12 Approach to Arteriovenous Access

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Introduction

A well-functioning and reliable dialysis access is an absolute requirement to provide life-sustaining dialysis treatment in end-stage kidney disease (ESKD) patients and is rightfully referred to as their "lifeline" [1]. The rising incidence and prevalence of ESKD have led to an increased burden on the healthcare system as the social and economic cost of ESKD care is disproportionately high. In the United States, the total ESKD Medicare expenditure rose to $35.4 billion in 2016 up from $29 billion in 2009, amounting to 7.2% of the entire Medicare budget [2, 3]. Hemodialysis (HD) vascular access (VA) dysfunction is the single most important cause of morbidity in ESKD patients [1, 2]. Care of dialysis access accounts for over $2.8 billion of this expense annually in the United States [4].

To optimize vascular access care, procedural aspects of nephrology have steadily evolved over the past two decades. Despite the concerted efforts of the nephrologists, surgeons, and radiologists to deliver timely care, treatment delays persist [5–7]. Endovascular procedures are increasingly being performed by the "interventional" nephrologists [8, 9]. The American Society of Diagnostic and Interventional Nephrology (ASDIN) was founded in 2000 to fulfill this unmet need, and its published training guidelines generated significant interest among nephrologists to master procedural skills in an effort to reduce morbidity and improve quality of life in the dialysis population [10, 11]. In spite of improved awareness, many aspects of vascular access care still remain poorly understood.

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Types of Vascular Access

The three principal forms of vascular access are native AV fistulae (AVF), synthetic AV grafts (AVG), and tunneled cuffed hemodialysis catheters (TDC). It is important to understand characteristics of each type of vascular access to be able to choose, prepare, and maintain an individualized access.

AV Fistulae (AVF)

AV fistulae are typically constructed with an end-to-side vein-to-artery anastomosis. The creation of an AVF at the wrist was first described by Brescia and Cimino [1, 12] (Fig. 12.1). The AVF commonly created at first is the lower forearm radio-cephalic fistula (RCF); however, this access often fails to mature in the elderly patient with underlying vascular disease, particularly in diabetics [14]. The next recommended site for AVF is the upper arm brachiocephalic fistula (Fig. 12.2). This type of AVF is being placed with increased frequency because of the high failure rate of RCF or as a secondary AVF in patients with failed forearm AV grafts [15]. Less commonly, native fistulae are created between the brachial artery and basilic vein, for which the basilic vein is usually mobilized laterally and superficially to allow easier cannulation (transposed brachiobasilic fistula) (Fig. 12.3) [16]. Radio-cephalic native fistula is generally recommended as the first choice to save more proximal veins, followed by brachiocephalic and brachiobasilic fistula as the second and third choice, respectively [17, 18].

Fistulae in the lower extremity, such as the superficial femoral and common femoral thigh transpositions, are rare, although adequate outcomes have been reported with good patient selection [19].

AVF, given their superior longevity, fewer complication rates, cost-effectiveness, and their salutary impact on patient outcomes, are considered the most "desirable" access for

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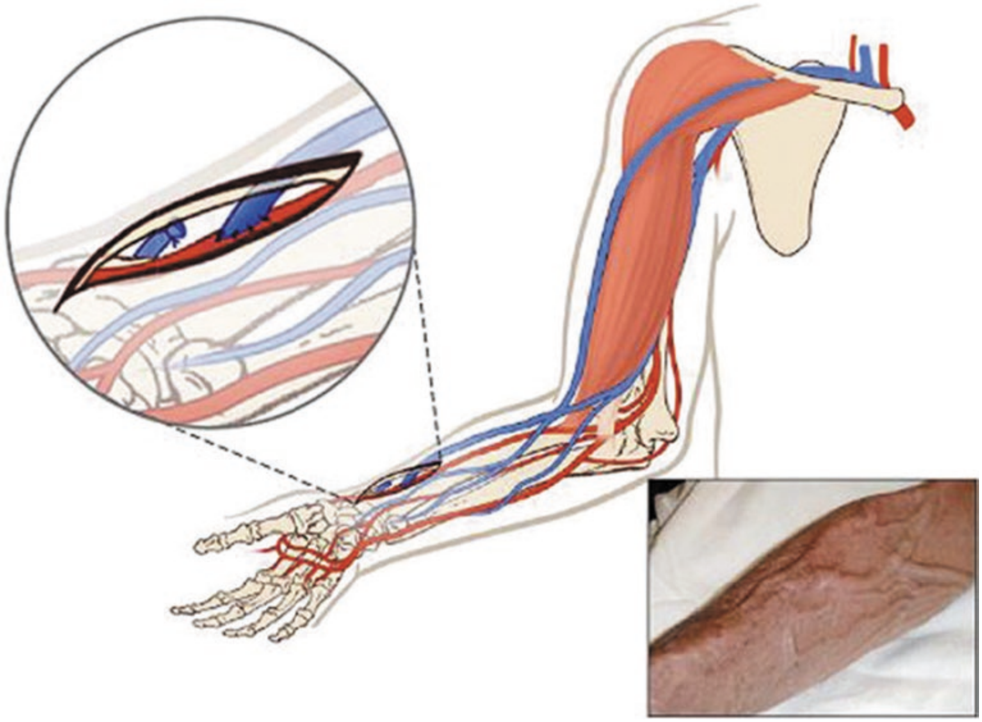

