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Chapter

Hemodialysis AV Fistula: What a Radiologist Should Know?

Vaidehi A. Patel

Abstract

Hemodialysis works as a lifeline for end stage renal disease patients. Creation and maintenance of vascular access for dialysis is the mammoth task. Due to increased references related to vascular access; number of complications are faced in pre as well as post operative period of vascular access creation. Ultrasound and color Doppler study play a major role in imaging throughout this period. Pre operative vascular mapping is very crucial to help surgeon to determine the proper site and surgical technique for vascular access creation. Early and delayed post operative complications can also be diagnosed with ultrasound and color Doppler study. Here we have tried to cover all the important points which a radiologist should consider during pre operative vascular mapping and post operative evaluation of vascular access as well as any associated complications.

Keywords: Hemodialysis, Arterio venous fistula, End stage renal disease

1. Introduction

Patients with end stage renal disease (ESDR) on maintenance hemodialysis (MHD) need vascular access to start and continue hemodialysis (HD) as a Renal Replacement Therapy. The Creation and maintenance of vascular access (VA) is a difficult task. With increased references related to VA to radiology department, we face several complications related to preoperative mapping, early postoperative maturity issues along with delayed complications related to VA. We have tried to address issues related to VA formation and maintenance along with providing basic information related to pre and postoperative duplex Ultrasonography (USG). Preoperative Ultrasonography aids to physical examination where patient criteria like obesity, history of access failure, vascular diseases and otherwise difficult examination hinder the clinical assessment of vessels for VA. Development of stenosis or thrombosis leading to failure or immaturity of VA is the main threat in postoperative period. Duplex Ultrasonography allows proper identification of cause of VA failure. Volume flow <500 ml/min or > 50% stenosis correlate with formation of thrombosis within 6 months [1]. Presence of co-morbidity like diabetes and peripheral vascular disease in most of ESRD patients and the always changing local hemodynamic factors complicate the VA commonly. Hence, imaging plays a major role in pre and post operation period for rapid diagnosis and management of VA related complications.

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2. Anatomical considerations

VA can be divided in to three types:

Arterio venous fistula (AVF), where anastomosis is surgically formed between artery and vein.

Arterio venous Graft (AVG), where a graft made of poly tetrafluoroethylele (PTFE) is placed between artery and vein.

Central venous catheters (CVC), where a double lumen tube is placed within the central vein usually terminating at or within the right atrium.

The upper extremities are most commonly used for VA. AVF or AVG is made by connecting a vein with artery or interposition of synthetic graft between them which provides a high flow circuit for percutaneous cannulation for hemodialysis. A mature AVF is better than AVG in given higher patency rates, lesser infection chances and reduced maintainace. Generally, the upper limb is used to create such communication. The Non dominant upper limb is the first choice to facilitate daily activities with

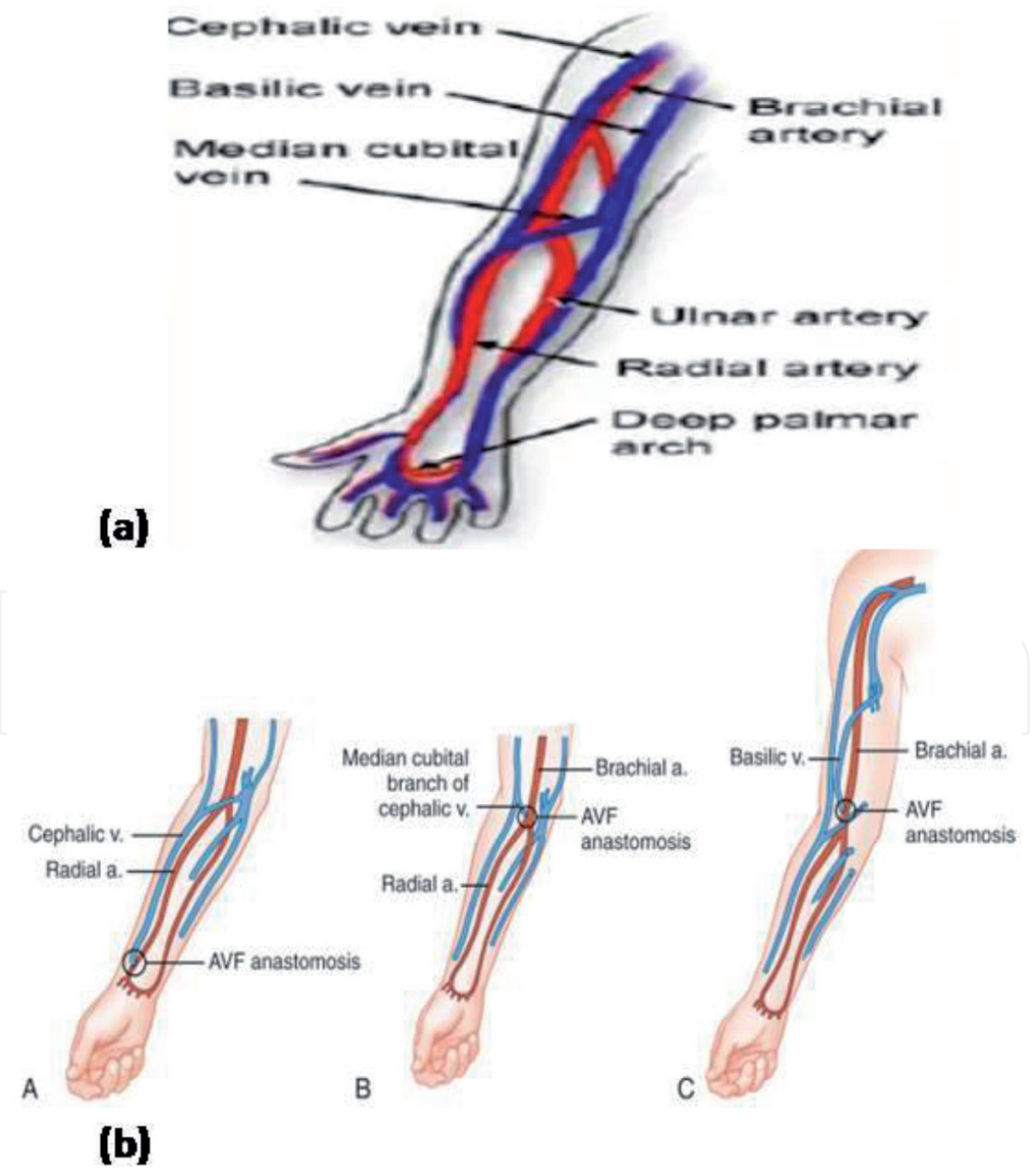


Figure 1.
Upper limb vascular anatomy (a) and (b) various types of AVF [3, 4].

dominant limb while providing adequate time to VA for maturation. Usually, AVF is considered in forearm to preserve the proximal vessels for future if required. Likewise, AVG is preferred in non dominant arm rather than forearm. AVF can be created through a surgical anastomosis between vessels where both the vessels may be in their normal position or the distal end of vein may be transpositioned more superficially to facilitate cannulation, while in Translocation, the entire vein is moved and anastomosis is done.

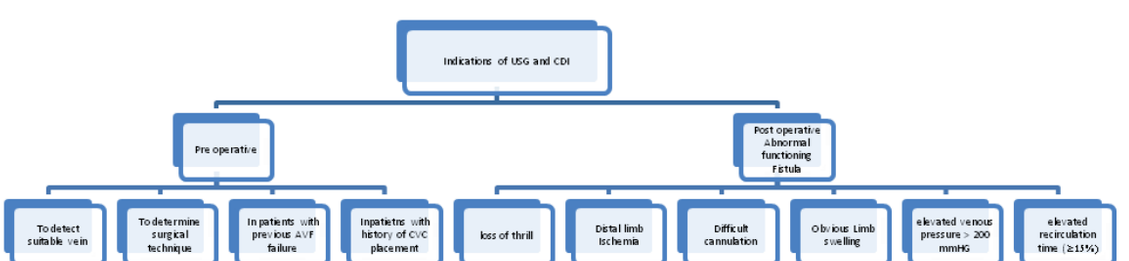
So, the preferred type and sites of anastomosis would be - forearm AVF > arm AVF > arm AVG > thigh AVG in respect to available vessels.

