Hemodialysis Access: US for Preprocedural Mapping and Evaluation of Maturity and Access Dysfunction

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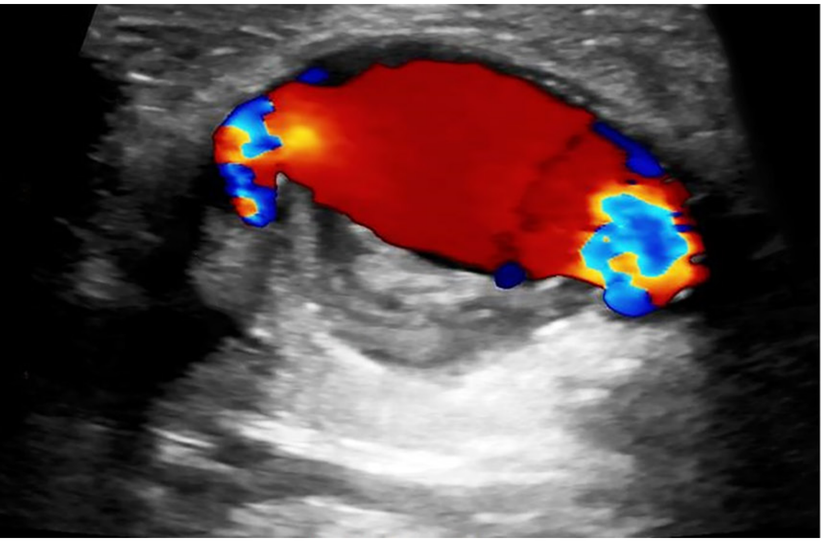
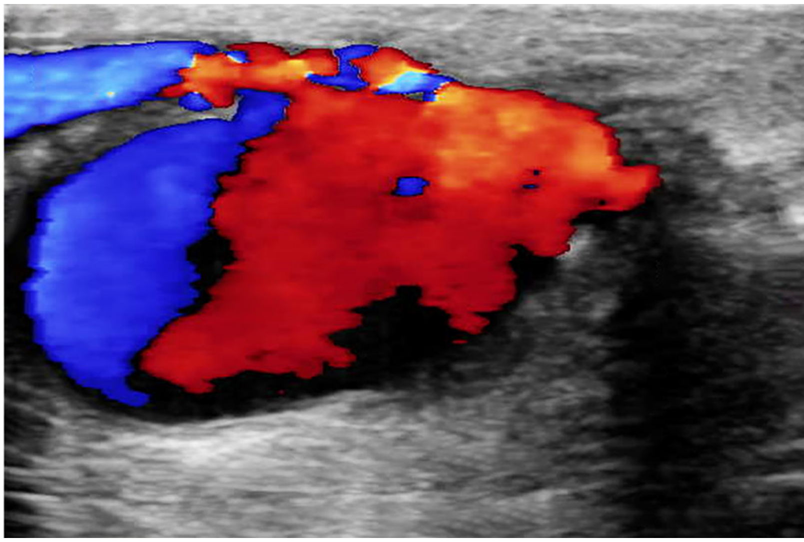
Patients with kidney failure require kidney replacement therapy. While renal transplantation remains the treatment of choice for kidney failure, renal replacement therapy with hemodialysis may be required owing to the limited availability and length of time patients may wait for allografts or for patients ineligible for transplant owing to advanced age or comorbidities. The ideal hemodialysis access should provide complication-free dialysis by creating a direct connection between an artery and vein with adequate blood flow that can be reliably and easily accessed percutaneously several times a week. Surgical arteriovenous fistulas and grafts are commonly created for hemodialysis access, with newer techniques that involve the use of minimally invasive endovascular approaches. The emphasis on proactive planning for the placement, protection, and preservation of the next vascular access before the current one fails has increased the use of US for preoperative mapping and monitoring of complications for potential interventions. Preoperative US of the extremity vasculature helps assess anatomic suitability before vascular access creation, increasing the rates of successful maturation. A US mapping protocol ensures reliable measurements and clear communication of anatomic variants that may alter surgical planning. Postoperative imaging helps assess fistula maturation before cannulation for dialysis and evaluates for early and late complications associated with arteriovenous access. Clinical and US findings can suggest developing stenosis that may progress to thrombosis and loss of access function, which can be treated with percutaneous vascular interventions to preserve access patency. Vascular access steal, aneurysms and pseudoaneurysms, and fluid collections are other complications amenable to US evaluation.





Introduction

Kidney failure, defined as an estimated glomerular filtration rate less than 15 mL/min/1.73 m^2, affects nearly 786 000 people in the United States, with 71% undergoing dialysis, and an estimated global prevalence of 13%, or over 840 million individuals affected worldwide (1–3). Once kidney replacement therapy is medically necessary, the options include hemodialysis (HD), peritoneal dialysis, and kidney transplantation, with transplantation preferred (4). HD continues to be the dominant form of kidney replacement therapy, often used in urgent settings and while patients await transplantation. HD is available in 93% of countries and accounts for approximately 80%–90% of all dialyses (1,5).

Supplemental Material

CME

Test Your Knowledge questions are available through through the Online Learning Center.

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Abbreviations: ACF = antecubital fossa, AV = arteriovenous, AVF = AV fistula, AVG = AV graft, EDV = end-diastolic velocity, HD = hemodialysis, KDOQI = Kidney Disease Outcomes Quality Initiative, PSV = peak systolic velocity

TEACHING POINTS

- High brachial artery bifurcation, or high origin of the radial artery, is the most common arterial variant in the upper arm, with the radial artery originating in the upper arm or axilla. The anatomy does not preclude AVF creation but may alter surgical technique, such as creating a wider anastomosis.
- Specific US criteria for access maturation vary in the literature but most commonly include a minimum draining vein diameter of 4–6 mm and blood flow rate of 500–600 mL/min or higher, with the combination of a draining vein greater than 4 mm and flow rate greater than 500 mL/min having a 95% likelihood of maturity.
- US examination should include evaluation of the cephalic arch insertion into the subclavian vein for cephalic vein AVF. Due to its unique anatomic characteristics, the presence of multiple valves and various biochemical changes associated with renal failure can alter flow dynamics at the cephalic arch, which can progress to stenosis.
- Steal syndrome requires the combination of arterial blood flow reversal into the AV access and away from the peripheral system and symptoms distal to the access anastomosis, which can include a cool extremity with mild numbness, intermittent symptoms during dialysis, or more severe sensory and motor impairment with ischemic rest pain and tissue loss.
- High-flow access is defined as access blood flow greater than 2000 mL/min or an access flow to cardiac output ratio greater than 30%–35%.

Selection of the appropriate arteriovenous (AV) access for HD requires preoperative evaluation of anatomic suitability, the cardiovascular system, and life expectancy, with the goal of creating a direct connection between an artery and vein that will have adequate blood flow and reliable and straightforward percutaneous access for HD several times a week. While a traditional creation relies on presurgical clinical and physical assessment with venography, the advent of US provides a reliable and noninvasive method to evaluate the vasculature. The National Kidney Foundation Kidney Disease Outcomes Quality Initiative (KDOQI) 2019 guidelines for vascular access recommend preoperative US mapping for patients with increased risk of AV access failure, peripheral vessel damage from repeated venipuncture, known or potential central venous stenosis, or difficult physical examination, without consensus for US mapping of all patients (4).

US mapping can help provide a more accurate assessment of the patient's eligibility for fistula creation, can optimize surgical planning by allowing identification of the most suitable vessels, and is associated with favorable HD access outcomes (6–9). US postoperative evaluation may be beneficial in the assessment of AV access maturation and aids in the detection of AV access dysfunction, which may allow early interventions such as thrombectomy, angioplasty, or stent placement to improve access longevity (4). US also helps evaluate complications such as palpable masses adjacent to the access, new swollen upper or lower extremity, and symptomatic steal (10).

We review the pertinent vascular anatomy for AV access placement and types of HD access. We also discuss the role of US before and after HD access creation and provide a description of imaging methods, normal and abnormal findings, and management of typical complications.

Upper and Lower Extremity Vascular Anatomy

Understanding the normal arterial and venous anatomy of the upper and lower extremities is helpful to perform vascular mapping US, understand specific AV fistula (AVF) and AV graft (AVG) options, evaluate for AV access complications, and plan treatment to preserve AV access patency.

Conventional upper extremity arterial anatomy is illustrated in Figure 1. Understanding variations helps the sonographer perform the examination; identification of variant anatomy is important for surgical planning (Fig S1). High brachial artery bifurcation, or high origin of the radial artery, is the most common arterial variant in the upper arm, with the radial artery originating in the upper arm or axilla. The anatomy does not preclude AVF creation but may alter surgical technique, such as creating a wider anastomosis (11,12). High brachial artery bifurcation can affect fistula outcomes, including higher maturation failure rates and reduced patency (13,14).

Normal upper extremity deep venous anatomy includes paired brachial veins and paired radial and ulnar veins that are parallel and adjacent to the corresponding arteries. The superficial veins include the basilic vein along the medial arm and forearm, joining one of the paired brachial veins near the axilla. The cephalic vein courses along the lateral forearm and along the lateral border of the biceps to join the subclavian or axillary veins, forming the cephalic arch (15). The perforator vein in the antecubital fossa (ACF) connects the forearm deep veins to the median cephalic vein, median basilic vein (tributary branches of the cephalic and basilic veins, respectively), or median cubital vein, which connects the cephalic and basilic veins (16).

Numerous superficial venous variations have been described (Fig S2) (17,18). The anatomy of superficial forearm veins usually does not restrict the possibility of AVF creation, but small vein caliber, thrombosis related to previous venipuncture or other access, or calcified thick-walled veins can exclude some veins from use (19–21).

Lower extremity AVGs are typically placed near the groin. The common femoral artery continues from the external iliac artery just distal to the origin of inferior epigastric artery and branches into the superficial femoral and profunda femoris arteries (22). The common femoral vein courses medial and posterior to the common femoral artery in the proximal femoral triangle, traversing posterior to the artery as they pass distally to enter the adductor canal. The great saphenous vein is the largest tributary of the common femoral vein seen along its anteromedial aspect, caudal to the inguinal ligament.

Types of AV Access

Surgical AVFs and AVGs

When feasible, an AVF or AVG is preferred over a central venous catheter, with creation of an AVF the preferred access

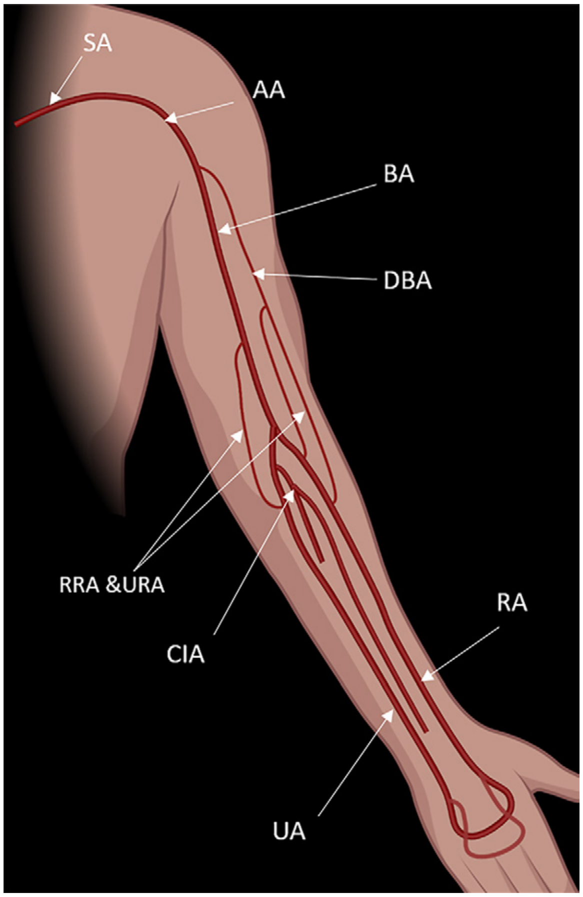


Figure 1. Schematic diagram shows the normal arterial anatomy of the left upper extremity. *AA* = axillary artery, *BA* = brachial artery, *CIA* = common interosseous artery, *DBA* = deep brachial artery, *RA* = radial artery, *RRA* = radial recurrent artery, *SA* = subclavian artery, *UA* = ulnar artery, *URA* = ulnar recurrent artery.

choice for HD over AVG (23). The AV access decision should incorporate vascular anatomy, underlying medical conditions, urgency of HD, and patient preference. An AVF is created by surgically or percutaneously connecting a major artery to a large enough and accessible superficial vein as far distal as anatomically feasible. AVGs are constructed by interposing a prosthetic or biologic graft between an artery and vein. AVFs demonstrate longer patency (3–7 years vs 12–18 months for AVG) and lower rates of the steal phenomenon, stenosis, thrombosis, and infection. However, AVFs have a longer maturation time of 4–6 weeks and higher primary failure rates compared with those of AVGs (50% vs 15%, respectively) (4,24,25). Unlike AVF, AVG does not require vein wall maturation and can be used for HD in as little as 24 hours after creation depending on the graft type, with a 2-week waiting period that is typical for most polytetrafluoroethylene grafts. AVG is considered a viable option for elderly patients with limited life expectancy.

