Vascular Access for Hemodialysis

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Introduction

Adequate care of hemodialysis (HD) patients is inseparable from the problems of creating and maintaining the patency of vascular access. An ideal permanent vascular access should:

- deliver an adequate blood flow rate,
- provide longevity of use, and
- have low complication rates for stenosis, thrombosis, and infection.

Delivery of optimal HD requires a well-functioning vascular access with a nominal blood flow rate of 400 mL/minute without access recirculation. Failure of access function limits the delivered dose of dialysis which in turn is one of the major determinants of survival on dialysis [1].

The autologous arteriovenous (AV) fistula introduced by Brescia and Cimino in 1966 comes closest to satisfying the requirements for delivering adequate blood flow while minimizing complications. It has the best 5-year patency rate and during this period requires much fewer interventions than other access constructions [2]. Although cuffed venous catheters have evolved into an alternative form of long-term vascular access for patients in whom a permanent AV access cannot be readily created, construction of a permanent vascular access is preferred since it permits repeated angioaccess for months to years while minimizing risks from infection.

Although the autologous AV fistula is the desired access for patients initiating HD, there is disproportionate use of prosthetic access (AV grafts) in the United States compared to AV fistulas and an increasing dependence on permanent indwelling silastic central catheters. Furthermore, the frequency of AV fistula placement in the US is still low compared to Europe and Canada even after adjustments for demographic differences that may influence the choice of access. The most recent report of the US Renal Data System (USRDS) indicates that 60 days after the start of HD, treatments were performed using a functioning autologous fistula in only 17.9 % of patients, while PTFE/Bovine grafts were used in 50.3%, and either a cuffed or temporary catheters in the remaining 31.8% of patients [3].

In the US, lack of early vascular access planning and type of medical care prior to onset of end-stage renal disease (ESRD) as well as socioeconomic factors result in a disproportionate number of patients initiating in-hospital HD via temporary dialysis catheters [4]. For example, in a study by Ifudo et al., temporary HD vascular access was used for the first dialysis in 100% of patients with no prior medical care and 69% of patients who received prior care from a non-nephrologist but in only 36% of patients who received prior care from a nephrologist [5].

The National Kidney Foundation-Dialysis Outcomes Quality Initiative (NKF-DOQI)

recommends the increased construction of AV fistulas as the access of choice for HD as well as earlier referral of chronic renal failure (CRF) patients to nephrologists to permit access evaluation and early construction of an AV fistula or graft, thereby minimizing the use of venous catheters. Early protection of potential sites for native AV fistula construction is also of utmost importance.

After the access is constructed, the major issues relate to:

- detection of access dysfunction prior to access thrombosis;
- maintenance of vascular access patency; and
- prevention of infectious, ischemic, and aneurysmal complications.

Like many other facets of the care of the dialysis patient, improvements require that the treatment team develop and implement Continuous Quality Improvement (CQI) methodology. Dialysis centers thus need to detect vascular accesses at risk, track access complication rates and implement procedures that maximize access longevity. Achieving these goals requires the concerted efforts of nephrologists, nephrology nurses, access surgeons, vascular interventionists, patients and other members of the health care team.

Consequences of Vascular Access Dysfunction

The cost of treating ESRD patients includes not only the cost of dialysis and medications (procedural costs) but also the cost of all inpatient permanent access and outpatient temporary access-related services following access complications. Vascular access complications are reported to be the largest single cause of morbidity among HD patients and a major contributor to HD cost. The total estimated direct medical payments for the ESRD program by public and private sources in the USA was $13.06 billion in 1995. Expenses arising from access complications and their associated hospitalizations account for a substantial proportion of all expenses. The number of hospitalization for vascular access problems in 1995 was projected to exceed 90,000. At a conservative estimated cost per hospitalization of $7,500, access related costs rise above $675 million annually [6].

Estimated expenditures are likely to underestimate current total vascular access-related costs for several reasons. First, the annual cost of vascular access maintenance has been growing faster than the HD population. The total number of vascular access related hospitalization as a percentage of all cause of hospitalization has increased from approximately 17% in 1986 to > 20% in 1991 [6]. Vascular access complications can account for up to 30% of hospital admissions in some chronic HD programs [7]. About three-fourths of patients undergoing HD will be hospitalized for a vascular access-related problem during a 2-year period [8]. According to Rocco et al. a total of 2.43 inpatient days and 1.05 outpatient encounters per year are directly and solely attributable to access complications [9]. Second, the costs for hospitalization frequently quoted do not include payment by insurers other than Medicare. Third, outpatient costs for diagnostic procedures like fistulography, Doppler ultrasonography and outpatient therapeutic procedures such as thrombolysis and angioplasty are incompletely included in the estimations. Thus the annual cost of increasing vascular access related morbidity likely exceeds $1 billion/year representing nearly 10% of Medicare ESRD expenditures.

One of the most important causes for increased morbidity from vascular access is the progressive decrease in the fraction of native AV fistulas constructed relative to those of polytetrafluoroethylene (PTFE) grafts and indwelling permanent catheters. This most likely results from the interplay of several factors including a perception of higher primary failure rate of native AV fistula in older diabetic patients with peripheral vascular disease (PVD) and the relative rapid usability of PTFE grafts and permanent catheters. In the US, it is presently estimated that < 25% of ESRD patients undergo construction of the native AV fistula [6, 8, 10]. In some geographic areas, up to 85% of patients undergo HD using prosthetic grafts or permanent catheters [10]. Construction of a greater proportion of PTFE or other prosthetic graft accesses is accompanied by increased event rates that translate into increasing costs. Several studies document that the event rate in grafts is 3 – 5-fold higher than in autologous AV fistulae [2, 11, 12]. The reported complication rate for autologous AV fistulas is 5/1000 patient-months as compared to 37/1000 patient-months for PTFE grafts [11]. Mehta reported equivalent assisted patency survival for AV fistulas and prosthetic grafts for the first 2 years, but a nearly 4-fold higher procedure rate to maintain such patency in grafts [2].

Data from Wave 1 study of the USRDS reported that despite the aging of the population, native fistulas had a greater primary survival (time to first failure) than grafts [13]. Besarab et al. reported that primary and secondary patency (time to complete failure) dated from time of construction was superior in native fistulas while complication/event rates were 70% lower than in PTFE grafts [14]. Unfortunately in this study as well as in the study by Ifudu et al. [5] and Hood et al. [4], more than half of the patients requiring dialysis presented without prior adequate medical care and required urgent dialysis. Besarab et al. [14] found that the odds ratio for placement of a graft were 2.2 for females (vs. males) and 4.1 if pre-ESRD care was provided by a non-nephrologist. Age, diabetes mellitus (DM), and frequency of clinic visits had no influence on the likelihood of AV fistula placement.

Driven by cost-control issues in the 1990s, most vascular access procedures have shifted from the in-patient to the outpatient setting. This has not reversed the increased use of grafts and catheters nor slowed the increase in access-complication associated costs [3, 15, 16].

Correction of inordinate delay in access placement is simply achieved by earlier referral of patients with CRF to nephrologists. This requires a paradigm shift among MCO/HMOs with specialists assuming care for pre-ESRD patients. Initial costs are likely to increase from such early participation by nephrologists and vascular surgeons. However, such early participation can significantly reduce the need for temporary catheters, reducing not only the direct procedural costs but also indirect hospitalization costs associated with catheter complications (pneumothorax, hemothorax, and sepsis). A mechanism for providing health care to the uninsured pre-ESRD patients must also be developed.

The other major source of costs attributable to vascular access arises from non-mechanical complications. Chief among these is access-related infection and bacteremia. Within our system of > 800 HD patients, almost half of the vascular-access related admissions result from line-related sepsis (temporary or permanent catheters). Infectious complications are a source of substantial morbidity and a common cause of death among HD patients, accounting for about 20 – 25% of all vascular access complications [12, 17, 18]. Data from

1995 USRDS indicate that 12% of all deaths among HD patients is attributable to infection [19]. Septicemia is the underlying cause in 76% of these infectious deaths. Sepsis from vascular access accounts for 12 – 25% of these septicemia-related deaths [19, 20]. Among HD patients, Keane et al. reported an average of 7.6 bacteremic episodes/100 patient-years, 48% of which were associated with access infections. AV fistulas have a much lower rate of infection than PTFE grafts [21, 22] or catheters [23].

Despite the considerable economic resources committed to the care of ESRD patients in the USA, death rates adjusted for age, race, gender and primary diagnosis during the first year of dialysis therapy remain high [24]. Cox proportional hazards models, stratified for DM, have examined the effect of delivered dose of dialysis on major causes of death after adjustment for other demographic covariates and comorbid diseases. These results indicate that low dose of dialysis is associated with a number of the major causes of death in the ESRD population [25]. Low doses of dialysis may promote atherogenesis, infection, malnutrition and failure to thrive through a variety of pathophysiologic mechanisms. HD vascular access dysfunction is an important cause for inadequate dose of dialysis.

Close attention to vascular access management has great potential for improving quality of life and overall outcomes for HD patients. The high overall costs and the large fraction of costs that still accrue from inpatient settings clearly indicate that opportunity for savings exist from optimizing vascular access care. The quality of life for dialysis patients in any center may reflect the standard of its vascular access service with poor access causing significant morbidity and mortality.

HD Vascular Access Types

The need for vascular access in patients with renal failure can be either temporary or permanent. Need for temporary access may vary from several hours (single dialysis) to months (if used to bridge maturation of a primary autologous AV fistula). Temporary access is usually established by the percutaneous insertion of a catheter into a large vein (preferably femoral or internal jugular; subclavian is less desirable).

Venous Catheters

As Acute Access for HD: These provide rapid and temporary access for HD. Uncuffed dual lumen central venous catheters are preferred because of the ease of insertion and immediate usability. They are inserted only when required and when functioning well these catheters provide blood flow rates of 250 – 300 mL/minute with a recirculation of < 2%. If the ports of the catheters are reversed the recirculation rate can increase up to 20%, compromising the adequacy of dialysis especially in hypercatabolic patients [26]. The common situations requiring acute vascular access are summarized in Table 1.

As Permanent Access for HD: Soft silastic cuffed catheters are emerging as an alternative form of long-term vascular access for patients in whom a permanent AV access cannot be readily created. Table 2 lists the indications for use of these catheters as permanent access.

