 weeks is the minimum frequency that is compatible with current HD staffing patterns. Derived static pressures need analysis from all available treatments for the month. Dynamic pressures should not be performed in grafts.

Measurement of access flow also was shown to be a valuable tool in determining the success of a therapeutic intervention. Failure to increase

access flow by at least 20% after an intervention reflects failure of the intervention to correct the underlying problem.<sup>282,369</sup> In 1 study, values before PTA and  $\Delta Q_A$  correlated with the subsequent decrease in  $Q_A$  ( $P < 0.005$ ).<sup>282</sup> It was observed that  $Q_A$  increased after PTA (from 371 mL/min to 670 mL/min in a total of 65 grafts and 33 fistulae), but in a substantial percentage of cases, not to levels greater than 600 mL/min.  $Q_A$  values before PTA and the increase in  $Q_A$  values correlated with long-term outcomes, whereas angiographic results did not. Unfortunately, in many of the studies, the literature has admixed results for flow and outcome for both fistula and graft, making it impossible to sort out effects in grafts as opposed to fistulae. The Work Group believes there may be important differences in the response of fistulae (compared with grafts) to PTA, and surgical approaches also may influence outcomes. Research is needed in this area.

A large number of studies that used historical control data showed that prospective surveillance/monitoring to detect stenosis reduces the rate of thrombosis, although at the expense of increased procedures.<sup>10,322,343,373,374</sup> A seminal study showed that a prospective program of dynamic pressure surveillance could detect stenotic lesions, reduce thrombosis rates, and reduce access replacement rates.<sup>322</sup> In that study, fistulae and grafts were not differentiated with respect to efficiency of the test. Unfortunately, criteria developed with needles designed for low-efficiency dialysis (16 G; pressure  $> 150$  mm Hg at a flow of 200 mL/min) were not adapted for larger bore needles (15 G and 14 G), and other investigators did not independently standardize their pressure criteria for the flow actually used (150 to 225 mL/min). Accordingly, results of this study generally were not duplicated.<sup>340</sup> Until such standardization is performed, DVP alone is not recommended. Additional studies using static pressure,<sup>10</sup> physical examination alone,<sup>352,353</sup> DVP combined with access recirculation plus physical finding,<sup>373</sup> DDU,<sup>284,374</sup> and  $Q_A$ <sup>341,366,369,375</sup> all showed a 41% to 67% reduction in thrombosis rate in grafts. A review suggested that the effect may be smaller in fistulae.<sup>374</sup>

Receiver operating characteristic (ROC) curve analyses have been performed to assess the overall performance of access flow and pressure in predicting thrombosis. Although in some studies,

a good AUC of 0.84 to 0.9 was achieved for access flow, overall AUC for 10 studies was only 0.7.<sup>376</sup> Addition of a change in flow increased AUC slightly to 0.82, but not to the value of 0.9 that an excellent test would produce (90% sensitive and 80% specific).<sup>377</sup> The sum of  $Q_A$  and  $\Delta Q_A$  did not perform any better than  $P_{IA}/MAP$ .

Unfortunately, the high baseline rate of thrombosis in grafts precludes a sensitive test that can unequivocally predict the likelihood of thrombosis or not over a specified time. During a 3-month observation period, grafts can clot in the absence of any stenosis and do so at flows equal to those that remain patent, 1,209 versus 1,121 mL/min.<sup>270</sup> In these cases,  $P_{IA}$  remains unchanged. Grafts that required intervention or that thrombosed because of an anatomic lesion had much lower access flows, 656 mL/min and 609 mL/min, respectively. At flows greater than the threshold, the incidence of thrombosis may be as high as 20% per 6-month period.<sup>375</sup> Even with flows in the highest quartile, greater than 1,395 mL/min, another study found a thrombosis rate of 9% during a period of 3 months (annualized risk, 36%).<sup>285</sup> Until more studies are performed that examine the frequency of thrombosis in the absence of stenosis and the frequency of patency in the presence of arterial or venous stenosis, the debate will go on.<sup>378-381</sup>

At the present time, the development of a surveillance abnormality should be correlated with other findings on physical examination and adequacy of HD. Any abnormality ( $Q_A$ ,  $P_{IA}$ ) must be confirmed before further referral for either DDU (stenosis characterization) or angiography.

### ***Randomized Trials of Preemptive PTA in Response to Surveillance***

To date, only a small number of studies have been performed prospectively to assess the impact of surveillance on outcome. These are summarized in [Table 16](#).