The most preferred type of AVF which is *Radio-cephalic fistula* made in forearm near wrist can also fail to mature in elder patients with underlying vascular or diabetic etiology [2]. *Brachio cephalic AVF* is usually made in antecubital fossa providing benefits of ease of cannulation due to larger surface area (**Figure 1**) [3, 4]. However it poses a major complication – steal syndrome (*will be discussed later*). As basilic vein is less commonly accessed for venipuncture, it is usually better preserved and is less commonly involved in post venipuncture phlebitis in comparison to cephalic vein. However, Brachio-basilic AVF in arm involves dual surgical procedure, difficult to cannulate due to medial location of basilic vein and more prone to infections.

Central venous catheters (CVC) provide short term access in emergency conditions, but they are associated with higher rates of failure, infection and mortality. Patients switching to AVF or AVG from CVCs have almost 50% reduction in mortality [5]. Moreover, previous CVC placement poses a risk of central venous stenosis due to endothelial injury and thrombosis caused by them.

3. Role of radiology

According to Dialysis Outcome Quality Initiative (DOQI) guidelines, AVF is preferred over AVG due to its greater lifespan and reduced incidence of infection. Detailed imaging of vascular anatomy prior to AVF creation provides good evaluation of veins that may be suitable for the creation of AVF, particularly in patients with previous failed AVF and/or history of CVC placement. Detailed preoperative imaging helps the surgeon to choose suitable efferent vein and surgical technique (in the form of AVF or AVG and transposition or translocation in AVF). Also, it helps to select the most functional vein which helps in decreasing postoperative failure and complications (**Figure 2**). However, a considerable number of AVFs fail to mature and in those patients, Ultrasonography can evaluate the etiology of immaturity. If the exact etiology is known, the role of Intervention (angioplasty of a stenosis) or Surgery (AVF revision or accessory vein ligation) can be cleared. VAs are commonly imaged by Ultrasonography and color doppler study (CDI); however other modalities like DSA, MRI and CT scan can also be used as and when necessary. But, we will focus on various aspects related to Ultrasonography and color doppler study in pre and postoperative imaging of VAs. Catheters in situ, overlying dressing, open wounds, Severe Edema and hematoma can hinder the visibility in USG.



Flow chart shows preoperative and Postoperative indications for USG and CD Imaging.

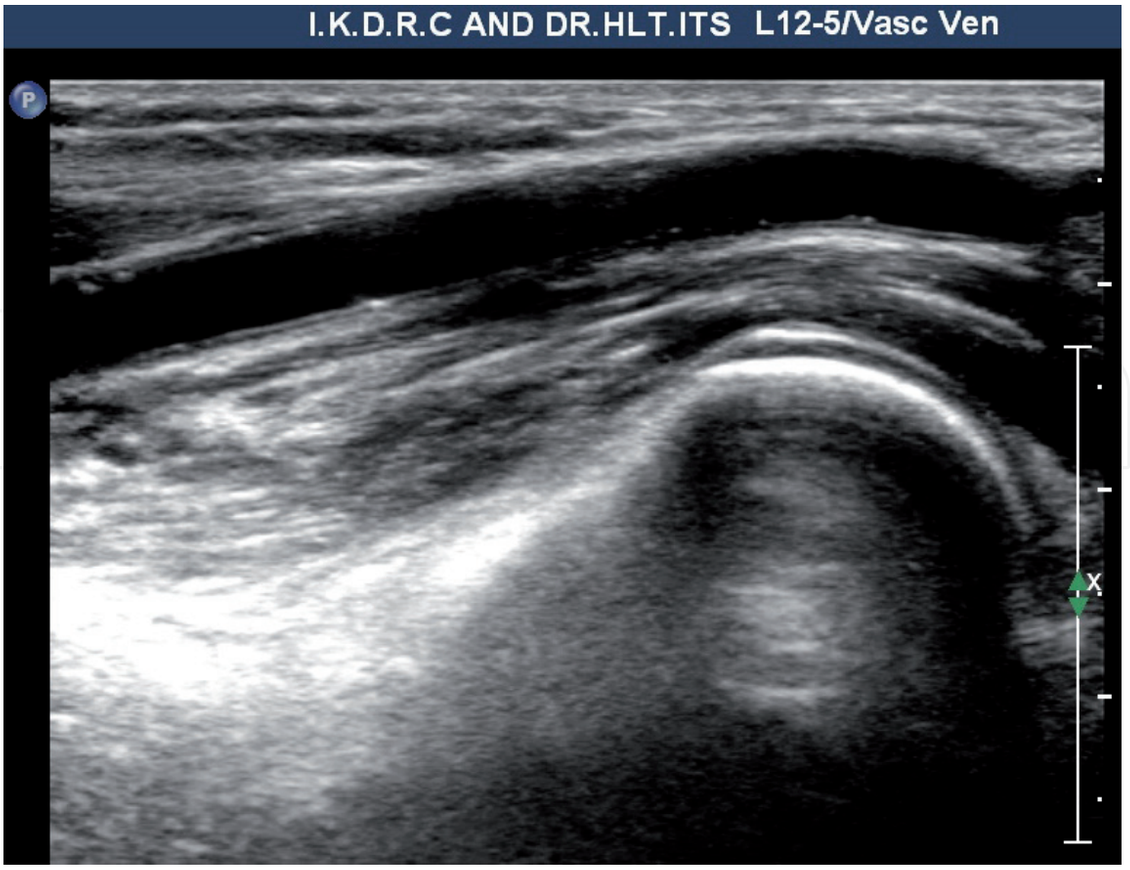


Figure 2.
Gray mode USG image showing minimal intimal wall thickening and multiple tiny flecks of calcification within the wall of brachial artery.

3.1 Preoperative evaluation of AVF/AVG

High resolution linear transducer (≥ 9 MHz) is used for vascular mapping. For ease of description, vessels towards shoulder will be considered proximal and towards the wrist will be considered distal vessels. The scanning is done at room temperature to avoid vasoconstriction in cooler temperature. Warm blankets or warm compression can be used if necessary. The patient should be relaxed and rested in sitting or supine position whichever is comfortable with proximal tourniquet binding. The non dominant arm is assessed first and is placed in extended position along his sides or on any support (like pillow) according to patient's position. The upper limb should be abducted and externally rotated for better visualization.

B mode axial plane imaging is ideal for evaluating vascular anatomy and to evaluate their diameter as well as wall thickness. Arteries are evaluated for presence of any intimo-medial thickening, wall calcification or stenosis. Presence of calcification in arterial wall hinders its distensibility and may contribute towards dysfunction (**Figure 3**). Veins are evaluated for compressibility (denoting to patency) and the depth of anterior venous wall from the level of skin. Color doppler study of arteries evaluates color filling of lumen and excludes luminal narrowing or thrombosis. Spectral waveform excludes any distal occlusion or vascular disease. Color doppler study of veins evaluates venous phasicity and respiratory variations.