Fig. 12.1 Illustration for radiocephalic arteriovenous fistula (Brescia-Cimino). (With permission from Vachharajani [13])

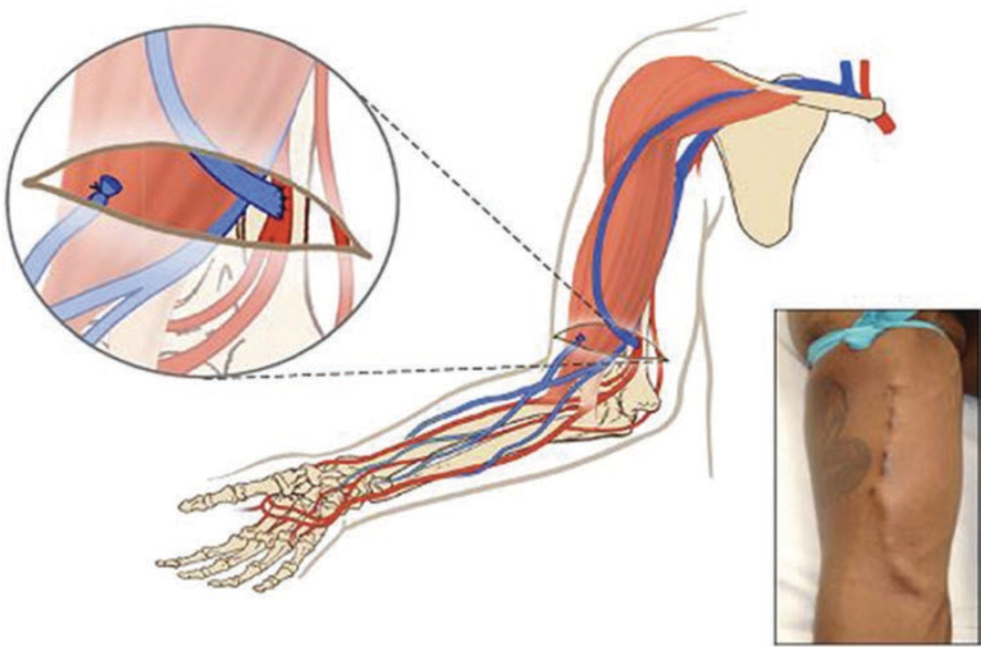

Fig. 12.2 Illustration for brachiocephalic AV fistula. (With permission from Vachharajani [13])

dialysis [15]. However, successful creation of AVF requires patent and good-sized arteries and veins and a timely creation to allow its maturation. Additionally, there is a high rate of failure to mature that often requires more than one intervention to make it functional. AVF usually require a maturation period of 4–6 weeks, though in practice it is common to wait for 10–16 weeks prior to cannulation for dialysis, with a median wait time of 108 days [3].

Synthetic Arteriovenous Grafts (AVG)

When the location or condition of the native blood vessels is not adequate for creation of AVF, a synthetic graft can be substituted. Synthetic arteriovenous grafts are constructed by anastomosing a synthetic conduit, usually polytetrafluoroethylene (PTFE), between an artery and vein [20, 21]. PTFE grafts are the second most preferred form of perma-

