ARTERIOVENOUS FISTULA, PART 2: DUPLEX DIAGNOSTICS AND TROUBLESHOOTING

ARTERIOVENOUS FISTULA DUPLEX DIAGNOSTICS AND TROUBLESHOOTING

INTRODUCTION

Arteriovenous fistulas (AVF) and grafts (AVG) are two common modalities for hemodialysis access, allowing for rapid blood removal and return of blood flow between the body and the dialysis machine. These conduits are relatively durable and relatively resistant to infection and allow patients to receive dialysis three times per week or more. These modalities, particularly AVF, have since become the standard for durable dialysis access due to their average durability compared to indwelling tunneled central venous catheters. The National Kidney Foundation's Kidney Disease Outcomes Quality Initiative (KDOQI) has released several guidelines on the use of access for hemodialysis. One of these in particular is the "Fistula First" initiative encouraging practitioners to increase the utilization of AV fistulas for first access. This practice is supported by accumulated evidence suggesting benefit for AV fistulas relative to other accesses in durability and infection risk[1].

AV fistulas and AV grafts are not without their problems, however, and as such have been described as both the lifeline as well as the "Achilles heel" of hemodialysis access[2]. The conduits and rapid blood flow, although usually tolerated physiologically very well by the body, still create abnormalities in flow and in the case of AVGs, physiologic reactions due to the presence of foreign material. This can result in AVF/AVG malfunction due to a variety of issues ranging from stenosis and infection to occlusion requiring abandonment of the access. Access issues due to hemodynamic abnormalities most often result from intimal hyperplasia of the outflow vein. This can include not just the outflow veins of a native AV fistula but also the venous anastomosis of an AV graft and often the subclavian and innominate veins. Duplex ultrasound can help to identify and troubleshoot issues with AV access in order to assist in surgical or interventional management.

UTILITY OF DUPLEX ULTRASOUND FOR INTERROGATION OF MALFUNCTIONING AVF

Duplex ultrasound can be used as a method of surveillance for AVF/AVGs, although the benefit of routine surveillance in the absence of access problems is unclear[3] due to the lack of evidence about utility and frequency. In many situations duplex ultrasound can be used as a first line tool to interrogate a malfunctioning AVF and to direct further invasive diagnostics or therapy such as fistulography or surgical revision. Duplex can readily identify areas of outflow vein stenosis or problems with the arterial or venous anastomosis.

AV FISTULA AND GRAFT MODES OF FAILURE

The most common mode of failure of a native AV fistula is outflow vein stenosis, followed by anastomotic stenosis[3]. Outflow vein stenosis can occur at a sclerotic, scarred or iatrogenically constricted area: as the vein matures and grows larger and hypertrophic, the sclerotic area is restricted by the scar tissue and remains the same size. Flow through this area is restricted and eventually can create an area of

increasing turbulence and intimal hyperplasia. This eventually leads to a critical stenosis causing slow flow and, if left alone, potentially occlusion and thrombosis of the AVF. Stenoses can also occur due to puncture sites that have damaged the vessel, or at the proximal or distal ends of a pseudoaneurysm. Arterial anastomotic stenosis can also cause slow flow and/or nonmaturation of an AVF and are often due either to technical errors in the construction of the fistula (in the case of nonmaturation) or intimal hyperplasia due to turbulent flow in the anastomotic hood (in the case of late anastomotic stenosis). Stenoses of the AVF, whether venous or arterial, can present as low flow volumes when the patient is on the dialysis machine; further localization of the stenosis can be done by examining the inflow (arterial) and outflow (venous) pressures of the machine. Arterial anastomotic stenosis is more likely to present with low arterial pressures while on dialysis as the machine is unable to withdraw enough blood into the circuit to run. Venous anastomotic stenoses, on the other hand, are likely to present as high venous outflow pressures on the machine. Venous outflow or central stenosis may also commonly present as prolonged bleeding after decannulation.

The most common mode of failure of an AV graft is neointimal hyperplasia at the venous anastomosis due to turbulent flow in the area[1]. Grafts can also develop stenoses along the length of the graft, or in the outflow vein, as well as stenoses of the arterial anastomosis although these etiologies are less common than venous anastomotic stenosis. Untreated hemodynamically significant stenoses can cause sudden failure and thrombosis of the graft requiring thrombectomy, thrombolysis, or sacrifice of the graft.