Usually the imaging is started from Radial artery. The vessel wall and internal diameter of radial artery at forearm are assessed. If the diameter is not at least 2 mm at wrist, the radial artery is not used for creation of AVF. If the radial artery is satisfactory, cephalic vein at wrist is evaluated. Brachial artery is also evaluated for possible

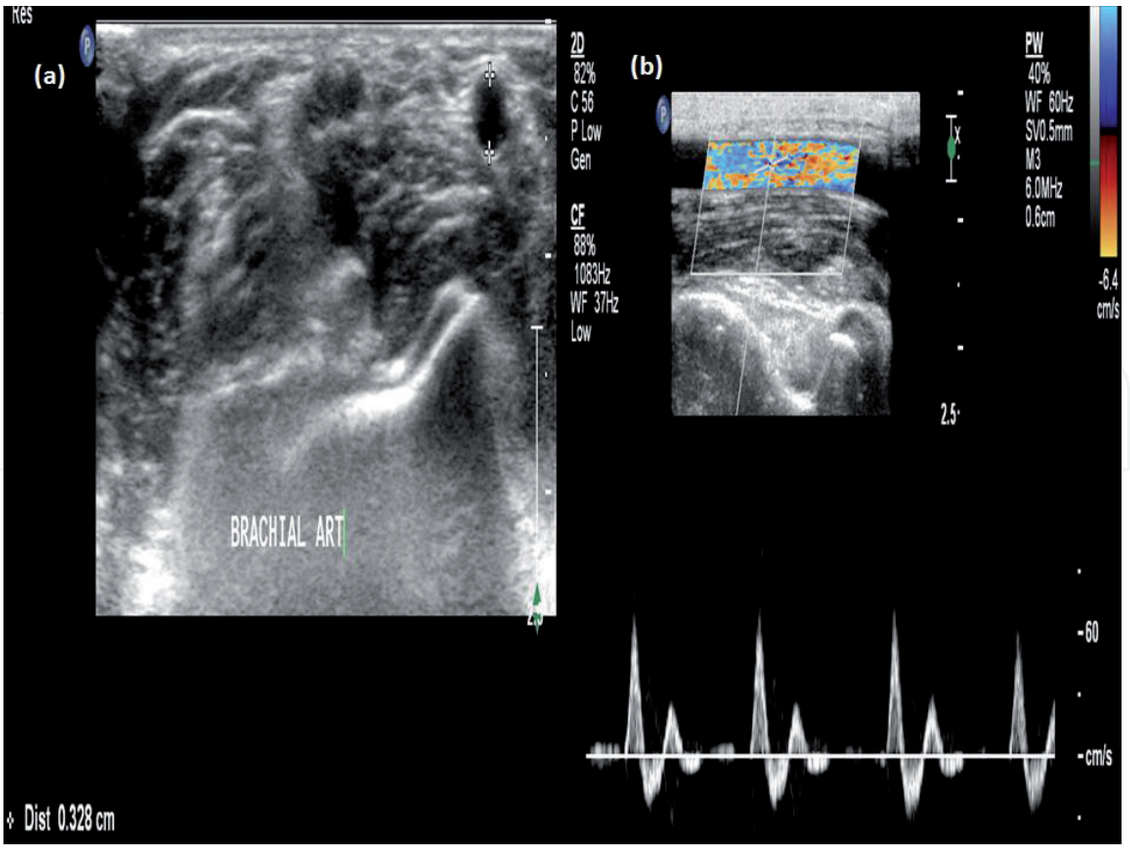


Figure 3.
(a) Gray mode image showing brachial artery at elbow with internal lumen diameter 3.2 mm, (b) CDI study showing normal color flow with triphasic waveform.

arm fistula placement. All the peripheral arteries show Triphasic waveform on CDI study (**Figure 4**). For evaluation of cephalic vein at wrist, tourniquet is tightened in proximal forearm and the distal limb is percussed for about 3 minutes. The main idea behind tourniquet and percussion is that the veins capable of distending up to 2.5 mm will be preferred for AVF due to their distensibility during higher venous pressures. Veins with diameter smaller than 2 mm will not distend up to adequate diameter in most cases. Cephalic vein is then assessed for continuity up to proximal forearm and if its adequate, then the tourniquet is shifted to a more proximal level. If the cephalic vein is narrow in caliber, discontinuous, stenotic or shows thrombus or thick wall, it is not adequate for AVF creation. Branch points must be thoroughly imaged, as they may show narrowing below 2.5 mm in veins. After the forearm is assessed, the vein should be traced up to axilla to evaluate the sites of deep venous communication. Evaluation of neck veins should also a routine practice in upper limb mapping as any abnormality in neck veins can contribute to future AVF failure. If cephalic vein is not adequate for AVF, basilic vein is assessed in the same manner (**Figures 5** and **6**).

If forearm vessels are not promising for wrist AVF creation, AVF at elbow is considered and brachial artery is imaged. Brachial artery internal diameter is measured above its bifurcation in to radial and ulnar arteries, which must be ≥2 mm. The cephalic vein is then assessed at antecubital fossa. Cephalic vein must be at least 2.5 mm in diameter and must extend about 2 cm distal to antecubital fossa. If cephalic vein is not suitable, basilic vein is considered and it must extend to about 4 cm proximal to antecubital fossa for AVF formation. Chronically thrombosed cephalic vein is a very frequent finding in ESRD patients due to frequent venipuncture. Cephalic vein appears narrow with thick walls and appears cord like with no internal color flow in such cases (**Figure 7**). However, sometimes median cubital vein may also be used as

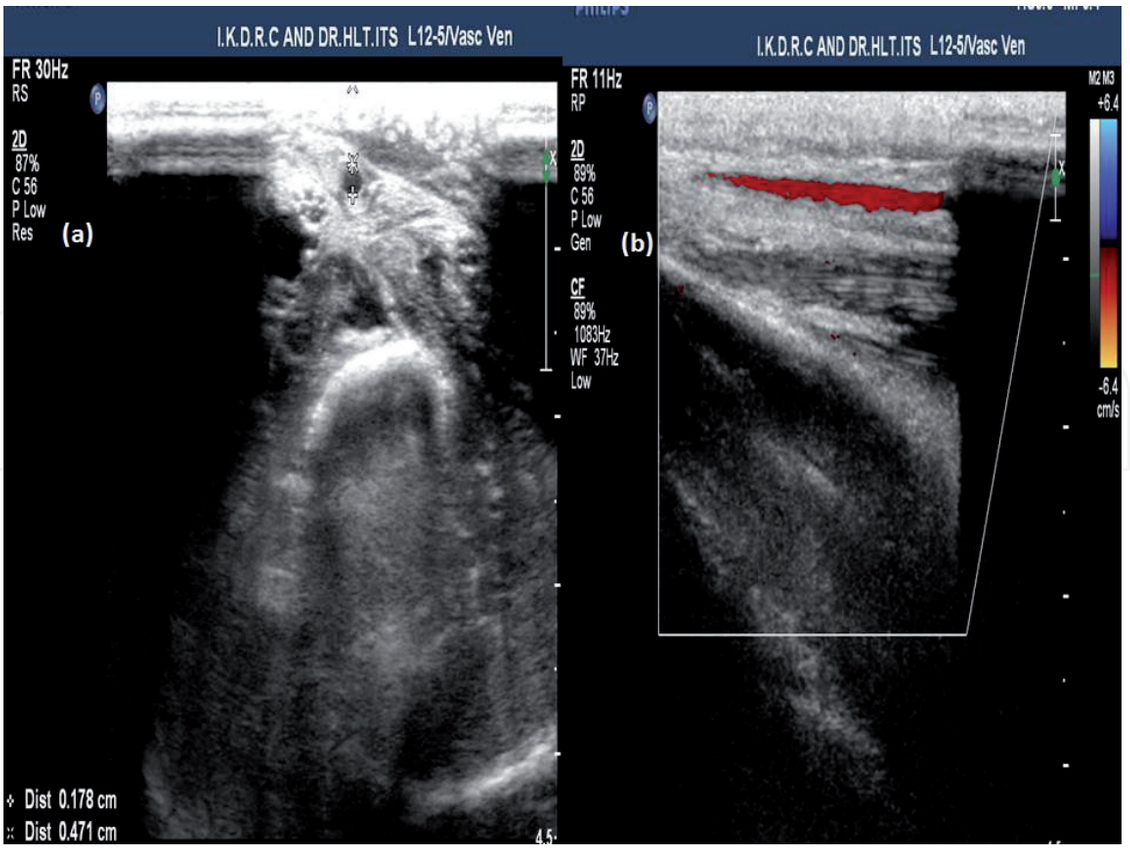


Figure 4.
(a) Gray mode image showing narrow Cephalic vein in forearm with internal lumen diameter 1.8 mm and depth from skin level measuring about 4.7 mm and (b) patent lumen on color doppler study.