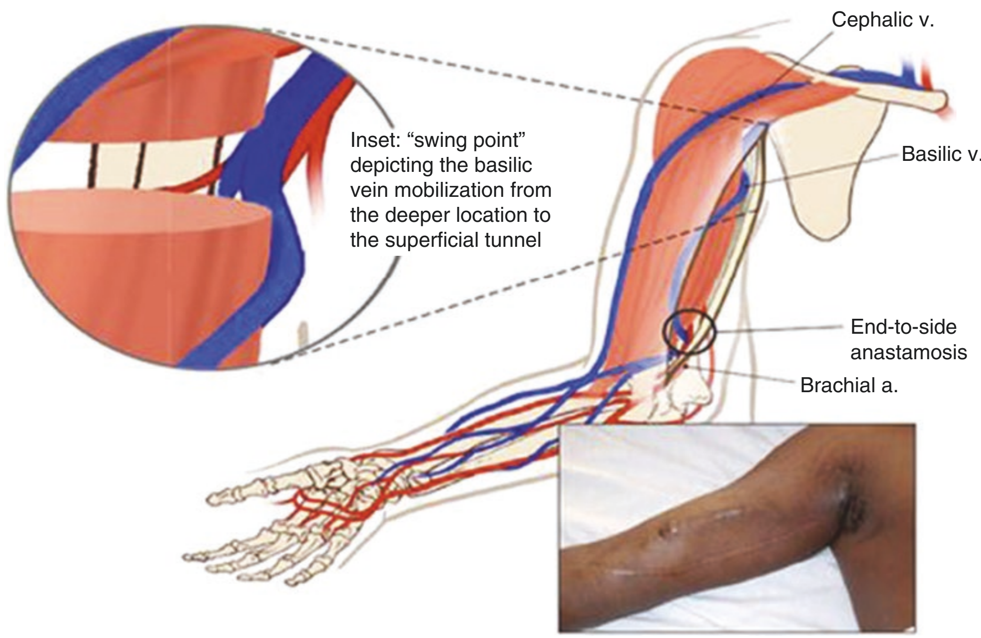

Fig. 12.3 Illustration for transposed brachiobasilic AV fistula. (With permission from Vachharajani [13])

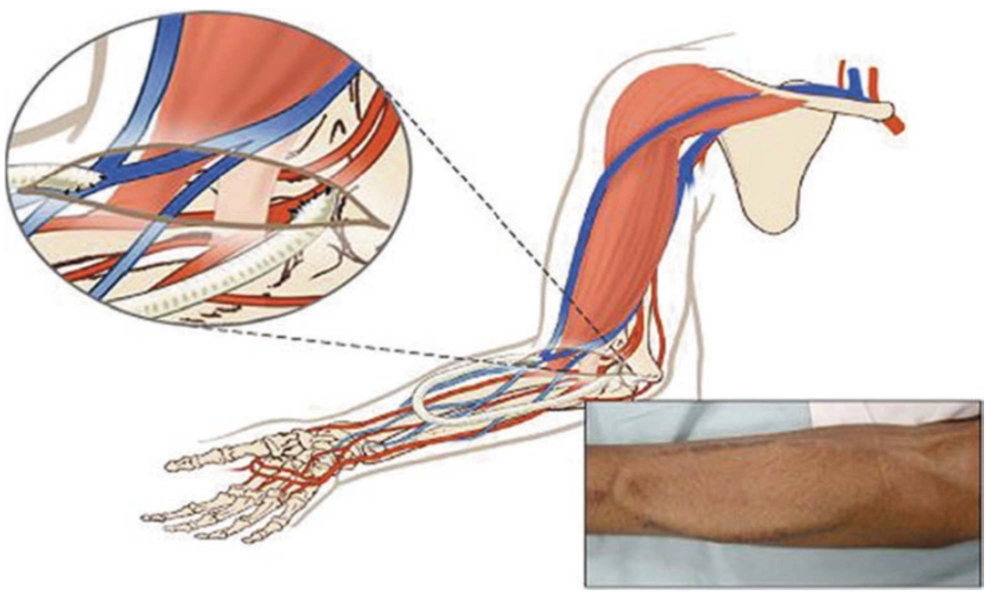

Fig. 12.4 Illustration for forearm loop graft (brachiocephalic). (With permission from Vachharajani [13])

nent dialysis vascular access. They have the advantage of being easier to create surgically, require a maturation time of only 2–3 weeks, and have a relatively large cannulation area [22]. Unfortunately, PTFE dialysis grafts have a poor primary patency rate (50% at 1 year and 25% at 2 years) [23]. Aggressive preemptive monitoring and intervention can result in a cumulative patency for PTFE grafts that matches the patency of AVF. This increase in cumulative patency, however, requires a sixfold increase in interventions (thrombectomies and angioplasties) [1]. Common AVG locations and configurations are straight forearm (radial artery to cephalic vein), looped forearm (brachial artery to cephalic vein) (Fig. 12.4), straight upper arm (brachial artery to axillary vein), or looped upper arm (axillary artery to axillary vein). Thigh grafts (Fig. 12.5), looped chest grafts, axillary-axillary (necklace), and axillary-atrial grafts have also been reported [24, 25]. Many synthetic materials other than PTFE have been used for the construction of grafts. The use of autologous tissue-engineered vascular grafts and drug-eluting grafts remains a subject of active research and not widely used in the clinical practice at the current time [26, 27].

