ARTERIOVENOUS FISTULA, PART 1: PLANNING AND INITIAL EVALUATION

INTRODUCTION TO FISTULAS FOR HEMODIALYSIS

Circulatory access for patients undergoing hemodialysis requires an access method that is durable, resistant to infection, and able to support high volume flow of blood to and from the dialysis machine[1]. This access is usually obtained through an indwelling central venous catheter, an arteriovenous fistula, or an arteriovenous prosthetic graft.

Arteriovenous fistulas (AVF) are the standard method for access in patients receiving hemodialysis. A superficial vein is anastomosed to an artery, creating a surgical arteriovenous shunt. Due to the intimal hyperplasia triggered by turbulent and high volume flow, the length of the superficial outflow vein distends and thickens over time to create a high-flow conduit that can be easily palpated under the skin and is fairly resistant to infection. Access from the fistula to the dialysis machine is obtained using large bore needles to puncture the fistula for dialysis under sterile conditions and removed afterwards, with hemostasis obtained by manual pressure. Multiple configurations of AVFs exist, with the most common ones utilizing the cephalic or basilic veins in the arm. The cephalic vein is ideal due to its superficial location on the lateral side of the arm which provides ease of access during dialysis sessions when the patient is seated with the arm supinated. Common sites for cephalic AVF creation are the radiocephalic (Cimino-Bresch) fistula at the wrist, and the brachiocephalic fistula at the antecubital fossa to either the cephalic vein or the median antebrachial vein.

The basilic vein is the other commonly used vein conduit for AVF creation. It is often a secondary choice to the cephalic vein as it is deeper and located on the medial side of the arm, decreasing the ease and comfort of access during dialysis sessions.

Common sites for basilic AVF creation are the forearm radiobasilic transposition and the brachiobasilic transposition proximal to the antecubital fossa. The forearm basilic vein requires surgical mobilization of the entire vein and transposition with subcutaneous tunneling to reach from the medial forearm to the lateral anastomosis with the radial artery. The proximal arm basilic vein also requires surgical transposition due to its depth, medial location, and location underneath a fascial layer, but also requires subcutaneous tunneling from the medial site of the brachio-basilic anastomosis to lateral and back to medial, making a “C” shape and allowing cannulation of the AVF on the lateral arm instead of medially on the inner arm. AVF construction using a basilic vein involving transposition due to the depth of the vein, results in either a longer operation and incision with more tissue mobilization or the need for a staged operation. Staged operations, with one operation for the fistula creation and a second for superficialization, may be beneficial in patients with questionable vein as maturation can be verified prior to the more extensive superficialization operation.

Arteriovenous grafts (AVG) are similar to AVFs but utilize prosthetic material instead of the patient’s own vein. AVGs may utilize prosthetic material such as polytetrafluoroethylene (PTFE) or bioprosthetic materials such as bovine carotid artery. AVGs may be utilized whenever a suitable vein is not present for AVF creation. Creation of an AVG involves tunneling a graft in a large curve subcutaneously, then creating anastomoses from the graft to an artery and a vein. The curve of the graft provides a suitable length for needle punctures during dialysis. Common configurations of AVGs include forearm loop graft situated on the inner forearm with anastomosis to the brachial artery, or an upper arm graft running in a curve along the outer arm from the brachial artery proximal to the elbow to the axillary vein in the proximal medial arm. The forearm loop graft may either be anastomosed to the brachial or basilic vein, and as such an ultrasound deep vein mapping may provide valuable information for the surgeon prior to operation. AV grafts may also be created in the groin if suitable recipient veins in the arm do not exist or if the central venous system is occluded.

ROLE OF DUPLEX ULTRASOUND IN FISTULA PLANNING AND DIAGNOSTICS

Duplex ultrasound is a useful tool in the planning, creation, diagnostics, and troubleshooting of AVFs. A preoperative vein mapping allows the surgeon to choose the configuration of AV fistula that provides the highest likelihood of maturation. This is important even in patients who have had mapping of previous AV fistulas as vein characteristics may change with time, especially if a previous AVF was created and has failed as the high flow may have improved the characteristics of the other superficial veins in the arm. The gold standard for vein mapping previously utilized an intravenous injection venogram with intravenous contrast dye under fluoroscopy, but duplex examination has replaced diagnostic superficial venograms for all but the most difficult cases and for evaluation of central venous stenosis[2]. Vein mapping using venography still remains useful for evaluating difficult planning cases where nonstandard veins may be utilized for access, for nonstandard venous anatomy, or if the ultrasound examination is not definitive.