The most common types of AV access are listed in Table 1 (Fig 2). The nondominant upper extremity is usually selected for access. However, a dominant arm AVF may be preferred over AVG in the nondominant upper extremity if the vascular anatomy is more favorable. The cephalic vein is preferred over the basilic vein because of its superficial location and easier access due to

Table 1: Types of HD Access In Descending Order of Preference of Access Creation

Fistula Types	Description
Radiocephalic AVF	Created between radial artery and cephalic vein at the wrist; most preferred fistula to preserve outflow vein sites in upper arm; lower flow rates compared with those at proximal sites; does not require superficialization in the majority of cases
Brachiocephalic AVF	Created between the brachial artery and cephalic vein in the upper arm Higher maturation and patency rates than those of radiocephalic AVF; provides a long length of straight vein for cannulation; higher blood flow but also higher incidence of vascular steal syndrome
Brachial artery–transposed basilic (vein AVF)	Created between brachial artery and transposed segment of the basilic vein in the upper arm, with superficialization in the same or different setting (one stage vs two stages to create) Technically difficult surgery with increased perioperative morbidity rates but a good rate of maturity
Brachial artery–antecubital (vein AVG)	Forearm AVG with loop configuration in the forearm Created between the antecubital brachial artery and the median antecubital vein, cephalic vein, brachial vein, or basilic vein (that meet criteria)
Brachial artery–axillary vein (straight AVG)	Most common configuration for AVG in the upper arm Arterial inflow from the antecubital brachial artery and outflow through the axillary vein
Brachial artery–axillary vein (loop AVG)	Arm AVG with loop configuration in the upper arm Arterial inflow from the proximal brachial artery and outflow through the axillary vein
Lower extremity AVG	Most commonly constructed in a loop configuration in the upper thigh or mid thigh Arterial inflow from the common femoral or superficial femoral artery and outflow through the femoral vein or great saphenous vein
Percutaneous fistula access (endovascular AVF)	All patients who meet vascular suitability criteria (described in main text); exclusion criteria are the same as those for surgical AVFs with additional antecubital criteria; according to KDOQI, radiocephalic AVF is preferred over endovascular AVF Minimally invasive, higher technical success, improved outcomes, reduces overall costs, and increases patient acceptance Requires more reinterventions during the 1st year to make them functional

Sources.—References 7, 10, 26.

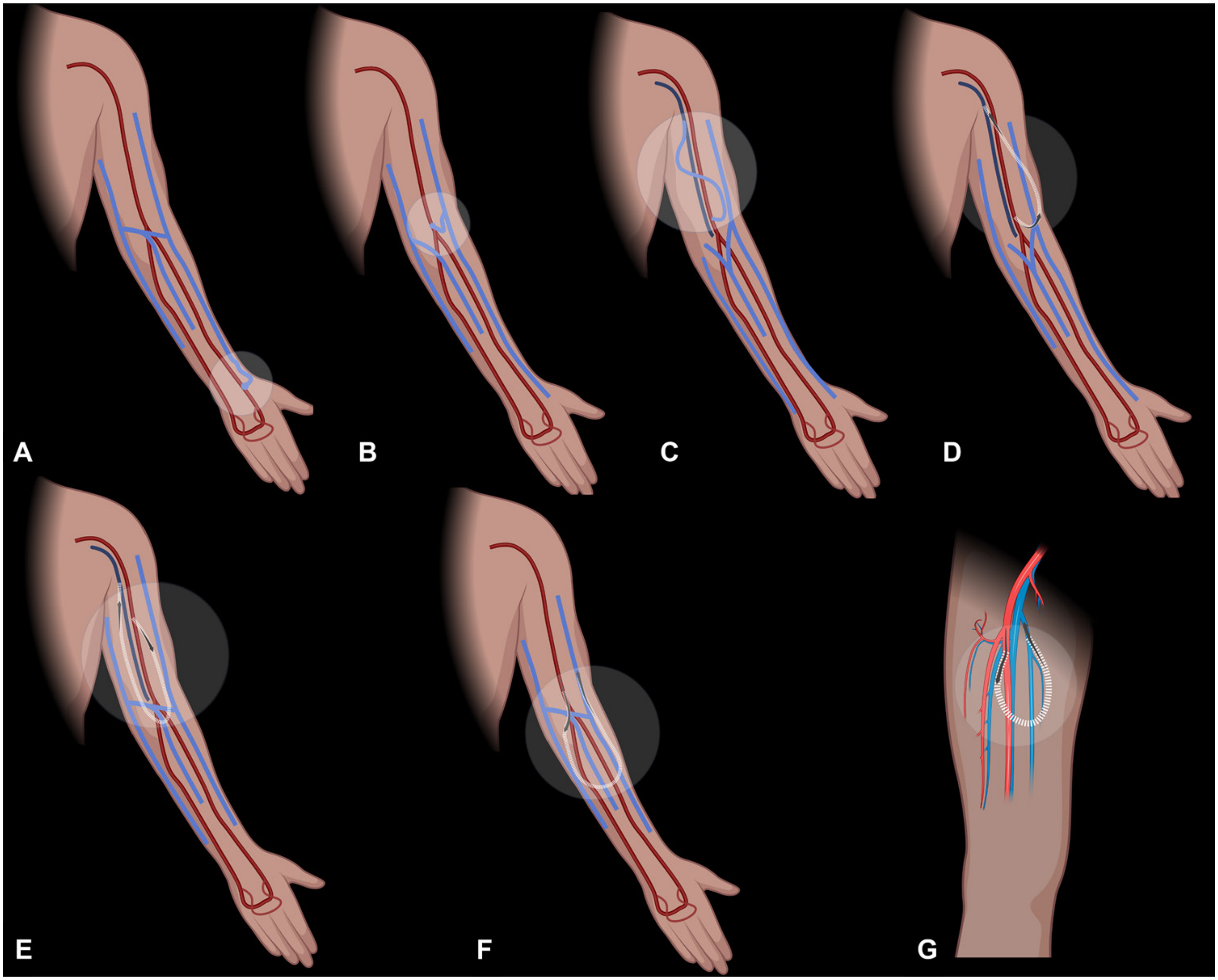


Figure 2. Illustrations show various surgical AVF and AVG sites. **(A)** Radial artery–cephalic vein AVF. **(B)** Brachial artery–cephalic vein AVF. **(C)** Brachial artery–transposed basilic vein AVF. **(D)** Brachial artery–axillary vein straight AVG. **(E)** Brachial artery–axillary vein loop AVG. **(F)** Brachial artery–cephalic vein forearm AVG. **(G)** Lower extremity femoral artery–great saphenous vein AVG. Arrows = flow direction.

the lateral location, requiring less dissection and venous manipulation. More distal AV access is selected in young patients to preserve the upper arm for future use. For patients with a limited life expectancy but relatively good vessels, an upper arm fistula first approach may be reasonable (4,26). Preoperative US mapping can help identify the most suitable vascular anatomy to allow planning access sites accordingly.

Endovascular AVF Creation

Endovascular devices to create an AVF percutaneously offer a potential alternative to a surgically created AVF. US or fluoroscopic guidance is used to create an arterial-venous anastomosis at an angle near 0 degrees, which has been shown to improve blood flow dynamics and decrease the risk of juxta-anastomotic stenosis. The procedure may reduce vessel trauma, resulting in less intimal hyperplasia, potentially helping AVF maturation, avoiding reinterventions, and improving patient acceptance (27–29). Currently, the two U.S. Food and Drug Administration–approved endovascular AVF devices are the WavelinQ EndoAVF System (Becton, Dickinson and Company) and Ellipsys Vascular Access System (Medtronic).

The Ellipsys system uses US to guide a single catheter through the perforator vein to create a fistula with the proximal radial artery by using pressure and thermal energy for tissue fusion. The endovascular AVF venous outflow may be the cephalic vein, basilic vein, or both (Movie 1) (30). After fistula creation, immediate angioplasty of the anastomosis is performed to improve the rate of fistula maturation (31).

The WavelinQ EndoAVF system involves the use of two catheters with fluoroscopic guidance to create an AVF between the deep arteries and veins in the proximal forearm by using radiofrequency energy, usually the ulnar or radial artery and adjacent adequate diameter vein. One of the paired caudal brachial veins can be embolized to direct blood flow from the

Table 2: Suggested Preoperative Mapping Protocol for AV Access (Based on Our Institutional and AIUM Protocols)

Upper extremity arterial evaluation: measure the inner wall anteroposterior diameter in the transverse plane
1. Evaluate the caudal third of the brachial artery and entire radial artery at gray-scale imaging. Assess for high brachial artery burfication and amount of wall calcification.
2. Measure the diameter, PSV and EDV of the axillary artery, brachial artery 2 cm cranial to the ACF, and radial artery 2 cm cranial to the wrist; if there is high bifurcation of the brachial artery, measure the PSV and EDV in the radial and ulnar arteries 2 cm cranial to the ACF.
3. Measure blood flow rate in the brachial artery 2 cm cranial to the ACF (three times at the same location).
4. If arterial stenosis detected, measure the PSV and EDV at the stenosis and 2 cm upstream to the stenosis for a PSV ratio calculation.
Upper extremity venous evaluation: measure the inner wall anteroposterior diameter in the transverse plane
1. Measure the cephalic vein diameter and anterior vein wall depth from the skin surface at 2 cm cranial to the wrist and mid and proximal forearm (approximately 4 cm caudal to the ACF).
2. Measure cephalic and basilic vein diameters at the ACF, mid and proximal upper arm, and cephalic vein anterior wall depth from the skin surface.
3. Measure the diameter of the median antecubital and axillary veins.
4. Evaluate the cranial and caudal internal jugular vein; medial, mid, and lateral subclavian veins with and without compression (where possible); and spectral waveform.
Additional evaluation for potential placement of the endovascular AVF
1. Measure the inner diameter of the perforator vein at the ACF; assess length; determine whether it is straight or curvy and what superficial vein it originates from.
2. Evaluation of additional vessels depends on the device selected.
a. WavelinQ device requires measurement of the inner diameter of the radial and ulnar artery and veins 2 cm distal to the brachial artery bifurcation.
b. Ellipsys device requires measurement of the inner diameter of the radial artery 2 cm distal to the brachial artery bifurcation and distance from the perforator vein.
Preoperative mapping protocol for groin AVG
1. Evaluate the common femoral artery and superficial femoral artery for stenosis, occlusion, and calcification. Obtain spectral Doppler images.
2. Evaluate the common femoral vein and femoral vein for thrombus and wall thickening. Obtain spectral Doppler images of the common femoral vein.
a. Measure inner luminal diameters of the common femoral artery and vein, GSV, and cranial and mid superficial femoral artery.
3. Measure the length of the GSV ≥4.0 mm from the insertion into the common femoral vein.

Sources.—References 18, 33, 37.
Note.—AIUM = American Institute of Ultrasound in Medicine, GSV = great saphenous vein.

deep venous system through the perforator vein into the target superficial access veins, which further helps with fistula maturation (Movie 2) (32).

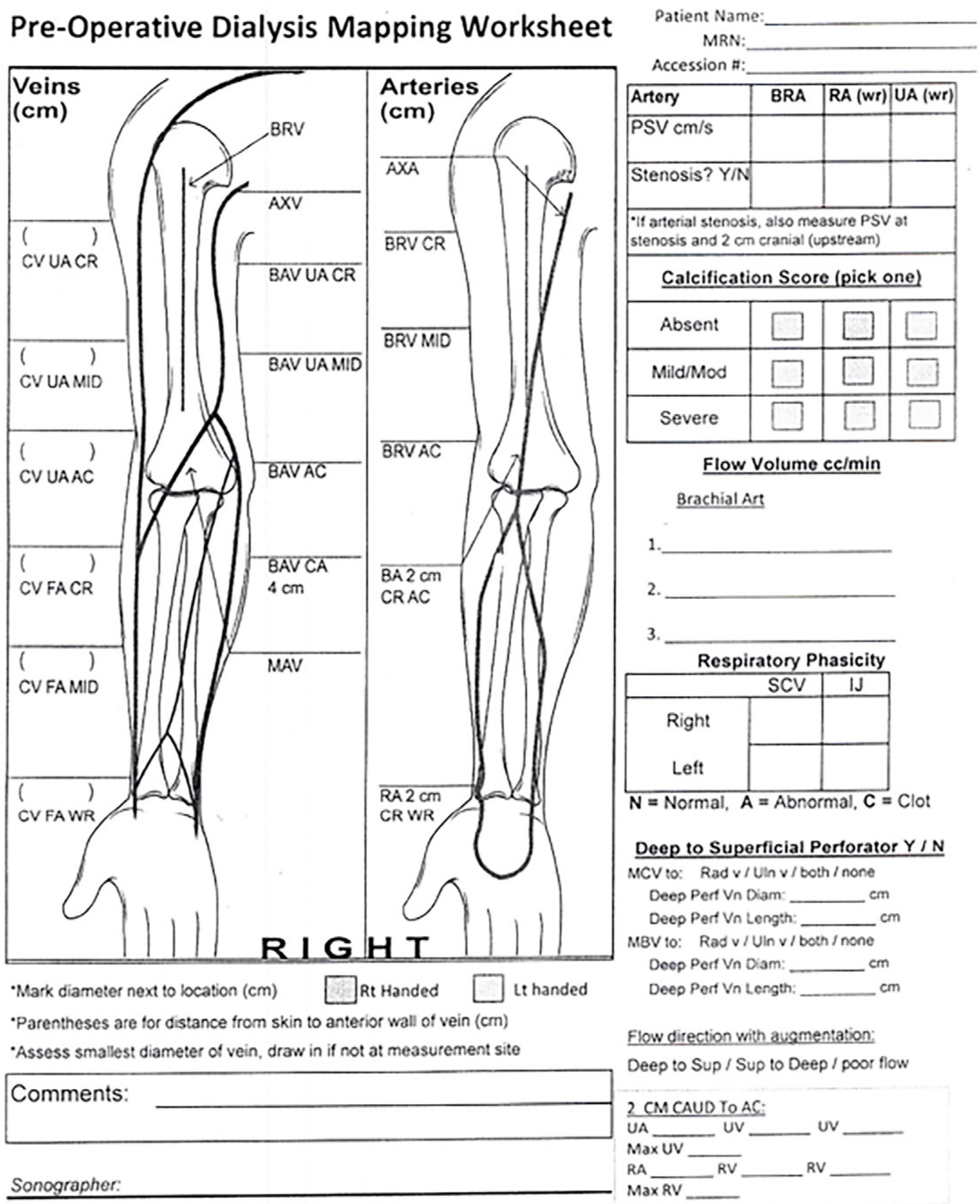
Preoperative Vascular Mapping with US

The use of US to map the extremity arteries and veins before AV access creation requires attention to technical and anatomic detail. Arm and forearm vessel evaluation is optimized with the patient seated upright and use of a tourniquet for venous measurements. The patient should be supine for evaluation of the subclavian vein, neck vessels, and groin vessels. The examination should be performed in a comfortably warm room with warmed gel to avoid triggering vasoconstriction. A high-frequency linear array transducer (12–15 MHz) is used to evaluate the superficial vascular structures, while a small-footprint curved-array transducer is used to evaluate the brachiocephalic vein and superior vena cava. To assess accurate vessel dimensions, apply only light pressure with an adequate amount of gel.