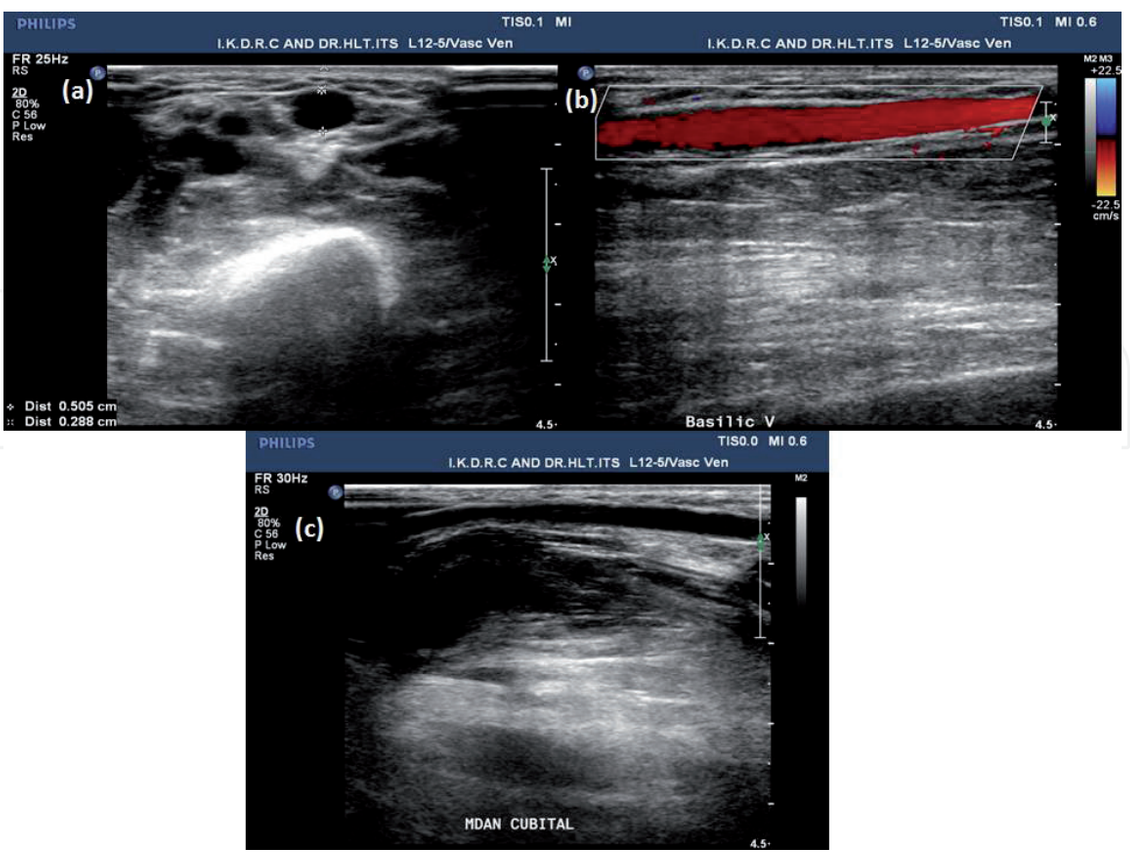


Figure 5.
(a) Gray mode image showing basilic vein at elbow with internal lumen diameter 2.8 mm and depth from skin level measuring about 5.0 mm, (b) CDI study showing normal color flow, (c) gray scale image showing normal median cubital vein in cubital fossa.

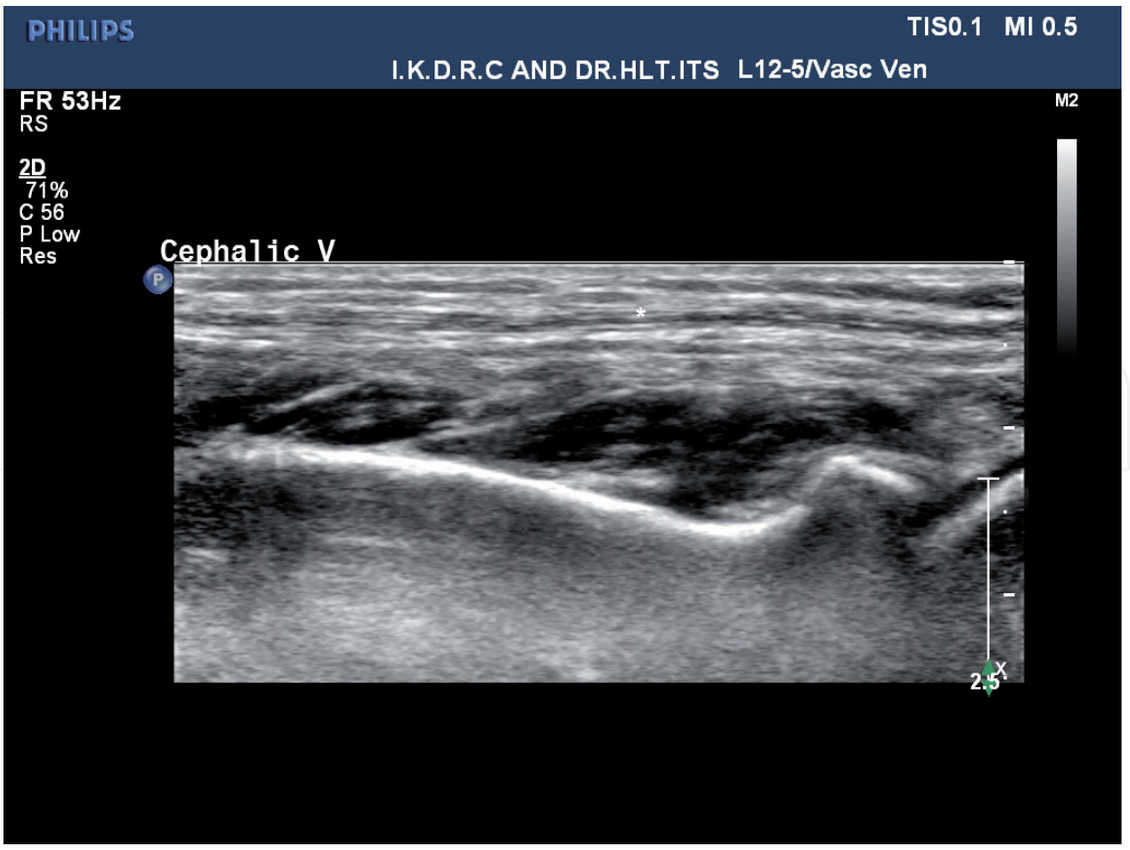


Figure 6.
Gray mode image showing chronically thrombosed narrow cord like Cephalic vein (*).