The concept that prophylactic or preemptive PTA would decrease graft thrombosis initially was refuted.<sup>382</sup> In a study of 64 patients identified to have a 50% stenosis by using DDU and confirmed by using angiography, preemptive PTA produced no change in 6-month or 12-month patency. Because of confounding issues, a subanalysis was performed on 21 “virgin” grafts that

**Table 16. Access Surveillance Studies with PTA Intervention**

Author, Year	Study Design	Surveillance Test	N	Type of Access	Follow-up (maximum)	Applicability	Difference in Access Survival	Quality
Moist 2003 <sup>386</sup>	RCT	UDT	112	100% AVG	450 d	↑↑	NS	●
Ram 2003 <sup>387</sup>	RCT	UDT and DDU	101	100% AVG	900 d	↑↑	NS <sup>a</sup>	●
Dember 2004 <sup>384</sup>	RCT	Static venous pressure <sup>b</sup>	64	100% AVG	Median 8.1 mo for Surveillance test and 16.5 mo for control (3.3 yr)	↑↑	NS <sup>c</sup>	●
Lumsden 1997 <sup>382</sup>	RCT	DDU	64	100% AVG <sup>d</sup>	Mean 15.2 mo (24 mo)	↑↑	NS	●
Martin e 1999 <sup>383</sup>	RCT		21	100% AVG	3.5 yr	↑		
Tessitore 2003 <sup>390</sup>	Prospective with concurrent control	UDT vs. Clinical exam	60	100% AVF <sup>f</sup>	Median 17.5 mo for UDT 13 mo for no PTA (40 mo)	↑↑	+	○

AVF=arterio-venous fistula; AVG=arterio-venous graft; DDU=duplex Doppler ultrasound; NS=not significant; PTA=percutaneous transluminal balloon angioplasty; RCT=randomized controlled trial; UDT=ultrasound dilution technique.

Access Survival defined as time to abandonment or time to intervention.

↑ Statistically significant beneficial effect of surveillance compared to "standard clinical evaluation"

a. UDT was ineffective; DDU for stenosis detection reduced thrombosis but increased PTA rates; no effect on graft survival

b. Static pressure ratio defined as systolic pressure in graft/mean arterial pressure; action level >0.4

c. Time to intervention was shorter in surveillance group. Proportion of patients with a thrombotic event was greater in the Observation group (72%) than in the Intervention group (44%) (P=0.04), but overall thrombosis rates were similar in the 2 groups.

d. Inclusion criteria: functional stenotic AVG

e. Subgroup of Lumsden 1997 with "virgin" AVGs

f. Inclusion criteria: functional stenotic AVF

had not previously clotted or required intervention.<sup>383</sup> Preemptive PTA from the time of diagnosis of stenosis reduced the thrombosis rate from 0.44 to 0.10 episodes/patient-year at risk. Both rates were much less than the rate of 0.91 in patients without virgin grafts. However, sample size was small ( $n = 19$ ). It should be noted that in this study, only anatomic assessment was obtained; no hemodynamic assessment was performed.

The small number of patients in this and all other prospective studies has limited assessment of efficacy. One prospective study using  $P_{IA}$  was performed.<sup>384</sup> Although the study itself was well designed, it was flawed by the surveillance technique. A preliminary study was performed in which monthly static venous pressure measurements were made during 2 consecutive HD sessions in all patients with a functioning upper-extremity graft in 2 HD units during a 16-month period. The method for deriving  $P_{IA}$  ratio differed significantly from that originally described<sup>10</sup> in that the ratio of systolic  $P_{IA}$  pressure to MAP was calculated instead of the ratio of systolic  $P_{IA}$  pressure/systolic blood pressure.<sup>385</sup> The net effect of this error is that the ratio would have been falsely elevated and the threshold value of 0.4 would not apply. In addition, measurements were performed less frequently than recommended. Not surprisingly, ROC analysis yielded curves with areas less than 0.64.<sup>383</sup> Subsequently, 64 patients with "elevated static venous pressure" measured in an upper-extremity graft were randomized to intervention (underwent angiography and repair of identified stenoses) or observation (underwent stenosis repair only in the event of access thrombosis or clinical evidence of access dysfunction), with the primary end point being access abandonment. Information on the fraction in the interventional group who had a stenosis is not provided. There was no difference in access abandonment (14 patients in each group) during the 3.5-year study period or in time to access abandonment. However, the proportion of patients with a thrombotic event was greater in the observation group (72%) than the intervention group (44%;  $P = 0.04$ ), but overall thrombosis rates were similar in the groups (ie, there was a difference in mean number of thrombosis per graft in the intervention group in grafts that did thrombose). Not detailed was the number of

PTAs that had to be performed in both groups during the entire study period.

Two randomized studies examined the role of access surveillance by using  $Q_A$ . In the first, it was found that stenotic lesions are detected more commonly by using  $Q_A$  ( $Q_A < 650$  mL/min or 20% decrease in  $Q_A$ ) than "routine surveillance" (physical examination plus  $DVP > 150$  mm Hg) in a total of 112 patients, but elective PTA for lesions greater than 50% did not alter thrombosis rate.<sup>386</sup> Rates of graft loss, times to graft loss, and overall thrombosis rates did not differ between the 2 groups. However, interventions increased by 30% in the intervention group. In the second study, 101 patients were randomized to 3 groups: control, low surveillance  $Q_A$  (Transonics) monthly, or stenosis detection by using DDU quarterly.<sup>387</sup> Referral for angiogram was based on clinical characteristics in all, less than 600 mL/min in  $Q_A$ , and greater than 50% diameter in the DDU stenosis groups.  $Q_A$  was measured in all 3 groups, but only used for referral in the flow surveillance group. Baseline thrombosis rates were 0.7 and 0.9/patient-year in the control and  $Q_A$  groups, respectively. Results showed that  $Q_A$  increased PTA rate marginally (from 0.22 to 0.33/patient-year) and had no effect on thrombosis rate. Stenosis surveillance increased PTA to 0.65/patient-year and reduced thrombosis rates to 0.5/patient-year, but did not affect 2-year survival rate.  $Q_A$  less than 600 mL/min was found in 4 of 18, 4 of 31, and 3 of 11 in the control,  $Q_A$ , and stenosis groups in grafts that clotted (overall, 11 of 60). However, 26 of 35 in the stenosis group underwent PTA for "stenosis." In both studies, 20% to 25% of accesses clotted without a surveillance abnormality, ie, in a totally unexpected manner.