A representative preoperative US mapping protocol is provided, which may vary by institutional preference (Table 2; Fig 3) (18,33). In general, anteroposterior inner lumen diameters of target vessels are measured in the transverse plane without any pressure from the transducer that may deform the vessel (Fig 4). The longitudinal plane is used for arterial calcification assessment (Fig 5) and for color and spectral Doppler waveform documentation and velocity measurement with an angle correction of 60 degrees or less. Operator preference may guide institutional criteria for vessel suitability for AVF or AVG creation. The KDOQI 2019 guidelines suggest an inner lumen diameter of the target artery greater than 2 mm and target vein greater than 2.0–2.5 mm for AVF creation. AVG has the same arterial threshold but larger minimum venous diameter of 4.0 mm (4). The criteria for endovascular AVF procedures include the radial or ulnar artery near the ACF that measures at least 2.0 mm, with a perforating vein diameter minimum of 2.0 mm (Fig 6) (34).

Upper extremity arterial evaluation includes inner lumen measurement of the caudal brachial artery 2 cm above the ACF and the radial artery 2 cm above the wrist. If high brachial artery bifurcation is identified, the radial and ulnar arteries are measured 2 cm above the ACF. Evaluation for endovascular AVF suitability includes additional measurements at the ACF: the radial artery inner diameter and distance to the perforator vein for Ellipsys and the inner diameter of the radial and ulnar arteries for WavelinQ (18). Spectral Doppler waveform with peak systolic velocity (PSV) and end-diastolic velocity (EDV) is obtained at each location. Arterial wall calcification is subjectively assessed as mild, moderate, and severe, because it can impact the ability to create an access. If arterial stenosis is suspected, additional PSV and EDV measurements are obtained 2 cm cranial to the stenosis to calculate the PSV ratio.

At some institutions, brachial artery flow volume is measured 2 cm above the ACF, with a normal volume ranging from



Pre-Operative Dialysis Mapping Worksheet

Patient Name:__________
MRN:__________
Accession #:__________

Veins (cm)

BRV
AXV
( ) CV UA CR
BAV UA CR
( ) CV UA MID
BAV UA MID
( ) CV UA AC
BAV AC
( ) CV FA CR
BAV CA 4 cm
( ) CV FA MID
MAV
( ) CV FA WR

Arteries (cm)

AXA
BRV CR
BRV MID
BRV AC
BA 2 cm CR AC
RA 2 cm CR WR

RIGHT

Artery	BRA	RA (wr)	UA (wr)
PSV cm/s			
Stenosis? Y/N			

*If arterial stenosis, also measure PSV at stenosis and 2 cm cranial (upstream)

Calcification Score (pick one)			
Absent	☐	☐	☐
Mild/Mod	☐	☐	☐
Severe	☐	☐	☐

Flow Volume cc/min

Brachial Art

1.__________
2.__________
3.__________

Respiratory Phasicity

	SCV	IJ
Right		
Left		

N = Normal, A = Abnormal, C = Clot

Deep to Superficial Perforator Y / N

MCV to: Rad v / Uln v / both / none
Deep Perf Vn Diam: _____ cm
Deep Perf Vn Length: _____ cm
MBV to: Rad v / Uln v / both / none
Deep Perf Vn Diam: _____ cm
Deep Perf Vn Length: _____ cm

*Mark diameter next to location (cm) ☐ Rt Handed ☐ Lt handed
*Parentheses are for distance from skin to anterior wall of vein (cm)
*Assess smallest diameter of vein, draw in if not at measurement site

Comments: __________

Sonographer:

Flow direction with augmentation:
Deep to Sup / Sup to Deep / poor flow

2 CM CAUD To AC:
UA ____ UV ____ UV ____
Max UV ____
RA ____ RV ____ RV ____
Max RV ____

Figure 3. Preoperative imaging protocol worksheet used at our institution. *AXA* = axillary artery, *AXV* = axillary vein, *BAV* = basilic vein, *BRA* = brachial artery, *BRV* = brachial vein, *CR* = axillary artery, *CV* = cephalic vein, *FA* = forearm, *IJ* = internal jugular vein, *MAV* = median antecubital vein, *MCV* = medial cephalic vein, *RA* = radial artery, *SCV* = subclavian vein, *UA* = ulnar artery, *WR* = wrist.

30 to 120 mL/min. For any vessel, flow volume is calculated as time-averaged mean velocity × area. The Doppler US range gate is increased to encompass the entire vessel including vessel walls, with a 60-degree angle or less parallel to the posterior vessel wall. The inner luminal dimension is measured perpendicular to the course of the vessel (Fig 7). This measurement is typically performed three times for accuracy (10).

Preoperative vein evaluation includes assessment of the deep and superficial veins for thrombus with compression where possible and with spectral waveforms in the deep veins. A monophasic waveform in the medial subclavian and caudal internal jugular veins is suspicious for brachiocephalic vein thrombosis, while bilateral abnormal monophasic waveforms in the internal jugular and subclavian veins suggest superior vena cava stenosis or occlusion. These findings should be further evaluated with MR venography, CT venography, or conventional catheter venography (Fig S3) (35).

Superficial veins with occlusive or nonocclusive acute thrombosis or postthrombotic change carry a higher risk of access failure. Measurements of the inner lumen diameter are obtained at multiple locations of the cephalic vein along the forearm and the basilic and cephalic vein along the upper arm. The distance from the skin surface to the anterior wall of cephalic vein is measured as well.

A modified Allen test using Doppler US can be performed during this examination or as a separate examination to evaluate the palmar arch (Fig 8). After documenting waveforms in the radial and ulnar arteries at the wrist, the US transducer is positioned on the thenar eminence to measure the superficial palmar artery flow direction before and during radial artery

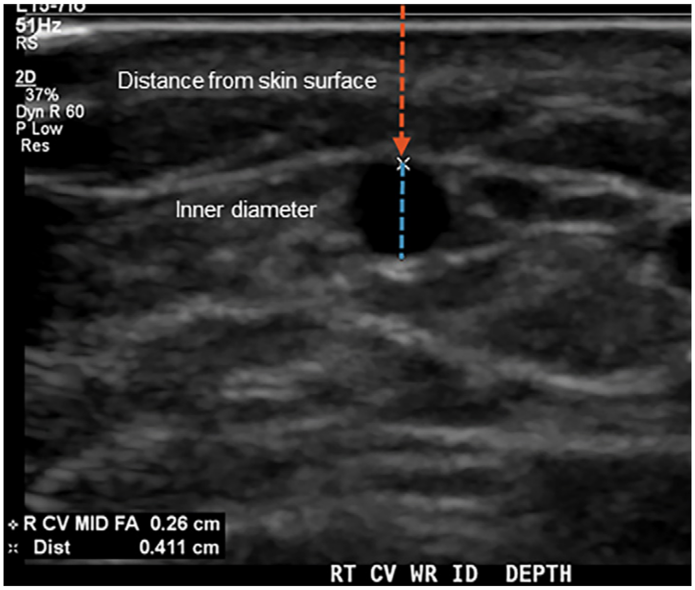


Figure 4. Technique for venous diameter and depth measurement. Transverse gray-scale US image of the cephalic vein *(CV)* at the wrist *(WR)* shows the measurement of inner diameter *(ID)* in the anteroposterior dimension (dashed blue line) and the anterior wall depth from the skin surface (dashed orange arrow).

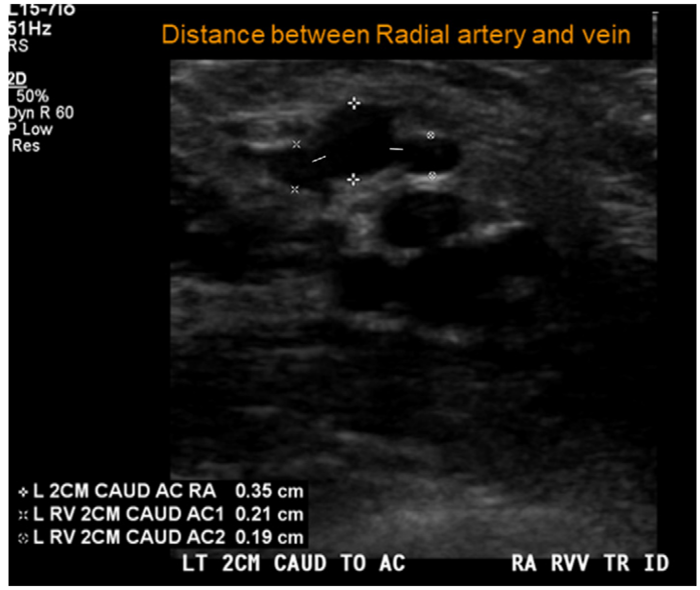


Figure 6. Vascular measurements in a patient considered for endovascular AVF. Transverse gray-scale US image of the forearm 2 cm caudal *(CAUD)* to the ACF shows measurements of the inner lumen diameter of the radial artery *(RA)* and radial veins *(RVV)* and the distance between the artery and veins (white lines) of less than 2 mm.

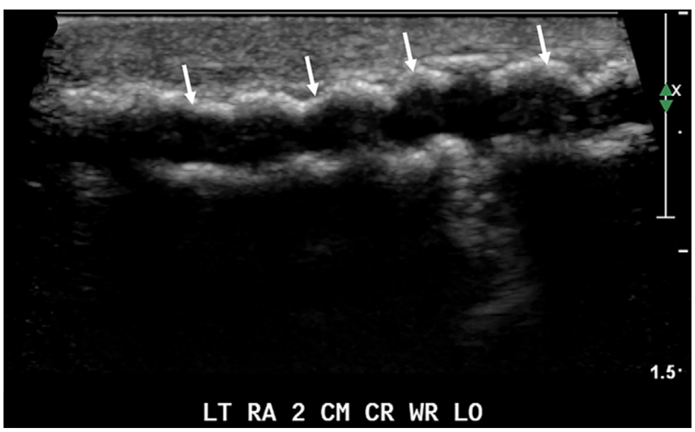


Figure 5. Assessment of arterial calcifications. Longitudinal *(LO)* gray-scale US image of the radial artery shows severe atherosclerotic wall calcifications (arrows) that pose potential difficulty for surgical suturing, possible increased risk of emboli at surgery, decreased distensibility, and decreased likelihood to mature due to inadequate arterial inflow. *CR* = cranial, *ID* = internal diameter, *WR* = wrist.

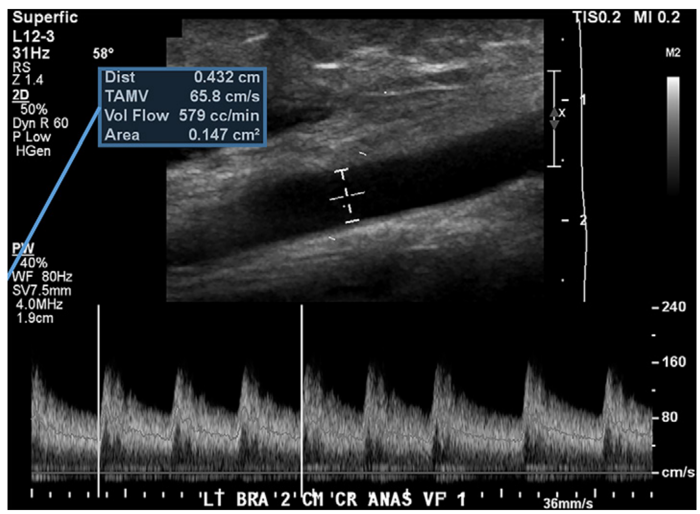


Figure 7. Technique used for blood flow volume measurement. Longitudinal US image at a straight segment of the vessel identifies an area without turbulent flow (color Doppler spectrum not shown). The Doppler gate is increased in size to encompass the entire vessel diameter and is corrected to an angle of 60 degrees or less, parallel to the posterior vessel wall. Only the antegrade flow is measured.

compression. Flow reversal during compression confirms a complete palmar arch since the ulnar artery is now the inflow vessel to the thenar eminence. If the palmar arch is not intact, flow is absent owing to a lack of ulnar collateral flow (Fig 9) (36).