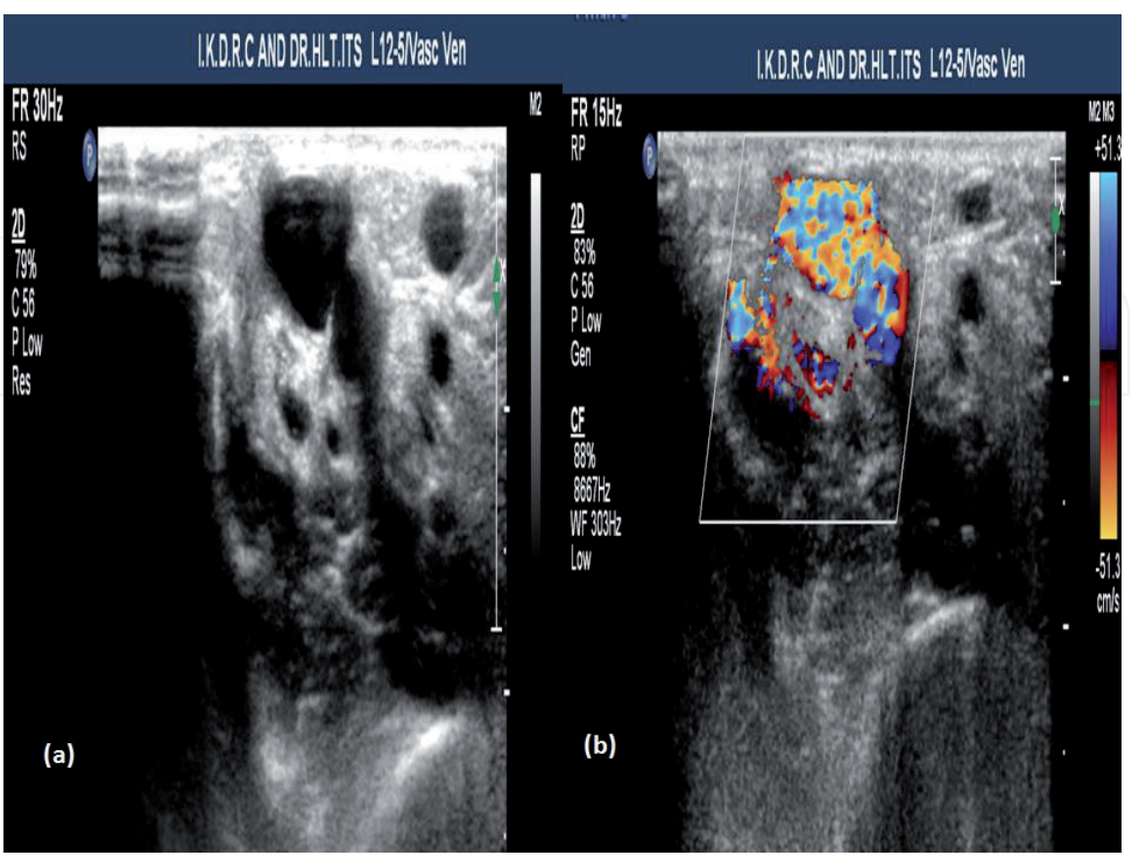


Figure 7.
(a) Gray mode image showing AVF (b) CDI study showing normal aliasing color flow within the AVF.

an alternative as it courses close to brachial artery. In any case, considerable length of patent vein is needed for the surgical procedure as well as during dialysis.

3.1.1 Important points for preoperative evaluation

- Prefer Non- dominant limb (if possible, preserve non dominant arm from the first consultation only)
- Consider the site of AVF placement as per recommendation and evaluate accordingly
- Arteries- evaluate anatomy, branching pattern, continuity, wall thickness, presence of calcification, internal diameter
- Veins- evaluate anatomy, lumen patency, wall thickening, internal diameter, depth from the skin surface, any focal areas of stenosis, branching points and regions of drainage in to deep veins. Neck veins are also evaluated for any possible thrombosis or stenosis
- If the cephalic vein in arm is not suitable for AVF, still cephalic vein in forearm can be used for AVF provided it drains in to brachial or basilic vein through adequate median cubital or other branch.
- Areas of focal stenosis should be looked for at any accessory vein branches which may significantly affect blood flow in AVF later.
- Normal diameter sized cephalic vein with deeper location (depth > 5 mm) may be difficult for palpation later for needle insertion. So the surgeon and patient must clear about future requirement of superficialization.
- High radial artery branching from brachial or axillary artery is a common variant that must be sought for because if present, it may contribute towards increased arterial steal.

3.2 Postoperative evaluation of AVF

According to National Kidney Foundation's Kidney Disease Outcomes Quality Initiative (KDOQI), clinical examination remains the key to determination of maturation. However, USG and CDI prove reliable for surveillance assessment and to find causes of immaturation and complications if any. USG evaluation of AVF is done with high resolution (≥9 mHz) probe without tourniquet. Minimal pressure is applied while scanning with generous amount of ultrasound gel for proper visualization.

The evaluation of AVF starts with clinical examination, where the AVF is palpated for a possible thrill which denotes its proper working. Scanning is then initiated from the feeding artery in axial and Saggital views. The artery is traced towards the draining vein and overall anatomy is evaluated. Feeding artery adjacent to AVF is examined for any wall thickening, lumen patency and areas of stenosis in B mode scanning. Color doppler study is used to see uniform color filling and aliasing color flow like AVF (**Figure 8**). Pulse wave doppler is used for noting biphasic waveform in artery instead of usual Triphasic waveform seen in preoperative artery (**Figure 9**). Peak systolic velocity (PSV) in the feeding artery increases to about 9 to 10 fold in comparison to pre AVF state in mature AVF. PSV is measured in the artery at the level of AVF and 2 cm proximal to it.

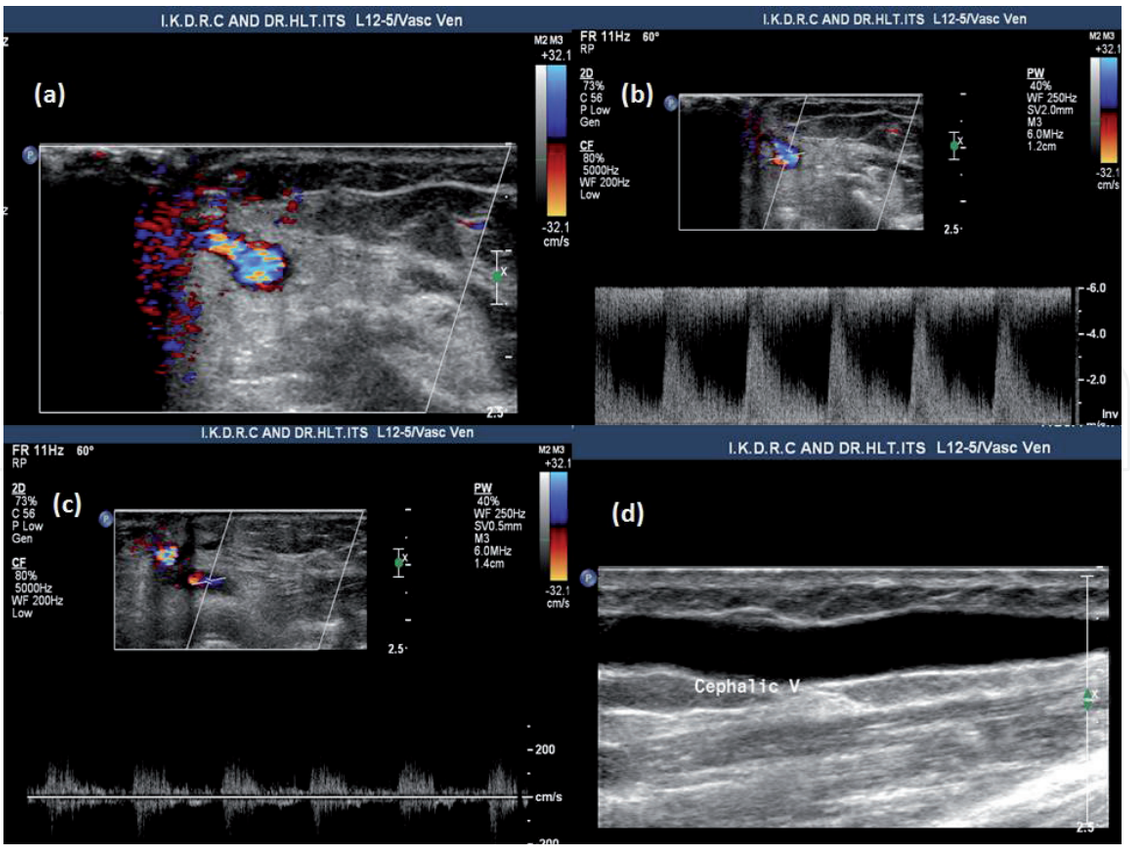


Figure 8.
(a) CDI image showing working AVF with colorailising, (b) CDI study showing normal spectral waveform with high PSV within the AVF, (c) normal post AVF biphasic waveform in brachial artery, (d) mild dilated cephalic vein with patent lumen.