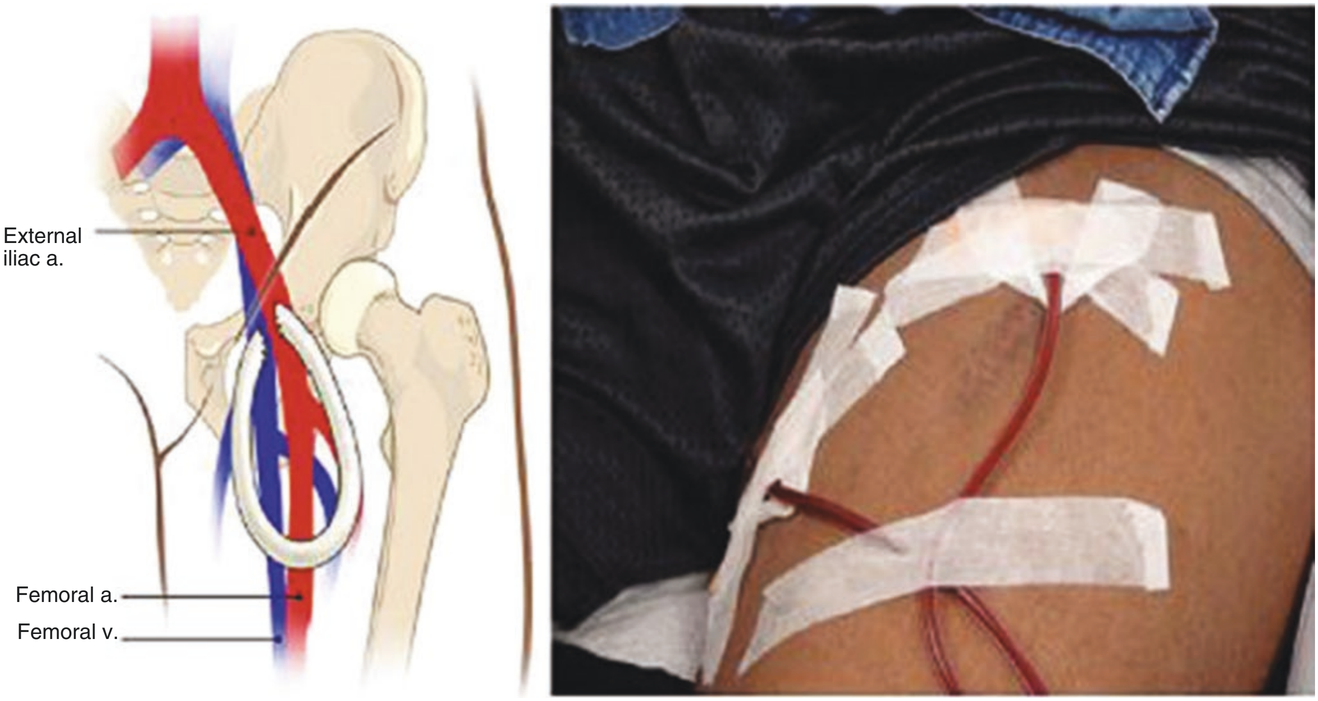

Fig. 12.5 Illustration for thigh AV graft (external iliac artery to femoral vein). (With permission from Vachharajani [13])

Tunneled Cuffed Hemodialysis Catheters (TDC)

TDCs are dual-lumen catheters usually composed of silicone or polyurethane composites. TDCs are commonly placed in the internal jugular vein and tunneled superficially to exit on the upper, anterior chest. Patency of central veins should be confirmed with ultrasound prior to insertion. Direct guidance with ultrasound is considered standard of practice and is highly recommended. The catheters are commonly positioned under fluoroscopy such that the tip rests in the middle of the right atrium when the patient is supine as it tends to move up with erect posture (Fig. 12.6). The use of subclavian catheters should be discouraged given the high incidence of subclavian vein stenosis with their use [18, 28]. The main advantage of using TDCs as dialysis access is that they can be used immediately after placement [1]. However, these catheters have many disadvantages including significant morbidity caused by thrombosis and infection, a substantial risk of permanent central venous stenosis or occlusion, a far shorter life span than AVF or AVG [29], and relatively lower bloodflow rates resulting in inadequate dialysis. There is a significantly negative impact of catheters on patient outcomes. Ideally, catheters should be used only as a bridge, while an AVF matures [1], or when the expected time to remain on hemodialysis is relatively short (e.g., pending transplant, converting to peritoneal dialysis, or a short life expectancy). Every attempt should be made to limit the use of TDCs whenever possible [1].