Postoperative AV Access Evaluation

Physical examination remains the main method to monitor for abnormalities once the AV access is in use. The "look, listen, feel" approach includes an examination of the access and overlying skin for dilatation, redness, or swelling; auscultation with a stethoscope for normal low-pitch continuous flow during systole and diastole; and palpation of the access to detect the presence of thrill and any temperature change or pain. Clinically significant AV access dysfunction may manifest as problems during the HD session, such as difficulty with cannulation, inadequate dialysis (low blood flow, decrease in the delivered dialysis dose, or reduced urea ratio), abnormal bleeding, or aspiration of clots (4).

US of AVFs and AVGs

Routine surveillance of the HD access in asymptomatic patients is not recommended by KDOQI. For assessment of

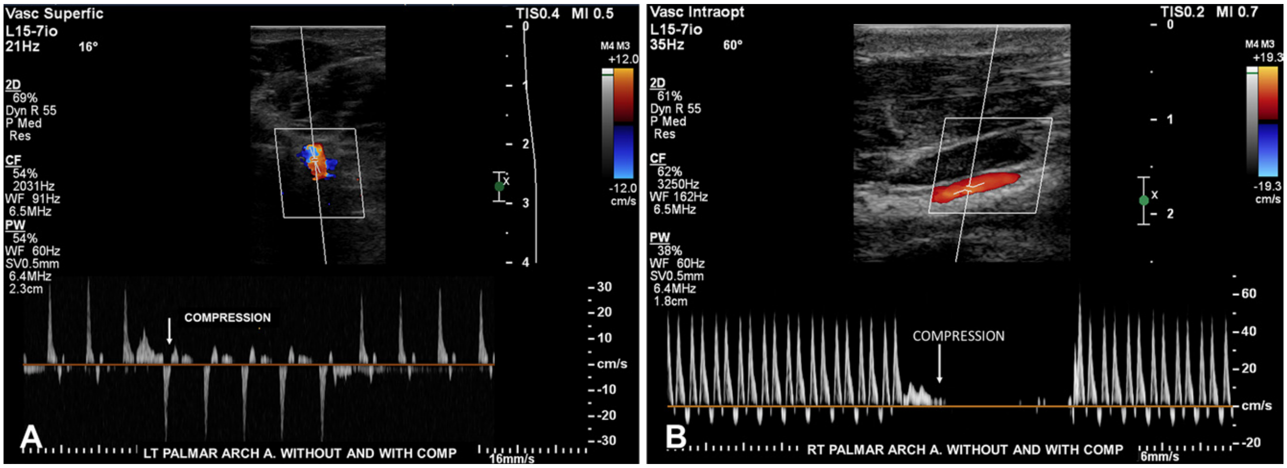


Figure 8. Modified Allen test using Doppler US. **(A)** US transducer is positioned on the thenar eminence to measure the superficial palmar artery flow direction during radial artery compression. Flow reversal during compression indicates a complete palmar arch, as depicted on this US image. **(B)** Doppler US image in a patient with an incomplete palmar arch shows there is no flow reversal in the obliquely oriented radial artery that occurs during compression since there is no collateral flow from the ulnar artery through the superficial palmar arch. White arrow in **A** and **B** indicates when compression is applied.

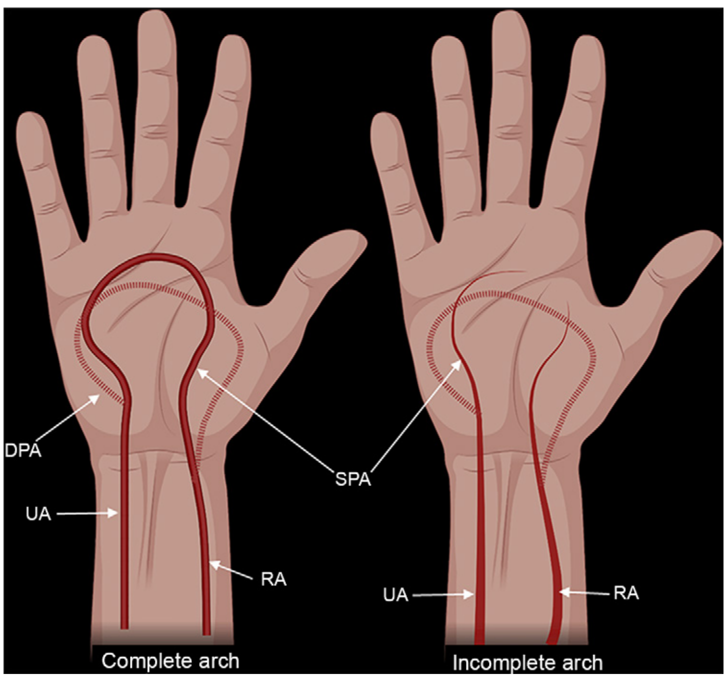


Figure 9. Diagram shows complete **(A)** and incomplete **(B)** palmar arches. *DPA* = deep palmar arch, *RA* = radial artery, *SPA* = superficial palmar arch, *UA* = ulnar artery.

maturation or for suspicion of a clinically significant AV access abnormality, patients are referred for Doppler US as the first-line imaging modality for examination, with the addition of CT or MR venography if central stenosis is suspected (4). The US examination includes an overview of the AV access anatomy and anastomoses, with a specific imaging protocol based on the access type and clinical concern (Table 3) (10,37). When available, surgical notes can be reviewed to help confirm the anatomic structures used for the specific AV access construct.

The US examination is performed to help evaluate the caudal third of the inflow artery, arterial anastomosis (and AVG venous anastomosis), and graft or draining vein along the entire venous outflow, including as much of the central venous system as possible (10). Each vessel and anastomosis should be assessed for narrowing or thrombus with gray-scale and color Doppler imaging for patency and to identify turbulent flow. PSV is measured in each vessel and at all anastomotic locations. If an area of narrowing or elevated PSV is identified, a PSV measurement should be obtained 2 cm upstream from the abnormal area to calculate a PSV ratio.

For AVF, any accessory vein branches from the draining vein are documented with the distance from the anastomosis and with the accessory vein diameter. Any thrombus or vein wall thickening extent is documented. Any outpouchings, graft defects, or fluid collections are evaluated on gray-scale and Doppler images. Multifocal abnormalities may be present (10). A document that shows a summary of AV access findings can be helpful (Fig 10, S4).

The inflow artery proximal to the AVF or AVG anastomosis has a low-resistance and high-amplitude waveform, while the artery distal to the anastomosis has a normal high-resistance arterial flow. The venous outflow has an arterialized waveform with spectral broadening, also seen in the graft. AVG wall material is identified by the typical tram-track appearance compared with the native vessel wall material of the AVF draining vein (Fig 11). Draining vein flow volume is typically obtained 10 cm cranial to the anastomosis, as this area encompasses the typical cannulation zone. Flow volume less than that desired is often due to large accessory veins diverting flow from the first 10 cm of the AVF draining vein or because a stenosis is present, as discussed later. Operators must take care to avoid transducer compression of the outflow venous tract, leading to vessel diameter distortion and inaccurate measurement.

Flow volume measurement in the brachial artery may be obtained and typically shows about a 10-fold increase from the preoperative value after access placement. This measurement can be helpful in evaluating total inflow versus outflow

Table 3: Suggested Postoperative US Protocol for AV Access (Based on Our Institutional and AIUM Protocols)

Arterial evaluation*
1. Assess the caudal third of the feeding artery for stenosis in AVF and AVG.
2. Measure the inner lumen diameter in the transverse plane 2 cm cranial to the anastomosis.
3. Assess the feeding artery at color and spectral Doppler US in the longitudinal plane.
4. Obtain PSV and EDV measurements in the feeding artery cranial to the anastomosis, at the AV anastomosis or arterial and venous AVG anastomoses, or jet from stenosis, with Doppler angle parallel to the jet. If elevated PSV is seen, assess for visual evidence of stenosis. Also assess flow volume measurements in the inflow artery.
Graft or draining vein evaluation*
1. The AVF or AVG draining vein is inspected for wall thickening, stenosis, and thrombosis along its entire length.
2. Measure inner lumen anteroposterior diameter of the AVF draining vein in the transverse plane, and measure the depth of the AVF draining vein from the skin surface at several locations along the vein from the anastomosis to 10–15 cm cranial to the AV anastomosis.
3. Accessory draining veins within 10–15 cm of anastomosis may divert flow from the main AVF draining vein. When identified, each accessory vein intraluminal diameter is measured, with the location documented by distance from the anastomosis.
4. Flow volume measurements are obtained within the mid portion of the draining vein of an AVF, typically at 10 cm cranial to the anastomosis in an area with parallel vessel walls, minimal vessel tortuosity, and no stenosis. Flow volume measurements in an AVF are made at the mid arterial and mid venous limb graft or the mid graft if a straight graft.

Source—Reference 10.
Note.—AIUM = American Institute of Ultrasound in Medicine.
* Juxta-anastomotic is defined within 2 cm of anastomosis in the feeding artery or draining vein.

in the draining vein. Doppler US of the established HD access is usually performed more than 24 hours after a dialysis session due to hemodynamic changes that may lead to false estimation of flow volumes (38).

AVF Maturation Failure

A *mature AVF* is defined as a fistula that can be repetitively cannulated over a continuous 4-week period with two needles for 75% of dialysis sessions (39). Maturation is associated with vascular remodeling, characterized by an increase in blood vessel diameter and wall thickness. Factors that affect maturation are listed in Table 4 (40,41). *Maturation failure*, or primary failure, is defined as an AVF inadequate for successful needle cannulation 12 weeks after placement (10). AVF maturation failure rates range from 24% to 65% (42), with 24%–42% of AVFs requiring intervention to facilitate maturation (43). Upper arm AVFs have higher maturation rates compared with those of the forearm.

Specific US criteria for access maturation vary in the literature but most commonly include a minimum draining vein diameter of 4–6 mm and blood flow rate of 500–600 mL/min or higher, with the combination of a draining vein greater than 4 mm and flow rate greater than 500 mL/min having a 95% likelihood of maturity (Fig 12) (39,44,45). If the draining vein is more than 6 mm from the skin surface, it may require a surgical procedure to bring the vein closer to the skin surface for successful cannulation.

Causes of primary AVF maturation failure include large accessory veins or stenosis of the inflow artery, anastomosis, draining vein, or central vein. Accessory veins are side branches arising from the primary draining vein that can divert blood flow away, preventing adequate flow volume (Fig 13). Clinically significant accessory veins divert more than 25% flow or have a diameter one-third that of the AVF draining vein. Embolization of these accessory veins can improve AVF maturation rate (46). AVG dysfunction or failure is primarily due to venous outflow stenosis near the graft-vein anastomosis secondary to neointimal hyperplasia. Diagnostic criteria for stenosis are discussed later.

Device specific maturation criteria for endovascular AVF are under active investigation. The brachial artery and cannulation zone should have blood flow greater than 500 mL/min, with a draining vein diameter greater than 4 mm and depth from the skin surface less than 5 mm (47). The reported 1-year primary, primary-assisted, and secondary patency rates with the Ellipsys system are 54%, 85%, and 96%, respectively (48). The cumulative patency with the WavelinQ system is 92.8% after 1 year and 91.6% at 2 years (49). Common causes of the lack of maturation for endovascular AVF include the inability to divert flow to a single outflow vein that dilates sufficiently for cannulation, requiring additional coil placement or angioplasty of the endovascular AVF site, and dilatation of the outflow vein. If the brachial vein dilates as the main outflow vein, it may need to undergo superficialization (50).

Dysfunctional AV Access

The KDOQI guidelines describe three types of vascular access complications: *(a)* thrombotic flow–related dysfunction resulting in a clinically important reduction in intra-access flow that threatens access patency, such as stenosis or thrombosis; *(b)* nonthrombotic flow–related dysfunction, such as access aneurysms and steal syndrome with clinical signs and symptoms, which may or may not threaten flow or patency; and *(c)* other complications including infection and fluid collections (Table 5) (4).