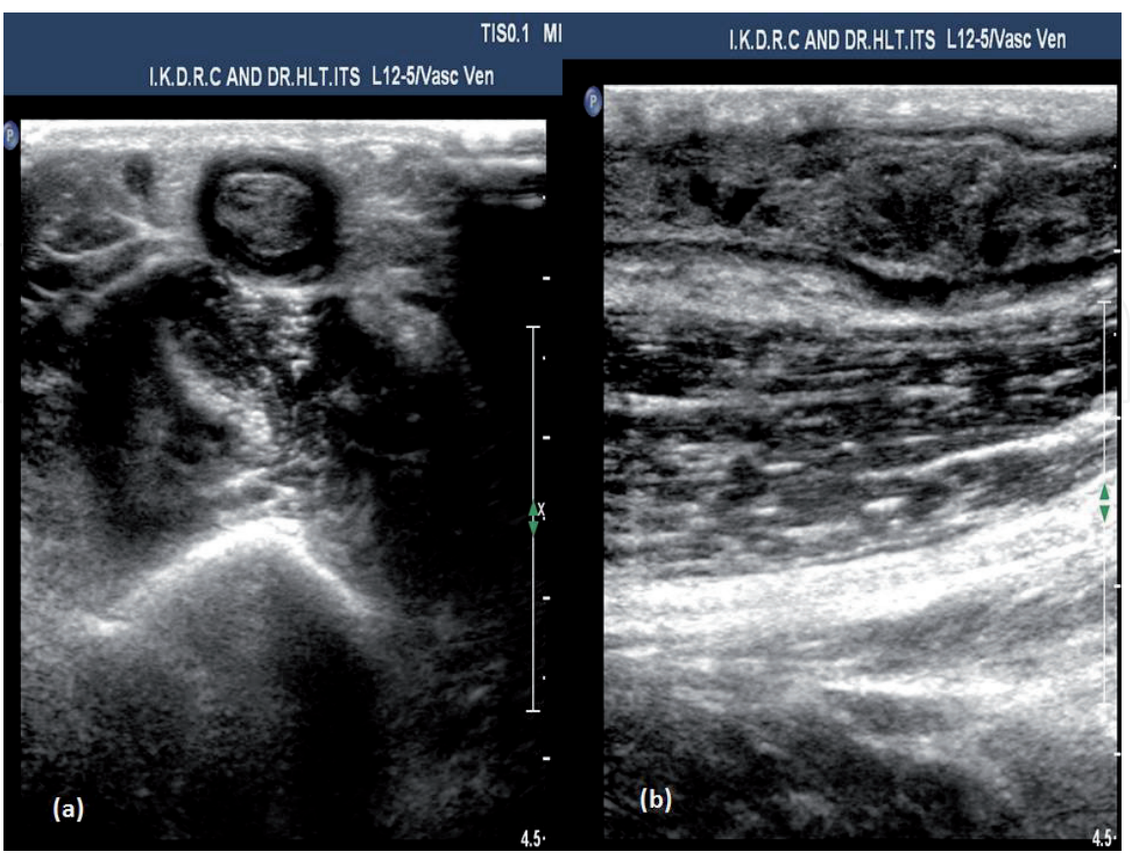


Figure 9.
Gray scale image showing complete thrombus in cephalic vein in (a) axial and (b) longitudinal scans.

3.2.1 PSV ratio: PSV at the anastomosis / PSV 2 cm proximal/distal to AVF

PSV ratio is useful to exclude stenosis. Blood flow is measured within the AVF in mid part. Measuring blood flow volume warrants specific technique where it must be measured in continuous nontapering segment of draining vein about 10 cm from anastomosis. It is measured in middle of the lumen with maximum gate and not more than 60 degree insonation angle. Time averaged mean velocity should be counted for 3 cardiac cycles and then internal diameter of the vessel is measured. According to these parameters, scanner calculates the volume flow in ml per minutes.

3.2.2 Volume flow: time averaged velocity X vessel cross sectional area

AVF itself shows aliasing color flow within it. Blood flow more than 500 to 600 mL/min is required in mature AVF along with the maximum venous diameter about 5 to 6 mm. Presence of both of these criteria confirms maturity in about 95% of AVF. National Kidney Foundation's Kidney Disease Outcomes Quality Initiative clinical practice guidelines defines a "rule of sixes," for maturation of AVF stating that it should have blood flow of ≥600 ml/min, a diameter of ≥6 mm, and a depth of ≤6 mm from the surface of the skin. Along with scanning of AVF, feeding artery and draining veins; evaluation of deep and neck veins should also be a routine practice in Postoperative imaging to rule out any complication at early stage.

3.2.3 Important points for postoperative evaluation of AVF

- Imaging of AVF in Postoperative 1st or 2nd day is counted as 1st scan followed by 2nd week and 6th week scanning
- Tourniquet is not used with minimal pressure and generous amount of gel
- Maximum gate with not more than 60 degree insonation angle used in the middle of vessel
- Feeding artery, AVF itself and draining veins are evaluated and they show aliasing color flow. Puncture sites are also evaluated for possible thrombosis.
- Vessels looked for patency and regions of narrowing
- Blood flow measured in mid part of AVF and continuous non tapering segment of draining vein about 10 cm from anastomosis
- Blood flow of ≥600 ml/min, a diameter of ≥6 mm, and a depth of ≤6 mm from the surface of the skin are ideal for mature AVF.
- Deep veins of upper limb should also be seen to rule out early deep vein thrombosis
- Neck veins are also evaluated for possible steal syndrome, obstruction or thrombosis
- Large vein branches are also looked for within first 10 cm of draining veins, which eventually decrease the blood flow in AVF contributing to immaturity.

Due to higher incidence of infection, stenosis and pseudoaneurysm; AVGs are less preferred over AVF. Preoperative vascular mapping for AVF is done in the same manner as in AVF. AVGs are assessed by USG or CDI if palpable focal mass is seen adjacent

to AVG. In such cases there may be graft stenosis. CDI differentiates hematoma from pseudoaneurysm. Symptomatic AVGs should be referred for angiography where it may be treated with angioplasty with or without stent placement if stenosis is present. However, in some cases graft degeneration also causes focal area of larger diameter presenting as palpable mass. In Postoperative evaluation of AVG, feeding artery, AVG, arterial and venous anastomosis and draining vein are evaluated. In loop grafts, identification of direction of blood flow is first step to facilitate identification of arterial and venous limb. The PSV is calculated at 2 cm proximal to arterial anastomosis (seen in the feeding artery) and 2 cm distal to venous anastomosis (seen in the AVG). If visible stenosis is present, PSV ratio (described earlier) is calculated at anastomosis. In presence of upper arm AVG, subclavian vein may show monophasic waveform even if there is no central stenosis. If the venous outflow from the graft is greater than the feeding arterial capacity, arterial steal occurs distal to arterial anastomosis [5].

4. Complications

Rate of complications is much lesser in AVF as compared to AVG or CVC. However they do occur in 1/3rd cases [2] and are addressed here. Most commonly seen complications of AVF are thrombosis, aneurysm, infection, stenosis, steal syndrome and heart failure. Complications are divided in early and late. However, fistula failure also occurs and that may be classified as primary (fistula that fails to mature even before cannulation) and secondary (delayed failure or after any intervention).

4.1 Early complications/early failure

It is defined as AVF which fails to mature or unable for use up to 3 months after creation. Causes of early failure may be related to inadequate arterialinflow, stenosis at anastomosis or outflow issues due to underlying fibrosis of vein. Various causes for early failure or complications are listed below:

- Demographic factors: Age, obesity, female, history of diabetes or peripheral vascular
- Disease
- Size of draining vein along with reduced distensibility
- Development of collateral circulation

4.2 Late complications/late failure

Fistula Failure occurring after 3 months duration after creation of AVF are classified as late failure. Various complications are seen like; Stenosis, aneurysm, steal syndrome, infection, cardiac failure, venous hypertension, median nerve injury.

