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Hemodialysis Access: Initial Considerations and the Difficult Patient

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1. Introduction

The population requiring hemodialysis (HD) in the United States continues to grow, with recent studies reporting over 370,000 Americans with end stage renal disease (ESRD) who are HD-dependent [1]. The creation of functional HD access is often the limiting step in utilization of renal replacement therapy (RRT). Since the 1960s, the creation of hemodialysis access has become one of the most commonly performed procedures in the United States with over 500,000 vascular access procedures performed per year [2]. This represents approximately 8% of the annual Medicare budget allocated to patients with ESRD [3]. The magnitude of the associated economic and human costs is further exemplified by the fact that up to 25% of patients with ESRD will die due to inadequate hemodialysis access [5]. This clinical situation and societal burden makes understanding the basic management steps and options for hemodialysis access of key importance to all healthcare professionals involved in the care of patients who require HD.

2. Timing of referral

There is only limited literature on the optimal timing of patient referral for placement of vascular access [6]. What has been shown is that patients with ESRD who are referred to a vascular access practitioner greater than one month before likely initiation of HD had a significantly lower chance of having a tunneled catheter as their first access option [7]. The early placement of arteriovenous access is also associated with a lower risk of sepsis and mortality [8]. At present, the Society for Vascular Surgery makes the following recommen-

dations regarding HD access: (a) Patients should be referred to vascular access surgeons for placement of permanent hemodialysis access when they have advanced renal disease defined as MDRD of <20 to 25mL/min who have elected to have hemodialysis as their choice of renal replacement therapy; (b) If upper extremity arteriovenous access is possible it should be constructed in these patients as soon as possible; (c) If prosthetic access is to be constructed this should be delayed until just before the need for dialysis [9].

3. Initial evaluation

The initial evaluation of a patient referred for HD access placement begins with an adequate history and physical examination. This aids in the determination of the most appropriate access option for the patient [10]. The initial questions should include attention to which is the patient's dominant extremity and any history of prior upper extremity interventions or symptoms of arm claudication. The physical examination should document any physical evidence that the patient has had a prior central venous catheter (CVC) and the upper extremity pulse exam as well as an Allen test (Figure 1) should be performed to evaluate the palmar arch patency. Further, the patient's chest, breast, shoulders, and upper arms should be evaluated for the presence of abnormally enlarged collateral veins which may indicate the presence of central venous occlusion or stenosis (Figure 2).
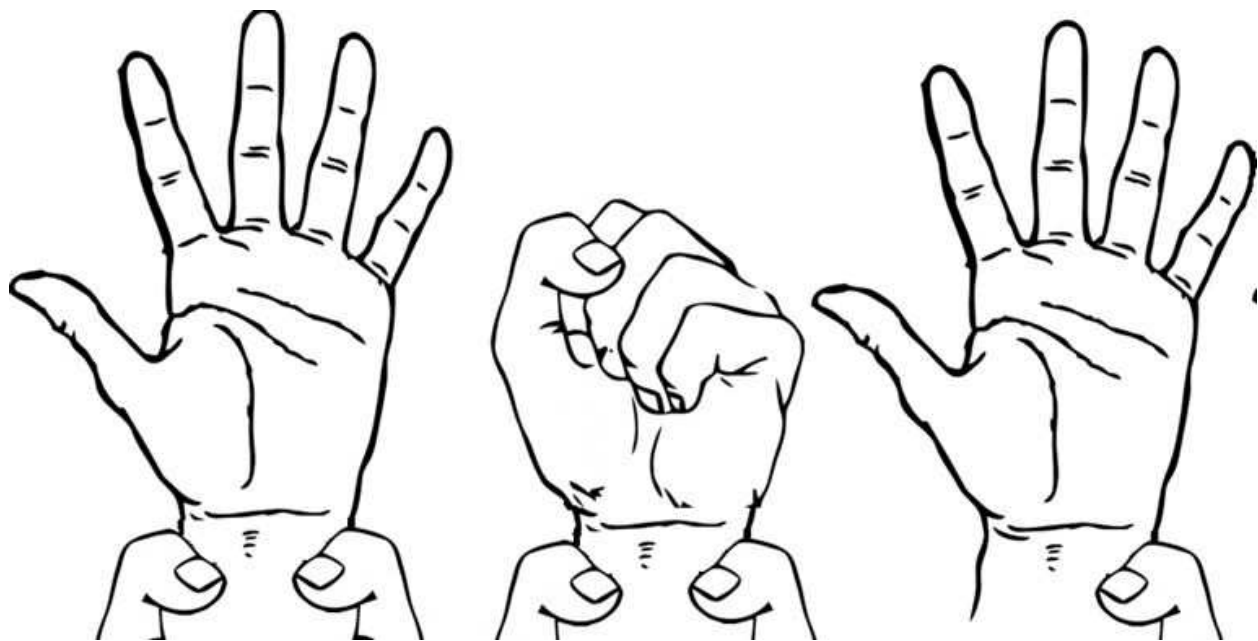
Figure 1. The Allen's test is used to assess the patency of both the radial and ulnar arteries. In this test, the physician compresses both arteries at the level of the wrist with the hand outstretched. The patient is then asked to open and close the hand into a fist several times with both arteries still compressed. The hand is then relaxed and the radial artery is released. The entire palm and digits should fill demonstrating good collateral flow. The test is repeated, with the ulnar artery being released. Again, the entire palm and digits should fill.
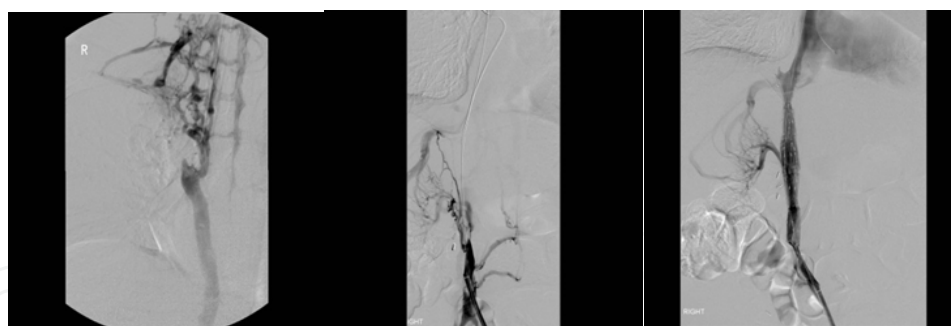
Figure 2. Superior vena cava (left) and inferior vena cava (middle) occlusion secondary to central venous catheter. The inferior vena cava underwent stent recanalization to allow future transplantation (right).