Thrombotic Flow–related Dysfunction

Stenosis

The most common cause of AV access dysfunction is stenosis, which can progress to thrombosis and loss of the functioning access. The causes of stenosis include neointimal hyperplasia, surgical manipulation, repeated cannulation, and angioplasty-induced trauma. Atherosclerosis and medial calcinosis lead to inflow arterial stenosis (4,51). While stenosis can develop anywhere from the inflow artery to the central veins, certain access types have typical stenosis locations (Table 6, Fig 14). The juxta-anastomotic region is the most common site of AVF stenosis and is located within 2 cm of the arterial-venous anastomosis, including the feeding artery and draining

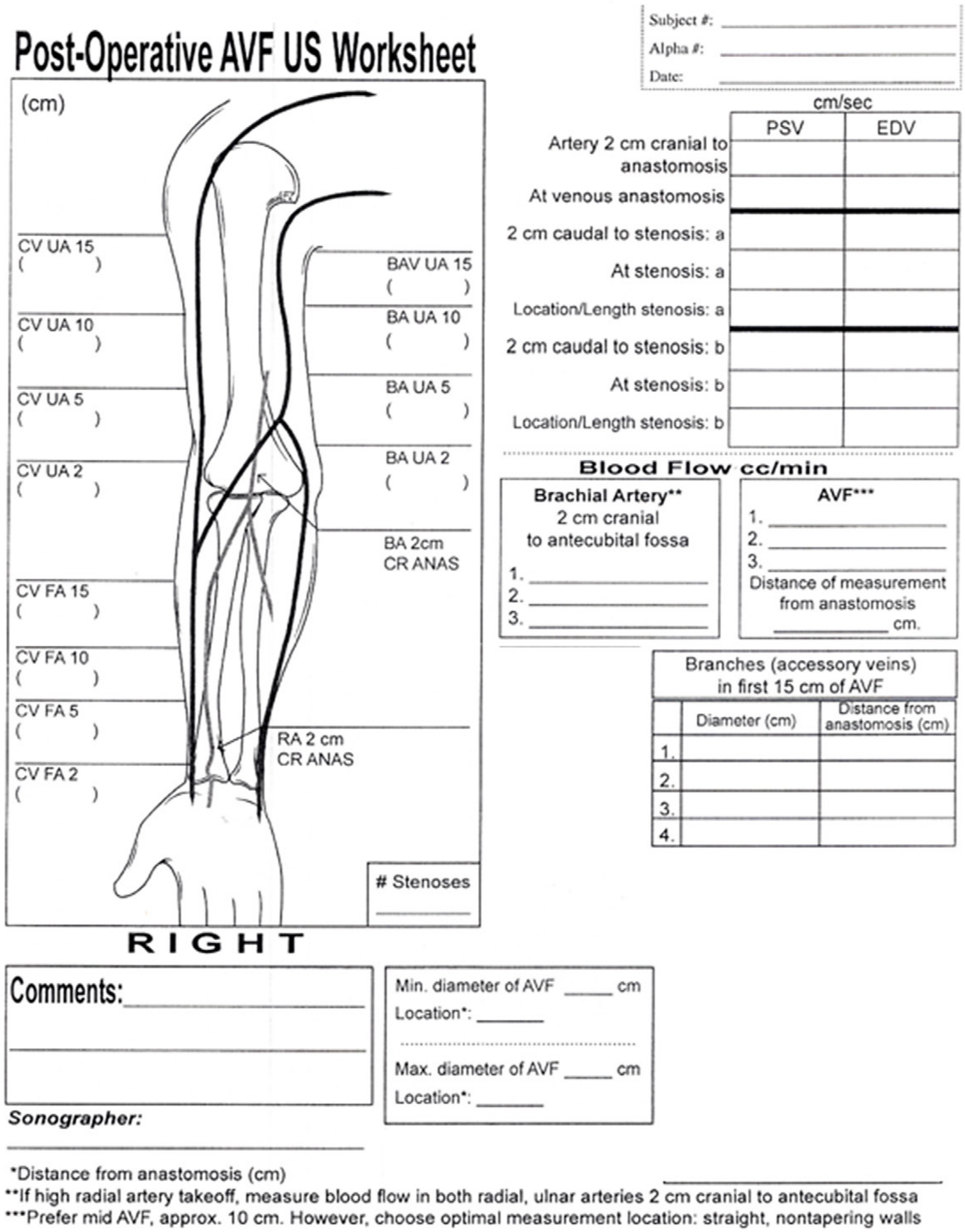


Figure 10. Worksheet used for communicating findings from postoperative AVF US examinations at our institution. *ANAS* = anastomosis, *BA* = brachial artery, *CV* = cephalic vein, *FA* = forearm, *UA* = ulnar artery.

vein. For AVG, the venous anastomosis is the most common location of stenosis (37,52,53).

US criteria to diagnose stenosis include a luminal narrowing of more than 50%, velocity greater than 400–500 cm/sec in the narrowed site, and elevated PSV ratio of the narrowed site compared with that of the upstream site; site-specific values are listed in Table 6 (Figs 15, 16). Actual diameter measurements of the stenotic area with regard to the normal upstream adjacent vessel are difficult to make reproducibly in practice, as the stenosis is often eccentric. The diameter cannot be compared with that of the downstream vessel owing to poststenotic dilatation. PSV ratios are usually more useful in stenosis assessment. If the anastomosis is tortuous, visual inspection should be performed to assess for the presence of a stenosis in an elevated PSV ratio (10,37,52,53). Flow volume rate reduction less than 600 mL/min or a relative decrease by 25% compared with prior measurement may indicate a clinically significant stenosis, but other criteria do not require serial measurements. Tandem stenoses are uncommon, but if present, the PSV gradient in the downstream stenosis may

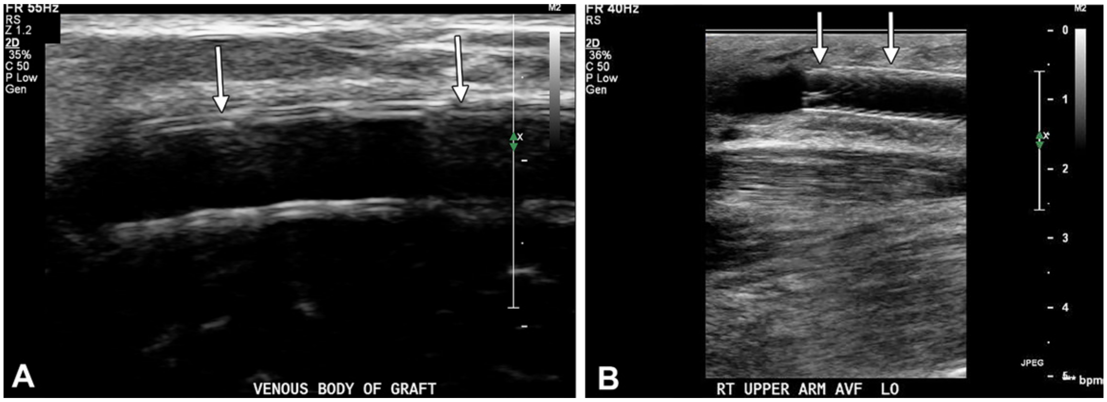


Figure 11. Normal gray-scale appearance of an AVG and vascular stent. **(A)** Longitudinal gray-scale US image of the upper extremity AVG shows a distinct linear echogenicity (arrows) or "tram-track" appearance. **(B)** Longitudinal gray-scale US image shows an endovascular stent within the venous side of an AVF and linear serrated hyperechoic stent wall.

Table 4: Risk Factors for AVF Nonmaturation

Local factors
Smaller arterial diameter
Atherosclerosis of the inflow artery
Surgical technique used for anastomosis creation and experience of the surgeon
Smaller anastomotic diameter
Accessory veins along the draining vein
Central venous stenosis
Systemic factors
Older age, female sex, obesity
Diabetes, hypertension, and peripheral vascular disease
Lower systolic blood pressure and lower left ventricular ejection fraction
Prothrombotic disorders

Sources.—References 40, 41.

be more significant than criteria indicate. US examination should include evaluation of the cephalic arch insertion into the subclavian vein for cephalic vein AVF. Due to its unique anatomic characteristics, the presence of multiple valves and various biochemical changes associated with renal failure can alter flow dynamics at the cephalic arch, which can progress to stenosis (15).

Central venous stenosis or occlusion may manifest with arm swelling, new superficial venous collaterals, or flow-related dysfunction and most commonly results from previous central vein catheter or indwelling cardiac devices. The increased flow after creation of an AV access can unmask a previously subclinical stenosis as evidenced by monophasic waveforms (Fig 17) (54).

Stenosis Management.—In the absence of any clinical indicators, such as extremity edema, pulse alteration, abnormal thrill or bruit, difficult cannulation, or clots at aspiration, stenoses do not require intervention. The KDOQI 2019 guidelines recommend treating clinically significant stenosis primarily with percutaneous angioplasty that includes a high-pressure balloon, including central stenoses (Figs 15, 17, S5) (4). Cutting balloon and self-expandable stents are used as a second-line treatment of lesions that are resistant to standard angioplasty. Self-expanding stent grafts are preferable to percutaneous angioplasty for clinically significant AVG anastomotic stenosis and for treatment of restenosis in AVF or AVG (4).

Thrombosis

Thrombosis accounts for the most common cause of access failure if patency cannot be restored. Risk increases with the degree of stenosis, with more than 90% of thrombosed AV accesses associated with underlying stenosis and only a few secondary to underlying hypoperfusion or hypotension (55). As stenosis severity increases, flow resistance results in increased intra-access pressures and decreased blood flow. AVG flow volume less than 600 mL/min has a greater rate of thrombosis, while AVF can maintain patency at a flow volume as low as 300 mL/min, although function may be affected. Approximately 65%–85% of access thrombosis cases lead to permanent access abandonment (56).

At US, thrombus manifests as an echogenic clot with lack of color flow and spectral waveforms on Doppler images. An indirect sign of thrombosis is a change in the normal low-resistance waveform within the artery proximal to the anastomosis to a high-resistance triphasic waveform and decreased PSV (Fig 18).

Thrombosis Management.—Mechanical or pharmacomechanical endovascular thrombectomy is the treatment of choice for thrombosis, with thrombectomy device and lytic agent selection dependent on operator experience and preference. Any underlying vascular stenosis should be treated by percutaneous angioplasty or stent placement after thrombectomy. Endovascular thrombectomy is contraindicated for infected AV access or recent access creation due to the risk for vessel wall rupture that requires surgical repair. Surgical declot with revision is reserved for failed percutaneous techniques and include interposition grafting and patch angioplasty (57–59).

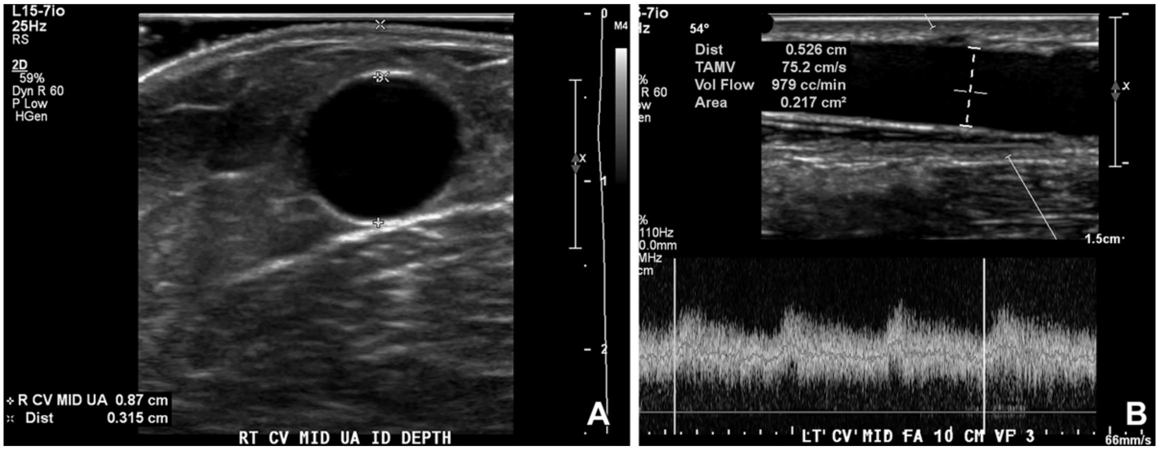
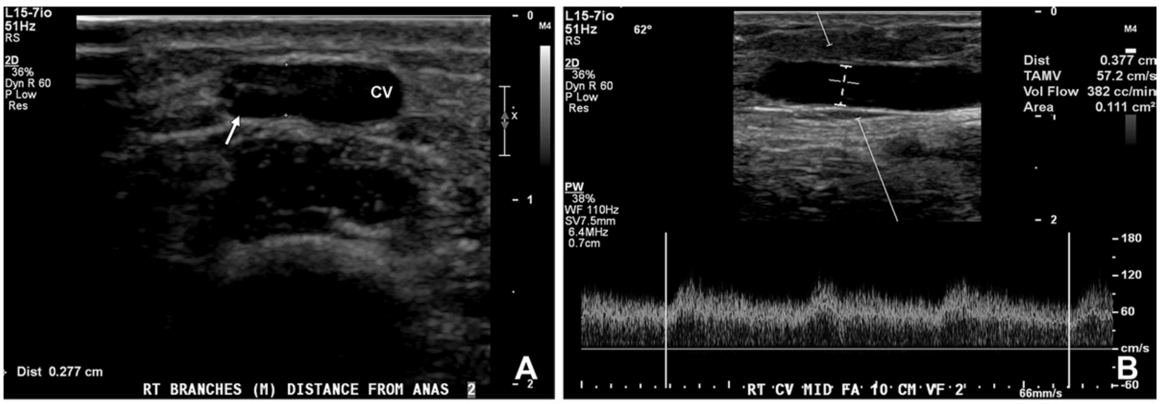


Figure 12. Mature AVF. **(A)** Transverse gray-scale US image shows the cephalic vein diameter is greater than 6 mm and depth is less than 6 mm from the skin surface. **(B)** Longitudinal US image shows the flow volume measurement is obtained within the outflow vein 10 cm from the anastomosis and is greater than 600 mL/min.