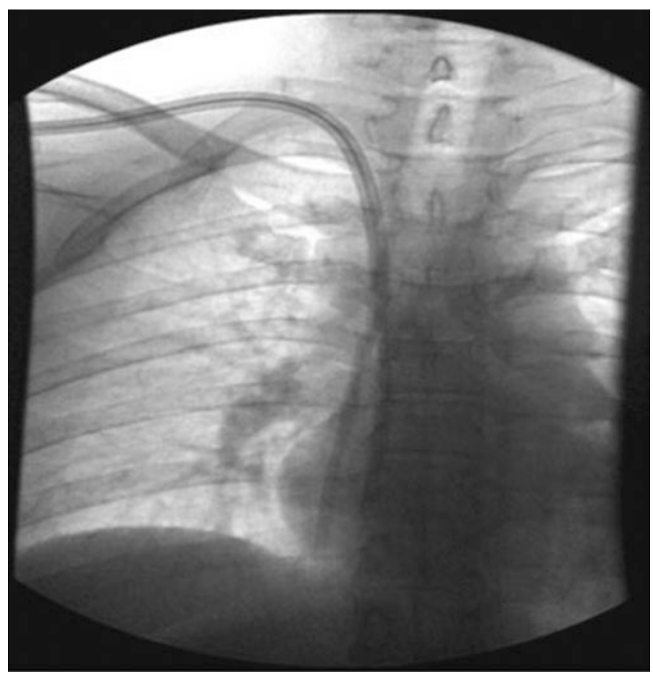

Fig. 12.6 Chest X-ray showing a right internal jugular split-tip tunneled dialysis catheter

Pre-dialysis Evaluation

The process of approaching vascular access begins long before the patient is referred for the creation of access. With the increase of comorbid conditions related to age and diabe-

Fig. 12.7 Well-preserved veins in the forearm and upper arm for creating a functional arteriovenous fistula. (With permission from Vachharajani [13])

tes mellitus, vascular problems are increasingly prevalent as evidenced by progressive peripheral vascular, carotid, and coronary artery disease in dialysis population [30]. Additionally, damage to the vasculature occurs from numerous blood samplings, infusions, and intravenous lines during hospitalizations especially in patients with advanced chronic kidney disease (CKD). Venous damage may thus occur even before the patient is referred to a nephrologist or access surgeon, emphasizing the need for timely nephrology referral along with the intensive strategies for vein preservation in CKD patients (Fig. 12.7) [30]. The Kidney Disease Outcomes Quality Initiative (KDOQI) and National Vascular Access Improvement Initiative recommend timely referral of CKD patients to a nephrologist usually at stage 4 so that the education for dialysis options including dialysis access evaluation can begin [3, 31, 32]. Thus, the timing of access placement, preferably an AVF, and the process of patient evaluation are extremely important for the successful use of vascular access. The new 2019 KDOQI clinical practice guidelines for vascular access recommend establishing an “ESKD life-plan” that is regularly reviewed and updated. This plan should be a multidisciplinary plan taking into account the patient’s priorities and input. While the majority of ESKD patients will require, or benefit the most, from an AVF, some may not require it based on their overall treatment goals [33].

Timing of AVF Creation

Creating the AVF well before it is required for dialysis allows for this process to take place in an adequate fashion prior to use. NKF-K/DOQI guidelines suggest that the patient be referred for the creation of an AVF when the patient’s estimated glomerular filtration rate (eGFR) is 15–20 ml/min/1.73 m^2 or less or when the rate of decline is rapid (>10 ml/min/1.73 m^2 per year) [33].

Early referral allows time for a second AV access attempt at an alternative site in patients with failed first attempt of AVF, without having to depend on TDC for dialysis initiation [34].

Patient Evaluation Prior to Access Placement

In order to determine the type of access most suitable for an ESKD patient, a thorough physical examination along with a focused medical history is imperative [34, 35]. Any scars should be noted in the neck or upper chest region since this might suggest the use of a previous central venous catheter (CVC) or previous surgery and ensuing anatomical abnormalities [36]. The presence of cardiac devices such as pacemakers or automatic implantable cardioverter-defibrillators (AICD) should also be noted, as these may be associated with central venous stenosis. The patient’s chest, breast, and upper arms should be evaluated for the presence of swelling or collateral veins; if present, they are strongly suggestive of central venous stenosis. Both the size and anatomical characteristics of the venous and arterial components of the AVF can affect the success of AVF placement and maturation.

Prior to AVF creation, both arterial and venous evaluation must be conducted.

Arterial Evaluation

The feeding artery must be capable of delivering blood flow at a rate adequate to support dialysis while simultaneously not jeopardizing the blood flow to the hand and digits. There are three important clinical features relative to the arterial system for a successful AVF creation [37]. Firstly, the patient should have less than 20 mmHg differential in blood pressure between the two arms; a greater difference suggests the presence of arterial disease that needs to be evaluated further, before access placement. Secondly, the palmar arch should be patent. The palmar arch can be tested for patency using the Allen test [38]. The test has been criticized as being unreliable given the considerable inter-operator variation in performance and interpretation, partly because of the subjective nature. Modification using either a pulse oximeter, to detect the pulse wave, or a vascular Doppler, to evaluate pulse augmentation, can increase the efficacy of the Allen test [39]. Failure of palmar arch pressures to increase during this maneuver suggests inadequate collateral circulation in the hand and predicts a higher risk for vascular steal if the dominant artery were to be used for access creation. And lastly, the arterial lumen should be at least 2 mm in diameter at the site proposed for AV anastomosis, which can be determined using color flow Doppler.