These silastic catheters can be used for extended period of time and presently account for 10 – 15% of the permanent vascular access in most dialysis centers [27]. However, survival rates for cuffed double-lumen catheters are about 60% at 6 months and 40% at one

Table 1. Indications for Acute Vascular Access

1. Acute renal failure requiring HD
2. Chronic renal failure patients needing urgent HD but without available mature access
3. Maintenance HD patients who have lost effective use of their permanent access and require temporary access until permanent access function can be re-established
4. Peritoneal dialysis patients whose abdomens are being "rested" prior to new peritoneal catheter placement
5. Transplant recipients needing temporary HD during severe rejection episodes
6. Patients requiring plasmapheresis or hemoperfusion

Table 2. Indications for Catheters as Permanent Vascular Access

1. Small children
2. Diabetic patients with severe vascular disease.
3. Morbidly obese patients
4. Patients with multiple failed AV access insertions in whom additional insertion sites for AV access are not available.
5. Patients with cardiomyopathy unable to sustain adequate blood pressures or access flows.
6. Patients who require frequent blood access (daily nocturnal home HD)

year if revisions are included [28]. A primary dysfunction rate of 2% and an infection rate of > 50%/year has been reported [29]. Adequate blood flow through cuffed venous catheters is a significant problem. Although such silastic catheters have a nominal blood flow rate of 400 mL/min in 73% of cases [28], actual flow rates of 350 mL/min can rarely be sustained and usually flow is limited to a value closer to 300 mL/min. These low flows have limited the use of permanent cuffed venous catheters in larger patients receiving high flux dialysis since adequate dose of dialysis (*Kt/V*) is difficult to achieve in < 4 hours. The advantages and disadvantages of tunneled cuffed catheter relative to other permanent access are shown in Table 3.

Because of the limitation of blood flow of most double lumen catheters, recent interest has focused on use of twin silicone rubber catheters (Tesio catheters), each with its own cuff for either long-term temporary or permanent access [30]. A higher flow rate with these catheters is claimed. Although mean flow rates (blood pump setting) are in the range of 400 mL/min, actual measured blood flow is 360 mL/min [31]. Other advantages of the Tesio catheters (none proven in randomized trials) are increased patient comfort, less positional dysfunction (as the outlet ports are wound spirally around the distal parts of each catheter), and perhaps increased longevity. However, they are more difficult, to place initially than other catheters.

Catheter material: Thrombogenicity and flexibility primarily determine the choice of the material. Acute catheters are typically made of polymers such as polyurethane, polyethylene and PTFE. Polyurethane is chemically stable and appears to offer the best balance between rigidity at room temperature and flexibility at body temperature and has less thrombogenic potential compared to other materials [32]. Soft silastic (silicone elastomer) catheters are the most pliable and least thrombogenic and produce less trauma to the vascular intima. Initial designs required peel-away sheaths for their percutaneous insertion. Newer designs have overcome this by incorporating an internal stylette. Incorporation of antimicrobial substances in the catheter material may reduce the rate of catheter-related infections.

Table 3. Advantages and Disadvantages of Tunneled Catheters as Permanent Access

Advantages	*Disadvantages*
– Universally applicable	– High morbidity from infection and thrombosis
– Multiple insertion sites	– Risk of central vein stenosis and occlusion
– No maturation time	– Discomfort and cosmetic effect of external appliance
– No hemodynamic consequences	– Shorter useful life span
– Ease and cost of placement	– Lower blood flows
– Ease of correcting thrombotic complications	
– No venipuncture requires	

Catheter Design: Dual-lumen venous catheters have one of 2 basic cross-sectional configurations for the 2 blood pathways: either a "double-D" configuration or a coaxial cylinder configuration. The double-D design delivers a higher blood flow rate [33]. The arterial ports are placed typically 2 – 3 cm proximal to the venous port to minimize recirculation. Advancement in catheter design, especially development of curved shafts in acute catheters, increases patients' acceptance because such catheters can be easily secured, allowing free head and neck movements.

Use of an uncuffed catheter for periods of time beyond several weeks results in a relatively high rate of infection. Bonded felt or Dacron cuffs were added to extend the use of venous catheters from weeks to several months by reducing line-related infection and catheter migration. Unequivocal demonstration that cuffs prevent infection has not been shown [34]. Cuffed catheters require "surgical" tunneling for placement, further increasing the complexity of the procedure. Therefore, non-cuffed catheters are usually chosen when the need for HD is projected to be < 3 weeks in duration, although some centers use cuffed catheters routinely for cases of acute renal failure (ARF), when the duration is expected to extend beyond 1 week. Cuffed silastic catheters are preferred if the need for dialysis is > 3 weeks duration. Use of cuffed catheters is especially useful when one is planning to or has just placed an AV fistula, which requires several months to mature properly.

Insertion sites: Uncuffed double-lumen catheters are inserted percutaneously by the Seldinger wire technique. The preferred site for both uncuffed and tunneled cuffed catheters is the right internal jugular vein, which offers a more direct route to the caval-atrial junction and together with its softness and flexibility causes less intimal trauma. The subclavian site should generally be avoided because of the high incidence of venous stenosis and thrombosis associated with its use that can compromise the creation of AV fistula or graft in the ipsilateral arm [35]. The rate of other complications (e.g. pneumothorax) related to subclavian vein cannulation is also higher compared to jugular vein insertion [36]. According to the NKF-DOQI recommendations, subclavian access should be used for cuffed catheters only when jugular options are not available and the tunneled cuffed catheter should not be placed on the same side as a maturing AV access.

Use of a portable real-time ultrasound to guide insertion is recommended to reduce

insertion-related complications. The central veins of the neck exhibit significant anatomic variability and one of them may occasionally be absent [37]. Atypical or ectatic carotid arteries are also a problem. The rate of successful internal jugular puncture on the first attempt increases 2-fold to > 80%, and the rate of carotid artery punctures is reduced from 8 to 0% when insertion is performed under ultrasound guidance [38]. The principal disadvantage of the jugular vein approach is that the catheter is difficult to fix to the skin in this position and neck mobility is impaired. These disadvantages can be overcome by tunneling over the clavicle to the skin exit site on to the anterior chest wall. The optimal tunnel design has not been clearly established. For the catheter inserted into the superior vena cava, curved tunnels permit smooth passage of the catheter to the anterior chest wall. Similarly curved tunnels permit approach from the lateral abdominal wall to the inferior vena cava. They therefore provide comfort to the patient and minimize kinking. Cuffed catheters are commonly used but are not necessary as long as the catheter is secured to prevent migration.

Fluroscopy is mandatory for insertion of all cuffed upper extremity dialysis catheters since the catheter tip has to be adjusted to the level of caval-atrial junction or beyond to ensure optimal blood flow and to ensure that complications have not occurred. Femoral catheterization is the preferred choice for most emergencies like pulmonary edema (the patient's head and chest can be kept elevated during insertion) or acute poisoning (catheter requirement is usually only several days) but the catheters should be ≥ 19 cm long to minimize recirculation. The increased rate of infection up to 10% at one week, along with the high dislodgment rate mandates the uncuffed femoral catheters to be left in place for no more than 5 days.

Arteriovenous (Scribner-Quinton) Shunt

The surgical implantation of paired, interconnected plastic tubes into an extremity artery and a nearby vein, first introduced in 1960, is now mostly of historic significance. The long-term usefulness of this vascular access method is limited by the need to sacrifice vessels. Patency of the shunt depended on the continuous flow of blood through it and provided extra-corporeal flows of only 200 mL/min, a flow too low for most modern HD. The Scribner-Quinton shunt is plagued by a multitude of problems chief among these being a high rate of thrombosis, recurrent infection, and the risk of accidental dislodgment. This form of access should never be used if there is even a slight possibility that the patient's condition will eventually require chronic HD. Double-lumen catheters have largely replaced it.

Complications of Catheters used for Acute Access

Insertion-related complications: Placement of dual-lumen catheters for temporary or permanent HD is associated with many short and long term complications. Although specific complications vary with site of insertion, distortion of the anatomical landmark from obesity, trauma, surgery, radiation, previous hematoma or other unrecognized vascular anomalies and the presence of coagulation disorders increases the rate of complications. The complications associated with insertion of catheters for HD is summarized in Table 4. Acute complications are defined as those occurring immediately or within several hours. Delayed complications may not occur for days or weeks.

Table 4. Complications of Catheter Access Insertion into the Superior Vena Cava

Acute complications	*Delayed complications*
External bleeding	Venous thrombosis
Subcutaneous hematoma	Venous stenosis
Internal bleeding	Sternal osteomyelitis
Hemothorax	Bacterial endocarditis
Pneumothorax	Artery to vein fistula
Air embolism	Hydromediastinum
Hemothorax/hemomediastinum	Superior vena caval syndrome
Cardiac tamponade	Pulmonary embolism
Damage to blood vessel	Unilateral breast enlargement
Arterial perforation	Chronic massive arm edema
Perforation of SVC	
Perforation of the thoracic duct	
Perforation of the trachea	
Perforation of the myocardium	
Damage to the brachial plexus, peripheral nerves or cervical sympathetic chain	
Acute bacteremia/septicemia	

The overall success of superior central vein cannulation and the complication rate depends upon the physician's experience and the use of ultrasound to localize the vein [36 – 40]. The sum of all major immediate complications should not exceed 5% of all central venous catheter placements. Subclavian vein cannulation carries a greater risk for immediate and late complications compared to the internal jugular approach [41]. Arterial puncture is a common complication of central line insertion. Direct compression is not possible in subclavian arterial puncture, resulting in serious hemorrhagic complications in 1% of the patients.

Prior to the use of ultrasound guidance, pneumothorax complicated 1 – 5% of the subclavian catheterization compared to < 1% with internal jugular cannulations [36, 39]. However, a 7 – 16% failure rate in accessing the internal jugular vein has been reported even when performed by experienced operators, probably as a result of aberrant anatomical position of the internal jugular vein in 14% of cases [42]. Puncture-related complications occurred in up to 11% of the cases [43]. Ultrasonographic-guided internal jugular vein cannulation increases the success rate of first attempt cannulation from < 40 – 60% to > 85% along with lower rates of complications [38, 44].

Myocardial irritation from guide wire or catheter contact produces atrial arrhythmias in up to 40% and ventricular arrhythmias in 10% of patients, but fortunately < 1% require anti-arrhythmic medication [45]. More serious life-threatening complications of central vein cannulation include perforation of vessel wall or atria leading to hemothorax or cardiac tamponade, respectively. Rare complications include strokes from paradoxical cerebral embolism from the catheter tip or atrial thrombus via a patent foramen ovale. Bleeding caused by heparin block or accidental disconnection

of the catheter clamp and cap can lead to exsanguination.

During femoral vein cannulation, inability to cannulate the vein results mostly from distortion of the anatomy since vascular anomalies in the femoral triangle are extremely rare. The common complications are arterial puncture and hematoma. Rarer complications include iliofemoral thrombosis, pulmonary embolism and retroperitoneal hematoma. As with internal jugular vein catherization, ultrasound guidance as compared to external land mark technique increases the success rate of femoral vein cannulation from 89.5% to 100% and reduces the complication of arterial puncture from 15.8% to 7.1% and that of hematoma from 2.6% to 0% [40].

HD access infection: Infection is the leading cause of catheter loss and as discussed previously increases morbidity and mortality [16 – 20]. Roughly one-fourth of all vascular access-related hospitalizations are attributed to access-related infection or inflammatory disorder [8]. In the most recent USRDS (1997) report, the fraction of adult HD patients dying of infection was 15.5%; access infection contributes significantly to this percentage. Even for dual-lumen tunneled cuffed catheters, the infection rate is 3.9 to 9 episodes/1000 catheter-days at risk, a value not different from that of 1.6 to 8.6 episodes/1000 catheter-days for uncuffed, untunneled catheters [34]. The mortality directly attributed to the use of central venous catheters appears to be in the range of 1% [35].