3.1. Initial evaluation: Doppler ultrasound and beyond

Two considerations are crucial when looking for an appropriate arterial target in the creation of an arterio-venous (A-V) access point. The artery selected must be capable of not only delivering blood flow at an adequate rate to support dialysis but must also have adequate flow to maintain the viability of the tissues distal to the A-V anastomosis [11]. The physical examination alone is often not sufficient to confirm appropriate vessel patency. One randomized trial demonstrated that the primary A-V fistula failure rate was as high as 25% when the pre-operative assessment depended on physical examination alone compared to 6% when noninvasive imaging was used [12]. Routine noninvasive testing should include bilateral upper limb segmental arterial pressures and Doppler ultrasound scanning or pulse volume recordings. The focus of this testing should be on documenting the following three characteristics: (a) the patient should have less than a 20 mmHg difference in systolic blood pressure between the two arms; (b) the palmar arch should be patent; (c) the arterial target should have a diameter of 2 mm or greater at the proposed anastomosis point [13, 14]. Doppler Ultrasound can further aid in identifying any stenotic arterial segments in addition to describing arterial diameter and flow [15, 16]. If any abnormalities are noted on noninvasive testing then secondary access site(s) should be considered or the patient should be referred for an angiogram [17]. Angiography is especially useful in patients with known peripheral vascular disease or in those with suspected proximal arterial occlusive disease.

The selection of an appropriate venous target is of critical importance. If there is a vascular problem that is going to cause technical difficulties in the creation of an arteriovenous fistula it is more likely to be venous than arterial in nature. Routine vein mapping provides improved functionality and patency of arteriovenous fistulas as well as primary fistula formation [18, 19]. Preoperative vein mapping has further been shown to decrease the rate of unsuccessful surgical exploration (18). Color flow Doppler ultrasound is considered superior to other forms of vein evaluation as it avoids the use of nephrotoxic dyes. Further, vein mapping by ultrasound allows for evaluation of the depth in addition to size of the vessel in question [20, 21]. When the history or physical evaluation raises the concern for central venous stenosis or occlusion then venography is superior to ultrasound duplex imaging [22]. Magnetic resonance venography (MRV) has been reported as an imaging option for perio-

perative evaluation of the central venous anatomy but has not been shown to be more clini-cally or cost effective than standard venography [23-25].

4. Tunneled catheters

Though the present clinical guidelines attempt to limit tunneled catheters to <10% of total permanent hemodialysis access, this percentage continues to be higher at most centers [26]. Beyond this, tunneled catheters often are required to serve as a bridging therapy to matura-tion of some A-V fistulas and grafts. Consequently, tunneled HD catheters constitute >250,000 dialysis access procedures in the United States every year [27].

4.1. Basic options

Dialysis catheters may be divided into short- or long-term devices. The distinction between the two catheter categories has little to do with anatomic considerations and more so with catheter type and placement technique. Short-term catheters may be placed at bedside using standard Seldinger technique into the internal jugular, subclavian or femoral vein. These are usually double lumen, non-cuffed, non-tunneled catheters. To achieve the best dialysis flow rates the catheter tip, when in the subclavian or jugular vein, should be located in the supe-rior vena cava (SVC) just above the cavoatrial junction. If femoral access is chosen, a longer catheter should be used to ensure that the tip is within the distal inferior vena cava (IVC). These short-term catheters are intended for the patient who requires acute HD access and should ideally be used for <3 weeks. The subclavian vein should be avoided to decrease the rate of central venous stenosis [28]. It should be noted that many of the temporary HD cath-eters are somewhat stiff and may cause some degree of trauma to the SVC, contributing to potential scar formation/stenosis. In the interest of minimizing such vascular trauma, silastic catheters can also be used in temporary capacity, without creating a subcutaneous tunnel and or burying the cuff.

Longer term external HD catheters are in general silastic double lumen catheters with felt cuffs which require tunneled placement under fluoroscopic guidance. These central venous catheters (CVC) can be inserted into the internal jugular, subclavian, external jugular or fem-oral veins and may be used for six months or longer due to their decreased incidence of in-fection [29, 30]. The right internal jugular location is preferred due to generally higher continuous blood flows available for dialysis and lower complication rates [30, 31]. Again, to decrease the risk of central venous stenosis dialysis catheters should be placed contralateral to the proposed future site of any A-V fistulas if possible [32]. Central venous stenosis ap-pears to occur more often with the subclavian (40-50% cases) than the internal jugular inser-tion (up to 10%) in long-term catheters [33, 34]. Reports estimate the average 1-year catheter patency at approximately 75% [35] with most catheters lost secondary to bacteremia [32].

**4.2. Tunneled dialysis catheter placement in the difficult access patient**

When standard catheter access options for HD have been exhausted in the internal jugular and subclavian positions, alternatives must be sought. The most common reasons for venous site "exhaustion" are venous stenosis or occlusion [36-38]. In an effort to reduce femoral access for placement of long-term catheters given the increased incidence of infection, and the risk of iliocaval thrombosis interfering with possible future renal transplantation, alternative upper extremity access points have been studied. Wellons *et al*, evaluated a novel method of accessing the SVC through a supraclavicular approach [39]. In their series fluoroscopic guidance was used to direct placement of the dialysis catheter at a point immediately cephalad to the head of the right clavicle into the SVC. In that study most catheters functioned from one to seven months.

