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Interventional Nephrology for Hemodialysis Vascular Access: Insight about an Evolving Branch

Theodore F. Saad

Nephrology Associates, Newark, Delaware, USA

The Origins of Interventional Nephrology

Over the past decade, there has been increasing interest and participation by nephrologists in the management of hemodialysis vascular access. Since the inception of chronic hemodialysis therapy, there has been a curious evolution of the nephrologists' role in the management of vascular access. The early days of dialysis were marked by advances in vascular access conceived and developed by visionary nephrologists, including the Scribner shunt [1] and the Brescia-Cimino arteriovenous fistula. [2,3] Some nephrologists have maintained this primary role in vascular access creation and maintenance, particularly in Europe, with Dr Klaus Konnor's experience standing out as a shining example. [4] During the 1970's and 80's, at least in the United States (US), nephrologists' interest and involvement in vascular access largely faded. This may have been due to progress in what was perceived as more scientifically rewarding areas of study. Certainly, neither technical proficiency nor rigorous academic attention to vascular access was emphasized in most US nephrology training centers during this time; in many programs and practices, management of vascular access was left mainly to the surgeons. At the same time in the US, there was increased promotion and utilization of bovine and polytetrafluoroethylene (PTFE) grafts in favor of native arteriovenous (AV) fistulae. This shift may have been driven by marketing and reimbursement practices, poor options of long-term venous access for bridging to native AV fistulae, and increasing emphasis on short, high efficiency dialysis treatments. The result for the US nephrology community was a large hemodialysis patient population with a high prevalence of PTFE grafts, low usage of AV fistulae, and incidentally, the highest dialysis patient mortality of all industrialized nations. [5] In 1999, 49% of US hemodialysis patients were dialyzing with AV grafts, 28% with native AV fistulae, and 23% with venous catheters. [6]

During this period of an increasing hemodialysis patient population, increasing PTFE graft utilization, and decreasing nephrologists' interest and ability to manage vascular access problems, there was a predictable crisis in the access-related medical care of these patients. Management of AV access dysfunction and thrombosis was reactive and primarily uti-

Reprint request and correspondence to:

Theodore F. Saad
Nephrology Associates
Newark, DE 19807
Delaware, USA

lized surgical techniques. The role of venous stenosis in AV graft failure was underappreciated. [7] In the late 1980's, interventional radiologists began to recognize these problems and to apply their tools and techniques to treating access dysfunction. In 1991, Valji *et al*. reported a method for declotting hemodialysis grafts using pharmacomechanical thrombolysis and angioplasty. [8] Numerous other reports and variations on this method followed, with increasing acceptance of percutaneous interventions in the management of hemodialysis access dysfunction. Largely however, the nephrologist remained on the outside, as vascular access continued to be the province of the vascular surgeon, and more recently the interventional radiologists. This collaboration of expert subspecialties might have been all that was needed to provide timely, high-quality hemodialysis access care. Undeniably, in some settings, this was the case. [9] Unfortunately however, in most practices, while access dysfunction was of critical and immediate importance to the patient, dialysis staff, and nephrologist, this was not always the first priority of the surgeon or radiologist, creating a service void and an opportunity for improvement in care. [10]

The central role of vascular access in the care of hemodialysis patients cannot be overemphasized. Comprehensive medical care of the hemodialysis patient, includes management of uremia, hypertension, sodium and water, anemia, mineral metabolism, metabolic bone disease, and nutritional status; none of this can even begin in earnest unless there is reliable, efficient blood access. Leaving this critical aspect of care entirely in the hands of others puts the nephrologist at a huge disadvantage. Under ideal circumstances, when the skills and priorities of the multispecialty access team come together, patient care may be very well served. Conversely, if the appropriate surgical or interventional services cannot be delivered in a timely fashion, the patient suffers in terms of delayed dialysis, temporary dialysis access, hospitalization, and other associated morbidities. This also results in a significantly greater financial burden to the health care system.