EVALUATING THE MALFUNCTIONING FISTULA AND GRAFT

An evaluation of a malfunctioning fistula or graft must encompass a comprehensive evaluation of the access in order to identify the problem. For a native AV fistula, the entire conduit from just proximalt to the anastomosis to the proximal outflow vein is interrogated. The arterial inflow may also be interrogated in select patients if there is suggestion of inflow problems proximal to the actual AV fistula. Brightness-mode grayscale imaging can be useful in identifying areas of tortuosity, physical stenosis, calcification, aneurysms, hematoma, or pseudoaneurysms. Color flow or power Doppler are used to confirm patency of the fistula. Spectral Doppler waveforms of the anastomosis, the proximal inflow, and the outflow vein are obtained. Flow volumes are calculated using the systolic velocity and diameter of the conduit 2cm central to the arterial anastomosis.

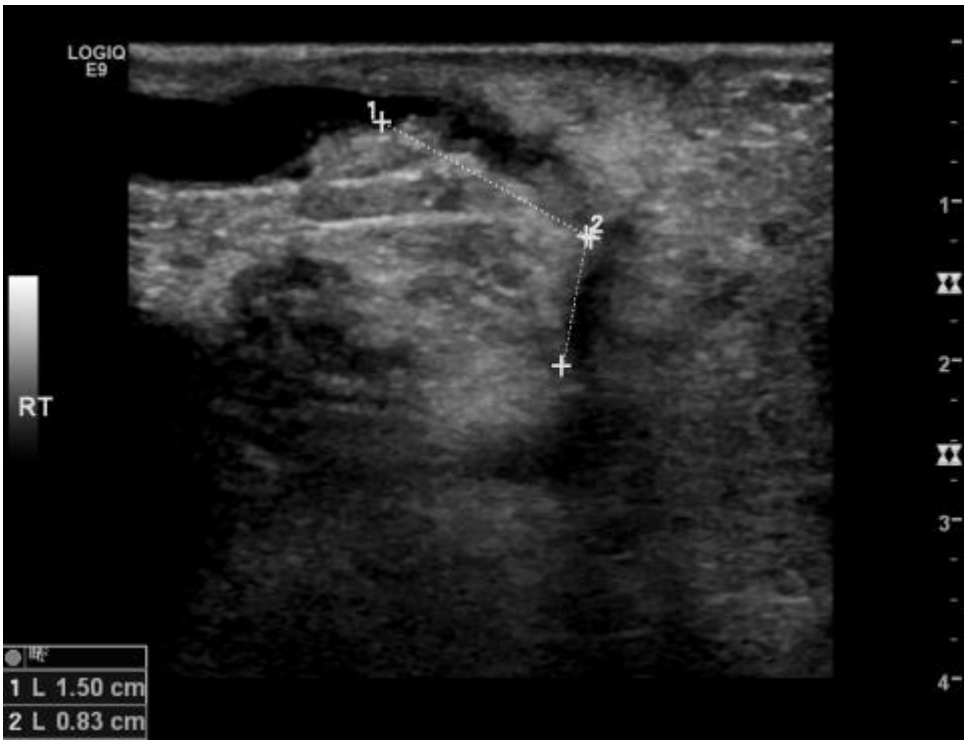

Figure 1: Stenosis of the fistula outflow vein demonstrated just past the anastomosis on B-mode ultrasound.

Arterial Inflow Issues

Hemodynamically significant anastomotic stenoses are identified based on velocity criteria. However, this can sometimes be difficult or misleading as the velocity at the anastomosis is often dependent on the velocity of the inflow artery. Therefore, a single velocity measurement at the anastomosis is often not enough for determining stenosis and rather a ratio of the anastomotic velocity compared to the proximal inflow artery should be used. A velocity ratio of greater than 3.5 is often suggestive of a significant stenosis[4]. In the situation of a nonmaturing fistula or a very significant stenosis, the velocity and flow volumes downstream of the anastomosis may be markedly decreased and spectral Doppler waveforms in the outflow vein may have a “parvus tardus” form suggesting hemodynamically significant proximal obstruction. Additionally, in a nonmaturing fistula, the velocities in the proximal inflow artery may not be significantly elevated beyond the physiologic norm and may present as normal high-resistance triphasic spectral Doppler waveforms rather than low resistance, high velocity pre-fistula waveforms.