Venous Evaluation

The cephalic vein is ideal for an AVF because of its location on the ventral surface of the forearm and the lateral surface of the upper arm, making it easily accessible for cannulation with the patient in a sitting position [34]. Venous mapping should be performed in all patients prior to the placement of an access. Routine preoperative mapping results in a marked increase in placement of AVF, as well as an improvement in the adequacy of forearm AVF for dialysis [37, 40].

The main goal of venous mapping is to identify a cephalic vein that is suitable for the creation of an AVF. In addition to a thorough physical examination, venous mapping can be done by Doppler ultrasound and angiography study as needed. During the physical examination, a blood pressure cuff is inflated to a pressure about 5 mmHg above diastolic pressure for no more than 5 min. Although in many patients the venous anatomy can be evaluated by physical examination only, most surgeons prefer a detailed venogram performed using either color flow Doppler ultrasound or angiography prior to surgery. Color flow Doppler ultrasound is considered to be the best method for visualizing the venous anatomy primarily because it avoids the use of radiocontrast. Optimum features on venogram for the creation of an AVF are a luminal diameter at the point of anastomosis of 2.5 mm or greater, a straight segment of vein, absence of stenosis, and continuity with the proximal central veins [37].

Alternative Strategies for Arteriovenous Fistula Creation

Use of the nondominant arm is preferred as an initial AV access site; however, if suitable anatomy is not found, the dominant arm should be evaluated. In instances in which the cephalic vein in the lower arm is not large enough to meet the size criteria, consideration should shift to an upper forearm or upper arm region [34]. If the cephalic vein is not deemed suitable for the AV access placement, attention must be directed toward evaluation of the basilic venous system. When a straight segment of vein suitable for cannulation is not present, the novel vein transposition techniques should be considered [41]. By this procedure, an otherwise unsuitable forearm vein is identified, exteriorized, and transposed to an optimal position on the volar surface of the forearm. This technique has yielded a primary patency rate of 84% at 1 year [34, 41]. If mapping reveals the presence of a suitable but a deep vein, superficial transposition can yield a usable fistula.

Endovascular AVF Creation (Endo-AVF)

An endovascular approach to create an AVF was first described in 2015 [42]. Two endovascular percutaneous AVF creation devices are currently approved by the Food and Drug Administration in the United States, the WavelinQ (Bard Peripheral Vascular, Tempe, Arizona, USA), and Ellypsis (Avenue Medical, San Juan Capistrano, CA, USA). Both devices take advantage of the close proximity of the arteries and veins in the proximal forearm. WavelinQ utilizes two catheters, one inserted into the artery and the other into the vein. Both catheters have magnets in them, and when the catheters are advanced to the chosen creation site, these magnets align together. An ablation is made with radiofrequency cutting current creating a connection between the artery and the vein, thus resulting in an AVF [43].

To create an AVF using the Ellypsis device, the operator would access the deep communicating vein in the mid-forearm under ultrasound guidance and cross into the proximal radial artery. The catheter is then inserted into the radial artery, and a connection between the vein and the artery is made through thermal ablation. A follow-up angiogram with angioplasty might be required to dilate the anastomotic area [44].

Factors Related to Successful Fistula Use

Once a fistula is created, it must develop to the point that it can be cannulated for successful dialysis. This requires adequate blood flow to support dialysis and maturation of physical characteristics to permit repetitive cannulation. Without adequate inflow, the fistula will simply not develop. The issue of repetitive cannulation involves characteristics that are often referred to as “maturation.” For the most part, these relate to the size, position on the extremity, configuration, and depth of AVF. In addition, there are subjective elements including the feel of the AVF by an experienced operator, which cannot be quantified. Robin et al. have shown that if the fistula diameter at 2–4 months after creatio was 0.4 cm or greater, the likelihood that it would be adequate for dialysis was 89% versus 44% if it was less than 0.4 cm [45]. Furthermore, the chances that the fistula would be adequate for dialysis were 84% if the flow was 500 mL/min or greater but only 43% if less. Combining both the parameters, a minimum fistula diameter of 0.4 cm and a minimum flow volume of 500 mL/min resulted in a 95% chance that the fistula would be adequate versus 33% if neither of the minimum criteria were met [45]. Of considerable interest was the fact that experienced dialysis nurses had an 80% accuracy in predicting the ultimate utility of a fistula for dialysis.

Frequently, the "rule of 6's" is used to describe a mature AVF. It suggests that a mature AVF should have a blood flow of >600 ml/min, a diameter of >6 mm, a length for >6 cm to allow 2 needles to be inserted, and that the AVF should be <6 mm deep.