Pathogenesis: Infection usually arises from the migration of the patient's own skin flora through the puncture site and onto the outer catheter surface, although it can also result from contamination of the catheter connectors or lumen contamination during dialysis. Catheters can also become colonized from more remote sites during bacteremia. Colonization of the intravascular portion of the catheter will generally express itself as a febrile episode during HD. Gram-positive bacteria (usually *Staphylococcus* species) are the most frequent organisms.

Classification: Infection of cuffed HD catheters is traditionally subdivided into exit site infection, tunnel infection and catheter-related sepsis. An alternative classification is provided in Table 5.

Risk factors and Prevalence: Factors contributing to catheter infection are listed in Table 6. The most important factor producing infection is the duration of catheter use. Immunocompromised patients, drug addicts, and patients with a previous episode of bacteremia are at increased risk for catheter-related bacteremia. The incidence of infection of central vein uncuffed catheters is generally < 8% by 2 weeks. By one month, 25% of uncuffed central catheters become infected and this figure doubles by the end of the second month. Catheter-related septicemia may occur in 2 – 20% of catheters. An infection of the exit site or subcutaneous tunnel infection has not been prominently reported as a precursor of catheter-related bacteremia

Table 5. Diagnosis of Central Venous Catheter Infection

Definite infection
– Erythema and tenderness along the catheter tunnel
– Fluctuance along the tunnel
– Loss of adhesion of anchoring cuff
– Purulence at exit site
Probable infection
– Sepsis without definite alternate source
– Fever >38 °C
– Rigors especially during dialysis
Possible infection
– Low grade fever
– Leukocytosis

Table 6. Factors Contributing to Catheter Infection

– Duration of the catheter use
– Immunocompromised status
– Nutritional status and co-morbidity factors such as diabetes
– Nasal *S. aureus* carriage
– Type of dialysis membrane
– Type of HD procedures and insertion techniques
– Injection drug use and previous bacteremic episodes

in HD patients. Infectious complications particularly septicemia ultimately limit the longevity of the indwelling catheters in at least 25% of patients.

Bacteriology: Gram-positive cocci, particularly *S. aureus,* account for 53 – 63% of all catheter-related bacteremias; 24% are due to gram-negative rods, and 11 – 12% due to multiple organism [34, 46]. Metastatic complications such as endocarditis, bone and joint infections have been reported in up to 23% of catheter-related bacteremia and up to 41% with *S. aureus* infection [34].

Management: There is no universal agreement about the management of cuffed HD catheter infection. Ideally all infected catheters should be removed, a stance limited by the practical necessity of maintaining HD access site in patients who have lost all other access sites. Localized exit site infections can be treated with systemic antibiotics combined with local care often without loss of the catheter. Patients with tunnel infection, abscesses or loss of anchoring of the cuff should have the catheter removed, as there is no hope of salvage. Salvage of the catheter in patients with catheter-related bacteremia without tunnel infection and catheter salvage is successful in only 32% of cases [34].

Attempting salvage of central venous catheters in patients with limited or no other access sites should be done carefully with frequent monitoring of the patient for signs of sepsis and blood cultures for continuing bacteremia during therapy. Initial antibiotics should cover both gram-positive and gram-negative organisms. Once cultures are available, the antibiotics can be tailored and therapy continued for up to 4 weeks. In difficult cases, antibiotics can be *"locked"* in the catheter between dialysis sessions in addition to the use of systemic antibiotics. The patient must be observed closely for signs and symptoms of sepsis particularly during HD. If these or hemodynamic instability, evidence of a tunnel infection, positive surveillance cultures during therapy, or metastatic infection develop, the catheter must be removed. If a new site is not available, an attempt at salvage can be attempted by changing the catheter over a guidewire [47]. Prolonged attempts to salvage an infected, cuffed catheter can lead to serious complications (endocarditis, osteomyelitis, suppurative thrombophlebitis). Spinal epidural abscess is a rare but serious neurological complication in HD patients. In one series, 50% of cases were associated with attempted salvage of an infected cuffed venous catheter [48].

Prevention of catheter infection is of prime importance. The use of dry gauze dressing and povidone iodine ointment at the catheter exit site can reduce the incidence of exit site infections. Surgical masks worn by the patient and nurse at any time the catheter is accessed reduces the spread of nasal droplet infection. Catheter hubcaps or blood line connectors should be soaked for 3 – 5 min in povidone iodine and than allowed to dry prior to separation and the catheter lumen should be kept sterile at all times and never remain open to the air. Prophylactic antibiotics should be given for procedures likely to produce bac-

Table 7. Types and Management of Catheter Thrombosis

Types of catheter thrombus	*Management*
Intracatheter (or) Luminal	Avoid forced irrigation, Intraluminal thrombolytics
Extracatheter	
Fibrin sleeve	Catheter venogram, low dose thrombolytics for 24 hours, catheter stripping.
Mural thrombus	Catheter removal, anticoagulation, catheter-directed thrombolysis. Surgical thrombectomy as last resort.
Ball valve thrombus	Catheter removal, anticoagulation therapy.

teremia (dental work, sigmoidoscopy, colonoscopy, and endoscopic retrograde chloledochopancreatography (ERCP)).

Catheter Dysfunction: This is a most vexing problem. It is classified as intracatheter, fibrin sleeve, or mural and the specific site of catheter obstruction may require diagnostic studies: catheter venograms, venograms, or intravascular ultrasound. When it occurs early, it is due either to malposition or to intracatheter thrombosis. Many dysfunctional catheters exhibit positional occlusion during dialysis. Early catheter dysfunction (< 5 days from insertion) is usually the result of intracatheter thrombosis or catheter malposition. Late dysfunction results from fibrin sleeves or mural thrombosis. The classification and management of catheter thrombosis is summarized in Table 7.

Intracatheter thrombosis (luminal obstruction) is the most common complication occurring in up to 10% of all dialysis treatments with cuffed silicone catheters [49]. These are easily detected since they interfere with extracorporeal blood flow. Most of these will respond to intraluminal thrombolytic injection of urokinase. It is important to initially fill the dead space of the catheter lumen with the thrombolytic agent and inject 0.3 ml of heparinized saline at 5 – 10 min intervals in order to permit the thrombolytic to reach and work on the clot. More than one instillation of urokinase may be necessary to re-establish patency. Patency is restored in 90 – 95% of cases.

Malposition or catheter tip thrombus presents as persistent low flow despite urokinase treatment. Fluoroscopy with or without contrast injection is needed for diagnosis. Large catheter tip thrombi usually require systemic thrombolysis (urokinase 20,000 U/hour for 6 hours or streptokinase 3000 U/hour for up to 24 hours). If a thrombus is absent and access sites are limited, the catheter can be changed over a guide-wire, but the problem is likely to recur.

Fibrin sleeves are the most common reason for late dysfunction. Virtually all central vein catheters develop a fibrin sleeve within one to several weeks after insertion. Fibrin sleeves are initially clinically silent until they obstruct the ports at the distal end of the catheter.

Saline infuses into a port easily but aspiration is difficult due to a check-valve effect. Fibrin sleeves can serve as a nidus for infection as well. A catheter venogram should be performed to confirm the diagnosis. A variety of methods can be used to handle fibrin sheaths. Low-dose systemic thrombolytics (urokinase 20,000 U/hour for 6 hours or streptokinase 3000 U/hour for up to 24 hours) are usually the first option. If unsuccessful, advancement of a snare from the femoral vein up the inferior vena cava to the occluded catheter permits stripping of the fibrin sheath. The adherent fibrin sleeve/thrombus pulled from the catheter usually embolizes into the lung. Clinically evident pulmonary embolism has been reported from this procedure, but is unusual. Alternatively because of the expense of snare catheter stripping, some centers merely exchange the catheter over a guidewire since it has been shown to be as effective as snare catheter stripping in the case of fibrin sleeve formation.

Mural thrombi usually develop at the vessel wall and can result in permanent vessel occlusion. Large mural thrombi can proceed to stenosis and central vein thrombosis. The usual manifestations consist of limb edema and distended or varicose collateral veins secondary to venous obstruction. A clot adherent to the end of the catheter is a *ball thrombus. Right atrial thrombus* result from an injury to the endocardium. Pulmonary embolism from mural thrombi or catheter-related thrombi is fortunately rare but can occur weeks or months after catheter removal, presumably by ongoing growth of thrombus on an injured endothelial surface. Diagnosis is best made by venography through the catheter. This problem is best handled by catheter removal followed by systemic anticoagulation, and if it is still refractory, radiologically-directed thrombolytics. Surgical thrombectomy is the method of last resort.

The incidence of early dysfunction due to malposition is strongly dependent on the experience of the person performing the insertion. Tesio type silicone catheters may have a lower incidence of positional dysfunction due to the spiral winding of their exit holes around the distal 3.5 cm of each catheter. Silicone catheters appear to have less fibrin formation than other catheter materials. Although chronic administration of warfarin or other anticoagulants may limit fibrin sleeve formation and catheter thrombus formation, there is no systematic study examining use of anticoagulants for this purpose. If used, we believe that systemic anticoagulation is required with International Normalized Ratio (INR) of 2 to 2.5 (personal experience).

Central Vein Stenosis: This is one of the more severe complications arising from the use of catheter access. Endothelial injury occurs at the site of catheter-endothelial contact. The major risk factors for central venous stenosis are use of stiff non-silicone catheters, associated catheter infections and prolonged use of catheters. Subclavian vein thrombosis or stenosis has been reported to follow 20 – 50% of subclavian catheter insertions. Surveillance venograms 6 months following catheter removal show a 3-fold higher rate of subclavian vein stenosis among patients with previous catheter-related infections than in those free of such infections [50]. The incidence is lower in the internal jugular vein as compared to subclavian vein approach (10% vs. 42%) [51]. Once a stenosis develops it may be asymptomatic and remain clinically silent until unmasked by the creation of AV fistula. Symptoms invariably are those of gross edema of the entire arm and in extreme cases venous skin ulcers. When the stenosis develops after an access has been placed, development of the edema is slower. Initial management with anticoagulation and elevation of the arm may ameliorate the symptoms and signs.

Angioplasty can definitely restore the patency but restenosis is common. Stent placement following angioplasty is indicated in elastic central vein lesions or if the stenosis recurs within a 3-month period. Ligation of the vascular access produces the most rapid improvement, but sacrifices the access. Some patients may be candidates for surgical axillary-internal jugular bypass of the affected subclavian vein. Pulmonary embolization is rare.

In summary, central venous catheters provide acceptable acute access for HD, but their use is fraught with a number of problems. Chief among these is the development of central vein stenosis that frequently precludes the establishment of a more permanent access. Infection remains a major problem. Impregnation of catheters with antiseptic substances may reduce the incidence of infection. To date, no catheter material or placement technique has the requisite properties that minimize trauma to the endothelium. Catheterization of the subclavian vein should be minimized in anyone potentially at risk for ESRD who might require future permanent access.