In the early 1990's, this problem was confronted by Gerald Beathard in Austin, Texas. He acquired training, adapted the reported interventional radiology techniques, and developed a nephrology service for percutaneous management of vascular access. [11,12] He then liberally shared this expertise, training many nephrologists from various practices and backgrounds, this author included. As these "second generation" interventional nephrologists brought these techniques to their practices, the field of "interventional nephrology" was effectively born. When nephrologists began to perform these access-related percutaneous interventions, our first priorities were to master the techniques, establish suitable facilities in which to work, and then deal with the multitude of day to day access failures, largely centered around the PTFE graft. While this promoted an immediate and dramatic improvement in care, it was very evident that the poor performance of PTFE grafts compared to native AV fistulae was contributing to an excessively high rate of access failure, and hence a large volume of percutaneous interventions. This was good business, but very bad medicine. This realization led to the next phase in the evolution of interventional nephrology, which was to become a comprehensive vascular access manager for the hemodialysis patient. In order to improve vascular access outcomes, it would be folly to address only the technical aspects of percutaneous interventions. To achieve optimal vascular access, other aspects of care take an equal or greater importance. These include:

- Preservation of peripheral veins for native AV fistulae.

- Avoidance of peripherally inserted central venous catheters and subclavian catheters. [13]
- Judicious use of internal jugular vein tunneled hemodialysis catheters for temporary hemodialysis access. [14]
- Early referral to surgeon for construction of native AV fistula. [15]
- Education and selection of surgical colleagues willing and able to master the techniques for creation of native AV fistula.
- Pre-operative imaging of veins and arteries, including ultrasound vein mapping and venography.
- Evaluation and treatment of poorly functioning or immature AV fistula. [16]
- Conversion from failing PTFE graft to "secondary" native AV fistula.
- Maintenance of complete and accurate clinical database with regular quality analysis including: AVF and catheter rates of usage, procedure technical success rates, complications, patient satisfaction.

Another essential principle must be recognized in order to provide optimal hemodialysis access care: For every scenario of access dysfunction, there is a "best solution." There has been a tendency for access solutions to follow "the path of least resistance," or worse yet, "the path of greatest reimbursement," both of which may be different from the optimal pathway. From the perspective of the interventionist, there is the temptation to view all problems as best solved using percutaneous means first. However, there are clearly situations where surgical solutions are preferable and should be employed. Therefore, it is essential for the interventional nephrologist to develop a comprehensive view of access management, and be able to direct the patient to the optimal solution. This of course works both ways. It would be equally poor care to perform repeated percutaneous declots and angioplasties on a failing graft, as it would be to attempt an open surgical declot of a fistula that thrombosed due to central venous stenosis. Knowing the anatomy and history of each patient is the critical element that allows these judgments to be made. In this regard, keeping a detailed clinical database is essential. This allows the operator to fully assess the vascular access problem at hand, make the most appropriate management decision, and perform the necessary procedure with the lowest risk and best possibility of a successful outcome. [17]

When a patient presents with access dysfunction, a timely solution is required. This may be an urgent problem such as a thrombosed AV fistula, requiring immediate intervention to salvage the access and provide dialysis. It may be a less immediate problem, such as prolonged bleeding from needle puncture sites related to venous outflow stenosis; this may not prevent dialysis, but puts the patient at risk, may lead to access thrombosis, and should be dealt with before it becomes an urgent problem. Other access problems may be relatively elective in nature, such as evaluation of limb swelling associated with central venous stenosis, or a slowly enlarging pseudo-aneurysm. In all cases, the goal of an interventional program should be to address each problem in an appropriate timely fashion. For every request, our goal is to respond, "We will take care of it". This is the service that our patients, dialysis units, and colleagues require and deserve. Nephrologists are in the ideal position to provide these services when equipped with the necessary skills, allowing for seamless delivery of care, and management of dialysis-related problems as required before, during, and after an interventional procedure. Alternatively, there are many practices where excellent care and service is provided by interventional radiologists or vascular surgeons. The title of the individual responsible for the vascular access interventions is not as important as his or her knowledge, skill, availability, and willingness to work with surgeons, nephrologists, and dialysis staff as part of the access management team.