Due to the development of central venous occlusion or stenosis many patients develop significant central venous collaterals. Techniques have been described whereby a wire and a snare is passed through these collaterals and attempted to be placed into a vein which can be visualized with duplex ultrasonography. Once this occurs the vascular practitioner must snare the wire into the IVC prior to passing the HD catheter using the conventional Seldinger technique [40, 41].

An alternative technique to femoral access for placing a cuffed dialysis catheter into the IVC is through a translumbar approach. Two case series described the use of this method for HD access [42, 43]. In this approach the patient is placed in the prone or left lateral decubitus position. A small incision is made approximately three centimeters lateral to the midline above the right iliac crest at the L3 vertebral level. Under fluoroscopic guidance a wire is inserted into the IVC. Under direct visualization the HD catheter is then passed in such a manner that the catheter tip is positioned at the junction of the IVC and the right atrium. For this approach preliminary data suggests that the rate of catheter thrombosis, fibrin sheath formation and infection parallel those of more traditional access sites [44-48]. The cumulative patency rate for this approach reported was 52% at 6 months and 17% at 12 months [43].

A somewhat more aggressive option for HD access is the transhepatic venous approach. This approach has been described mainly in case reports or small patient series [49-52]. The main concern regarding this approach is not its utility as a functional HD access, but rather the significant associated morbidity and mortality. In particular, the risks of catastrophic bleeding, biliary tract fistula formation, infection, hepatic dysfunction, and high rates of dislodgement make this approach too risky for most patients [53]. From a technical standpoint it requires more skills than standard venous access approaches. A guide needle is placed under fluoroscopy approximately halfway through the liver in a direction parallel to the right and middle hepatic veins and directed toward the confluence of the hepatic veins. Once an acceptable hepatic vein is engaged, a guide wire is advanced toward the right atrium. The tract is then dilated until the double lumen dialysis catheter can be placed [54, 55]. In one of the case series, the complication rate was as high as 29% with one death from massive hemorrhage [54]. This approach has a high rate of catheter malfunction requiring frequent repositioning [55]. Most authors stress that this approach should be used only as a last resort.

A hybrid device between an arteriovenous graft and catheter is the HeRO access option (Figure 3). This device type is specifically designed for patients who central venous stenosis which would prevent a fistula or graft from providing enough flow to maintain functional dialysis. The device is tunneled underneath the skin. An outflow synthetic tube is inserted into the central vein and advanced past the point of stenosis into the right atrium in order to provide continuous outflow to the system. A secondary PTFE 6mm graft component is then anastomosed to a peripheral artery.
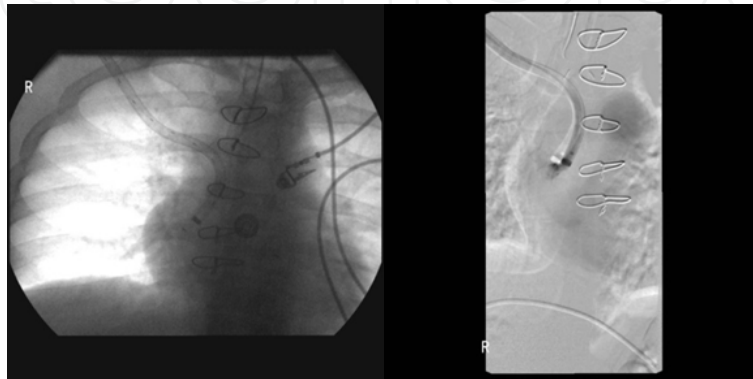

Figure 3. HeRO device with the tip at the cavo-atrial junction.

5. Arteriovenous fistulas

Of all HD access alternatives available the native A-V fistula is at present preferred. The NKF-K/DOQI guidelines have prompted the "fistula first" campaign to encourage A-V fistula as the first access option [56]. The native A-V fistula has the lowest infection rate, best long term primary patency rates and requires the fewest interventions of any type of access to remain functional [57, 58]. The society for vascular surgery makes the following Grade 1 recommendations regarding the placement of native A-V access: (a) That the access be placed as far distally in the upper limb to preserve proximal sites for future use; (b) Upper limb access sites be used first with the non-dominant arm given preference over dominant arm only when all other access opportunities are equal [9].

5.1. Forearm access

The first considerations for creation of the A-V fistula must focus on which distal vein to use. Within the forearm there are several readily attainable anatomic options: the cephalic, basilic, and antecubital veins. When considering the distal inflow options the arterial choices include the radial, ulnar and brachial arteries. The distal cephalic vein (Figure 4) is the preferred venous option due to its location and the minimal surgical dissection involved [59].
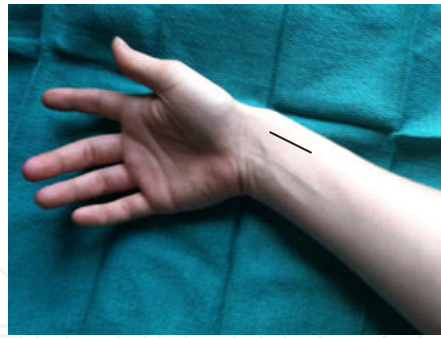
Figure 4. The anatomy of the patient guides the direct access type. The classic first option for most patients is the creation of a Brescia-Cimino-Appel Fistula, an autologous radial artery to cephalic vein fistula [4]. If one can readily appreciate the arterial pulse and vein then a single longitudinal or curvilinear incision over the anterior aspect of the wrist is used.