Duplex ultrasound is also important for diagnosis and troubleshooting of AV fistulas. Ultrasound can be used to evaluate AV fistulas to see whether the volume flow is adequate for hemodialysis, in conjunction with physical exam. A nonfunctional or nonmaturing fistula can be interrogated with duplex to identify any anastomotic problems or outflow vein stenosis, and can be used to follow growing pseudoaneurysms or confirm continued patency after infiltration. Duplex examination can also identify large branches that may be stealing flow from the main outflow vein resulting in lower volume flow or delayed maturation of the vein. These issues with the fistula can then be evaluated for intervention either with revision or interventional methods.

VEIN MAPPING FOR FISTULA PLANNING

Ultrasound vein mapping for fistula planning is usually the first step in evaluation for fistula creation. In the case of a first-time fistula, both arms are mapped, while in patients with previous failed fistulas or difficult access specific areas may be requested to be mapped by the surgeon. In order to be considered adequate for AVF creation, a superficial vein must be a continuous conduit, at least 2.5mm in diameter and easily compressible without signs of damage, sclerosis, thickened walls or thrombus. These signs of vein damage are often present in areas of frequent intravenous catheter placement, such as the antecubital fossa. These undesirable characteristics do not automatically preclude use in AVF creation, but the likelihood of fistula maturation can be significantly decreased if using a subpar vein conduit[3]; therefore, evaluation of the rest of the vein conduit must be completed even if a damaged portion of the vein is found. In addition, external factors during the examination can affect vein size and spasm such as room temperature or patient anxiety. These characteristics are readily recognizable on ultrasound and provide strong incentive for physicians to identify suitable veins early in patients approaching dialysis in order to instruct patients to protect their extremity from blood draws, intravenous catheter placement, or peripherally inserted central line (PICC) placement.

Figure 1. Normal vein map of cephalic vein in the upper arm. The cephalic vein at this level shows an adequate diameter for construction of an AV fistula.

A 9 or 11MHz probe is used to visualize the superficial veins in the arm. The cephalic and basilic are both mapped with the patient in a sitting or supine position. A tourniquet may be used to visualize vein diameter and distensibility according to laboratory protocols. The continuity of each superficial venous conduit and diameter are noted, along with areas of thickening, sclerosis, internal webbing, noncompressibility, or thrombus. Diameter of the vein should be recorded at both representative and possible anastamotic sites, including the wrist, mid forearm, antecubital fossa, distal arm, and proximal arm.

It is important to note that many factors affect the quality of a vein as visualized under ultrasound examination and consistently small veins may not necessarily indicate a poor quality conduit. The temperature of the room, peripheral vasospasm, and other factors can affect the size of the vein and make it appear to be too small. It is imperative that a good mapping be performed to completion in order for the surgeon to evaluate the vein as a complete conduit vein on the small side may still be utilized in the operating room to create a functioning AV fistula.

In the case of AV graft planning, the quality of the deep veins of the arm should be evaluated as surgical graft placement involves anastomosing a prosthetic or bioprosthetic graft from an arm artery to a deep venous outflow. The brachial veins at the antecubital fossa and the axillary vein at the proximal arm are typically evaluated in this scenario for patency, diameter, and compressibility. Undesirable characteristics such as webbing, thickening, sclerosis, and thrombus should be noted. Spectral Doppler waveform analysis of the axillary vein at the proximal arm may also be useful for identification of central venous problems which may affect graft placement strategy. Loss of respiratory phasicity in the axillary vein at this level may suggest hemodynamically significant central stenosis or occlusion. Undesirable factors identified on vein mapping may require venography to evaluate the central veins for stenosis or occlusion prior to AV graft construction.