The American Society of Diagnostic and Interventional Nephrology (ASDIN) was founded in 2000 to promote the proper application of procedures in the practice of nephrology. [18] These include ultrasound imaging and peritoneal dialysis catheter placement, in addition to the full complement of percutaneous interventions required for hemodialysis vascular access. A major goal of this society was to develop standards for training, certification, and accreditation. These were published in 2003. [19] Previously, there were no standards directly referable to any of the procedures of interventional nephrology, with tremendous variation in training and credentialing requirements of health care facilities. [20] It is expected that this will become much more uniform, with increasing acceptance of these criteria in the US and elsewhere, ultimately improving quality and accountability. Over the past several years, interventional nephrology programs have begun to develop at US academic centers, [21] which have promoted additional interest, growth, and credibility. As these centers develop, they should be expected advance the standard for training, quality, and clinical research related to vascular access. [22]

Endovascular Procedures of Interventional Nephrology

There are several core procedures of interventional nephrology. [17,23] These include placement and management of venous hemodialysis catheters, diagnostic imaging of arteriovenous access and native veins, percutaneous angioplasty, and declotting of thrombosed arteriovenous access. Other related procedures included placement of venous stents, implantation of subcutaneous venous HD access ports, and ligation or embolization of native fistula accessory branches.

Venous Hemodialysis Catheters

Venous catheters are the least desirable method of HD access. In a sense, every venous catheter placement represents a failure: failure to prepare a native AVF in advance of initiating dialysis; failure to detect failing AV access and maintain its function, or create a suitable alternative. Nevertheless, catheters are an unavoidable necessity for many patients who do not have functional AV access for any reason. [14] For most interventional nephrologists, insertion of tunneled dialysis catheters (TDC) is the first and most basic procedure acquired, building on the common skill of temporary HD catheter placement. The use of real-time ultrasound guidance is essential for safe and efficient venipuncture. [24] The low posterior approach to the right internal jugular (R-IJ) vein is ideal; this keeps the catheter low on the neck, with minimal patient discomfort and a good cosmetic result, while allowing for a very gentle bend of the catheter. Fluoroscopy is also recommended for proper catheter tip positioning, although there is limited evidence to support this requirement. There is general agreement that TDC performance is optimized with the catheter tips in the right atrium, and DOQI guidelines support this approach. [25] Nevertheless, this remains controversial, and achieving the desired tip position is difficult, even with fluoroscopy and careful attention to anatomic landmarks. [26] There is some evidence that TDC catheter placement using landmarks without fluoroscopy can be done safely with similar results. [27] Ultimately, to achieve the best possible TDC outcomes, the operator must adhere to meticulous sterile surgical technique, utilize ultrasound guidance for venipuncture, and pay careful attention to tip positioning using fluoroscopic and/or landmark guidance. Figure 1a shows a poorly placed TDC, with a very high anterior R-IJ puncture, a tightly formed bend with the catheter kinked, and