If however, the vein and artery are separated by too great a distance then two separate longitudinal incisions are made and the vein is ligated distally prior to being passed through a subcutaneous tunnel to create the A-V anastomosis. An additional option is the creation of the so called "snuffbox fistula" whereby an anastomosis is created between the end of the cephalic vein and the posterior branch of the radial artery located in the anatomic snuffbox. This anastomosis requires a single longitudinal incision overlying the palpable pulse of the branch of the radial artery. After these initial options have either failed or have been deemed impossible due to anatomic factors, consideration must be given to more proximal sites in the forearm. The radial artery and cephalic vein may still be a viable A-V paring more proximally but these procedures in general require transposition of the vein and will be discussed later.

5.2. Upper arm access

Upper arm access options which do not mandate either transposition or translocation procedures typically use the cephalic or antecubital veins and the brachial artery. In this situation, a single transverse incision is created and the cephalic or antecubital vein is mobilized prior to dissecting out the brachial artery. In cases where the vein and artery are anatomically remote from one another, two separate incisions are created and the vein is tunneled toward the artery prior to preforming the anastomosis. In comparison to radiocephalic fistulas, the brachiocephalic A-V fistula (Figure 5) has been shown to mature faster and has higher long term patency rates [60].

5.3. Transposition procedures

The objective of a transposition fistula is to move the vein to a more superficial position to ensure that the vein, once mature, is optimally position for safe HD cannulation. As in all other fistula formation, care must be taken to evaluate underlying anatomy and access options for the individual patient. Several options are available, each with unique limitations and technical considerations.
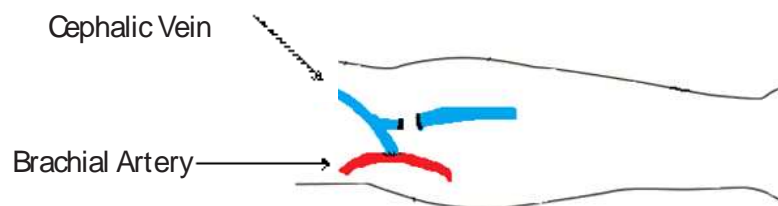
Figure 5. Diagram of brachiocephalic A-V access anatomy.

A radial artery to cephalic vein transposition may be required in the obese patient [61]. For this particular procedure, sufficient wrist inflow must be available with adequate forearm cephalic vein size which would otherwise be too deep for successful HD cannulation. In this option, the cephalic vein is identified in the wrist and mobilized to the antecubital fossa. The radial artery is identified within the distal portion of the incision. The cephalic vein, after ligation of the distal aspect, is then tunneled superficially and laterally to the radial artery to perform the anastomosis. If the distal radial artery is not amenable to create the A-V anastomosis then a similar approach may be used to mobilize the cephalic vein. However in this case, the brachial artery is identified in the proximal portion of the incision. The cephalic vein is again tunneled superficially in a forearm loop configuration to the brachial artery in order to perform the anastomosis after the distal cephalic is ligated.

A forearm fistula may still be planned if the cephalic vein is not acceptable. In this situation the basilic vein may be used, although its deeper position makes this more technically challenging. An access option may still however be planned using the basilic vein and radial artery. The basilic vein is identified in the wrist and mobilized to the antecubital fossa. The radial artery may then be identified through a separate longitudinal incision, after which the basilic vein is tunneled superficially and laterally to the radial artery to perform the anastomosis. Again, if the radial artery is not amenable for use in A-V access creation the basilic vein may be anastomosed to the brachial artery. The basilic vein is mobilized from the wrist to the antecubital fossa and the brachial artery is identified within the proximal portion of the incision or through a separate incision if necessary. The basilic vein is then tunneled superficially in the forearm in a loop configuration after the distal aspect is ligated prior to performing the A-V anastomosis. In general, the primary patency rates for brachiobasilic fistulas are higher than for brachiocephalic [62]. However, secondary patency appears to be equivocal.

If anatomic considerations preclude the use of a forearm fistula or if forearm fistulas have already failed, then attention is directed toward the upper arm. There are several upper arm transposition procedures available. Due to technical considerations, the brachiocephalic upper arm transposition is in general preferred to brachial basilic upper arm transposition access options.

In brachiocephalic upper arm transposition, the cephalic vein is identified just proximal or distal to the skin crease at the elbow and mobilized toward its origin. The brachial artery is

identified in the distal aspect of the incision. The cephalic vein is then ligated distally. The superficial aspect of the vein is labeled to ensure that no torsion of the vein occurs during tunneling. The vein is then tunneled superficially and medially so that it comfortably aligns with the artery. If vein mapping demonstrates a cephalic vein <4 mm in diameter then this procedure may be performed in two stages, whereby the distal cephalic vein is anastomosed to the brachial and then transposed in four to six weeks [63]. The two stage approach is beneficial as the small caliber cephalic vein is relatively fragile and may be damaged by an attempted transposition procedure initially. It is felt that it is better to allow arterialization of the proximal small cephalic vein such that it becomes more robust prior to attempted transposition. A basilic vein to brachial artery approach may be performed similarly, with technical limitations again being the anatomy of the basilic vein and the required deeper dissection. Much as in the brachiocephalic transposition a two-step staged operation may be warranted [64]. The described functional patency of these two-stage brachial-basilic fistulas was 76% at one year [64]. Maturation rates for these two staged transposition procedures range from 47% to >95% [64-66]. Studies that compare brachiobasilic fistulas with upper arm grafts have generally found improved primary patency, cumulative patency, and less risk of infection for fistulas, but mixed results for other complications [66, 67].