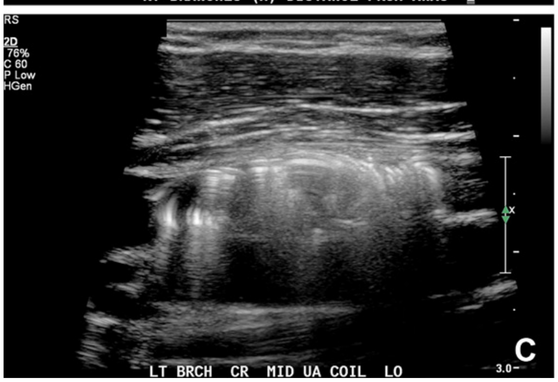


Figure 13. Immature AVF with large accessory veins. **(A)** Transverse gray-scale US image of the forearm draining cephalic vein *(CV)* shows a large accessory vein (arrow) arising 2 cm from the anastomosis (not shown). **(B)** Spectral US image of the flow volume measurement shows a reduced draining vein flow volume of 382 mL/min, measured in the cephalic vein 10 cm from the anastomosis. **(C)** Gray-scale US image shows typical shadowing from coils used to occlude the accessory vein.

Table 5: HD Access Complications

KDOQI Category	Causes
Thrombotic flow–related dysfunction	Stenosis, thrombosis
Nonthrombotic flow–related dysfunction	Steal syndrome, high-outflow–related cardiac failure, aneurysm and pseudoaneurysm
Other complications	Seroma, hematoma, abscess

Source.—Reference 4.

Table 6: Common Stenosis Locations for HD Access*

HD Access Type	Most Common Stenosis Location	PSV Ratio for Diagnosis
Radiocephalic AVF	Juxta-anastomotic	3:1
Brachiocephalic AVF	Cephalic arch or draining vein	2:1
Brachiobasilic transposition AVF	Venous swing segment	2:1
AVG (arm or thigh)	Venous anastomosis	2:1

Sources.—References 10, 37, 52.
Note.—Juxta-anastomotic stenosis is defined within 2 cm of the anastomosis in the feeding artery and draining vein.
* Additional criteria used: for feeding artery stenosis, include PSV ratio of 2:1; for AVG arterial anastomosis or within the graft, include PSV ratio of 2:1; and assessment of AVF anastomosis visually for greater than 50% stenosis to exclude tortuosity as the cause of elevated velocity.

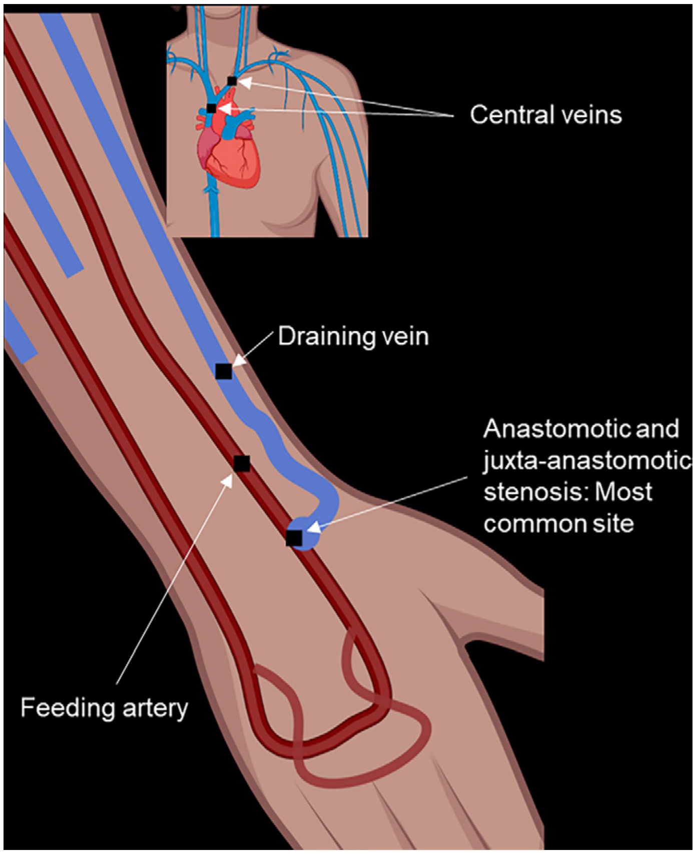


Figure 14. Diagram shows common sites of stenosis in a radiocephalic AVF.

Nonthrombotic Flow–related Dysfunction

Steal Syndrome

AV access creation results in complex hemodynamic changes including shunting of high-pressure arterial flow into the low-pressure venous system. In some cases, these changes lead to flow reversal in the artery distal to the access anastomosis, known as physiologic steal (Movie 3). Symptomatic steal syndrome is rare owing to adequate collaterals and compensatory vasodilation. Steal syndrome requires the combination of arterial blood flow reversal into the AV access and away from the peripheral system and symptoms distal to the access anastomosis, which can include a cool extremity with mild numbness, intermittent symptoms during dialysis, or more severe sensory and motor impairment with ischemic rest pain and tissue loss (4,38,54). Risk factors for steal syndrome include the use of a proximal limb artery for access creation (5%–10% brachial AVF vs 1%–2% radiocephalic AVF), prior access surgery in the affected limb, female sex, age older than 60 years, diabetes mellitus, and stenosis due to atherosclerosis. If the results from a preoperative clinical Allen test are abnormal or equivocal, the modified Doppler US Allen test can identify patients with an incomplete palmar arch (Figs 7, 8), which places them at greater risk for hand ischemia.

Physiologic steal is detected on Doppler US images as reversal of flow in the artery distal to the anastomosis (Fig 19) or uncommonly arterial occlusion without associated symptoms.

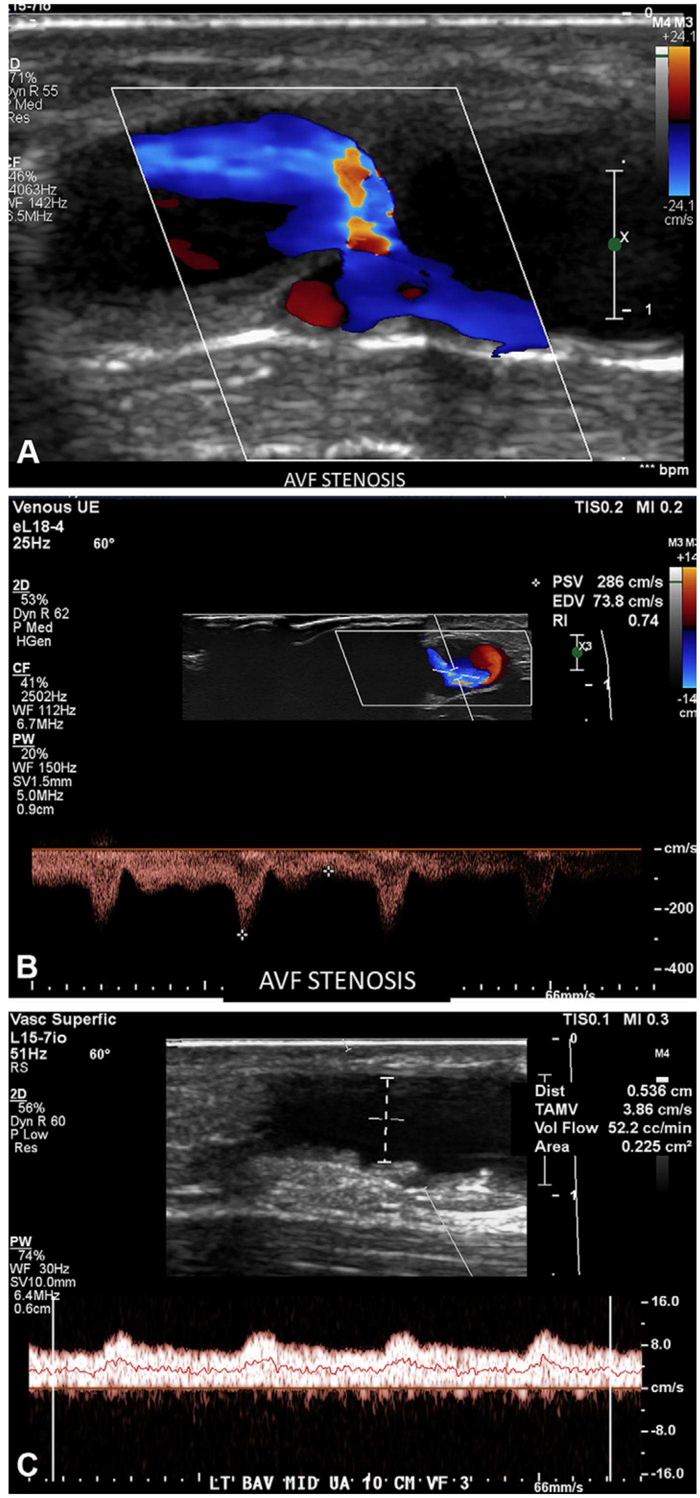


Figure 15. Juxta-anastomotic stenosis treated with percutaneous angioplasty in a 48-year-old man with brachial artery–basilic vein AVF. **(A, B)** Color Doppler **(A)** and spectral Doppler **(B)** US images at the AVF anastomosis in an area of focal visual narrowing show the color aliasing and elevated PSV of 286 cm/sec, compared with a brachial artery PSV of 54 cm/sec (not shown), giving a ratio of 5.2 that is consistent with stenosis. **(C)** Spectral Doppler US image shows reduced flow volume in the draining basilic vein of 52 mL/min. Interventional images are shown in Figure S5.

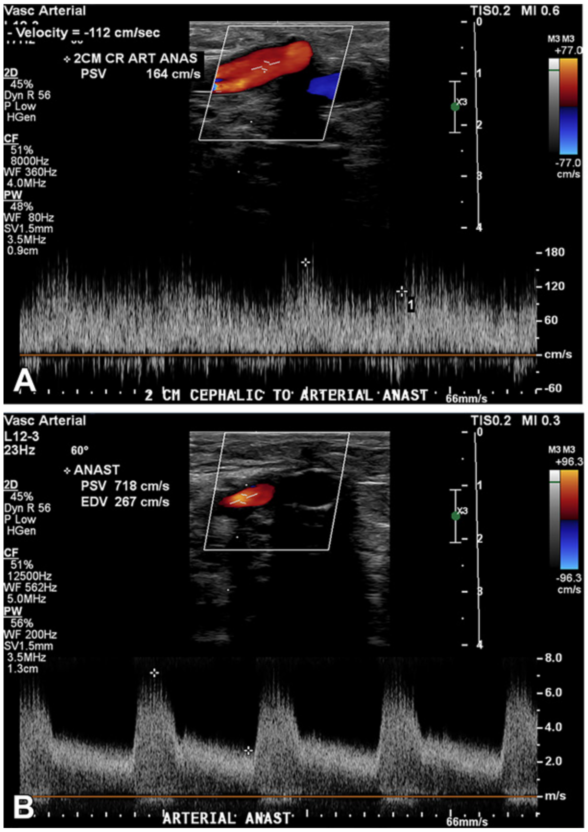
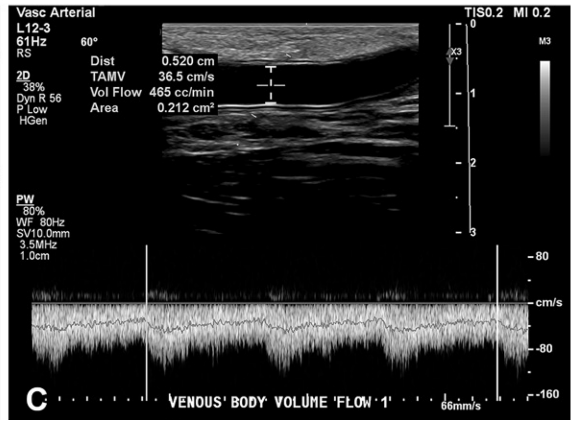


Figure 16. AVG anastomotic stenosis in a dysfunctional AVG in a 44-year-old woman. **(A)** Spectral Doppler US image of the right upper arm brachiocephalic AVG shows a PSV 164 cm/sec in the brachial artery 2 cm cranial to the arterial anastomosis (upstream). **(B)** Doppler US image shows an elevated PSV 718 cm/sec at the arterial anastomosis results in a PSV ratio of 4:4, consistent with that of stenosis (gray-scale image not shown). **(C)** Doppler US image shows that the low-flow volume at the venous end of the AVG measures 465 cc/min.