Permanent Arteriovenous (AV) Access

Since vascular access failure is the major cause of morbidity and hospitalization for HD patients, the NKF-DOQI has enumerated 4 key issues relating to vascular access care in HD patients. At the heart of the recommendations is the need to create a higher proportion of native AV fistulas that provide long-term access with the fewest access procedures [4, 10, 14]. Anticipation of need is paramount.

Protection of the cephalic veins, especially of the nondominant arm, is crucial in patients with progressive renal failure. This permits construction of native AV fistula preferably at the wrist and, if not possible at this site, then at the elbow.

The need for AV fistulas should be anticipated in advance of the need to initiate HD. This requires earlier referral of CRF patients to the nephrologist for planning of dialysis modalities and advanced discussions about access construction. If a native AV fistula is not possible, access may be established using a PTFE graft or a transposed brachial-basilic vein fistula. If all of the above measures are still not possible, then placement of a cuffed tunnel central venous catheter as a permanent vascular access is appropriate.

Periodic monitoring of the accesses for hemodynamically-significant stenosis prior to thrombosis is necessary. If present, expeditious management by angioplasty or surgical revisions is necessary. This minimizes the number of catheters needed and reduces the risks of underdialysis from catheters.

Educational programs on the importance of the care of the vascular access should be provided to patients and to care providers.

Preoperative Evaluation

Characteristics of the patient's arterial, venous, and cardiopulmonary systems determine the access most suitable for a given patient. Life expectancy may also influence the type and access location. Comorbid conditions like severe coronary artery disease or malignancy that limit life expectancy may preclude anything but a cuffed catheter as permanent access. Patients who are likely to undergo preemptive living transplantation might also not require permanent vascular access surgery.

History: Crucial features in the history are previous placement of a central venous catheter or transvenous pacemaker because of the possibility of vein stenosis. Hemodynamics

and cardiac function in a patient with marginal heart function can be adversely affected by any AV access. History of arterial or venous vascular disease or the presence of DM also limit access construction options. Previous surgery or trauma to the arm, chest, or neck can limit access site construction.

Physical Examination: Examination of the arterial and venous systems supplemented by hand-held Doppler when necessary is usually sufficient. The blood pressure should be measured in both arms, an Allen test performed, and arm sizes measured and compared. The patient should be examined for evidence of previous central vein catheterization and for trauma or surgery of the arm, chest or neck. Some surgeons perform tourniquet-assisted venous mapping to select the best veins for access. In patients with progressive renal disease, every attempt must be made to preserve upper extremity veins that can be used to construct future accesses. The presence of 6 cm segment of cephalic vein at the wrist is needed to create a wrist AV fistula. Whenever possible, construction of AV fistula is preferred but not always possible.

Radiologic Studies: Doppler ultrasound or venography may be required to exclude central vein stenosis [52]. Indications include edema in the extremity, collateral veins around the shoulder or on chest wall, differential extremity size, previous or current transvenous pacemaker, and multiple previous access constructions in the extremity. Doppler measurement of brachial artery flow > 80 mL/min prior to access construction is predictive of maturation of access [53]. Doppler venous studies may also identify suitable veins for AV construction that are not readily visible on the surface. Arteriography is done only if pulses in the desired access location are markedly diminished or absent.

Anticipating the need for autologous access fistula construction: This requires that venipuncture or placement of intravenous (IV) catheters into forearm veins be minimized in patients with progressive renal failure. The dorsum of the hand should be used. The AV fistula should be created 4 – 6 months prior to the initiation of HD; the latter can be anticipated from the rate of rise of the plasma creatinine level. Patients should be referred to the surgeon when the serum creatinine is > 4 mg/dL.

Construction in patients on peritoneal dialysis (PD): With the increased ability to bridge PD patients through a period of temporary loss of peritoneal access (from catheter obstruction, infection, leakage, or hernia) by using percutaneous venous catheters, the previous common practice of creating an AV fistula in patients planning to start PD has been abandoned by many centers. However, the high incidence of catheter malfunction, peritonitis, and technique failure places these patients at risk each time a temporary catheter has to be placed, a risk avoided by AV fistula creation [54].

Construction principles: The surgical consensus as articulated by Palder et al. [55] promotes the use of the non-dominant arm, beginning as distally as possible and moving up the arm proximally as access fails. When all sites in the non-dominant arm have been exhausted, the dominant arm is used.

Autologous Arteriovenous Fistula

These fistulas consists of a subcutaneous anastomosis of a artery and an adjacent vein. Maturation, a process of dilatation and thickening of the wall of the venous limb of the fistula to permit repeated insertion of dialysis needles requires 3 – 4 months. Therefore, an AV fistula should be constructed in advance of the need for HD. The fistula is usually created in the non-dominant arm to facilitate

self-dialysis and limit the consequences of any functional disability should any occur.

Characteristics: AV fistulas are the safest and the most durable permanent vascular accesses. Their advantages compared to other access types include excellent patency, lower morbidity associated with their creation, and lower complication rates (infection, stenosis, and steal). For equivalent degrees of assisted patency, the AV fistula requires a 3 – 4-fold lower number of procedures [4, 14]. Disadvantages include the long maturation time as well as failure to develop adequate blood flow sufficient to support the dialysis prescription in some patients.

Creation of an adequate AV fistula may not be possible in some diabetic patients or those with severe atherosclerotic arterial disease. Marked obesity, the presence of small or deep veins, or veins damaged by multiple venipunctures may also limit the possible creation of an adequate AV fistula. It is generally believed that elderly patients are less likely to have suitable anatomy to create an AV fistula. In our experience, age has not been a factor, although more attention must be paid to maturing the access [14]. Doppler ultrasound mapping studies may identify veins not readily apparent to nephrologist or surgeon.

Construction: Wrist radial-cephalic *(Brescia Cimino 1966)* and elbow brachial-cephalic AV fistulas are the 2 types most often created. Other options include a "snuff-box" fistula, wrist ulnar-basilic and a transposed elbow brachial-basilic fistula. The anastomosis can be made either side-of-artery to side-of-vein or side-of-artery to end-of-vein. In both instances, blood flow through the artery distally is preserved. With the side-to-side method, higher pressure may sometimes be transmitted to the veins in the hand resulting in venous hypertension and swelling. The side-of-artery to end-of-vein anastomosis prevents venous hypertension of the hand because the distal vein is tied. The surgery is usually performed in the operating room under regional anesthesia. Details of the operative technique are beyond the scope of this chapter.

Postoperative care: The arm should initially be kept elevated. Tight circumferential dressings must be avoided. The fistula blood flow should be checked several times during the first 24 hours and then daily by palpating for a thrill at the fistula site and by listening for the associated bruit. The fistula should never be used for venipuncture. Failure to develop superficial veins of the fistula may result from inadequate arterial (brachial or radial artery) inflow, from an anastomotic stenosis due to fibrosis or from flow into deep side branch veins. In the latter situation (diagnosed by venography), ligation of such veins may result in successful maturation.

Maturation: This is a process of dilatation and thickening of the wall of the venous limb of the fistula and is necessary in order to repeatedly insert dialysis needles. Maturation of the AV fistula takes from 1 – 6 months. Regular hand exercises with or without a lightly applied tourniquet can aid in access maturation. An AV fistula should not be used before it is mature. Use of percutaneously placed cuffed catheters can bridge the period of several months if dialysis is needed prior to AV fistula maturation. Premature access cannulation is associated with infiltration and compression of the vessel and with permanent loss of the fistula. Infiltrated fistulas should be rested.

Arteriovenous Graft

When an adequate autologous AV fistula cannot be created, the AV connection can be made using *a tube* graft made from a variety of synthetic or biologic materials. Synthetic

polytetrafluoroethylene (PTFE) grafts are the preferred materials since they provide superior performance compared to biologic bovine heterografts. Dialysis AV grafts can be tapered or uniform, externally supported, thick- or thin-walled. AV grafts have the following advantages over AV fistulas:

– easy surgical handling characteristics,
– easy cannulation,
– large surface area, and
– short maturation time.

Long term patency of an AV graft is inferior to an AV fistula despite a 3 – 4-fold increase in salvage procedures.

Configuration and location: Grafts may be placed in straight, looped or curved configurations. The location is determined by patient-specific features as well as the projected length of the need for HD. In general, more distal placement preserves potential sites but such grafts may experience more frequent bouts of thrombosis. A distal graft (e.g. straight forearm graft from radial artery to an antecubital fossa vein) can sometimes be used to mature an upstream vein for future AV fistula construction. The most common initial sites for AV graft placement are in the non-dominant forearm and include a straight graft from the radial artery at the wrist to the basilic vein, a loop graft in the forearm from the brachial artery to the basilic, or an antecubital vein or an upper arm graft from brachial artery to axillary vein. The anastomoses in all instances are made between the end of the graft and the side of the vein or artery, minimizing interference with blood flow through the native vessels. The axillary artery can be used for loop grafts in the upper extremity. The graft can extend from the arm to the internal jugular vein to bypass a subclavian stenosis on the same side.

Grafts can also be placed in the thigh, although such placement is associated with a higher complication rate. Thigh grafts are usually attempted after upper extremity sites have been exhausted. Long-term dialysis patients frequently have had both upper extremities used for access. In extreme cases, chest wall grafts (necklace) have been constructed. All grafts should maximize the surface area for cannulation.

Surgical placement: AV grafts are placed in the operating room under regional anesthesia (with backup for general anesthesia) by a surgeon skilled in performing vascular anastomoses. Prophylactic antibiotics (e.g. second-generation cephalosporins) are commonly administered immediately prior to the operation. Short length grafts have no advantage over long grafts in terms of patency and longevity and should not be constructed. Whenever possible the graft should maximize surfaces available for cannulation and permit good site rotation. Postoperative care of grafts is the same as that for fistulas. The extremity is kept elevated for several days and graft function is checked regularly by assessing for venous pulsation, thrill, and bruit. Most constructions are now performed on an outpatient basis. Because of anatomical variations in veins, the surgeon should provide a “road map” of the access for future reference. This is particularly important if a loop is reversed and the arterial limb of a loop graft is not on the medial side of the forearm.

Maturation of AV grafts: Although some surgeons and nephrologist have advocated use of a AV graft for dialysis within 1 – 2 days of its construction, adhesion of the subcutaneous tunnel and graft requires about 2 weeks. Hematoma in the tunnel from early cannulation can compress and ruin the access. In most circumstances, the use of AV grafts should be delayed for 2 – 3 weeks if possible to allow for healing of the subcutaneous tunnel and incorporation of the graft into the tissues. Temporary catheters can be used if urgent

dialysis is needed. A graft is considered mature when edema and erythema have resolved and the graft course is easily palpable. Cannulation of a graft that cannot be easily palpated or is edematous invites inaccurate needle insertions, leading to hematoma formation or frank laceration. In some patients, erythema along the course of the graft develops within the first several days. This is a normal variation of the healing response and not necessarily indicative of graft infection or cellulitis.