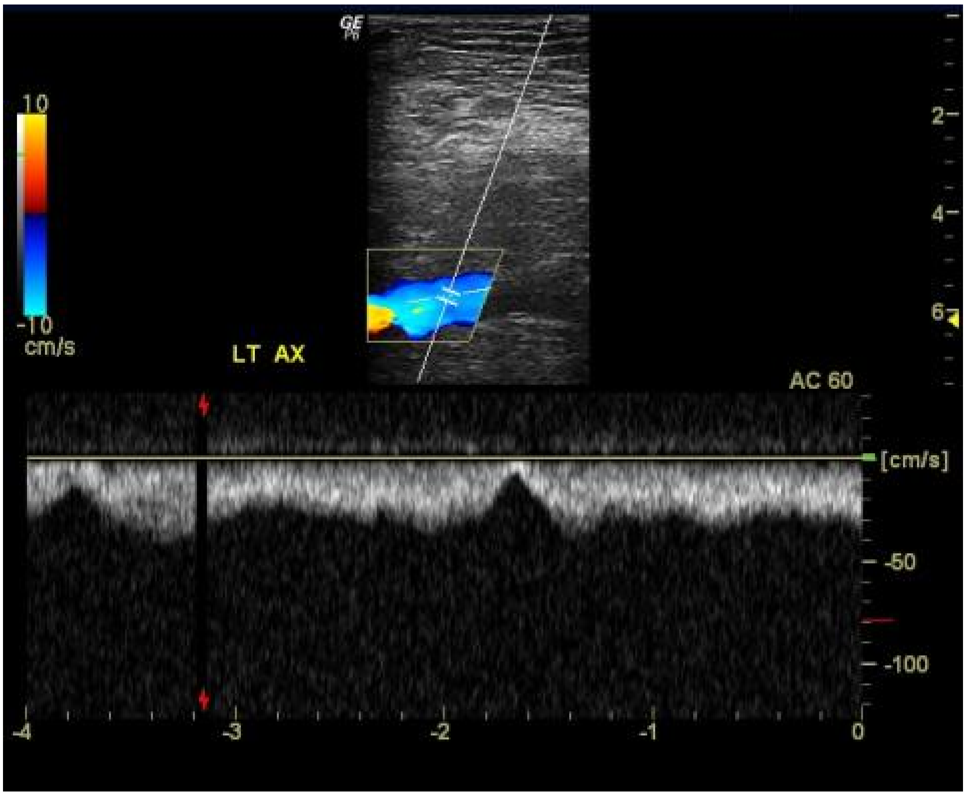

Figure 2. Normal axillary vein spectral Doppler showing phasicity. This suggests not only a patent axillary vein but a patent central system as well.

The arm arterial system is also examined during a vein mapping, as inflow disease can decrease fistula maturation rates and potentially result in ischemic steal. The radial, ulnar, and brachial arteries in each arm are examined in a limited fashion. The radial and ulnar arteries are evaluated at the wrist, noting the presence of any vessel calcifications or areas with lack of flow. Spectral Doppler waveform analysis of the vessels are also performed and can help highlight turbulent flow suggestive of arterial disease or dampened waveforms suggestive of proximal inflow disease. The brachial artery at the antecubital fossa is interrogated in the same manner, with close attention paid to systolic velocities and spectral Doppler waveforms that may suggest proximal disease.

Figure 3. Normal radial artery spectral Doppler. Constructing an AV fistula with a diseased or low-flow radial artery can increase the chances of physiologic steal.

A complete report of upper extremity vein mapping should therefore include the continuity of the cephalic and basilic veins from the forearm to the proximal arm, diameters and compressibility of the vein with or without tourniquet placement at representative sites throughout the arm, and notation for any undesirable vein characteristics identified on B-mode imaging. The report should also include the limited evaluation of the radial, ulnar, and brachial arteries. Deep venous evaluation should be reported if requested by the surgeon for AV graft planning.

POSTOPERATIVE FISTULA EVALUATION AND MATURATION

An AVF typically requires 4-8 weeks after surgical creation before the conduit thickens enough and there is enough volume flow for hemodialysis[4]. Duplex examination of the AV fistula can be performed to evaluate whether the fistula is appropriate to be used for dialysis.

An evaluation of the maturity and adequacy of an AVF encompasses the conduit size, depth, and volume flow. As a rule of thumb, the fistula should generally be greater in diameter than 6mm, be less than 6mm from the surface of the skin, and provide a volume flow of greater than 600 mL/min to be suitable for use in hemodialysis[1].