Evaluation of AVF at 30 days to detect problems with adequacy has been recommended [46]. This practice is based upon the observation that an AVF that did not appear to be adequate at that time was generally not adequate later. Studies have suggested that there is no significant difference in AVF blood flow in the second, third, or fourth month following creation and that vessel diameter changes very little [47]. Given the fact that there is very little change in the AVF blood flow or diameter after the first month along with the finding that AVF maturation can be judged with high accuracy via physical examination, it is recommended that all newly created AVF should be evaluated by an experienced examiner at 4 weeks [34]. An angiographic study should be performed for non-maturing or poorly mature AVF, so that a procedure to mature the AVF can be undertaken, if necessary.

Assessment of AV Access by Physical Examination

Physical examination of the AV access is easily performed, is inexpensive, and provides a high level of accuracy [20, 48]. The examination of AV access – both AVF and AVG – has the following essential components:

Pulse: A normal AVF should *not* be pulsatile. When a pulse is felt, it is indicative of a downstream obstruction. The severity of this obstruction is reflected in the strength of the pulse.

Thrill: A thrill, or bruit, at the anastomosis is indicative of flow. When feeling for the thrill (or listening to a bruit), it is important to focus on both the diastolic and systolic components [20]. Normally, a very prominent continuous thrill is present at the anastomosis. A systolic thrill at any point other than the anastomosis is indicative of a stenotic lesion at that point. With stenosis, the diastolic portion of the thrill becomes shortened and will eventually disappear, leaving only the systolic component [21]. The thrill generated by a central venous stenosis may be palpable in the axillary or subclavian region, especially in thin-chested individuals.

Arm elevation: When the extremity is elevated to a level above the heart, the AVF should collapse, at least partially. If stenosis is present at some point in the fistula's drainage circuit, then the portion of the AVF distal (peripheral) to the lesion will stay distended, while the proximal (central) portion will collapse [20].

Pulse augmentation: If the body of the AVF is manually occluded several centimeters from the anastomosis, the pulse in the AVF distal to that point should become hyperpulsatile. This maneuver is referred to as "checking the pulse augmentation." The degree of pulse augmentation is directly proportional to the arterial inflow pressure. In a hyperpulsatile AVF, the degree of augmentation can be used to gauge the degree of stenosis. Although this is a subjective assessment, very useful information can often be obtained from this evaluation, especially by an experienced examiner.

When an abnormality is detected by physical examination, further diagnostic evaluation of the access should be pursued. The development of an inflow or outflow stenosis perpetually results in access dysfunction which can not only cause inadequate dialysis but also culminate in access thrombosis with the risk of losing the access permanently. Further AV access diagnostic testing can be accomplished by using ultrasound imaging or angiography. If a lesion is detected, it can be treated by percutaneous endovascular intervention with a high success rate [49]. The interventions include angioplasty of a stenosis or ligation of an accessory vein and are discussed in the chapter on approach to a non-mature AVF.

Special Considerations Related to AVG Examination

AV graft examination entails the following additional points.

Detection of Direction of Flow

The direction of blood flow in an AVG can vary depending upon the surgeon's choice or due to the location of the suitable vessels. If the orientation of the dialysis needles does not correspond to the direction of blood flow, a gross recirculation is unavoidable. The blood flow can be determined easily by occluding the graft with the tip of the finger and palpating on each side of the occlusion point for a pulse (Fig. 12.8). The side without a pulse is the downstream side

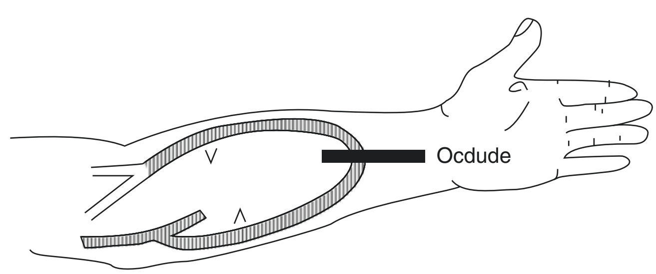

Fig. 12.8 Detection of direction of flow in a graft. When the graft is occluded, the upstream portion (*A* arterial limb) continues to be pulsatile while the downstream portion (*V* venous limb) should be nonpulsatile. (Source: Beathard [20])

of the graft, also referred to as a venous limb. The upstream pulse will increase in intensity during the occlusion, also known as the arterial limb. This should also be communicated to the dialysis staff to ensure proper cannulation of the AVG.