Once standard upper extremity A-V access options have been exhausted, lower limb access may be considered. As with other non-standard access options, the literature supporting the use of distal extremities is still limited. The use of a saphenous vein loop transposition to the common femoral artery was first described in 1969 [68]. In this option, the saphenous vein is exposed and mobilized from the saphenofemoral junction to the knee. The vein may be harvested via open or endoscopic approach. Once an adequate length has been mobilized the distal component is ligated and the vein is tunneled superficially in a loop configuration so that it reaches comfortably to the proximal superficial femoral artery. Recent case series demonstrate poor maturation potential of this technique with nearly 30% of the studied patients not achieving functional maturity [69]. In those patients who do obtain functional maturity the time to secondary failure is approximately 16 months [70]. There are significant limitations with this technique that must be considered. In patients who are morbidly obese this may not be a viable option if the pannus overlaps the loop graft preventing comfortable needle cannulation. Further, the great saphenous vein does not dilate after arteriovenous creation and only veins which are greater than 3mm in diameter should be used.

If the patient's saphenous vein is not anatomically usable due to size, but a lower extremity A-V access is still required for the patient, a femoral artery to femoral vein transposition may be considered. In this approach, the femoral vein is exposed and mobilized down to the popliteal vein at the knee. The profunda femoral vein is preserved to prevent venous hypertension and compartment syndrome. The femoral vein is ligated distally at the knee and transected. The vein is then tunneled superficially through the subcutaneous tissues lateral to the vein harvest incision so that it comfortably reaches the superficial femoral artery. The reported primary and secondary patency rates for this technique at 12 months are 73% and 87%, respectively. However, in the largest reported case series for this technique, limb ischemia requiring additional surgery was common occurring in >30% of patients [71, 72]. One of

the 25 patients studied developed compartment syndrome which ultimately required an above knee amputation [71]. Further, the reported flow rates for femoral vein transpositions can be has high as 2000 mL/min [73] which requires considerable caution in the use of this technique for patients who have or are at risk for congestive heart failure.

5.4. Translocation procedures

Saphenous vein to forearm translocation procedures for development of A-V access are of mostly historical note. In overview, the saphenous vein is harvested distal to the saphenofemoral junction to above the knee. Once the vein is harvested, attention is turned to the forearm of choice. The saphenous vein is placed in a straight configuration between the radial artery and either the antecubital or the cephalic vein. The saphenous vein is then tunneled superficially between these two vessels and an anastomosis is performed [74]. Studies examining this technique are in general older and do not describe outcomes in terms of functional patency. Due to this fact comparing this technique to outcomes reported in the contemporary literature is difficult.

An alternative approach uses a translocated superficial femoral vein. It is critical in this approach that the patient's lower extremity arterial circulation is adequate to heal the wounds from the vein harvest site. In addition to vein mapping, the patient should undergo Duplex ultrasonography with segmental pressures to ensure sufficiency of the arterial system. It must also be determined that the femoral vein itself is patent and has a diameter >6 millimeters.

In this technique, an incision is made in the groin and extended along the medial border of the Sartorius muscle. The muscle is retracted laterally in the proximal thigh and medially in the distal thigh to allow for adequate exposure of the femoral and popliteal vein. The femoral vein is harvested next to the profunda vein but significant care is taken not to damage the profunda vein in order to minimize the development of venous hypertension and distal compartment syndrome. Attention is then turned toward the upper arm of choice. The brachial artery proximal to the antecubital fossa is isolated. A tunnel is then created between the brachial artery and axillary vein over the ventral upper arm. The femoral-popliteal vein is then reversed and tunneled superficially so that it reaches comfortably between the axillary vein and brachial artery. Huber *et al.* reported on the outcome of 30 saphenous vein translocations [75]. In this series, the primary, primary assisted, and secondary patency rates for the saphenous vein translocation accesses were 79%, 91%, and 100%, respectively, at 12 months; and 67%, 86%, and 100%, respectively, at 18 months. Two patients developed lower extremity compartment syndrome after the vein harvest, and nearly 30% of patients developed upper limb critical ischemia requiring re-intervention.

6. Prosthetic access

If no autogenous access options exist in the upper extremities then consideration of upper extremity prosthetic access may be considered. The additional risks of infection in prosthetic grafts are offset by the fact that prosthetic access options meet maturity for hemodialysis

sooner than autogenous options. As with all forms of hemodialysis access options, care must be taken to tailor the surgical approach to the patient's anatomy and specific dialysis needs.

6.1. Forearm

The main prosthetic access options in the forearm, is the brachial artery to antecubital vein forearm loop access graft. In this technique a transverse incision is made proximally to the skin fold crease at the elbow. The brachial artery and antecubital vein are isolated. A 6 mm or tapered 4-7 mm prosthetic graft is then tunneled in the subcutaneous space of the fore‐ arm. This requires a small distal transverse incision to be made so that the graft may be ap‐ propriately aligned. The anastomoses are then created. A straight line prosthetic graft may also be used between the radial artery distally and the antecubital vein within the antecubi‐ tal fossa. The vein is again exposed through a transverse incision distal to the skin crease of the elbow and a distal longitudinal incision is made over the pulse of the radial artery. The prosthetic graft is then tunneled superficially and laterally such that it is readily amenable to performing the two anastomoses. In general, prosthetic grafts have inferior primary and sec‐ ondary patency rates and higher incidence of complications including infection and throm‐ bosis when compared with autogenous fistula [66, 76-78].

6.2. Upper arm

Upper arm options for prosthetic graft placement are varied. The brachial artery may be used but if this is difficult owing to scar formation or prior infection, the axillary artery may be utilized as inflow. In general, the axillary or basilic veins are used with the graft in either a loop or straight configuration. Grafts in this area may be cannulated for dialysis access within 2-4 weeks sooner than native fistula formation [62]. Non-maturity failure is relatively low in patients receiving an upper arm graft with reported incidence of <10-20%.