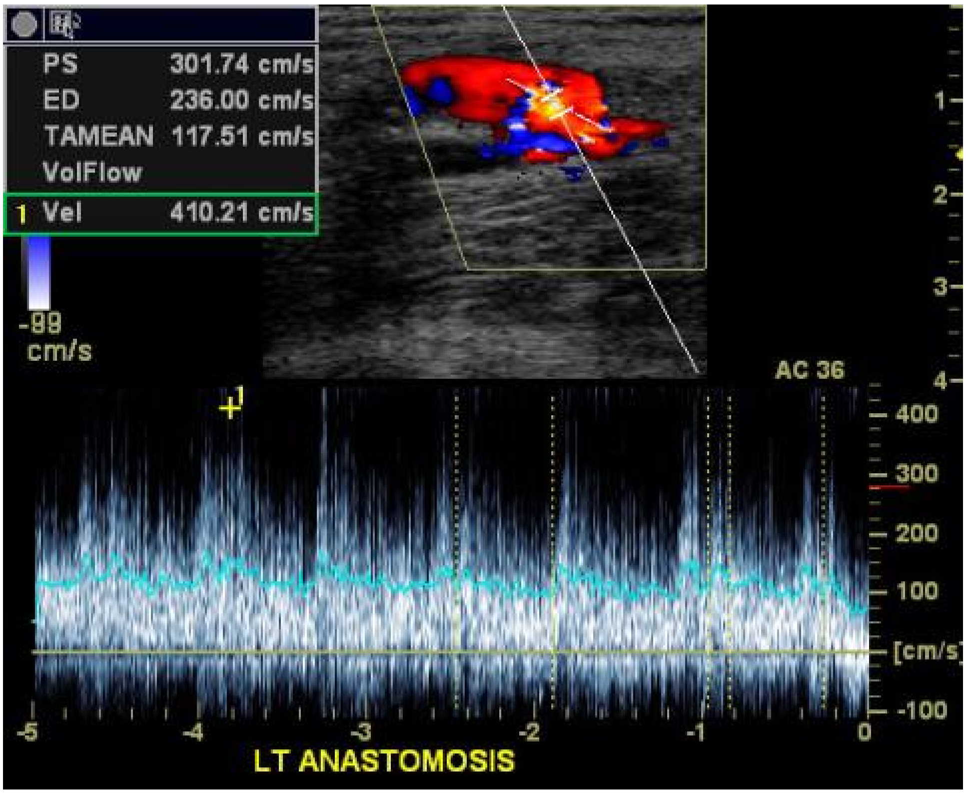

Figure 4. Spectral Doppler analysis of an AV fistula at the anastomosis. Normal flow at an AV fistula anastomosis is usually turbulent and high-velocity.

A thorough duplex evaluation of a newly created AVF begins with evaluation of the anastomosis and moves proximally along the arm along the length of the outflow vein. The anastomosis is imaged both in brightness mode and with spectral Doppler waveform analysis with a 9 or 11 MHz probe. Velocities in both the brachial artery proximal to the fistula and the fistula itself should be elevated due to the new increase in blood flow through the AVF, and turbulent flow should seen in the anastomotic area. The outflow vein should have pulsatile flow throughout the entire length of the conduit and flow should become more laminar as distance from the anastomosis increases.

Volume flow is calculated in the outflow vein 2cm distal to the anastomosis based on the flow velocity and the measured diameter of the outflow vessel with an angle of insonation of 60 degrees. The technologist should be careful to accurately measure the diameter of the vessel as small inaccuracies may significantly affect the calculation of the volume flow. Although the potential for significant errors of measurement of the volume flow exist, adequate training and experience has been shown to result in fairly consistent estimates of volume flow across technologists[5].