PTFE grafts reinforced with additional layers of fiber windings have been marketed and promoted as having the desirable property of undergoing cannulation within 5 days of insertion. The additional extra windings ostensibly limit the extravasation of blood on needle withdrawal and the accompanying risk of perigraft hematoma formation. Grafts withstanding early cannulation would reduce or eliminate the need for a venous catheter access as a bridge for the maturation. Despite initial enthusiasm, however, the first of such early use grafts has not been widely adopted. They are more difficult to insert without benefits of patency. In fact, they appear to have a lower patency rate and possibly a higher rate of infection.

Access Cannulation

Needle size: During the initial use of a permanent vascular access, some nephrologists recommend the use of smaller 16-gauge needles and lower blood flow rates of 200 – 250 mL/min, particularly in AV fistulas. In mature accesses, larger 15-gauge needles are needed to support the higher blood flow rates of 350 mL/min or greater needed for high-efficiency or high-flux dialysis.

Needle orientation and placements: Two needles are placed into the dilated vein(s) of the AV fistula or graft. In an autologous fistula, the arterial needle leading to the dialyzer blood inlet is always placed in the more distal segment of an access but at least 3 cm away from the AV anastomotic site. The arterial needle may point either toward the heart or the hand. The venous needle should be inserted pointing toward the heart ≥ 5 cm proximal to the arterial needle. In a graft the venous needle should be inserted into that part that is closest to the venous anastamosis. Separation of the needles is needed to minimize recirculation. Pointing the arterial needle toward the heart is popular in many countries, since the "flap" left behind following needle withdrawal tends to close more naturally with the flow of blood. There is, however absolutely no evidence that this in fact aids in hemostasis or reduces insertion-related complications. Some caregivers advocate 180° rotation of each needle after insertion. Whether this actually reduces injury to the back wall of the access has not been systematically studied.

Special care must be taken during cannulation of forearm loop grafts. In > 80% of such grafts, the arterial limb will be medial (ulnar), but in the remainder the arterial limb may lie on the radial side of the forearm. A "road map" of the access from the surgeon is very useful but not always available as patients may be operated on at another center, and a diagram or description of the inserted access may not be readily available. Inadvertent reversal of needle placement substantially increases the amount of recirculation to a mean of 20 – 25%, an amount that produces inadequate delivery of dialysis. When in doubt, a careful physical examination with transient occlusion of the access and palpation on either side of the occluding finger will reveal the direction of blood flow in almost all cases. The arterial limb is the side with a pulse. Transient occlusion does not injure the access.

Needle placement strategies: The manner in which needles are inserted affects the long-term patency and survival of accesses, particularly AV fistulas. The "ladder" or rotational approach uses the entire length of the access without localizing needle sticks to any 2 areas. Grouping needle-sticks in 1 – 2 specific areas weakens the wall producing an aneurysm. In AV fistulas, a less commonly used alternative is the "button-hole" method. With this method, the AV fistula is always punctured through a limited number of sites, that are rotated. The needle must be placed precisely through the same needle tract used previously [57]. Special "dulled" needles are used to minimize laceration of the buttonhole tract. There is no published experience with the buttonhole method in AV grafts.

Anesthesia: In pain-sensitive patients, a topical anesthetic cream can be applied to the skin prior to puncture. Use of local anesthetics (xylocaine) is infrequently used in many dialysis centers although there is no evidence of benefit or harm. There has been no systematic study whether local anesthetics affect the frequency of infiltrations or other complications. It is our observation that in a significant number of patients adequate site rotation is difficult without use of local anesthesia.

Hemostasis: This is achieved by direct pressure following needle removal. One must prevent hematoma at the wall of the access puncture as well as control bleeding at the skin exit site. The 2 puncture sites are not identical because of the oblique path of the needle. Pressure must be held for at least 10 min before checking the needle site for bleeding. Prolonged bleeding > 20 min may indicate increased intra-access pressure and is common in patients on therapeutic doses of warfarin. Adhesive bandages should not be applied until complete hemostasis is achieved.

Complications

Complications related to vascular access are a common reason for hospitalization in chronic dialysis patients. The USRDS reports that access failure (usually due to thrombosis) is the most frequent cause for hospitalization. In some centers, access complications accounts for the largest number of hospital days in ESRD patients [58].

Poor flow: Intra-access flow inadequate to meet that prescribed leads to access recirculation, decreasing dialysis efficiency. In autologous native fistulas, access recirculation can at times be detected by sequential monitoring of the urea reduction ratio (URR) or *Kt/V* and looking for signs of underdialysis. A common sign of inadequate access flow is excessive negative pressures at the arterial needle [59]. Stenosis distal to the usual placement of the needle will produce, in the absence of collaterals, a high venous resistance. The most common cause of poor flow with AV fistulas is a fibrotic stenosis/stricture *within* the venous limb resulting from improper site rotation or infiltrations. Because poor flow eventuates in thrombosis, early detection and treatment may salvage the fistula. Injection of angiographic dye into the fistula (fistulogram) can often locate the obstructed area and angioplasty can correct the stenosis. At times, a surgical revision using a bypass graft is needed.

Unlike the situation in AV fistulas, a flow low enough to produce chemical abnormalities in URR, *Kt/V*, or in the measurement of recirculation percentage as premonitory signs of impending access failure is the exception rather than the rule [60]. Most problems arise from venous outlet stenosis that is heralded by increases in intra-access pressure fistula.

Stenosis: Over 85% of AV graft thromboses are associated with a hemodynamically significant stenosis. Stenoses arise from intimal

fibromuscular hyperplasia [61] usually at or within several cm of the venous anastamosis [62]. There is no way of preventing this process at present. Numerous trials in the coronary circulation using a variety of pharmacologic agents including fish oil, antiplatelet drugs, anticoagulants, corticosteroids, and calcium channel blockers to prevent vascular restenosis have shown no effect on frequency nor severity of the process. In vascular accesses for HD the experience is similar [63] although less extensive [64]. The most active area of current research is the evaluation of intraluminal radiation (brachytherapy) following angioplasty. Gamma irradiation affects self-renewing tissues by arresting cell-division and blunting local cytokine release.

In autologous AV fistulas, the cause of stenosis tends to be more varied, and may be due to turbulence, pseudoaneurysm formation, and needle-stick injury. Early detection permits correction of stenosis (by angioplasty or surgical revision) prior to thrombosis and extends the useful life of the access. Monitoring of vascular access for stenosis also helps maintain adequate blood flow to prevent underdialysis.

Thrombosis: In AV fistulas, occurrence of thrombosis occurs bimodaly, occurring either soon after construction or as a late event. Early thrombosis results from technical factors, maturation failure, or inadvertent compression while sleeping and necessitates surgical correction. Poor flow precedes late thrombosis in most cases, but may be precipitated by hypotension or hypercoagulability. Treatment of thrombosis is difficult. Neither surgical nor percutaneous methods using urokinase provide good results. The recent development of atherectomy and hydrodynamic thrombectomy devices increase the likelihood of salvaging thrombosed AV fistulas. Technical success varies inversely with occlusion time [65]. Thus it is advisable to intervene as early as possible after thrombosis occurs. Salvage of the access should be attempted if the fistulogram demonstrates a correctable site of obstruction in the venous limb after declotting.

In synthetic AV grafts, thrombosis can be managed by surgical thrombectomy or by mechanical or pharmacomechanical thrombolysis. The expertise of the medical center as well as availability of interventionalists frequently determines the choice. However, it is essential that the following be considered:

- treatment performed within 48 hours to avoid the need for femoral vein or other central vein catherization for dialysis;
- access evaluation post declotting with fistulography to detect residual stenosis [66]; and
- residual stenosis corrected with balloon angioplasty or surgical revision.

Early thrombosis after initial technical success is rather frequent after percutaneous treatment or simple surgical thrombectomy. Patients who clot with intra-access flows greater than 1000 mL/min should be educated about avoiding the application of excessive pressure to their accesses, worked up for hypercoagulability, and/or monitored for delayed hypotension. They should be taught how to avoid excessive pressure over the needle sites following dialysis and to check their access for patency several times each day. The role of antiplatelet drugs or warfarin in patients with recurrent thrombosis is unknown. There are no prospective, randomized studies demonstrating a beneficial effect of vitamin K antagonists in preventing graft thrombosis. Similarly no single trial of aspirin, alone or in combination with dipyridamole, has unequivocally demonstrated reduction in access thrombosis [67]. Newer agents that block ADP, thrombin, serotonin, and PAF-induced platelet aggregation hold promise since these mediators are more likely to be generated at

or accumulate at sites of endothelial injury and vascular stenosis. Prospective clinical studies are needed to prove clinical effectiveness in preventing access thrombosis.

Ischemia in the access extremity: Ischemia distal to an AV access can occur at any time varying from hours to several months following access construction. Mild ischemia is manifested by coldness or parasthesias but in the absence of sensory or motor loss, it can be managed expectantly. Pain in the hand on exercise or in extreme instances occurring at rest, a "steal" effect, or the development of non-healing ulcers in the access extremity are indications for surgical intervention. Severe ischemia with nerve injury is an emergency.

With the usual radiocephalic side-to-side fistula, the radial artery anastomosis regularly steals blood flow from the ulnar artery system. Converting the side-of-artery to an end-of-artery anastomosis can sometimes treat ischemia due to steal. The risk factors for steal are the same for AV fistulas and synthetic grafts. Patients with DM, older persons with atherosclerosis, and those with vascular anomalies are at greatest risk. However, because the access flow increases rapidly and is maximal within days of constructions with an AV graft, the symptoms can develop more rapidly and the danger of permanent nerve damage is greater than with a native fistula. Cholesterol embolic events to the fingers can occur with AV grafts necessitating surgical ligation of the graft. Even though the embolic source is not corrected, the decrease in shear stress from a 10-fold reduction in flow reduces the likelihood of continued embolization form the ulcerated plaque.

Edema of the hand: This results from increased pressures in the veins draining the hand. With a native wrist fistula, treatment is by converting the anastomosis from a side-of-vein to an end-of-vein opening or by selectively tying off affected veins in the hand. A small increase in circumference (2 – 3 cm) of the forearm or arm bearing the access is common particularly when the access is constructed above the elbow since, even with a well functioning access, venous pressure increases in the draining veins due to the large increase in flow. Larger pressure increases indicate venous hypertension due to venous outlet stenosis. In native fistulas these occur within 5 – 6 cm of the AV anastamosis and frequently at venous valves. In grafts, the stenosis typically is within 2 – 3 cm of the venous anastamosis. Stenosis also results from previous use of central vein catheters on the same side as the access.

Pseudoaneurysms and aneurysms: In AV fistulas, pseudoaneurysm of the venous limb is much more common than a true aneurysm. In both fistulas and grafts, pseudoaneurysms occur from the lack of proper needle site-rotation as well as from inadequate hemostasis with extravasation of blood following dialysis needle removal. Both kinds of aneurysms are treated by simple observation and by avoiding needle insertions near the aneurysmal site. Large lesions can prevent adequate needle placement and thus limit potential puncture sites. Marked enlargement may compromise the integrity of the overlying skin leading to hemorrhage from aneurysm rupture. Aneurysms that are rapidly expanding or threaten the viability of the overlying skin should be treated by resection and insertion of an interposition graft. In grafts, expansion to a size > 12 mm in diameter is also an indication for correction.