6.3. Lower extremity access

Lower extremity prosthetic options are reserved for cases where upper extremity access op‐ tions have been exhausted. The main disadvantage of the lower extremity prosthetic graft is the increased rate of infection compared to upper limb access options [79-84]. The infection rates vary from a low of 8% to a high of 41%. Further, there is an associated limb loss with the prosthetic lower extremity graft which is not observed in upper extremity graft [80-84]. The operation itself is relatively simple due to the large size and anatomic locations of the femoral vein and artery. This anatomic consideration is reflected in the relatively superior patency rates for lower extremity access grafts compared to upper limb grafts. Studies which use the standard convention established by the American Association for Vascular Surgery (AAVS) demonstrated that the secondary patency rates ranged from 41-85% at 1 year and 26-83% at 2 years [79-84]. Due to anatomic considerations, the surgical manage‐ ment of complications associated with this type of HD access are somewhat easier to man‐ age than chest wall grafts and high axillary grafts. Finally, the patient has both hands free during HD which theoretically may improve their quality of life.

Lower extremity A-V graft placement is usually performed under general anesthesia. A longitudinal incision is made overlying the femoral pulse. The femoral artery and greater saphenous vein are exposed. The superior femoral artery and greater saphenous vein near the saphenofemoral junction or femoral vein (depending on anatomy) are isolated. The superficial femoral artery is preferred as an inflow option over the common femoral artery due to the presumed advantage in dealing with complications such as infection and arterial "steal" phenomenon in this artery. To perform the mid-thigh loop access, an incision is made along the medial border of the Sartorius muscle. The muscle is then retracted laterally to gain access to the femoral vessels. The artery and vein of choice are then mobilized and controlled. The graft must be tunneled over the anterolateral aspect of the thigh which helps ensure positional access for hemodialysis without the patient having to externally rotate the thigh. In general, a 6 mm graft is used though some authors describe the use of 8mm synthetic graft.

6.4. Prosthetic cervical and chest wall access

Most patients who are considered for a cervical or chest wall access procedure have already had prior central venous HD catheters and multiple upper extremity procedures and interventions. Therefore, in patients where these unusual approaches are considered it is imperative that appropriate imaging studies are performed to confirm central venous patency prior to any surgery. In addition to anatomic considerations, the dominant handedness of the patient influences the choice of right or left sided procedures much as it does in the standard A-V access options.

Prosthetic chest and cervical access reports date back to 1978 though the information regarding patency rates and complications is mainly limited to case-based evidence [85-88]. Described options for chest and cervical A-V access options include: (a) brachial artery to jugular vein access; (b) axillary artery to contralateral axillary or jugular vein; (c) axillary artery to ipislateral axillary vein loop access. The described secondary patency rates for these procedures range from 37% to 80% at two years [85-88]. Chest and cervical prosthetic access options appear to be associated with a significantly lower infection rate than those of the lower extremity. The described infection rate for these options ranges from 4% to 15% [85-88]. Further, this access option may be beneficial in patients who are morbidly obese in whom the anatomic limitations of a lower extremity access option include the size of the pannus [85]. One major disadvantage of these access options is the technical difficulty in obtaining proximal control of the axillary vessels.

7. Arterial-arterial access procedures

Arterial-arterial access procedures (Figure 6) should only be considered after all conventional options have failed. The literature describing these procedures is relatively scant and relies mainly on a few case series and reports [89, 90]. Bunger *et al*. reported a series of 20 patients who had axillary artery to axillary artery interposition with PTFE grafts [89]. These patients had a 30% re-operative rate. However, at 6 months the grafts had primary and sec-

ondary patency rates >90%. Limb ischemia was reported in one patient whose access graft thrombosed but this resolved after thrombectomy. Zanow *et al* published a series which looked at arterial anastomoses involving axillary and femoral arteries [91]. The primary patency rates in this series at one year were >70% and >50% at three years. These access procedures have been suggested for patients who have previous access-related limb ischemia and high output cardiac failure. There are significant concerns with the arterial-arterial access options. First, the dialysis units should be aware of the nature of these patients' access and should treat each needle cannulation as an arterial stick requiring at least 20 minutes of hemostatic pressure. Second, the flow rates reported in some case series demonstrate that the arterial-arterial loop access does not appear to provide flow rates as high as standard A-V access options and therefore dialysis blood flow rates exceeding 400 mL/min may cause discomfort for the patient. Finally, this access option should not be used to infuse medications during dialysis as described by the original authors.
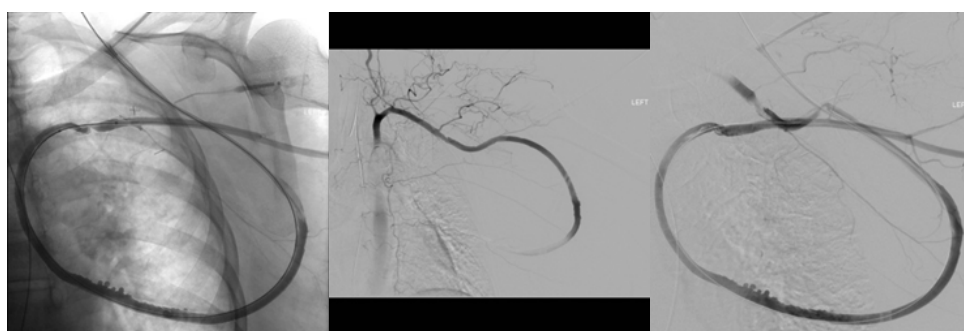
Figure 6. n example of an arterial-arteial "last resort" hemodialysis access. An arterio-arterial loop graft was placed in a patient whose venous access options had been exhausted. She later developed graft dysfunction which on angiography proved to be due to neointimal formation at the outflow anastomosis (left image). This responded well to balloon angioplasty (right-most image).

8. Complications of arteriovenous access

As with all surgical procedures care must be considered in the creation of arteriovenous fistulas. A wide variety of complications are described in the literature but the following bear special deliberation.