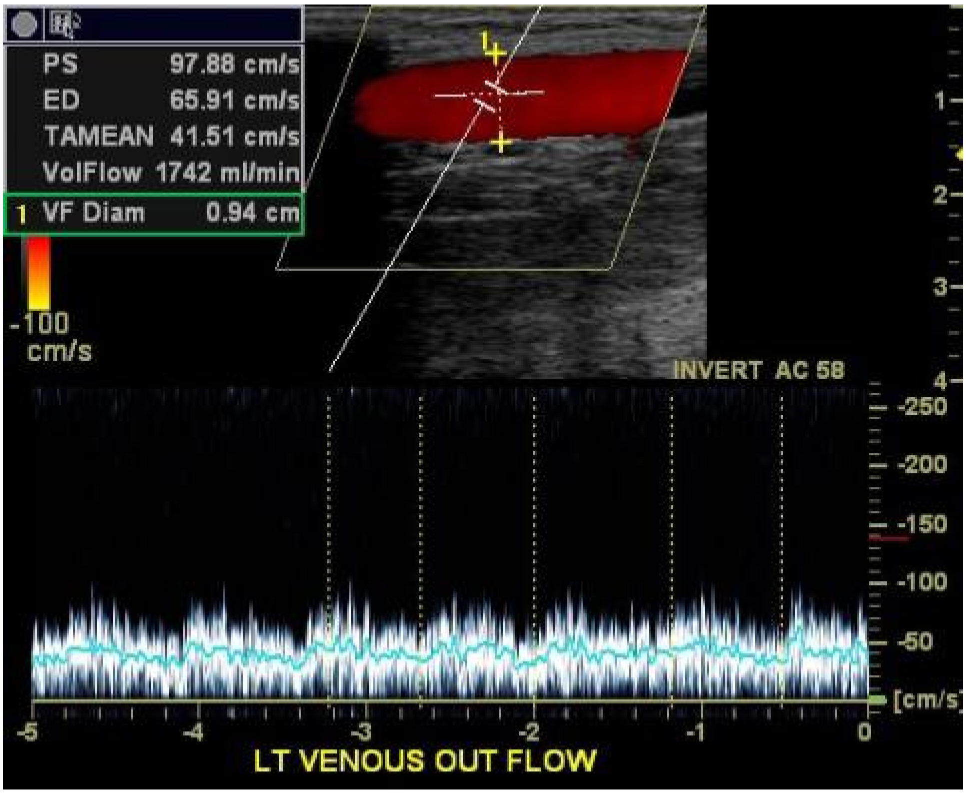

Figure 5. Calculation of the flow volume in the outflow vein of an AV fistula based on the velocity and vessel diameter.

Evaluation of an AV graft follows similar procedures as that for an AVF. Both the arterial and venous anastomoses will demonstrate turbulent flow, and volume flows can be calculated from the body of the graft calculated using the flow velocity and measured diameter of the graft. Early evaluation of an AV graft, within the first week after placement, may result in limited visualization if using a prosthetic material such as PTFE which contains air in the graft wall, until the graft is fully incorporated. Imaging of these PTFE grafts soon after placement is therefore not recommended. In some situations, such as troubleshooting of an immediate-access graft, imaging may be helpful in diagnosis and treatment and may be attempted with the understanding that visualization may be hampered by artifacts from the graft and postoperative inflammatory tissue.

Duplex ultrasound examination purely to document maturity of an AV fistula is not often necessary, as physical exam alone can be an accurate indicator of maturity in many native AV fistulas. Duplex examination can be helpful in troubleshooting if a new AVF or AVG does not perform as expected, with low flows, infiltration, or prolonged bleeding after decannulation. Infiltration is particularly common after attempted puncturing of a new fistula due to the lack of scar tissue and the mobility of a new outflow vein. This occurs when a hematoma develops anterior or around the outflow vein either during cannulation or after decannulation. If significant, this infiltration can cause significant discomfort and can impede reaccess of the fistula for dialysis. Ultrasound examination of infiltration most often does not demonstrate a discrete hematoma but diffuse infiltration of blood into the tissues pushing the fistula deeper from the surface of the skin.

CONCLUSIONS

AV fistula and graft planning benefit significantly from the usage of duplex ultrasound. Ultrasound provides a noninvasive means of documenting adequate vein conduit for fistula planning and confirming the presence of adequate arterial inflow. Duplex also provides a way to quantify maturity of AV fistula or adequate flows through an AV graft when deciding whether a conduit is ready for dialysis or whether adjunctive procedures need to be performed.

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