4.2.1 Thrombosis

Thrombosis is noted within the fistula in early as well as late Postoperative period. Early thrombosis is most often related to an inflow issues and late thrombosis due to an outflow stenosis. Either of these can result in thrombosis of the fistula if left untreated. Difficult cannulation, sudden reduction in VA flow or a new onset low flow in VA should trigger the possible diagnosis of thrombosis. Physical

examination may show absent thrill in AVF and pulsatile anastomosis is felt. On USG and CDI, the affected vein may be dilated and show echogenic thrombus filling the lumen with no internal color filling. Partial thrombus is also seen. Needle insertion sites should be evaluated carefully as there may be partial thrombus at these sites. In case of thrombosis in draining vein, AVF itself shows no evidence of aliasing color flow and the feeding artery shows triphasic normal spectral waveform instead of biphasic spectral waveform seen in working AVF.

4.2.2 Stenosis

It is often due to outflow stenosis. Venous stenosis is more commonly seen in AVF than AVG. However, it is common cause of failure. Swelling of upper limb, prolonged bleeding after dialysis, difficult cannulation and/or slow flow are common symptoms of venous stenosis. In radio cephalic AVF, inflow lesions due to inadequate arterial flow is confirmed by negative arterial pressure during HD session and physical examination by pulse augmentation. In brachio cephalic AVF, cephalic arch stenosis is very commonly (in up to 77% cases) seen causing failure. Cephalic arch is the final bend in cephalic vein when it enters in to axillary vein. Cephalic arch stenosis causes swelling in head and neck, high venous pressure with thrombosis. Venous or arterial stenosis can be successfully managed by angioplasty [2]. Cephalic arch stenosis warrants stent placement due to its elasticity and resistant nature to repeated angioplasty. During pre and Postoperative scanning, entire length of vessels should be traced for any possible stenosis or narrowing. PSV ratio is measured in feeding artery at the level of AVF and 2 cm proximal to it.

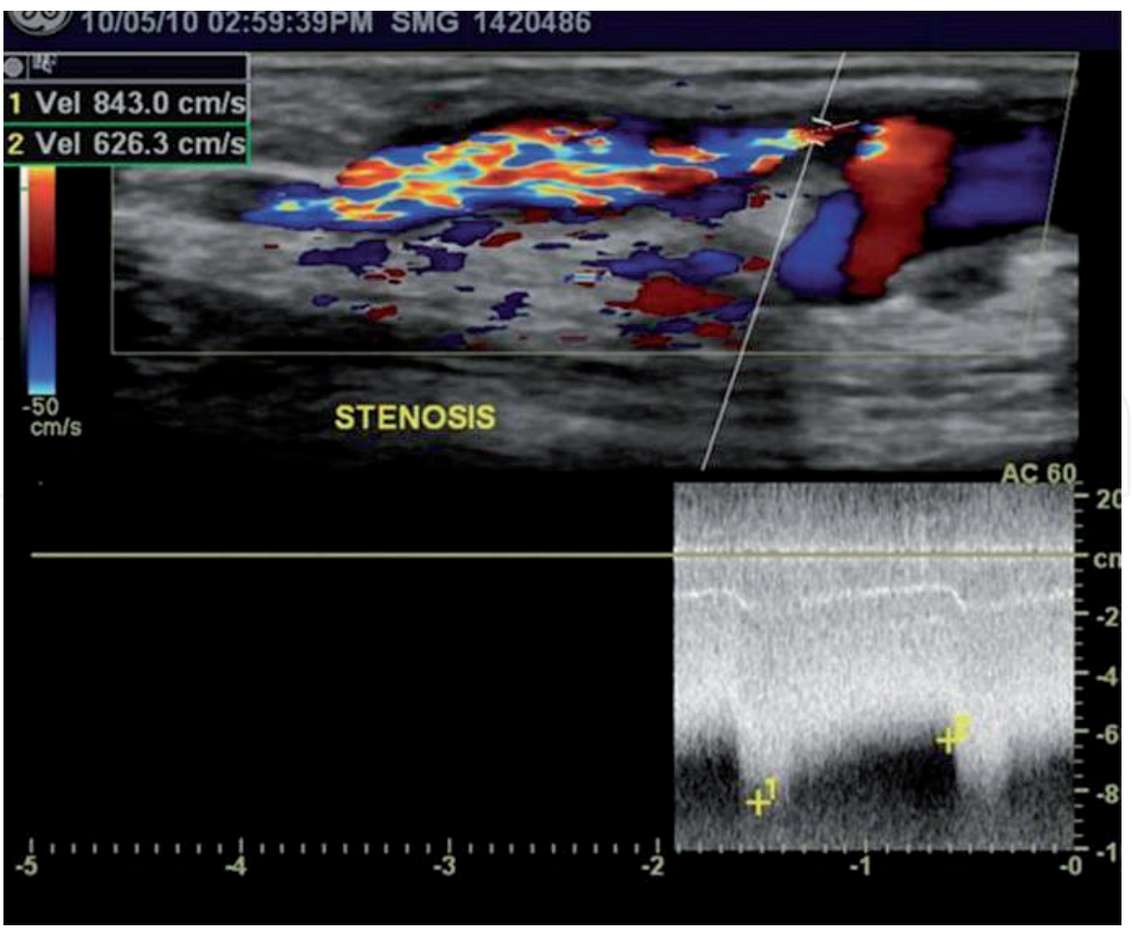


Figure 10.
Gray scale image showing stenosis with post stenotic turbulent color flow and marked elevated PSV and EDV [6].

If the PSV ratio is ≥3.0 and PSV is >400 cm/sec, stenosis is present. If the draining vein is visibly narrow, PSV is measured at stenosis and at 2 cm caudal to stenosis. If the PSV ratio is ≥2.0, stenosis is considered (**Figure 10**). Most frequent site of AVF stenosis is adjacent to anastomosis. Presence of adequate collaterals, low systemic pressure, poor Dopplerinsonation angle and central venous stenosis are some of the factors which can hinder the diagnosis of stenosis. However the degree of stenosis is not absolute in AVF failure prediction.

4.2.3 Aneurysm

Repeated cannulation at repetitive sites or turbulent blood flow due to stenosis is the major causes of formation of aneurysm. It is seen in about 5 to 7% cases. Physiological and esthetic complications due to aneurysm lead to surgery in many cases and may cause failure subsequently. Increased infection risk and prolonged bleeding after dialysis along with complex surgery are common associated complications of aneurysm. On scanning, outpouching with or without color flow is seen arising from vessels (**Figure 11**). Most common site is the needle insertion site. The aneurysm may show to and frocolor flow and peripheral thrombosis. In case of thrombosis, patent lumen commonly shows color flow. The entire length of vessel should be traced as finding more than one aneurysms is not uncommon. Totally thrombosed aneurysm sometime look like old hematoma and in such cases proper history and careful evaluation in terms of connection with the vessel wall should be done. Internal color flow can clear the doubts in such cases. Treatment of aneurysm consists of its prevention in the form of careful cannulation techniques and surgical correction techniques [2].