8.1. Access failure

The mode of failure is usually related to the type of access constructed. Catheter function is usually limited by the formation of fibrin sheaths at the catheter tip. The life expectancy of catheters, as previously mentioned, is severely limited by their propensity for infection. For both native and synthetic arteriovenous accesses the issue is very often the development of outflow stenosis leading to limited flow dynamics. Such central venous stenoses were classically treated with angioplasty or stenting. Of interest, a novel technique has been described

using radiofrequency (RF) activated wire, and snare technique for recanalization of chronic central venous occlusions in order to allow passage of HD catheters [92].

Prosthetic grafts have a higher thrombosis rate than native fistula but their functionality is often more readily returned after intervention. Intimal hyperplasia is the greatest unresolved problem in hemodialysis access. It can occur anywhere in the outflow tract and severely limits functionality and dialysis flow. It is likely the number one driving factor in primary patency failure rates after basic anatomic considerations. The literature reports a wide degree of primary patency rates and as such recognizing this critical problem rather than exact percentages is of more clear clinical benefit.

Access	1 year primary patency*
Upper Extremity Catheter	43-65%
Femoral Catheter	14%
Translumbar Catheter	17%
Transhepatic Catheter	52%
Forearm extremity AV fistula	60-75%
Upper Extremity AV fistula	64-95%
Upper Extremity AV graft	34-84%
Lower Extremity AV graft	40%

Data based on references [2, 28, 29, 31, 34, 35, 59, 60, 62, 63, 66-68, 70, 75, 77-79, 82, 84, 93-97]

Table 1. Primary 1-year patency rates of different hemodialysis access modalities.

8.2. Steal phenomenon

Ischemic lesions which result from an arterial steal phenomenon directly related to arteriovenous fistula formation (Figure 7) have become more frequent in this increasingly elderly and high co-morbidity patient population. Clinically significant steal syndrome occurs in 1% of autogenous AV distal access options verses 9% prosthetic AV graft. There are in general two distinct types of this steal phenomenon: high flow and low flow. The more readily correctible of the two is high flow steal. In this situation the fistula with a very low resistance is able to redirect or 'steal' blood from the distal anatomy creating critical ischemia of the digits. In theory, this should be readily correctable by decreasing the size of the anastomosis and reducing blood flow through the fistula [98, 99]. Recalling the physics of fluid dynamics and Poiseuille's law, one understands that the resistance of a column of fluid is in relation with the fourth power of the radius. Essentially, this requires that significant reduction in the fistula lumen's size is needed to adequately address the flow steal phenomenon. This reduction of course poses the risk of low flow, thrombosis, and destruction of an otherwise functional fistula. This can be achieved by banding the fistula's venous outflow to reduce flow demands on the distal arterial system or revising the fistula to a more distal artery itself.

The low flow fistula requires more consideration and is significantly more difficult to ad-
dress. In general, this results from stenosis of the peripheral arteries such that even normal
blood flow across a fistula will create critical distal ischemia. There are only a few therapeu-
tic options available. The first is to abandon the fistula via ligation and use a central catheter
as the patient's only hemodialysis option. An alternative to this is the so called DRIL or dis-
tal revascularization-interval ligation [100, 101]. In this situation, the artery distal to the arte-
riovenous fistula anastomosis is ligated such that the fistula no longer feeds off the distal
arterial vessels. The distal artery is then fed via an interposed segment of either vein graft or
synthetic graft.

Figure 7. An example of advanced stage "steal syndrome".

Stages of Steal Syndrome	Grade	Clinical Signs
Stage I	Mild	Pale, blue or cold hand without pain.
Stage II	Moderate	Pain during exercise or hemodialysis
Stage III	Severe	Pain at rest
Stage IV	Limb Threatening	Ulcers, necrosis, gangrene

Table 2. Steal syndrome has been classified into four different stages based on the clinical impact and degree of effect
on the limb in question [93]

8.3. Congestive heart failure

High fistula flow may cause hyper-circulation and thereby congestive heart failure in the already cardiac compromised patient. Hypercirculation occurs when the outflow resistance is too low. The most common cause of this is an anastomotic lumen which is too large. An additional advantage of the native arteriovenous fistula over synthetic graft is that this engorged lumen rarely occurs in native tissue [101, 102]. The only way to confirm that the fistula flow is the direct cause of a patient's increased congestive heart failure is to perform quantitative flow studies. Once a diagnosis has been confirmed, banding procedures are recommended to decrease the fistula's lumen size. These procedures have varying rates of success. If necessary the fistula should be ligated to improve the patient's outcomes after placement of a central catheter has occurred

8.4. Paget Schroetter syndrome

Paget Schroetter Syndrome or stenosis of the central veins may unfortunately be present in this patient population prior to vascular access formation. In most patients it is clinically asymptomatic prior to the demands placed upon the central veins from the arteriovenous flow dynamics. If a central stenosis is unable to accommodate the flow rates required by the vascular access point the result will be swelling of the affected limb, cyanosis, and the formation of significant collaterals. In general, central stenotic regions are the result of prior subclavian catheters [33, 103]. As with other fistula related complications, onetreatment option includes ligation of the anastomosis and the use of another limb after exclusion of bilateral stenosis. However, given the available endovascular techniques, correction with balloon angioplasty or stenting should be attempted first with surgical correction of the venous outflow stenosis also a final option [104-106]

8.5. Aneurysm

The formation of aneurysms, in A-V fistulas, is usually the result of progressive destruction of the venous vessel wall over time with replacement of normal tissue with inferior scar collagenous tissue [107-109]. Once an aneurysm has developed there is a tendency for progression due to the wall stress placed on the vessel. Wall tensile stress increases as the diameter of the vessel increases such that the larger an aneurysmal dilation gets the greater the flow dynamic changes which occur within its boundaries. Conditions which favor the formation of an aneurysm and which may be prevented include the repetitive single site puncture of a fistula for dialysis access. Also any areas of stenosis with their resultant pre-stenotic rise of outflow pressure and direct increase in tensile flow force changes will increase the likelihood for aneurysm formation. Aneurysms are cosmetically unappealing to most patients but beyond this they have the chance for significant complications including rupture and infection. Therapeutic treatment of aneurysmal disease within a fistula includes partial or complete resection and the correction of any accompanying stenosis [107-109].