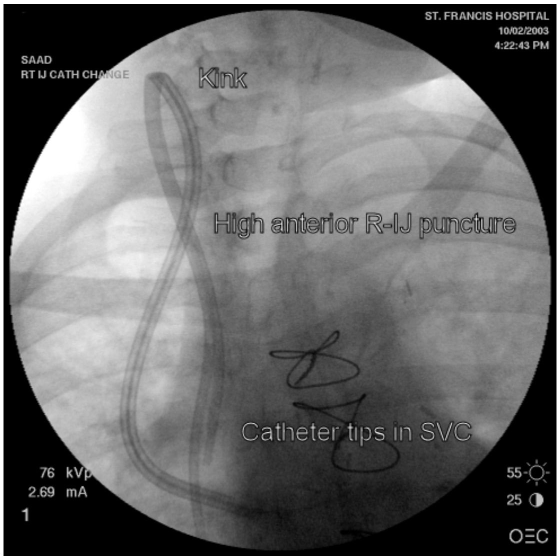

Figure 1a

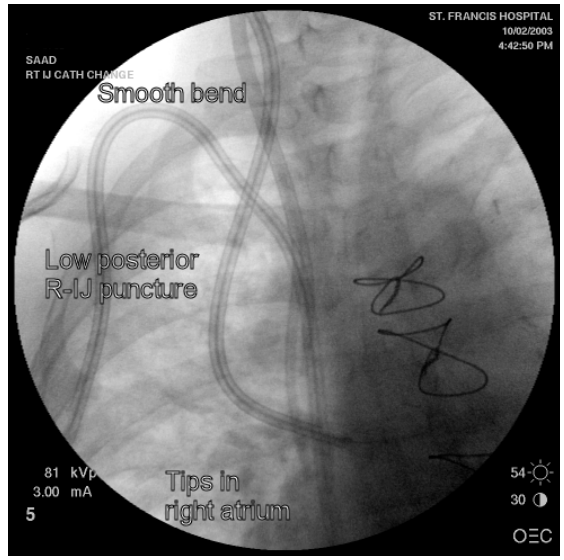

Figure 1b

Figure 1a: Poorly placed right internal jugular vein tunneled cuffed hemodialysis catheter using a high-anterior approach. Bend is sharply kinked in the neck and tips are high in the superior vena cava. Blood flow was insufficient to support dialysis.
Figure 1b: Same patient with properly placed right internal jugular catheter using a low-posterior approach, with a smooth bend and tips in the right atrium, prior to removal of faulty catheter.

its tip barely extending into the superior vena cava. Needless to say, this catheter did not function well for dialysis. Figure 1b shows this catheter as it was replaced using a new low posterior R-IJ puncture with a catheter extending into the high right atrium.

Over the past several years, two totally implantable venous hemodialysis access devices have been developed. These include the LifeSite hemodialysis valve (Vasca Inc., Tewksbury, MA, USA) (Figure 2), and the Dialock Access System (Biolink Inc., Norwell, MA, USA). [28] In the United States, only the LifeSite device is available. The LifeSite has been shown to provide improved device survival, and lower infection rates than conventional TDC. [29] There is however considerably greater time, skill, risk, and expense associated with these device implantations; these factors must be weighed when considering its use. Interventional nephrologists have been instru-

Figure 2: LifeSite® hemodialysis valve and cannula system, available as a totally implanted long-term temporary or chronic venous hemodialysis access. Two separate valves and cannulae are utilized for blood draw and return with 14 gauge needles inserted via uttonhole tract into each valve.

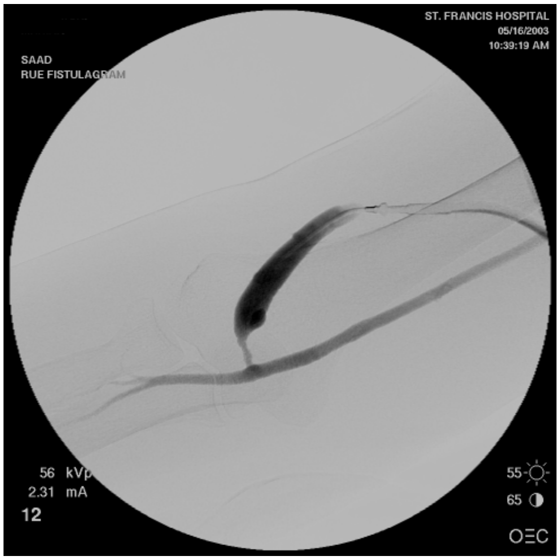

Figure 3a

Figure 3b

Figure 3a: Right upper arm cephalic vein AV fistula with poor flow due to severe stenosis at the arterial anastamosis and peripheral portion of cephalic vein.
Figure 3b: Arterial anastamosis following balloon angioplasty to 5mm, with improved fistula flow and performance.

mental in the LifeSite clinical trials, and its application in practice. This role is important, given the special considerations in the use of this device as a bridge to native AVF or as a chronic permanent venous access.