Infections: In AV fistulas, infections are rare and usually staphylococcal in origin. The overall frequency of infection is < 1% over the entire life span of the fistula. Diagnosis is based on local signs of inflammation. Prompt therapy with anti-staphylococcal antimicrobials after local and blood cultures have been obtained is often curative. Duration of therapy

is the same as for bacterial endocarditis. Only septic emboli during therapy warrant removal of the fistula.

Infection in grafts is more common, occurring in 5 – 20% of grafts placed. Thigh grafts have a higher rate of infection than upper extremity grafts because of the differences in hygiene. Prophylactic antimicrobials should be used when HD patients with vascular grafts undergo procedures capable of inducing bacteremia such as dental extraction, genitourinary manipulation, colonoscopy, or ERCP. Most graft infections are staphylococcal, but gram-negative organisms such as *Escherichia coli* may be occasionally cultured, particularly if the access is in the thigh. Initial antibiotic coverage should include gram-negative and -positive organisms as well as *Enterococcus*. Local infection of a graft can be treated with antibiotics based on culture results and by incision/resection of the infected portion. Extensive graft infection requires complete excisional removal. Hemorrhage may occur due to rupture of an infected graft. A graft placed within 30 days that has become infected should always be removed.

Septicemia may occur without local signs. A technetium- or indium-labeled leukocyte scan may help reveal a graft infection, but care must be taken to remove any blood soaked dressings prior to scanning, as they may lead to a falsely positive result. As discussed by Schwab et al [1997], prophylactic antibiotics should be used (cefazolin or vancomycin) to minimize the risk of access infection when the access is surgically manipulated or placed [68].

Congestive heart failure (CHF): Blood flow rate through a fistula or graft can vary from barely adequate (400 mL/min) to over 2000 mL/min. Wrist fistulas have lower flows than elbow level fistulas. Similarly, graft accesses constructed in the forearm have lower flows than those placed in the arm since the brachial artery provides a larger diameter vessel than does the radial artery. Thigh grafts are sometimes constructed with an arterial taper or banding to avoid very high flows. CHF is unusual with a wrist fistula or forearm graft but may occur in patients with arm or femoral access. Surgical narrowing or banding should be done only after cardiac studies have shown marked changes in cardiac output following transient occlusion of the fistula. Long-term cardiac function is generally unaffected by the presence of a fistula. High cardiac output can also be seen in patients who are severely anemic or receiving direct vasodilators and are not on a beta blocker.

Early Detection and Treatment of Vascular Access Malfunction

AV access thromboses are associated with a hemodynamically significant stenosis in most cases. Early detection permits correction of stenosis prior to thrombosis and extends the useful life of the access. Intervention with percutaneous transluminal balloon catheter angioplasty (PTA) or surgical revision to correct stenosis before thrombosis occurs dramatically reduces thrombosis rates and the loss of AV grafts [69 – 71]. Maintenance of access patency depends on blood flow but the threshold values below which the risk of thrombosis increases depends on the type of access. The usual flow through a native wrist AV fistula averages 500 – 800 mL/min whereas in upper extremity grafts the flow is higher, typically > 1000 mL/min with occasional patients having flows as high as 3L/min. In our experience, autologous AV

fistula may maintain patency at flows as low as 200 mL/min. By contrast, the risk for thrombosis in AV grafts begin at access flows between 600 – 800 mL/min [72, 73], flows that provide adequate dialysis but offer few clinical premonitory signs that the access is at risk for thrombosis. Therefore, monitoring of vascular access for stenosis has 2 primary goals: maintenance of adequate blood flow to prevent underdialysis, and prevention of thrombosis.

Stenoses detected by a monitoring program can be treated electively by surgery or angioplasty to decrease the risk of clotting and loss of the access site. PTA can be used to open stenoses at anastomotic sites, within arteriovenous grafts, in the main veins of a native arteriovenous fistula, or in the subclavian vein draining the access arm [74]. Lesions not amenable or resistant to angioplasty can be corrected with an atherectomy device [75], a stent [76], or by surgical revision [77].

The most common cause of stenosis in AV grafts is myointimal hyperplasia, which usually occurs at or just distal to the graft-vein anastomosis. Myointimal hyperplasia occurs whenever there is injury and is a stereotypic response. Vascular smooth muscle cells (VSMCs) proliferate and migrate from the media into the intima. The process probably starts with increased basis fibroblast growth factor (bFGF) released by damaged VSMCs followed by local expression of platelet-derived growth factor (PDGF) originating from platelets, macrophages, and smooth muscle. A portion of VSMCs rapidly enters a replicative cell cycle within 48 hours and this cohort continues to proliferate. Since injury is induced by all procedures that correct the stenosis, it is clear that stenosis is likely to recur. Frequently after angioplasty, the degree of late loss of luminal cross sectional area appears to be proportional to the amount acutely gained. Understanding and controlling the injury process may permit better results following angioplasty. Clearly, the long-term solution requires direct inhibitors of the stenotic process [61] Until then, accesses should be monitored to detect dysfunction.

Risk factors for thrombosis: The risk of thrombosis is dependent on access flow and access type as previously discussed. Native AV fistulas frequently maintain patency at flows as low as 200 mL/min whereas AV grafts thrombose at access flows between 600 – 800 mL/min. The risk of access failure is higher in patients with severe vascular endothelial disease, a useful marker of which is high plasma thrombomodulin [78]. A variety of other comorbid conditions such as DM, hypotension, hypoalbuminemia, anticardiolipin antibodies, hyperhomocysteinemia, and increased serum lipoprotein (a) levels increase thrombosis risk [79]. For primary fistulae, development of stenosis during a 2 year cross-sectional study in non-diabetic patients correlated with higher serum levels of monocyte chemoattractant protein B1 and interluekin-6, cytokines that regulate VSMC proliferation [80]. Patients who developed stenoses in native fistula also had hyperinsulinemia, hyperlipidemia, and increased plasma levels of plasminogen activator inhibitor, factors that affect VSMC function.

Clinical indicators of stenosis: Recurrent clotting (defined as more than one episode/month), difficult needle placement (usually due to strictures), difficulty with attaining hemostasis (within 20 min of needle withdrawal and usually due to intra-access hypertension), and a persistently swollen arm, all suggest that a stenosis is present. These as well as the usual indicators of underdialysis (reduced URR and *Kt/V*) are generally late manifestations of access dysfunction.

Despite the limitations of physical examination, it should be performed at monthly intervals particularly in programs without

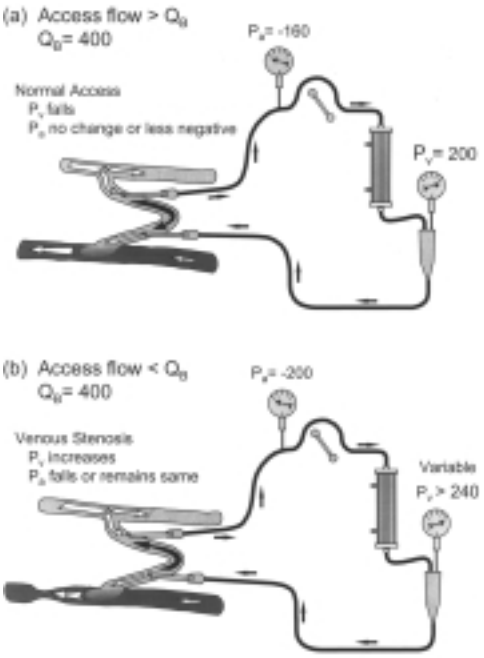

Figure 1. "Poor man's" test for recirculation using compression between the needles. The top panel depicts a well functioning access without stenosis. Access flow is sufficient to meet blood pump demand. With 15-gauge needles, pre-pump pressures are > –220 mmHg and venous drip chamber pressure is < 250 mmHg. Bottom panel depict the effect of venous outlet stenosis with access flow decreased to less than pre-pump. Under these conditions, access recirculation is obligatory. Compression of the access between the venous and arterial needle eliminates the recirculation and forces all of the flow to exit through the venous outlet. As a result the venous drip chamber pressure increases markedly.

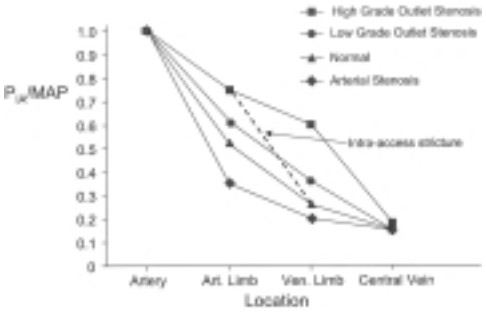

Figure 2. Pressure profiles within prosthetic graft vascular accesses. In a well-functioning graft access, pressure decreases to one-half of mean arterial pressure at the arterial segment and to one third of mean arterial pressure at the venous segment. A venous outlet stenosis increases all pressures proximal to the lesion. A stenosis in the body of the graft between the needles elevates only the arterial limb pressure. An arterial segment stenosis lowers all pressures. By contrast, native fistulas (not shown) have low pressures throughout which typically are unaffected by development of stenosis because of collateral flow.

other monitoring capabilities. A palpable thrill at the arterial, body, and venous segments of an AV graft predicts a flow > 450 mL/min [81]. Loss of the thrill, conversion to a pulse, indicates loss of high turbulent flow. Another sign of low flow in a graft is a discontinuous, water-hammer type of pulse. It has been suggested that a discontinuous, systolic, harsh, high-pitched bruit over the access site is also suggestive of stenosis. This contrasts with the continuous, soft, low-pitched bruit heard over a well-functioning access site [82].

We have found that a simple test as described by Depner will detect critically low access flow when the access flow is less than that demanded by the blood pump, that is when access recirculation is occurring [83]. If gentle occlusion of the graft segment between the dialysis needles during dialysis results in a marked rise in venous chamber pressure, then an outflow stenosis is likely (Figure 1a). An increase in the negativity of the pre-pump arterial pressure suggests that arterial inflow is inadequate, usually due to stenosis (Figure 1b.). This simple test is most useful in native AV fistula.

Pressure-flow relationships in vascular accesses and the effect of stenosis: Access flow, intra-access pressure, and resistance are mathematically related. However the axial pressure profiles of grafts and native fistulas differ significantly (Figure 2) when pullback

pressures are performed [84]. In AV fistulas, blood entering the venous system continues its return to the heart via multiple collateral veins. Even when a stenosis develops, a major increase in venous limb intra-access pressures is prevented unless the outflow stenosis is very central (axillary or central veins). Inflow stenosis in AV fistulas also tends to be silent with venous pressure measurements alone.

By contrast, blood entering an AV graft can only exit through the venous outlet and its draining veins. In an AV graft, the intragraft pressure is normally < 50% of the mean arterial pressure (MAP). Most of the arterial pressure is dissipated across the 2 anastomoses (45% arterial and 20% venous) unless an intragraft stenosis is present. When outflow stenosis develops, usually as a result of neointimal hyperplasia in proximity to the graft-vein anastomosis, intragraft pressure rises (Figure 2). The magnitude of rise is proportional to the degree of stenosis. When intragraft pressure rises above 50% of the MAP, a 50% by diameter stenosis is likely.