8.6. Pseudoaneurysm

Temporary HD catheters, as previously discussed, are not free of complications. The most common is of course infection, followed by central stenosis. A further and more localized complication is the formation of pseudoaneuryms. Pseudoaneuryms occur after arterial puncture. The puncture site in HD access is in general unplanned, and unintended arterial punctures do occur. When the arterial puncture site fails to seal, allowing arterial blood to jet into the surrounding subcutaneous tissue, a pseudoaneurysm may form [110]. These lesions do not have a true wall and their borders are formed by the congealed border of hematoma on subcutaneous tissue. The presentation of a pseudoaneurysm can be varied and may be as nonspecific as localized discomfort to as ominous as a pulsatile, expanding hematoma. Doppler ultrasound should be done promptly if the clinical suspicion for pseudoaneurysm is present. This allows the practitioner to characterize the anatomy of the lesion as well as its size. In general, observation is the appropriate management choice for smaller pseudoaneurysms. However, ultrasound-guided thrombin injection or surgery may be required if there is significant bleeding or the concern for limb ischemia develops. If procedural indications are not present, the practitioner may place the patient on strict bed rest, remove all optional anticoagulation, and apply focal compression. If the anatomy of the lesion is favorable then an ultrasound guided thrombin injection into the aneurysmal neck can immediately resolve nearly 75% of cases [111, 112].

8.7. AV Fistula/Graft thrombosis

The most common post procedural complication of arteriovenous fistula formation is thrombosis. The initiation of dialysis causes flow dynamic changes within the venous outflow. This stimulates intimal hyperplasia mainly at the outflow anastomosis in prosthetic grafts and potentially anywhere along the utilized vein within the native fistula [93, 113-115]. Defining why the graft or fistula has thrombosed is key to returning it to functional flow. Initially evaluation of the graft can occur within the dialysis center itself when the fistula is accessed. The fistula can be cannulated and the dialysis pump stalled. The venous needle pressure is then measured. If it is greater than fifty percent of the mean arterial pressure this is indicative of outflow malfunction. More reliable is ultrasound assessment and measurement of flow velocities across the graft. Both of these studies indicate graft malfunction and provide a tentative understanding of the abnormalities at work. Contrast imaging however gives greater anatomic information. Additionally, invasive venography provides an opportunity to treat both venous and arterial stenosis through the option of balloon angioplasty or more aggressively stent placement [116, 117]. When hybrid diagnostic and endovascular techniques fail then open operative intervention may be required to salvage the graft. Attempted thrombectomy may be done but this should also be performed in the conjunction with surgical revision of the stenotic segment. Surgical revision for fistula/graft stenosis is usually by use of an interposition graft or patch angioplasty [118].

9. Summary

Hemodialysis dependent patients require careful evaluation prior to the placement of initial and subsequent dialysis access sites. Patient factors such as age at presentation, previous history of central venous access, and long term prognosis must be factored into the consideration of HD access choice. Distal upper extremity fistulas should be attempted first unless patient factors preclude them. Only if the feasibility of native fistula options is ruled out should prosthetic grafts be used in the upper extremity. Central venous catheter HD access placement should be used sparingly and hopefully as a bridge to the maturation of native fistula or synthetic upper extremity graft. Lower extremity dialysis options should be reserved for only those patients who have exhausted upper extremity choices. Non-standard A-V or arterial-arterial fistula options should be limited to patients who have no other alternatives and should be performed by surgeons who have had experience in dealing with these more complicated procedures. Likewise, nonstandard central venous catheter placement should not be performed unless no other options for HD access are available.

I. Catheters	
	A. Internal Jugular
	B. Subclavian
	C. Femoral
	D. Translumbar
	E. Transhepatic
II. Forearm: Native Tissue	
	A. Posterior radialcephalic direct access "snuffbox"
	B. Radiocephalic anterior acces " Cimino"
	C. Radial cephalic forearm transposition
	D. Bacial cephalic forearm loop transposition
	E. Radial basilic forearm transposition
	F. Ulnar Basilic forearm transposition
	G. Bacial basilic forearm loop transposition
	H. Radial anticubital indirect femoral vein translocation
	I. Brachial antiecubital forearm indirect loopoped femoral vein translocation
	J. Radial antecubital forearm indirect saphenous vein translocation
	K. Brachial antecubital forearm indirect saphenous vein translocation
III. Forearm Prosthetic	
	A. Radial antecubital forearm straight access
	B. Rbracial antecubital forearm looped access
IV. Upper Arm: Native Tissue	
	A. Brachial cephallic direct

	B. Brachial cephalic upper arm transposition
	C. Brachial basilic upper arm transposition
	D. Brachial axillary upper arm indirect femoral vein translocation
	E. Brachial axillary upper arm indirect saphenous vein translocation
V. Upper Arm Prosthetic	
	A. Brachial axillary upper arm straight access
	B. HeRO hybrid graft
VI. Lower Extremity	
	A. Femoral vein transposition
	B. Prosthetic mid-thigh loop femoral-femoral access
VII. Chest Wall options	
	A. Axillary artery to axillary vein loop graft
	B. Axillary artery to jugular vein straight graft
	C. Axillary artery to axillary artery loop graft

Table 3. Summary of currently available hemodialysis access options

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