Angioplasty

Percutaneous transluminal angioplasty (PTA) of vascular stenosis has become an essential tool in the management of hemodialysis access dysfunction. Stenosis can affect any portion of the arteriovenous access system, whether native fistula or synthetic graft. This includes the arterial anastamosis (Figures 3a & 3b), the draining vein, central veins, and in the case of synthetic grafts, the venous anastamosis or the graft itself. The tools and techniques of PTA are fundamental to interventional nephrology. For both native AVF and grafts, when stenosis is suspected based upon clinical findings or other screening criteria, the patient may be referred for evaluation and PTA. This is the ideal scenario, allowing for convenient elective procedures in stable patients, without disruption of the dialysis schedule. Alternatively, if stenosis is not detected, access thrombosis may result, requiring a declotting procedure, either percutaneous or surgical. It is imperative that underlying stenoses be recognized and corrected at the time of declotting, otherwise the access will likely soon fail again.[25] The principles and techniques of PTA are well established, and these must be mastered by the interventional nephrologist, radiologist, or surgeon performing the procedure.[30] It should be noted that many venous stenoses are quite resistant to expansion and may require very high-pressure balloon PTA. Conventional angioplasty balloons are rated with "burst pressures" of 12-15 atmospheres. This pressure may not be sufficient to dilate certain resistant lesions, requiring the use of balloons with much higher pressure ratings, up to 25 atmospheres (Figures 4a – 4d).