However, the overriding conclusion of the studies that surveillance using  $Q_A$  and PTA in response to a threshold value of  $Q_A$  did not alter graft survival has to be tempered by the small sample size of the studies, the comparator used, and the efficacy of the intervention. Graft survival studies require a sample size of approximately 700 patients to detect an increase in graft survival of 1 year or a 33% difference in survival by 3 years (H. Feldman, personal communication). None of the studies had 20% of this number. It also is important to assess the skill level of the staff. If the staff can reach a positive predic-

tive value of 80% (when stenosis is present and needs intervention) through use of physical examination and clinical characteristics (monitoring), use of a surveillance method that has a sensitivity of only 80% will produce no benefit over good monitoring. Determining which lesions should undergo correction has already been addressed. Elastic recoil needs to be assessed.

In contrast to grafts, the role of  $Q_A$  surveillance appears to be more established in fistulae. In 1 study, the positive predictive value, negative predictive value, sensitivity, and specificity of ultrafiltration method for vascular access stenosis (OABF CritLine III) were 84.2%, 93.5%, 84.2%, and 93.5%, respectively. Vascular access thrombosis rates in 50  $Q_A$  surveillance patients were less (2 of 50 patients; 4%) than in 94 patients not followed up with flow measurements (16 of 94 patients; 17%;  $P = 0.024$ ).<sup>242</sup>

In a second study, a 5-year RCT of blood flow surveillance and preemptive repair of subclinical stenoses (1 or both of angioplasty and open surgery) with standard monitoring and intervention based upon clinical criteria alone was carried out in Italy.<sup>388</sup> Surveillance with blood pump flow ( $Q_B$ ) monitoring during HD sessions and quarterly  $Q_A$  or recirculation measurements identified 79 fistulae with angiographically proven significant (>50% diameter) stenosis that were then randomized to either a control group (intervention done in response to a decrease in delivered dialysis dose or thrombosis;  $n = 36$ ) or preemptive treatment group ( $n = 43$ ). Kaplan-Meier analysis showed that preemptive treatment decreased the failure rate ( $P = 0.003$ ) and the Cox hazards model identified treatment ( $P = 0.009$ ) and greater baseline  $Q_A$  ( $P = 0.001$ ) as the only variables associated with favorable outcome. Access survival was significantly greater in preemptively treated than control fistulae ( $P = 0.050$ ), with greater postintervention  $Q_A$  as the only variable associated with improved access longevity ( $P = 0.044$ ). This study provides evi-

dence that active blood flow surveillance and preemptive repair of subclinical stenosis reduce the thrombosis rate and prolong the functional life of mature forearm fistulae and that  $Q_A$  greater than 350 mL/min before intervention portends a superior outcome with preemptive action in fistulae.

Finally, in a third study, a prospective controlled open trial to evaluate whether prophylactic PTA of stenosis not associated with access dysfunction improves survival in native virgin radiocephalic forearm fistulae, 62 stenotic functioning fistulae (ie, able to provide adequate dose of dialysis) were enrolled: 30 were allocated to control, and 32, to PTA.<sup>389</sup> Kaplan-Meier analysis showed that PTA improved fistula functional failure-free survival rates ( $P = 0.012$ ) with a 4-fold increase in median survival and a 2.87-fold decrease in risk for failure. A Cox proportional hazards model identified PTA as the only variable associated with outcome ( $P = 0.012$ ). It was found that PTA increased  $Q_A$  by 323 mL/min ( $P < 0.001$ ), suggesting that improved fistula survival is the result of increased access flow. PTA also was associated with a significant decrease in access-related morbidity, halving the risk for hospitalization, central venous catheterization, and thrombectomy ( $P < 0.05$ ). Because prophylactic PTA of stenosis in functioning forearm fistulae improves access survival and decreases access-related morbidity, it supports the use of a surveillance program for the early detection of these stenoses.

### LIMITATIONS

At present, a vascular surveillance program to identify patients who may benefit from angiography and PTA appears to offer the most likelihood of benefit and may reduce thrombosis rates. However, we need additional studies to examine the characteristics of stenoses that produce incomplete responses to PTA so that patients are adequately treated at the time of their interventions.