In more uncommon cases, issues with the arterial inflow itself may be causing low flow into the fistula. This is most often due to arterial occlusive disease of the inflow vessels. Disease of the radial artery inflow of a radiocephalic fistula is the most common, but more proximal arteries such as the brachial artery or even isolated lesions in the axillary or subclavian artery can contribute to low fistula flow. In situations of more proximal inflow lesions, concomitant symptoms of arm ischemia may also be present. Atherosclerotic disease of the inflow vessels is common due to the propensity of dialysis patients to develop significant vessel calcification, but significant stenosis leading to AVF malfunction is less common[5]. Duplex examination of a malfunctioning AVF may suggest significant inflow disease if low flows persist throughout the AVF despite no identifiable area of stenosis. The area just proximal to the anastomosis will also demonstrate post-obstructive “tardus parvus” monophasic waveforms. This should prompt further evaluation of the upper extremity arterial tree by B-mode and spectral Doppler for areas of severe calcification and stenosis.

Outflow Vein Stenosis

Outflow vein stenoses are the most common causes of access-related issues, resulting in high venous pressures or low flow causing inadequate dialysis sessions or prolonged bleeding after decannulation. These stenoses can be identified on B-mode imaging as areas that appear narrowed or kinked, or on color Doppler as areas with turbulent flow, and further confirmatory imaging using spectral Doppler can confirm a hemodynamically significant stenosis using velocity criteria. As in the case of anastomotic stenoses, velocities can vary depending on the conduit type and size, and so single velocity criteria are not adequate for diagnosis. A velocity ratio of the stenotic velocity compared to the upstream velocity is necessary to accurately identify a stenotic segment.

In severe instances of outflow vein stenosis, the outflow vein will demonstrate lower velocities similar to an arterial conduit. Spectral Doppler upstream of the stenosis may show a triphasic waveform suggesting puslatile inflow with high resistance outflow very similar to an arterial waveform, and the overall flow volume of the fistula will be very low. These findings may represent an access at immediate risk of failure. Further treatment with fistulography and balloon angioplasty can then be performed.

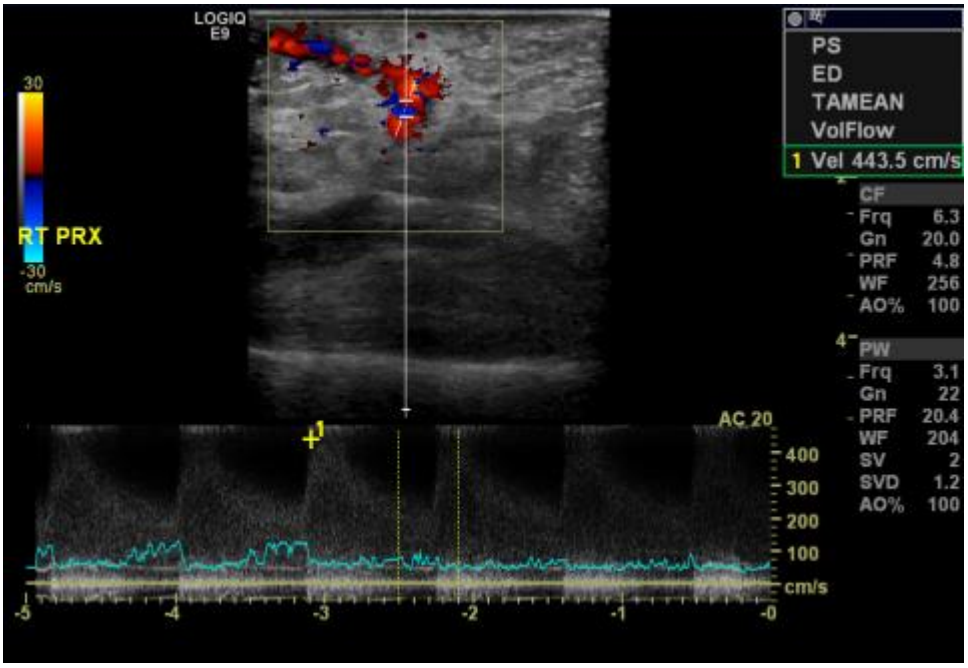

Figure 2: AV fistula outflow vein stenosis as demonstrated by spectral Doppler.