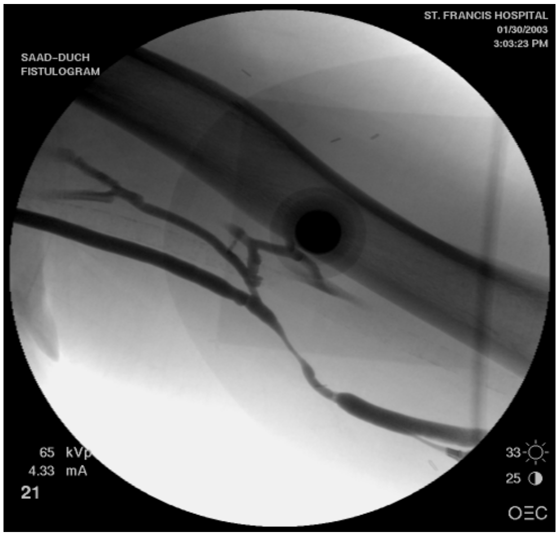

Figure 4a

Figure 4b

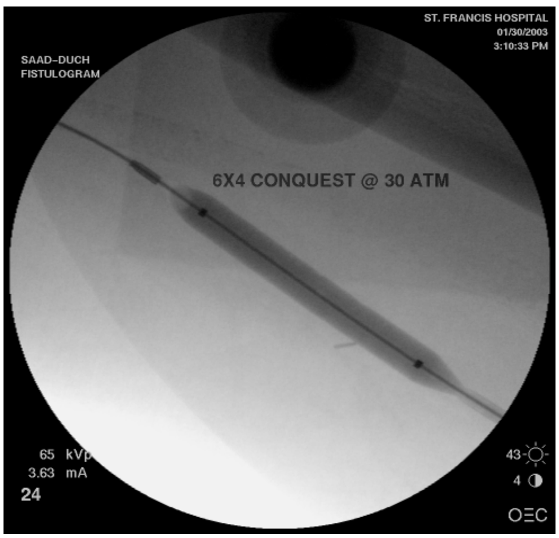

Figure 4c

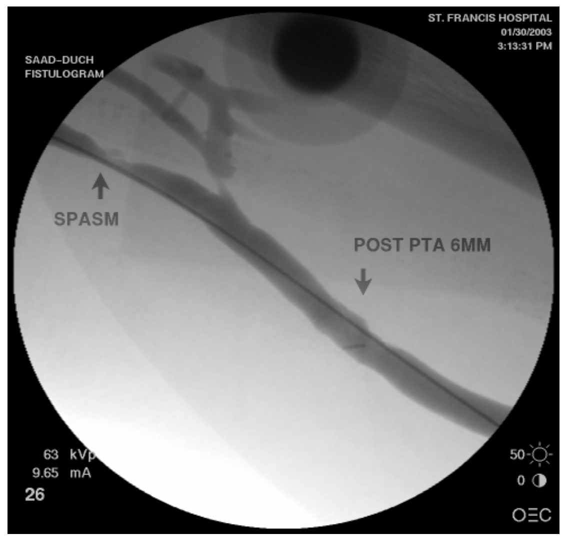

Figure 4d

Figure 4a: Left upper arm brachial artery to transposed basilic vein AV fistula with severe venous stenosis. Poor flow with prominent fistula pulsation and poor thrill.
Figure 4b: High pressure balloon angioplasty at 25 atmospheres, with persistent severe balloon waist.
Figure 4c: Balloon waist effaced at 30 atmospheres.
Figure 4d: Post angioplasty stenosis resolved, with improved flow. Note area of apparent narrowing is central to the site of stenosis and angioplasty, representing post angioplasty venous spasm, not true stenosis.

Declotting Procedures for AV Access

Prior to the 1990's, management of AV access thrombosis was almost exclusively surgical. Diagnosis of associated venous stenosis was limited, and there was very little preventative intervention. Since the first reports on percutaneous methods for declotting AV grafts, [8] many devices and techniques have been reported for declotting hemodialysis access. For the most part, no one method or device has been shown to have any advantage over others, in terms of procedure success, complications, or duration of access patency. [31] The principal determinant of outcome is the correction of underlying stenoses or other conditions responsible for the thrombosis. Notable progress has been made in the management of native AVF thrombosis. Until very recently, it was commonly accepted in the surgical and interventional radiology communities that salvage of thrombosed native AVF was not possible. [23] In fact, a recent published recommendation [32] stated that, "*Once an AV fistula fails, the veins are so sclerotic and diseased, they will rethrombose in a very short time - often in a matter of days. Therefore we do not advocate opening a clotted fistula. It is a waste of time and puts the patients at undue risk of an interventional procedure"* Given the precious nature of an AVF for a dialysis patient, this would be a disheartening approach. Thankfully, it has now been shown in several studies that results of percutaneous native AVF declotting can be excellent, ranging from 76 to 94%. [33-36] Most of these studies, and our own technique, [37] involve a combination of pharmacologic thrombolysis and/or mechanical clot removal or maceration, with no proven difference in efficacy or safety between different methods. Long-term secondary fistula patency after successful declotting is also quite favorable, with 50 to 86% remaining patent at 24 months. It should be emphasized that to achieve this secondary or "assisted" patency, and avoid rethrombosis, other percutaneous interventions may be required. In the US, as we continue to improve our utilization of native AVF, and in other countries where this has already been achieved, there clearly will be more emphasis on the application of percutaneous interventional techniques for the maintenance of native AVF function.

Venous Stents

The role of endovascular stents in the management of stenosis associated with AV hemodialysis access is poorly defined and rather controversial. At best, this role is very limited. As a general principle, a stent should not be placed at a site where a definitive surgical revision would be technically feasible. Stent placement should be considered only after failure of conventional angioplasty, either due to immediate recoil, rupture, repeated rapid restenosis, or in the management of complete vessel occlusions. [25,38] Potential sites for stent placement include the peripheral draining veins related to a native AVF (Figures 5a- 5c) or synthetic graft, central veins (Figure 6a & 6b), graft venous anastamosis, or intragraft. There are a variety of stents available for this purpose, although only the stainless steel self-expanding Wallstent® endoprosthesis (Boston Scientific, Natick, MA, USA) is approved in the United States for a venous indication. Other stents have biliary or arterial indications, but may be used in the venous system "off-label". These are primarily nitinol stents which may have improved material properties and clinical performance over stainless steel. Clearly further study will be needed to determine the appropriate indications for venous stents. One of the challenges for the interventional nephrology community is to take the lead on such study and advance the clinical scientific basis for vascular access care.