Blood flow and the risk of thrombosis: Blood flow in an AV fistula increases progressively over the first few months while the access is maturing. Flow through a native AV wrist fistula commonly averages 600 – 1000 mL/min whereas elbow level fistulas can exceed 2 L/min. Blood flow in AV grafts is maximal within 6 weeks of construction, then decreases variably over time among patients. Forearm grafts average about 1L/min, whereas upper extremity grafts flow is somewhat higher and may range up to 3L/min. In cross-sectional and longitudinal follow-up studies of vascular accesses, the pressure-flow profiles of fistulas and grafts differ substantially [85]. Intra-access pressure is independent of flow in native fistulas [85] and native AV fistulas may maintain patency at flows associated with marked recirculation and decreased dialytic efficiency. By contrast, as grafts develop increasing degree of stenosis (sometimes within months), a pressure gradient develops increasing the intra-access pressure and decreasing the flow (Figure 3). If a stenosis develops in the body of the graft between the areas used for arterial and venous limb cannulation, intra-access pressure at the venous needle will remain normal but flow will still decrease. AV grafts begin to thrombose at access flows between 500 – 800 mL/min [72, 73, 85], flows that can provide adequate dialysis but that offer few clinical warning signals or signs that the access is at risk for thrombosis. The likelihood of thrombosis within 6 months increases 4-fold when access flow decreases below 600 – 700 mL/min. Thrombosis rates also increase with the degree of stenoses [73]. The development of stenosis among patients with grafts is highly variable. Some patients develop stenoses within months while others develop no lesions over several years.

Methods to detect accesses at risk for thrombosis: All methods directly or indirectly evaluate access flow. The most useful clinical techniques to screen patients for functionally significant stenotic lesions have been the use recirculation, post-dialyzer venous drip chamber pressures (P_{DC}) at low flows (dynamic pressures), and intra-access pressure (P_{IA}) under no flow (static) conditions. On-line flow measurements are increasingly used. The following considerations must be kept in mind when using any diagnostic test and then planning corrective action for the lesion(s). First, as discussed above, the ability of a test to detect functionally significant stenoses depends on the prevalence of the lesion. Since development of stenosis is common, particularly in grafts, tests which do not achieve sensitivity and specificity of ≥ 80% or better are not useful. No test has perfect accuracy or predictive power. Unfortunately, accuracy of some tests also depends on location of the

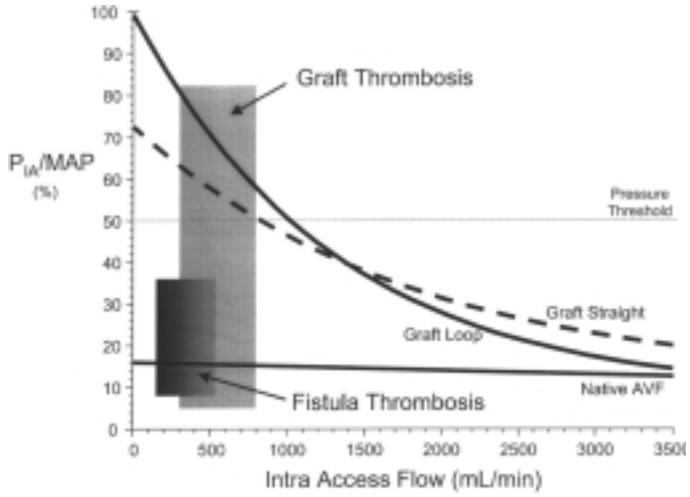

Figure 3. The relationship of intra-access pressure to flow in permanent vascular access. Venous pressure in the access (P_{IA}) is normalized by the mean arterial pressure (MAP). The profiles differ between native fistulae and AV grafts. Normalized intra-access pressure is independent of access flow in native fistulae even with stenosis. In contrast, intra-access pressure increases proximal to the recording venous needle in both loop and straight in AV grafts. Access flows associated with thrombosis in grafts is depicted by the light gray shaded area which extends to the right of usual dialyzer blood flows. Risk of thrombosis in native fistulas is shown by the darker gray shaded area

lesion(s) within the access or its outflow tract. Second a test should be able to detect the lesion before it proceeds to thrombosis. Therefore, it is important that the lesion be detected when its severity is moderate (i.e. degree of luminal reduction that is < 70%), so that there is adequate time to plan non-urgent intervention.

Recirculation

Access recirculation does not develop until access flow decreases to a level equal to or less than that being drawn by the blood pump [60]. Its chemical effect is to produce underdialysis since the return of dialyzed blood to the arterial needle dilutes the blood urea nitrogen (BUN) concentration in the blood going to the dialyzer. As shown in Figure 4, if the brachial artery supplying the access delivers a flow 60 mL/min greater than that demanded by the blood pump, access recirculation will be absent [86]. Thus, barring inadvertent needle reversal or improper needle placement, access recirculation will not be present until access flow falls to the range of 350 – 500 mL/min. By turning down the blood flow, it is always possible to attain a dialysis without recirculation but not one that provides the prescribed dialysis within the prescribed time.

Use of peripheral venous blood for the systemic sample to calculate recirculation overestimates access recirculation substantially because the BUN from this site exceeds that in arterial blood due to AV disequilibrium from cardiopulmonary recirculation and venovenous disequilibrium from regional blood flow inequalities. Recirculation values of ≥ 10% result from these non-access effects and from laboratory measurement imprecision. Patients with CHF can have even greater values (up to 25 – 40%). Access recirculation can be accurately measured by a method in

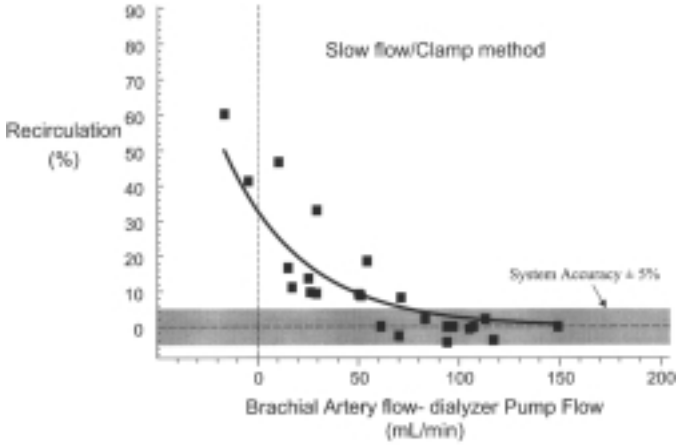

Figure 4. The relationship of the degree of mismatch between arterial artery blood flow supply and dialyzer blood pump demand and the magnitude of access recirculation. The shaded area reflects the accuracy of BUN stop-flow measurements (± 5%). The difference between arterial flow and blood pump flow represents nutrient flow to the extremity. Access recirculation develops when the mismatch increases to the point that nutrient flow is compromised (< 50 mL/min). Adapted from Besarab A, Sherman R. Am J Kid Dis 29: 223 – 229, 1997.

which the peripheral sample is obtained 10 seconds following a sudden reduction in blood pump to a blood flow of 120 mL/min [88]. This method correlates quite well with non-urea based methods for measuring access recirculation. All use an *indicator dilution principle.* A solution (usually saline) is injected into the *venous* return line and a *signal* (a change in temperature, conductivity, ultrasound velocity, or hemoglobin concentration) is detected in the *arterial* line. These non-urea dilution methods show that recirculation is zero (detection limit of 1 – 2%) in the overwhelming majority of patients if the access is properly cannulated [89, 90].

Recirculation is most useful in detecting the failing native vein fistula since patency is likely to be maintained even at flows less than those commonly prescribed (i.e. blood pump flows in the range of 200 – 400 mL/min). Also the benefits of screening AV fistula for access recirculation are not necessarily only to prevent thrombosis, but rather, also to prevent underdialysis. By contrast, the graft with an access blood flow < 600 – 700 mL/min is at risk for thrombosis but since the flow is greater than the prescribed dialyzer blood flow (350 – 500 mL/min) the risk can not be detected when recirculation is used as a screening method. At such graft flow rates, which are still above the usual blood pump settings, access recirculation measurements should still be zero. True recirculation in an AV graft is an urgent indication to study the graft, as the risk of thrombosis at a graft flow rate of 350 – 500 mL/min is quite high. Unfortunately, the majority of HD angioaccesses in the US are grafts; this explains the relative infrequency of abnormal access recirculation measurements in the setting of frequent access thrombosis [90].

Pressure Measurements

Dynamic pressure measurements: The finding of a persistently elevated venous drip chamber pressure (P_{DC}) is a well-accepted

means of screening for the presence of a functionally significant venous stenosis [71]. The measurement is made at low dialyzer blood flow rates (200 – 225 mL/min) due to the recognition that the resistance in the blood lines and venous needle at higher blood flow rates confounds the interpretation of the pressure measurements. However, even at the recommended blood flow rate, the measured venous pressure is still about 4-fold higher than the actual intra-access resulting largely from needle resistance [69]. The pressure that triggers further access evaluation varies significantly with needle gauge as illustrated in Figure 5. The critical value for 14, 15 and 16 gauge needles is 80 – 90, 110 – 120, and > 150 mm Hg, respectively, with the 5 – 10 mm Hg variation for each needle gauge resulting from differences in hematocrit (HCT) between 20 – 35%. The critical value must be exceeded on multiple occasions since partial occlusion of the venous needle orifice can result in high pressures even at low flows.

A baseline should be established when the access is first used (new). The pressure should be measured within the first 2 – 5 min into dialysis and the venous needles must be within the lumen and not partially occluded by the vessel wall. The threshold should be exceeded on 3 consecutive dialysis treatments to be meaningful. Trend analysis is more important than any single value. Stenosis at the venous anastomotic site is suggested by progressive increase in P_{DC}. A lesion within the body of the access will be missed if the lesion is proximal to the venous needle.

Static intra-access pressures (P_{IA}): It is logical that the sensitivity and specificity of pressure measurements is improved if intra-access pressures are used to screen patients rather than the venous drip chamber pressures. Measurement of P_{IA} eliminates flow or the effects of partial occlusion of the needle orifice. Since systemic blood pressure influences intra-access pressure, the utility of intra-access pressure measurements is further refined by using a ratio of intra-access pressure to systemic pressure rather than the intra-access mean arterial pressure alone (MAP) [69]. Indeed, data suggest that measurements of P_{IA}/MAP are superior to venous pressures as a screening modality to detect stenoses in AV grafts [91]. A reproducible observation is that venous outlet stenotic lesions in PTFE grafts are more likely to manifest increased pressures than in native vein fistulas. This results in part from greater compliance in native than in PTFE accesses and in part, as discussed previously, from differences in flow patterns between the 2 types of accesses. In PTFE grafts, blood entering the access must exit through the venous outlet and its draining veins. As outlet stenosis develops, a pressure gradient develops that increases the intra-access pressure. In native fistulae, blood entering the venous system can return through multiple collateral veins proximal to an upstream stenosis, thus preventing a major increase in pressure unless such collateral ves-

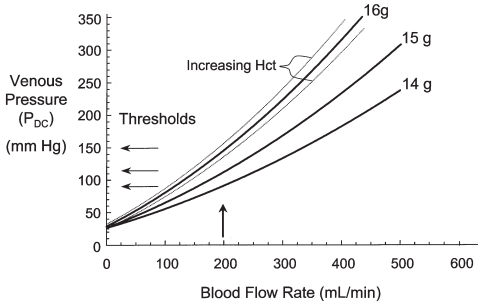

Figure 5. The relationship of venous drip chamber pressure to blood pump flow as a function of hematocrit and needle gauge. Needle gauge is a strong determinant of pressure. At a blood flow of 200 mL/min used for dynamic pressure monitoring, the critical pressure as shown by the horizontal arrows varies from 90 mm Hg for a 14-g needle to 150 mm Hg for a 16-g needle when hematocrits are 30%. A variation in HCT of 5 points around the mean value of 30% produces changes of 5 – 10 mm Hg. Note that at zero flow (static), these influences disappear.