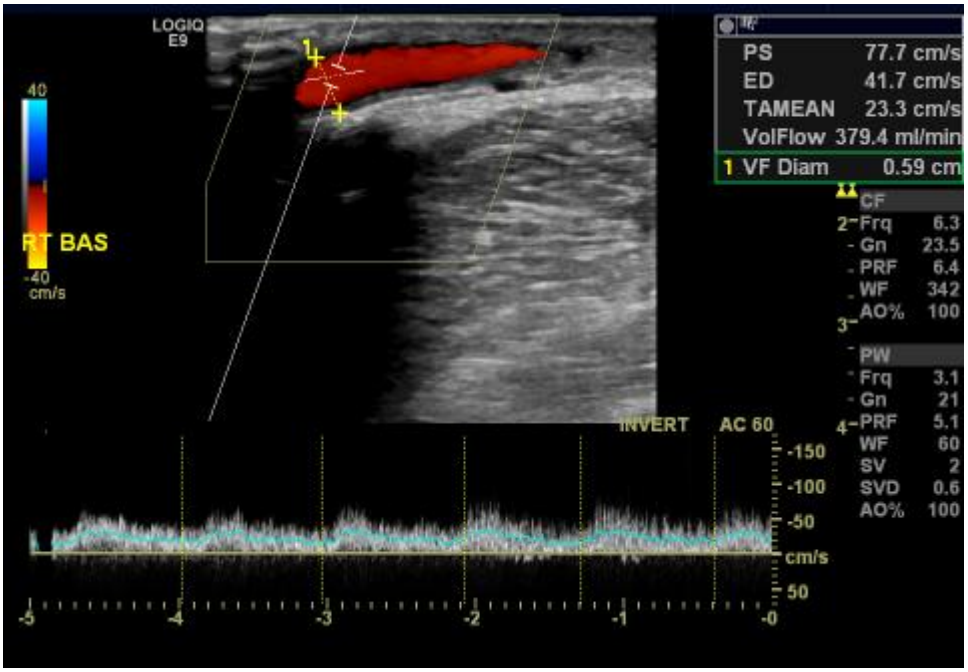

Figure 3: The outflow vein more central to the stenosis demonstrates low flow and post-obstructive waveforms.

Arteriovenous Grafts

AV graft malfunctions are most often due to stenosis at the venous anastomosis due to neointimal hyperplasia from a fibrotic reaction to the foreign graft material. Neointimal hyperplasia can also cause stenoses along the graft wall. For grafts, careful imaging must be performed at both anastomoses as well as along the entire length of the graft to identify any problem areas. Velocity criteria for stenoses of AVG are similar to that of AVF, with the velocity ratio the most sensitive/specific indicator of hemodynamically significant stenoses[1]. Early duplex of newly-constructed AV grafts using polytetrafluoroethylene (PTFE) may also be complicated by difficult visualization of the interior of the graft, as newly implanted PTFE contains air within the wall of the graft that can hinder propagation of the ultrasound beam and result in acoustic shadowing limiting evaluation of the graft by color or spectral Doppler[6].

Central Venous Stenosis

Central venous stenosis or occlusion can often cause increased venous backpressure in an extremity with an AVF or AVG. The increased arterial pressure against a central lesion can result in unilateral arm or

facial swelling, as well as the development of large collaterals in the shoulder and chest. These lesions are caused by intimal hyperplasia in the innominate or subclavian veins due to turbulent, abnormally high volume AVF/AVG flow. Central stenosis can also be caused or worsened by indwelling lines such as pacemaker leads, or injury from previous subclavian venous catheter placement and thrombosis. The most common presentation of central venous stenosis in a hemodialysis patient is unilateral arm or neck/facial swelling and prolonged bleeding from the cannulation sites after decannulation. Ultrasound evaluation of the axillary and subclavian veins showing loss of respiratory phasicity can be indicative of a central lesion. The actual lesion may or may not be visible under duplex ultrasound as often lesions are in the subclavian vein central to the thoracic outlet; brachiocephalic and proximal subclavian lesions are difficult to visualize clearly and color or spectral Doppler analysis may be unreliable. These lesions are notoriously difficult to treat, responding poorly to balloon angioplasty or stenting[7], often recur, and can cause significant discomfort for the patient.