Fistula Accessory Branch Ligation

In order to be usable for hemodialysis access, a native AVF must have sufficient flow through an accessible vein. In selected cases, accessory veins divert flow from the dominant fistula vein into branches that are not suitable for needle access. This may leave insufficient flow in the dominant vein for dialysis, especially when there is relatively poor inflow due to

Figure 5a

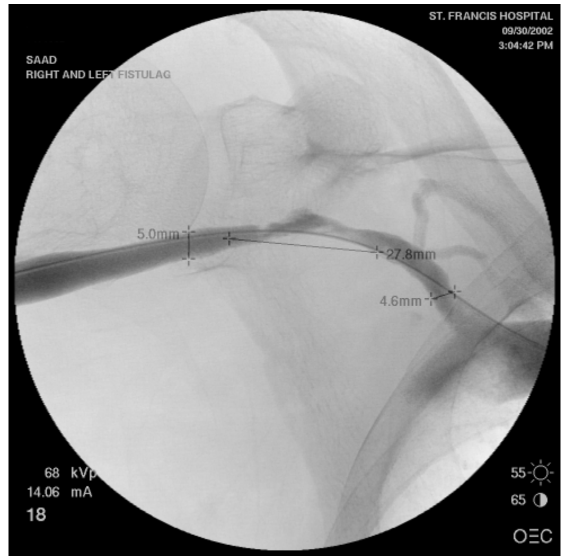

Figure 5b

Figure 5c

Figure 5a: Right upper arm cephalic vein fistula with severe stenosis at cephalic arch.
Figure 5b: Post angioplasty recoil and venous dissection with persistent poor flow, absent thrill.
Figure 5c: Following placement of 8 mm x 20 mm Wallstent® with restoration of good flow and thrill.

small or diseased peripheral arteries, or poor cardiac output. In these circumstances, in addition to correcting any flow-limiting stenosis, ligation or embolization of accessory veins may result in improved fistula performance. [16,39] This can be done using minimally invasive techniques, and confirmation of successful occlusion can be obtained immediately. When selecting accessory veins for occlusion, great care must be taken not to sacrifice veins that might themselves eventually be suitable for needle cannulation or useful for a surgical revision. Furthermore, collateral veins that are providing outflow due to occlusion or

Figure 6a

Figure 6b

Figure 6a: Right subclavian stenosis and near-occlusion of right brachiocephalic vein associated with right upper extremity graft. Venous hypertension evident by numerous dilated collateral veins. Cancer patient with previous subclavian vein catheters, note left sided infusion catheter tip in superior vena cava. Figure 6B: Following placement of right sub-clavian and brachocephalic vein 14 mm x 40 mm Wallstent®.

stenosis of the dominant vein should never be sacrificed.

Conclusion

Interventional nephrology is an exciting and rapidly developing field. It is highly gratifying to resolve the critical vascular access problems for our patients. Our ability to provide high-quality, timely, efficient, and cost-effective service is essential to the care of these patients, and to the operation of our dialysis units and practice. Our central role in their medical care also allows us multiple opportunities for improvement in vascular access, including vein preservation, pre-dialysis access preparation, minimizing venous catheter use, monitoring and screening for access dysfunction, and planning for new native AVF in anticipation of access failure. We have been characterized by some as "pioneers," I believe incorrectly. We are in fact merely "settlers" now. Others have led the way and established the basic tools and techniques of this field. Our challenge is to utilize these skills to improve the quality of access care that we deliver for our patients.

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