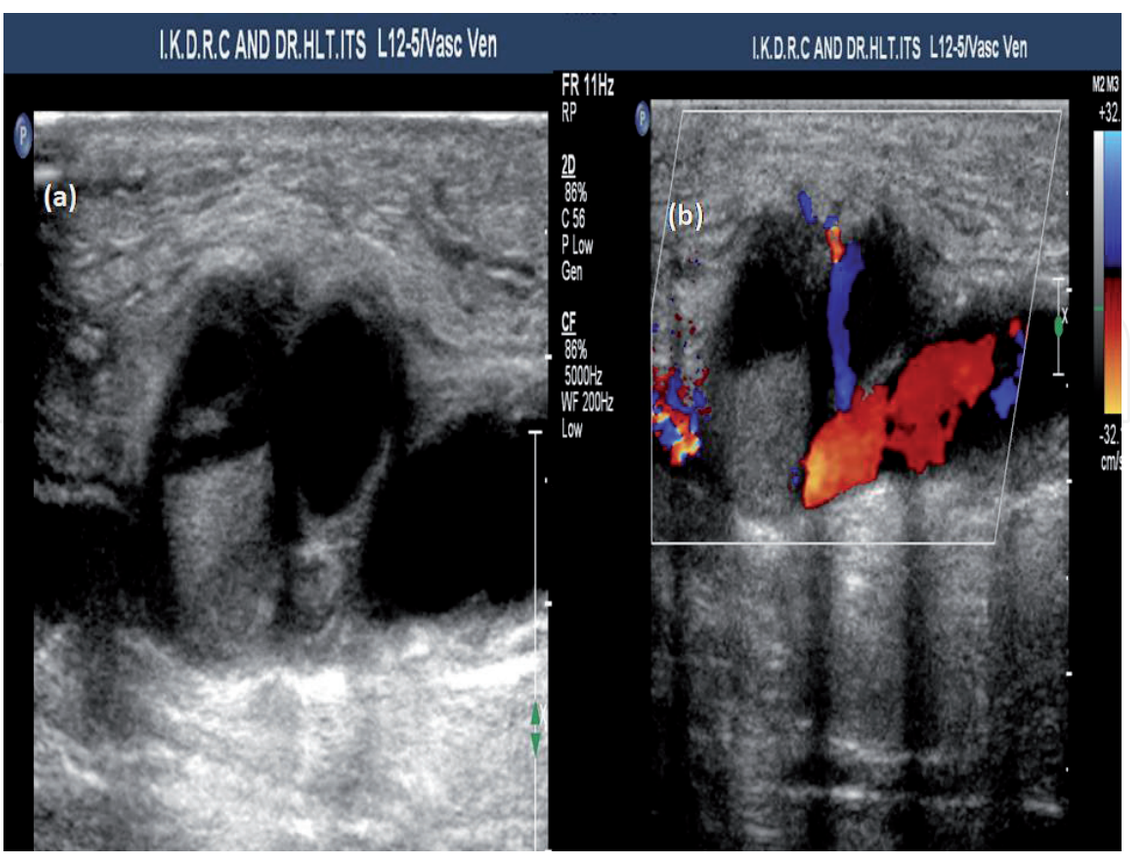


Figure 11.
(a) Gray scale image showing aneurysm arising from brachial artery in mid arm with peripheral thrombosis and (b) CDI study showing color flow in patent lumen.

4.2.4 Infection

Infection affects AVF (20% of all complications in AVF) less commonly than AVG (10 fold increased risk of infection in comparison to AVF). Perivascular cellulitis manifesting as localized redness and oedema is seen in cases of infection of AVF. Physical examination readily detects presence of infection. So, USG or CDI is not very commonly advised but it the sign symptoms persist after antibiotic regime, imaging can be advised. In Gray mode USG, subcutaneous oedema with or without fluid collections at AVF site is noted. The AVF is working in most of the cases. In cases of associated thrombosis, AVF may be non working with presence of thrombosis in draining vein or AVF. If associated aneurysm, hematoma or abscess are present, meticulous imaging and prompt treatment in form of surgical excision or drainage is done [6].

4.2.5 Steal syndrome

Distal hypo-perfusion of the limb in case of severe peripheral vascular disease due to pulling of arterial blood flow in AVF causes steal syndrome. Failure of adequate collateral formation and/or excessive blood flow is the main causes of symptomatic steal. About 3 to 8% cases may present with steal syndrome [7]. Brachiocephalic AVF tend to cause steal more than radio-cephalic AVF. Hand ischemia, pain, numbness are some of the symptoms where steal syndrome may be present. AVF shows normal color flow and high PSV.

For arterial steal, radial artery at wrist is usually examined. In complete arterial steal, direction of flow distal to the graft is reversed, however in partial steal, the spectral waveform becomes biphasic. Steal syndrome is confirmed if gentle compression of graft reverses the direction of flow and normal spectral waveform is achieved (**Figure 12**). Symptomatic steal may require graft ligation. However, asymptomatic steal is also seen which warrants no clinical significance.

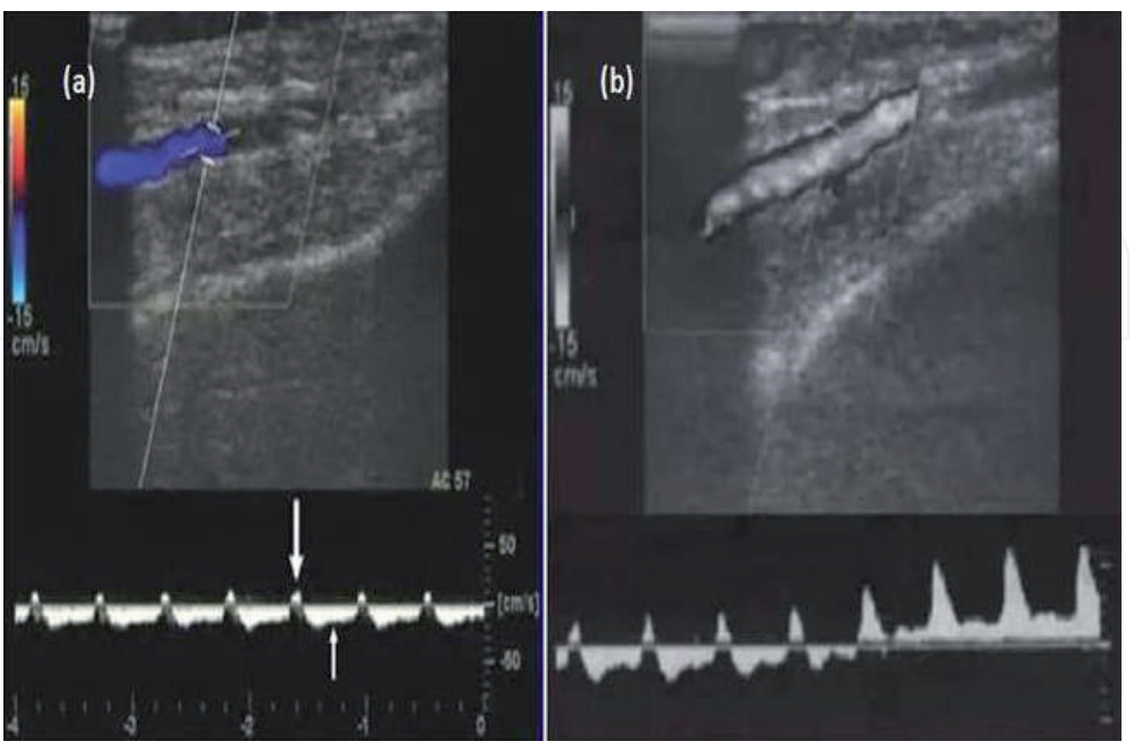


Figure 12.
(a) CDI image showing antegrade flow during systole and retrograde flow during diastole in radial artery distal to anastomosis (b) on gentle compression of AVF, elevated systolic flow and diastolic flow is noted confirming arterial steal syndrome [8].

Other complications like cardiac failure, venous hypertension and median nerve injury are also noted in relation to AVF. However, they are not very common and role of radiology is not prevalent. Venous hypertension may be seen as reversal of blood flow in color doppler study. Median nerve injury may occur from ischemic injury due to steal syndrome or direct compression of median nerve due to hematoma or amyloid deposition in late phases of AVF. In such cases, radiology can evaluate the primary etiology.

5. Conclusion

This chapter has reviewed important aspects of pre and Postoperative evaluation of hemodialysis AVF. USG and CDI are principal imaging modality due to various advantages like easy availability, non invasive, non-ionizing and cheap modality. A detailed protocol for performing and interpreting USG and CDI studies for VA has been developed through our vast experience and we have tried to provide a proper performa for VA evaluation.

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