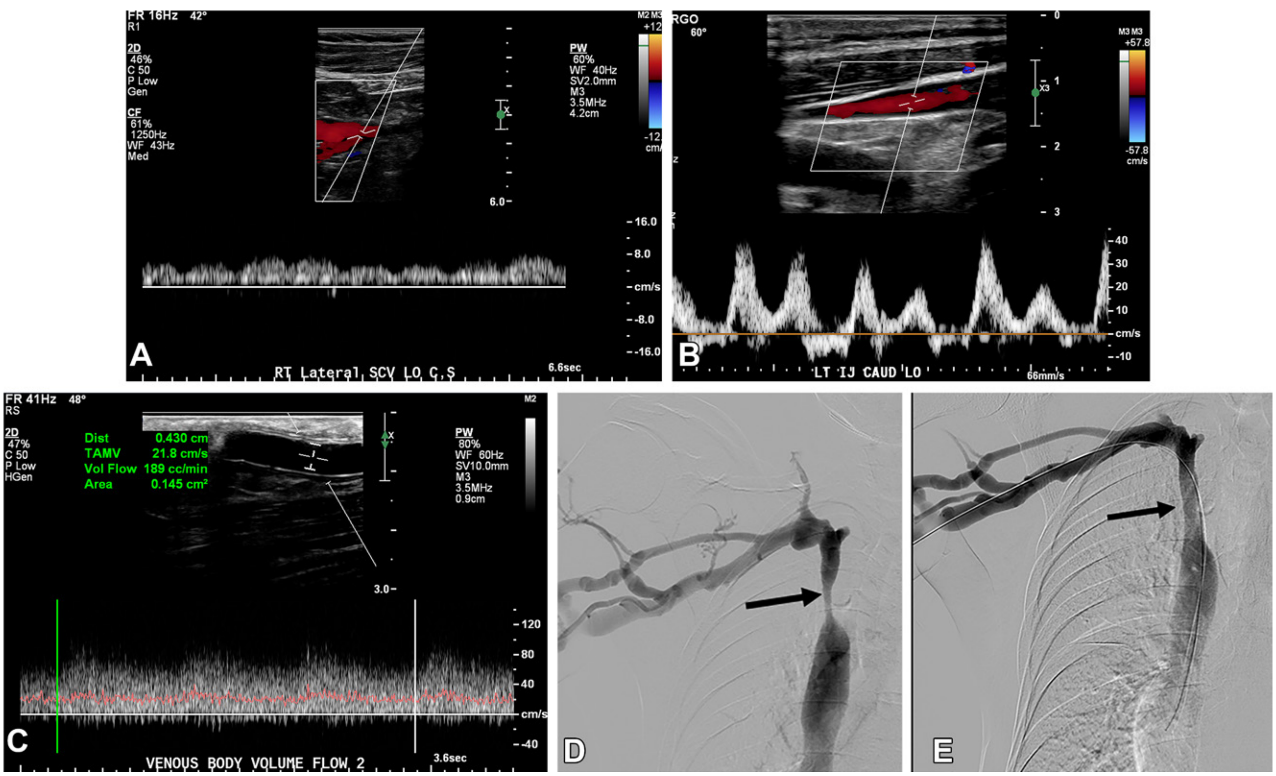


Figure 17. Central venous stenosis in a 55-year-old woman with an AVF of the right upper extremity. **(A, B)** Spectral Doppler US images show a monophasic slow-flow waveform in the right subclavian vein **(A)**, while the contralateral Internal jugular vein **(B)** and left subclavian vein (not shown) have normal phasic waveforms. **(C)** Spectral Doppler US image shows reduced flow volume at the venous outflow of the AVF that measures 189 mL/min. **(D)** Digital subtraction venogram of the right upper extremity shows moderate to severe stenosis of the right innominate vein (arrow). **(E)** Digital subtraction venogram of the right upper extremity after balloon venoplasty shows no residual stenosis within the right innominate vein. Posttreatment US (not shown) showed significant improvement in draining vein flow volume.

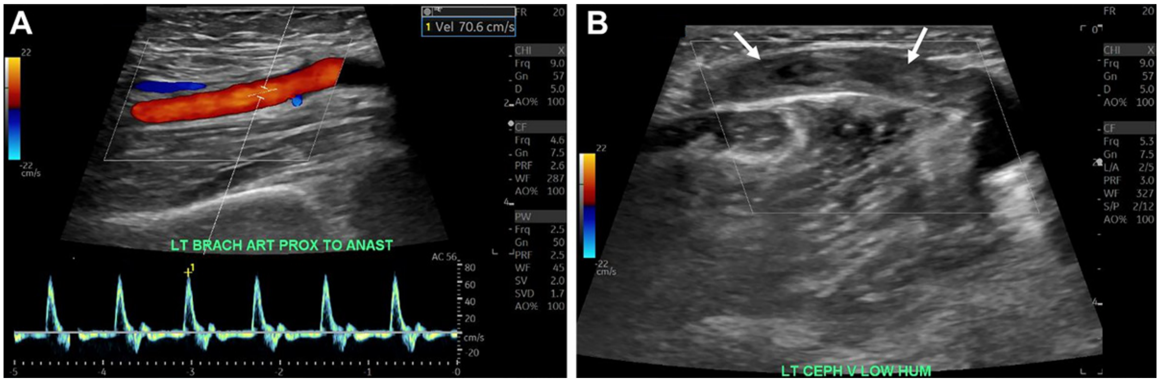


Figure 18. Left brachiocephalic AVF thrombosis in a 52-year-old woman with arm pain and loss of AVF thrill. **(A)** Longitudinal spectral Doppler US image of the left brachial artery proximal to the AVF shows a high-resistance waveform with reversed diastolic flow ("knocking waveform"). Normally, there is low-resistance flow in the artery proximal to a patent AVF or AVG anastomosis. **(B)** Longitudinal spectral Doppler US image of the left cephalic draining vein shows an avascular echogenic occlusive clot, with loss of blood flow and spectral waveform in the cephalic vein.

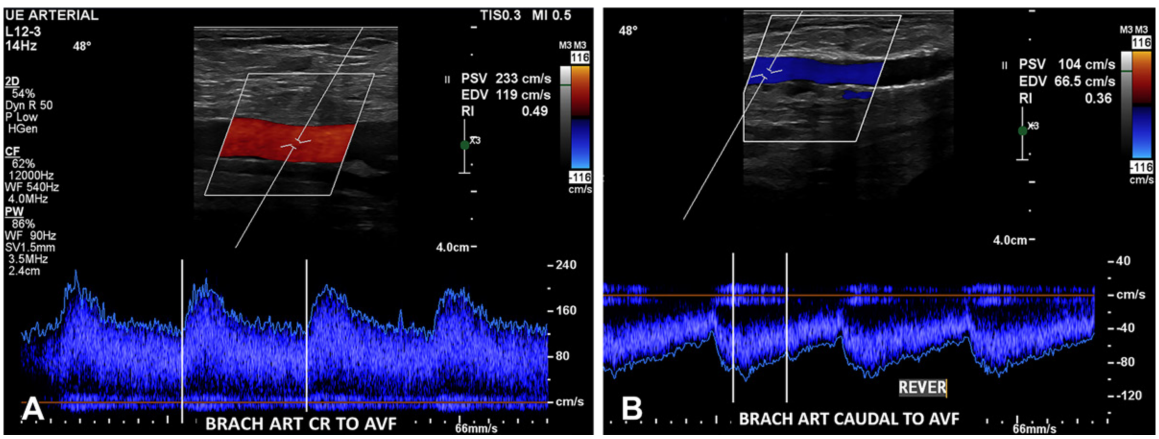


Figure 19. Asymptomatic arterial steal phenomenon in a 54-year-old man with a left arm brachiocephalic AVF. Doppler US images of the brachial artery proximal to the AVF **(A)** show a low-resistance monophasic waveform while the artery distal to the AVF **(B)** has reversal of flow, suggesting arterial steal.

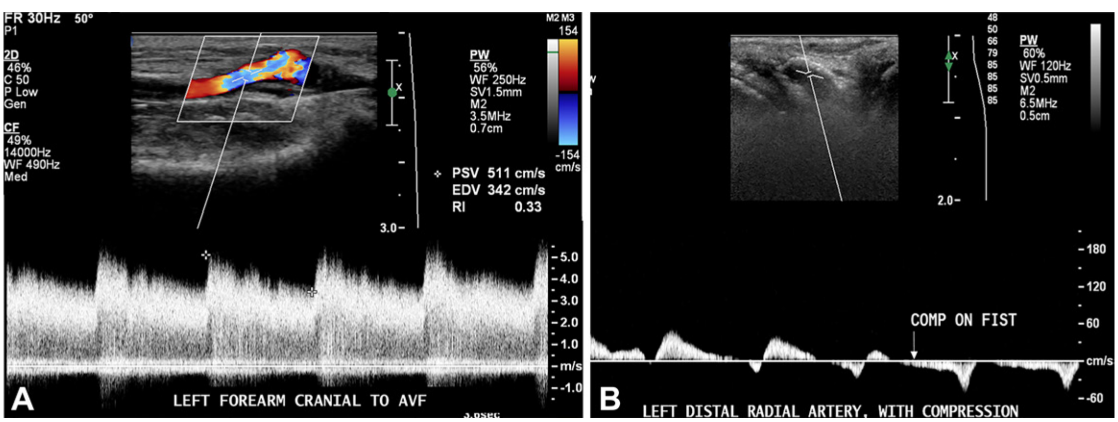


Figure 20. Arterial steal syndrome in a 62-year-old woman with right radiocephalic AVF who presented with hand pain and numbness. **(A)** Spectral color Doppler US image of the radial artery cranial to the AVF shows antegrade flow. **(B)** Spectral Doppler US image of the radial artery caudal to the AVF anastomosis shows retrograde flow changing to antegrade flow during manual compression of the AVF.

When suspected, brief manual compression of the AV access at the anastomosis or outflow vein shows a change in the reversed arterial flow, producing an antegrade high-resistance flow pattern toward the hand or foot (Figs 20, 21).

Management of Steal Syndrome.—Treatment options for AV access steal syndrome depend on the underlying cause and severity. Mild symptoms are managed conservatively with hand-warming techniques by using glove or blankets, reducing antihypertensive agents if appropriate, and performing hand exercises (60). Interventional management is indicated for moderate to severe symptoms with concern for distal extremity ischemia. Arterial inflow stenoses are treated with percutaneous angioplasty or stent placement. Access banding and ligation of collaterals can be used for AVF with a high flow (>1200 mL/min). Distal radial artery ligation or coil embolization can be performed in patients with distal radial AVF to stop the retrograde flow in cases with complete palmar

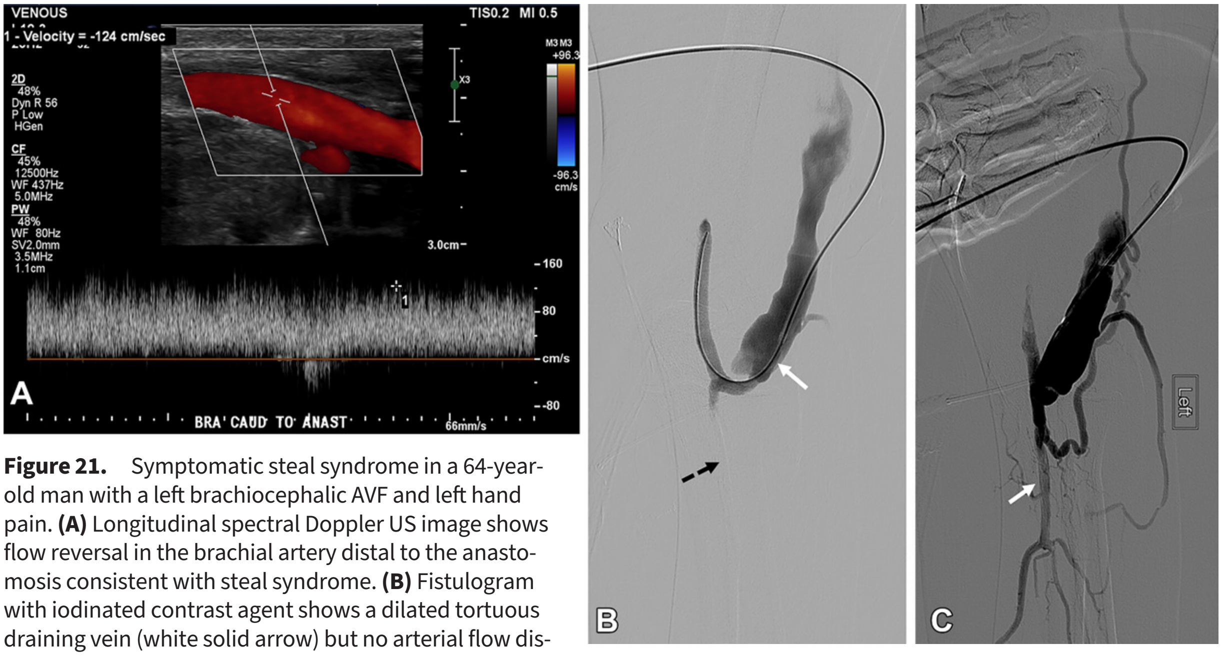


Figure 21. Symptomatic steal syndrome in a 64-year-old man with a left brachiocephalic AVF and left hand pain. **(A)** Longitudinal spectral Doppler US image shows flow reversal in the brachial artery distal to the anastomosis consistent with steal syndrome. **(B)** Fistulogram with iodinated contrast agent shows a dilated tortuous draining vein (white solid arrow) but no arterial flow distal to the anastomosis (dashed black arrow at the expected course of the radial artery). **(C)** Manual compression of the AVF outflow during angiography shows antegrade flow in the brachial artery (arrow), distal to the anastomosis. This patient was successfully treated with surgical banding of the AVF.

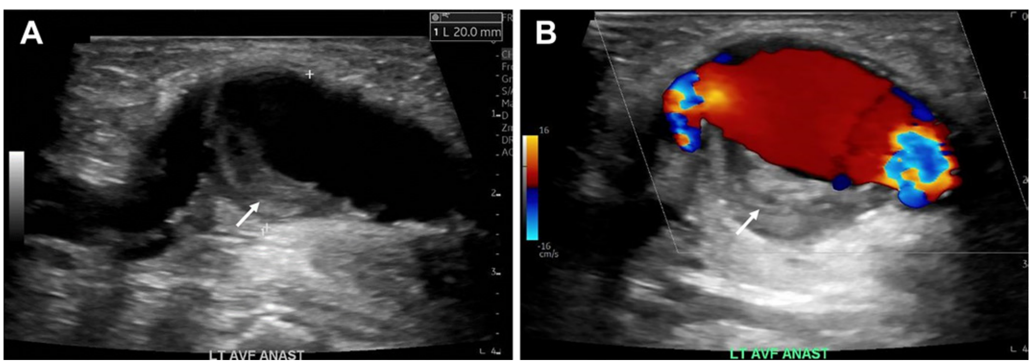


Figure 22. Left brachiocephalic aneurysm in a 75-year-old man. **(A)** Longitudinal gray-scale US image shows aneurysmal dilatation involving all three layers of the vessel wall at the anastomosis, with an area of nonocclusive eccentric intramural thrombus (arrow). **(B)** Color Doppler US image shows flow within the aneurysm with eccentric mural thrombus (arrow). The ratio of aneurysm size (20 mm) to the outflow vein diameter (6 mm; measurement not shown) is 3:3.

arch (61). Ligation of the AVF should be considered a last treatment option for patients with severe symptoms, tissue loss, or a poorly functioning access.