ANEURYSMS AND PSEUDOANEURYSMS

Both aneurysms and pseudoaneruysms can develop along the length of an AVF or AVG. Pseudoaneurysms at the cannulation sites are more common due to the mechanical introduction of a weak spot in the fistula wall, compared to true aneurysms which involve all three layers of the vessel wall. Both pseudoaneurysms and true aneurysms can continue to enlarge over time and can affect the flow of blood into and out of the dialysis circuit, as well as contribute to discomfort from skin tension and large size of the aneurysms.

Pseudoaneurysms can be initially identified by the visualization of a large collection outside of the fistula or graft. These can be differentiated from hematoma surrounding the conduit by the presence of an active chamber that freely communicates the flow of blood from the conduit into the chamber, then back into the conduit, with each pulsation. Flow into the active chamber is classically described as to-and-fro flow on spectral Doppler with flow both toward and away from the probe during each cardiac cycle, and as a classic “yin-yang” sign on color Doppler. AVF and AVG pseudoaneurysms, however, may have shallow and enlarged entry points from the vessel into the pseudoaneurysm to where visualization of the to-and-fro spectral Doppler signal is not guaranteed. Pseudoaneurysms due to puncture sites in an AVF tend to grow over time especially if the same puncture site is used repeatedly, resulting in increasing skin tension and increased risk of rupture.

Findings of any aneurysms or pseudoaneurysms should be noted on the final report, including the presence of any mural thrombus and the maximum cross-sectional diameter as well as any flow into the active chamber of the pseudoaneurysm. Aneurysms and pseudoaneurysms are generally benign and do not typically require surgical repair until they either grow to a large size, grow rapidly, or result in skin tension. Prolonged tension from underlying aneurysms or pseudoaneurysms can result in skin breakdown, ulceration, and bleeding requiring emergent surgical intervention.

INTERVENTION AND POST-INTERVENTION EVALUATION

Interventions for malfunctioning or failing AV accesses span a wide range of procedures, including open revision, angiography and balloon or cutting balloon angioplasty, or even stenting across areas of resistant stenosis. The utility of post-intervention ultrasound evaluation has not been established and, unlike the lower extremity literature, no consensus for velocity thresholds or ratios has been established for restenosis after balloon angioplasty or stenting. Therefore, standards for practical interpretation of these studies vary from laboratory to laboratory. The standard in our practice is to forgo routine post-intervention ultrasound testing and rely on measured parameters (flow volumes, arterial/venous

pressures, post-decannulation bleeding) during dialysis to identify potential issues.

SURVEILLANCE AND MONITORING

End-stage renal patients on hemodialysis are uniquely dependent on their accesses in order to survive and maintain adequate quality of life. Therefore, maintenance and monitoring of their AVFs and AVGs are paramount to ensuring that they continue to have functional accesses. Similarly to post-intervention surveillance, the extent to which surveillance of AV accesses should be performed is a subject of some differing opinion and controversy[3]. Currently evidence suggests that monitoring of venous pressures during dialysis and looking for prolonged bleeding after dialysis sessions is sufficient to catch and fix problems with AV access malfunction1. However, recurring surveillance using either duplex ultrasound or fistulography is also widely used by some practitioners. The ideal frequency and invasiveness of surveillance monitoring remains unclear.

CONCLUSIONS

Arterio venous accesses, whether in the form of an AV fistula or an AV graft, are a lifeline for those who undergo hemodialysis access, and a properly functioning durable AVF or AVG is crucial for continued survival and quality of life. Duplex ultrasound can help identify the existence or location/etiology of a problem in a noninvasive fashion for someone suspected to have a malfunctioning AVF or AVG, before proceeding to invasive fistulography. The most common lesions are stenoses of the outflow vein or anastomotic lesions. The possibility of a central venous stenosis can also be suggested using duplex ultrasound. Pseudoaneurysms and aneurysms do not pose as severe a threat to fistula patency but can cause compressive or bleeding issues late and should be identified and noted on any duplex ultrasound study.

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