Detecting Recirculation

Recirculation occurs when the blood flow of the access falls below the rate demanded by the blood pump during hemodialysis. This results in varying degrees of reversal of flow between the needles depending upon the severity of the recirculation [20]. Presence of access recirculation can be detected by simple physical examination. To perform this maneuver, simply occlude the graft between the two needles while the patient is on dialysis and observe the venous and arterial pressure gauges (Fig. 12.9). With a normal well-functioning graft, very little or no change is observed in either the venous or arterial pressure readings. If recirculation is secondary to outflow obstruction (venous stenosis), the venous pressure will rise since the lower resistance recirculation route has been occluded [20]. As pressure limits are exceeded, the alarm will sound, and the blood pump will stop. The arterial pressure may become slightly more negative as the pressure head generated by the venous side is no longer transmitted given the graft occlusion [20]. If recirculation is due to poor inflow (arterial stenosis or insufficiency), arterial pressures will become more negative as the blood pump demands more blood than is available with the recirculation route cutoff. In this instance, the venous pressure may remain unchanged [20]. If the needles are too close together, this assessment might not be possible.

Diagnosis of Venous Stenosis

Venous stenosis is a very common occurrence in AV access. A strong pulse or a vigorous thrill is often mislabeled as a good access with excellent flow rather than an abnormal finding [21]. A well-functioning graft has a soft, easily compressible pulse with a continuous thrill present only at the arterial anastomosis. The normal graft has a low-pitched

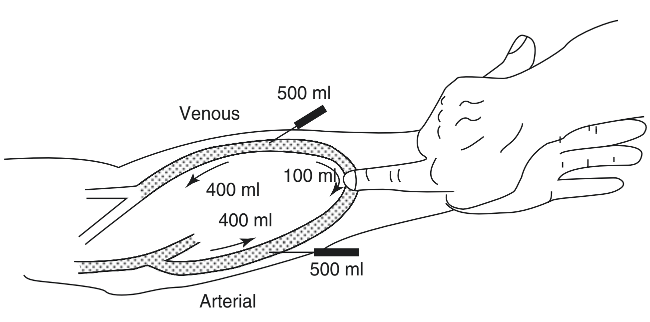

Fig. 12.9 The technique of graft occlusion to detect recirculation. (Source: Beathard [20])

bruit, which is continuous with both systolic and diastolic components. With the development of significant venous stenosis, downstream resistance increases, and the graft becomes hyperpulsatile. The increase in the force of the pulse within the graft proximal to the stenosis is noted and may have a “water-hammer” character particularly in the presence of severe stenosis [20]. Like the AVF exam, as the degree of stenosis increases, the velocity of flow increases, and the pitch of the bruit rises, and with severe stenosis, the bruit is high pitched, and only the systolic component is audible.

The diagnosis of intra-graft stenosis is even more perplexing. Abnormal thrills are generally not present. In some instances, it is possible to detect a change in pulsation within the graft as one crosses the stenotic lesion, although this is not a uniform finding and often the area distal to the stenosis becomes pulseless [20]. Normally, if the outflow of the AVG is manually occluded, there will be a considerable augmentation of the pulse. In cases of diffuse intra-graft stenosis, this augmentation does not occur [21]. The bruit does reflect the hemodynamic changes characteristic of a stenotic lesion – it is high pitched and of short duration.

Secondary AV Fistula Creation

A SAVF is defined as an AVF that is created following the failure of a previous access. Type 1 SAVF utilizes the outflow vein of a previous distal failing AV access. Since this vein has been exposed to prolonged pressure and high flow, it has already undergone the process of maturation. This change makes these veins excellent candidate for the creation of an AVF when the primary access fails. In type 2 SAVF, the fistula can be created anywhere other than the outflow vein of previous AV access, including a different extremity. The main advantage of SAVF is minimum or no catheter exposure as the outflow vein is generally already mature.

A large percentage of patients with dialysis access dysfunction are excellent candidates for a SAVF. In one study, for example, 74% with a forearm loop graft had one or both upper arm veins that appeared to be optimum for the creation of a SAVF, based on the angiographic images [50]. To create a SAVF, the venous anatomy should be evaluated preferably when the lower arm access is still functioning, and the veins of the upper arm are under pressure [51]. Although vascular mapping is usually the first step, angiographic studies are often performed. The 1-year patency rates for SAVF are encouraging, with one study reporting the 1-year patency rate for SAVF (58%). Although lower than that for primary AVF (75%), these are superior to the reported primary patency of the synthetic grafts at 1 year (25–50%%) [36, 52].

Conclusions

A functioning vascular access is the key to successful management of a HD patient and can be cultivated by early nephrology referral, multidisciplinary collaboration among the nephrologist, access surgeon, interventional nephrologist/radiologist, and preferably a vascular access coordinator. A nephrologist's knowledge and understanding of ESKD patients and their needs demands them to attain a lead role in creating and maintaining a functional AV access.

Once the access is created, physical examination is the key to monitor access maturation and should be a part of the standard care of dialysis patients. Surveillance with access blood flow and venous pressures should be used as an "adjunct" and should not "substitute" for the monitoring by access examination [20, 21]. Providing conscientious and high-quality access care will lead to early identification and treatment of access-related problems. Furthermore, it has a great potential to reduce morbidity, improve quality of life, and reduce costs of healthcare in the dialysis population.

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