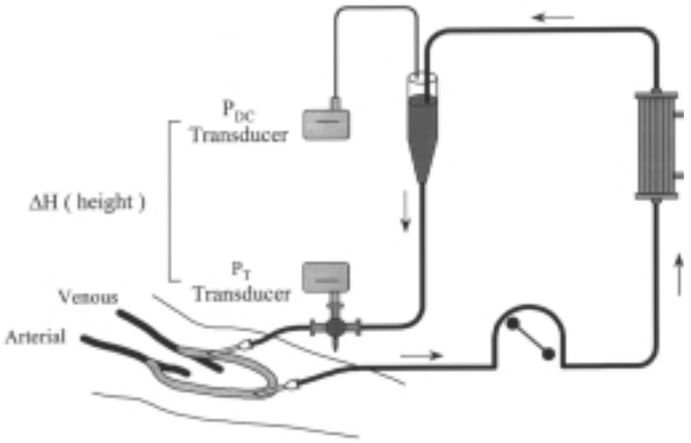

Figure 6. Diagrammatic representation for measuring intra-access pressure. Venous pressure can be measured at the level of the access by a separate transducer system or at the venous drip chamber. Under usual conditions the drip chamber records a pressure less than the separate transducer because of the presence of the hydrostatic column of blood.

sels are absent. As a consequence, pressure measurements appear to be of only modest value as a screening modality in native vein fistulas.

It is impractical to measure intra-access pressures directly. The technique for measuring P_{IA} has evolved to utilize commonly available dialysis equipment [92] rather than a specialized external transducer as is illustrated in Figure 6. When there is no flow, the only difference in pressure between an external transducer and the drip chamber transducer is the difference in height relative to the fistula. Correcting for this offset permits the sequential measurement of an equivalent intra-access pressure ($_{EQ}P_{IA}$) in a prospective way without any special equipment or cost.

The simplified technique for determining $_{EQ}P_{IA}$ uses the pressures from the *venous drip chamber* measured with the blood pump turned off, a "cuff" blood pressure, and an offset. After the blood pump is stopped, a clamp is placed upstream to the venous drip chamber. After 30 – 40 seconds, the pressure in the venous drip chamber stabilizes and is read. This "static" pressure reflects intragraft pressure if the transducer is properly calibrated, but there is the offset: namely, the vertical distance between the top of the blood column in the venous drip chamber and the patient's access. One can measure this vertical distance and correct for it, thereby estimating the intra-access pressure. A value of $_{EQ}P_{IA}$/ MAP > 0.5 is highly specific for a 50% luminal stenosis outlet stenosis in an AV graft.

Flow Measurements

Since a flow < 600 – 800 mL/min in AV grafts is associated with a high risk of subsequent graft thrombosis, flow measurements would be the preferred method of monitoring accesses were it not for associated expense. As mentioned above, pressure measurements indirectly reflect flow and can be used to select patients for referral. However, several "direct" methods of measuring access blood flow are now available. It is reasonable to believe that access flow and recirculation measurements as well as pressure measurements will become routine in the future as these devices are incorporated into dialysis delivery systems.

On line direct measurement of flow: New methods for measuring access flow while on dialysis hold great promise. All of the proposed methods utilize the dilution principle.

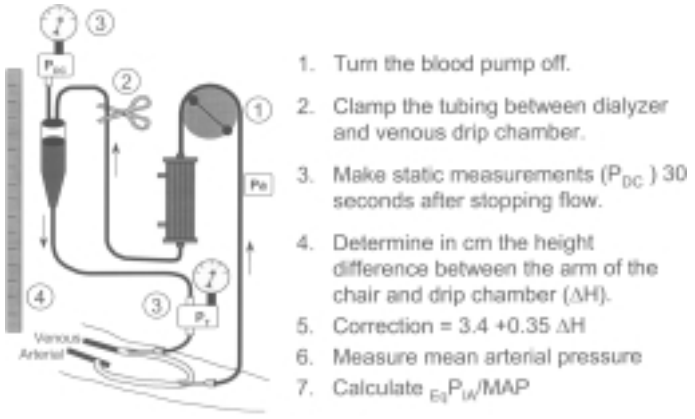

Figure 7. Method for measuring intra-access pressures. The steps are followed in sequence to calculate an equivalent pressure.

Using the method developed by Krivitsky, the blood lines must be reversed as illustrated in Figure 8a so that a signal injected into the venous limb can mix and be diluting by the arterial blood flowing into the access [93]. The blood pump must be stopped sometime during dialysis and the bloodlines transiently reversed in order to perform this measurement. Reversal of the access lines produces an obligatory "recirculation" through the access when the pump is restarted (Figure 8). The percent recirculation that occurs is dependent on the ratio of the blood pump flow rate to the access blood flow rate. This percent recirculation is determined by the injection of saline into the venous line that returns to the upstream position. Once the percent "recirculation" under such reversed line conditions is measured, the access blood flow is calculated algebraically because the blood pump flow rate is known

(Access flow = Blood pump flow [(1 – R)/R]; R = recirculation).

The most accurate results are obtained if 2 detectors are used, one to measure the magnitude of the original signal and one in the arterial line to measure the degree of dilution (Figure 8b). The sensors can also be used to calibrate the pump.

These methods are able to measure access recirculation, access flow, and cardiac output during dialysis. Ultrasound dilution measurement of flow velocity has been evaluated most thoroughly to date and appears accurate and easy to use. However, methods that use and can detect changes in conductivity, hemoglobin, or thermal energy are feasible. The signal does not need to be a bolus of saline into the bloodlines. One method suddenly increases the dialyzer ultrafiltration rate thereby increasing the HCT exiting the upstream bloodline. Another method changes the dialysate temperature cooling the blood entering the access from the upstream bloodline. In still another variation of the theme, concentrated saline is infused into the upstream bloodline. The principle remains the same: the extent of the perturbation in the upstream bloodline that is detected in the downstream bloodline depends on the ratio of blood pump to access flow rates.

Doppler ultrasound This noninvasive technique allows imaging of flow through AV grafts and fistulas. A variety of machines are used with differing algorithms for calculating flow velocity. Certain machines systematically underestimate and overestimate flow [94]. Flow measurement by Doppler depends on accurate measurement of velocity and ves-

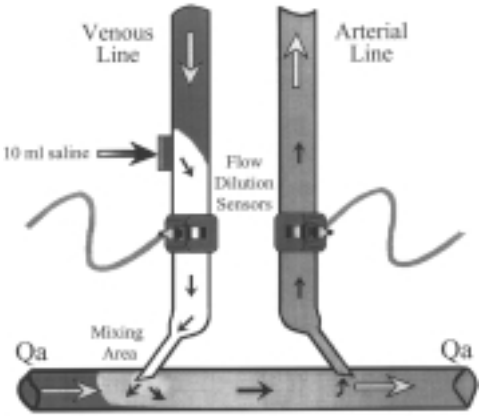

Figure 8a.

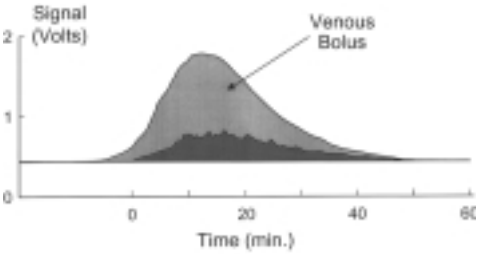

Figure 8b. Method of measuring access flow using the method of Krivitsky. The venous return is placed upstream and the arterial supply to the dialyzer is placed downstream (panel A). As a consequence obligatory recirculation occurs. Arterial inflow mixes with the blood flow returning from the dialyzer. When saline is injected into the venous line it produces a reference signal (area under the curve) for ultrasound velocity of plasma (panel B). After mixing, the arterial sensor measures a lower signal because the mixing dilutes the original signal. Arterial inflow is then derived algebraically.

sel diameter, difficult when flow is turbulent in an access. In such cases, flow is better measured at the brachial artery, where the vessel is a smooth cylinder and where flow is less turbulent. Since all but 60 – 80 mL/min of nutrient flow in the brachial artery flows into the vascular access, brachial artery flow correlates very well with access flow rate [86]. Since lesions can develop within 2 – 3 months of construction or intervention, Doppler flow measurements are prohibitively expensive for routine assessment.

Magnetic resonance angiography: This technique measures access flow quite accurately but is too expensive for routine use.

Imaging the Vascular Access

Ultrasound Imaging: This radiologic method has been useful in the detection of stenoses, and characterization of aneurysms [95, 96]. Its chief role is in the evaluation of flow and anatomy in accesses screened by other techniques. Some centers refer patients with a high probability of stenosis as determined by low cost methods directly for angiography and balloon angioplasty.

Digital subtraction angiography (DSA): Contrast angiography (fistulography) with reflux into the arterial anastamosis (BP cuff inflated) is the gold standard in evaluating the luminal anatomy of the access and its venous runoff systems. Immediate correction of any detected venous stenoses by percutaneous transluminal angioplasty (PTA) can follow the fistulogram. Because visualization of the arterial inflow is often suboptimal by fistulography, intravenous DSA is preferred by some as it provides excellent images of the arterial inflow and distal venous drainage.

Treatment of Stenosis

Percutaneous transluminal angioplasty vs. surgery: A percutaneous technique via a 16-gauge dialysis needle inserted into the graft is used for angioplasty. PTA or surgical revision to correct stenosis before thrombosis occurs. Such interventions dramatically reduce thrombosis rates and the loss of AV grafts [69,

70]. Successful angioplasty or surgical revision should be accompanied by a decrease in either dynamic (blood pump running) or static (blood pump off) access pressures into the "normal" range. Flow usually doubles. Restenosis over a period of 3 – 12 months is a frequent event. PTA yields 90-day patency of 30 – 40% but the procedure can be repeated many times [66, 97 – 99]. Surgical revision provides longer patency but utilizes veins [100]. Subclavian restenosis rate is considerably higher, with only 30% of treated subclavian veins functional at 6 months. Stents may have a role in a small subgroup with elastic stenoses or rapid recurrence.

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