High Outflow–related Cardiac Failure

Growing evidence indicates high-outflow cardiac failure (HOCF), or symptoms of heart failure (dyspnea on exertion, fatigue, and fluid retention) with an above-normal cardiac index, may occur secondary to HD access, representing an underdiagnosed reason for potentially reversible heart failure (62,63). High-flow access is defined as access blood flow greater than 2000 mL/min (Fig S6) or an access flow to cardiac output ratio greater than 30%–35% (64). High-flow access is an independent predictor for HOCF and is associated with dilated left ventricular dimension and impaired left ventricular systolic function. High-flow access is present in up to 24% of patients with HD. Upper arm AVF with a brachial artery anastomosis diameter greater than 4–6 mm, male sex, and volume expansion have been linked to the development of HOCF (65,66).

After a kidney transplant, over 25% of AVFs require closure owing to cardiac failure with subsequent improvement in symptoms (64). Resolution of symptoms with closure of the AV access is essential for diagnosis (54). Banding can treat AVF-related HOCF as well as medical treatment, but identifying patients at risk for HOCF for suitability of AVF placement is also important, with distal access selection, graft placement, or peritoneal dialysis as alternative options to avoid upper arm access (65).

Aneurysm and Pseudoaneurysm

Repeated cannulation of the AV access can cause wall injury that results in aneurysm, pseudoaneurysm, or hematoma formation. At clinical examination, aneurysm and pseudoaneurysm are pulsatile masses, which differentiates them from hematoma or seroma. Diffuse aneurysmal dilatation of the AVF can occur over time and is visible at clinical examination as a tortuous subcutaneous structure.

Aneurysm is a saccular or fusiform dilatation that involves all three layers of the vessel wall, with a diameter greater than 18 mm or equivalent to three times the diameter of the outflow vein in a mature AVF (4,67,68). US demonstrates a fusiform or saccular dilatation of the vessel (Fig 22). Color Doppler US

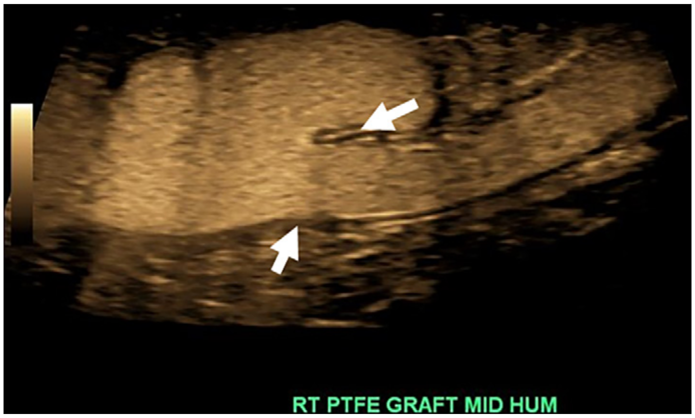


Figure 23. Pseudoaneurysm of the right upper extremity graft in a 35-year-old woman. B-flow US image shows communication of the pseudoaneurysm with the graft (arrows).

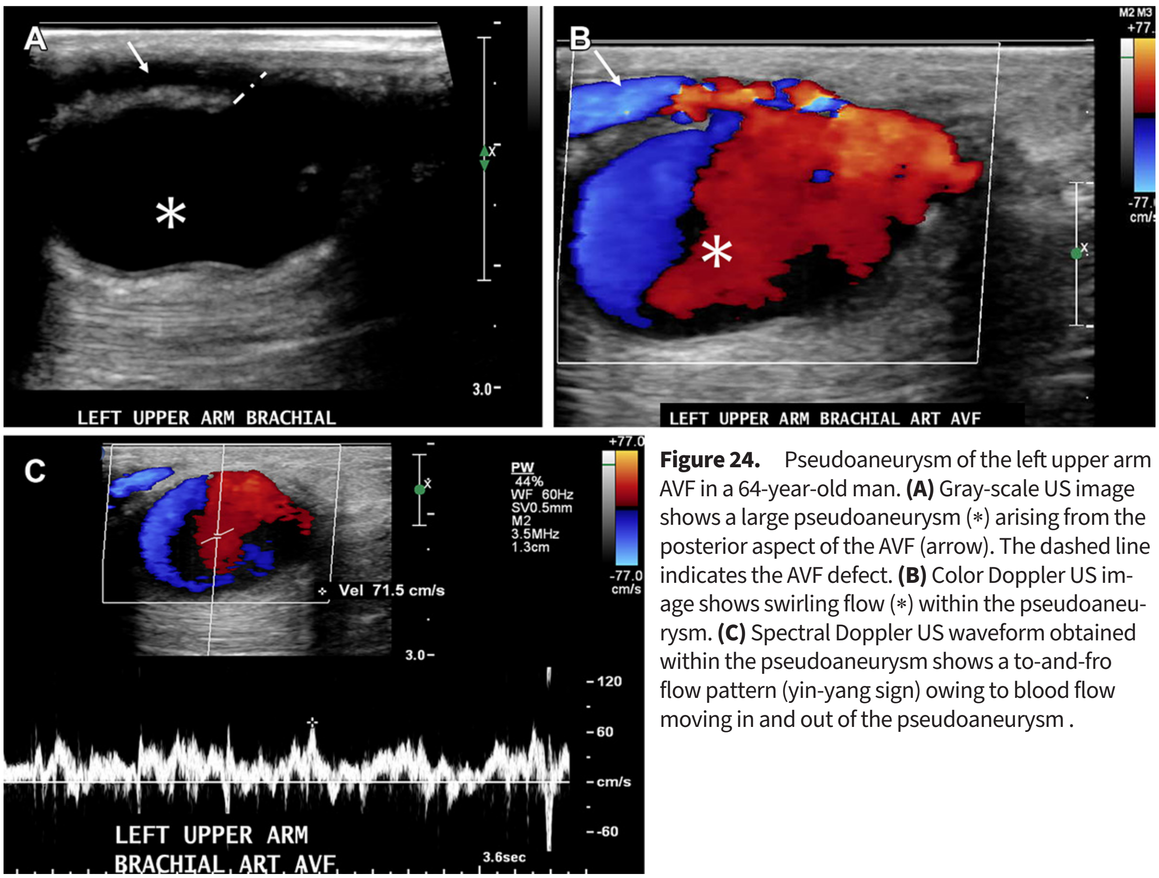


Figure 24. Pseudoaneurysm of the left upper arm AVF in a 64-year-old man. **(A)** Gray-scale US image shows a large pseudoaneurysm (*) arising from the posterior aspect of the AVF (arrow). The dashed line indicates the AVF defect. **(B)** Color Doppler US image shows swirling flow (*) within the pseudoaneurysm. **(C)** Spectral Doppler US waveform obtained within the pseudoaneurysm shows a to-and-fro flow pattern (yin-yang sign) owing to blood flow moving in and out of the pseudoaneurysm .

images often show a slow circular flow (68). Treatment of AV access aneurysm is determined clinically and not by specific size criteria.

Pseudoaneurysm or false aneurysm is a perivascular collection without a true intimal wall that is lined by fibrous reactive tissue in continuity with the adjacent vascular lumen via a vessel wall defect (68). Pseudoaneurysm formation is often due to inadequate compression after access cannulation or repeated cannulation at the same location, resulting in vessel wall injury, and is more common in AVG (4). Graft synthetic material degeneration is a unique complication of an AVG that is associated with diffuse or focal pseudoaneurysm along the length of the graft wall (Figs 23, S7). Venous outflow stenosis contributes to further development and enlargement of pseudoaneurysms owing to increased intra-access pressures (54,68). Pseudoaneurysms have a higher risk of rupture than comparably sized aneurysms and require careful monitoring and often treatment (68).

Findings of pseudoaneurysms on US images show simple or complex fluid with a well-defined neck that connects the collection to the HD access. Color Doppler US images demonstrate internal blood flow that distinguishes it from other fluid collection (Fig 24). The characteristic “yin-yang” sign on color Doppler US images is due to the to-and-fro swirling motion of blood entering and leaving the aneurysmal sac during systole and diastole, respectively (69). Identification and measurement of the neck help determine the point of communication with the artery and are useful in treatment planning (69,70).

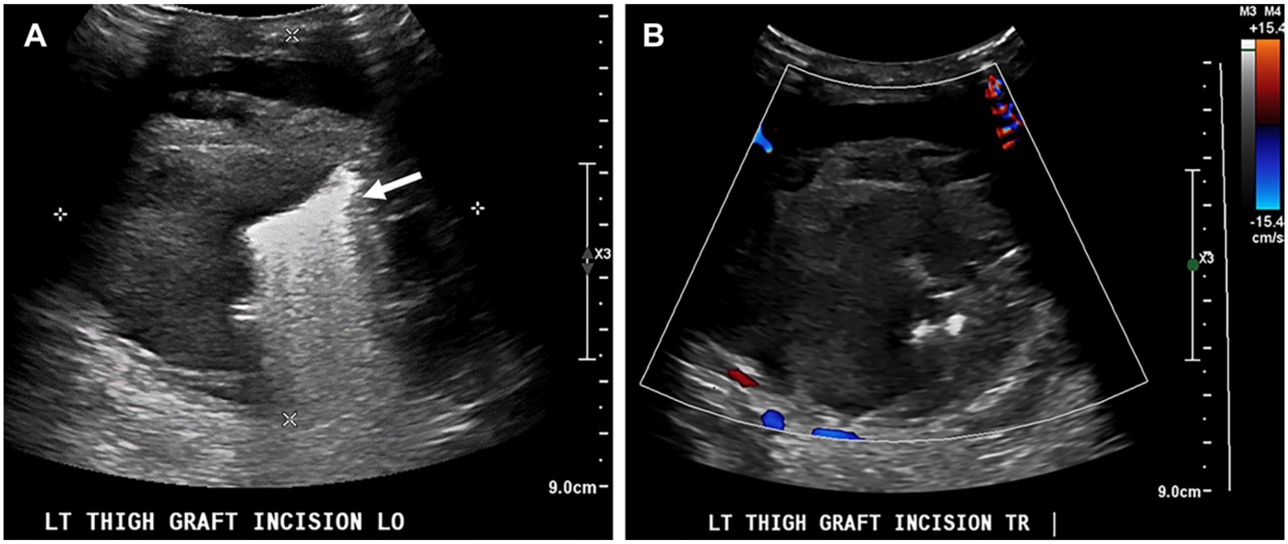


Figure 25. AV access–associated fluid collections. **(A)** Gray-scale US image of an abscess shows a complex fluid collection that contains air (arrow). In the setting of clinical signs of infection, this is characteristic of an abscess. **(B)** Color Doppler US image of the abscess shows no internal flow.

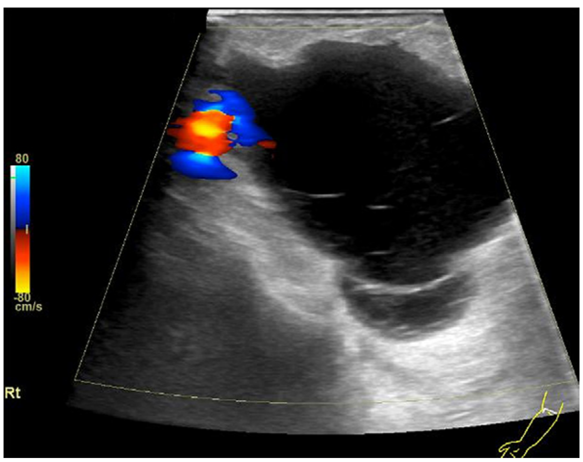


Figure 26. AV access–associated fluid collections. Color Doppler US image of a seroma near the arterial anastomosis of an AVG shows an anechoic collection with a few thin septa. Note there is no flow within the collection.

Aneurysm and Pseudoaneurysm Management.—Size alone is not an indication for treatment. Aneurysm and pseudoaneurysm management depends on symptoms or threatened skin. Physical examination findings that indicate high risk for rupture and require urgent evaluation include an enlarging aneurysm; thin, shiny, or depigmented skin; and prolonged bleeding from puncture sites (4). Anastomotic aneurysms and pseudoaneurysms have a higher risk for rupture and should be managed by surgical or endovascular revision (54). Arterial pseudoaneurysms require treatment. However, a small outflow vein pseudoaneurysm may undergo clinical surveillance, and a small puncture site pseudoaneurysm can be observed and may resolve without further treatment (54,68). In select cases, small or recent pseudoaneurysms can be treated with compression by using the US probe or with thrombin injection. Surgical repair is preferred for an aneurysm or pseudoaneurysm of the feeding artery, anastomosis, or prosthetic graft, especially with overlying skin complications. Endovascular stent placement has a high risk of infection and can make it difficult to access the cannulation zone. Temporary stent graft placement should be considered if the patient is at high risk for rupture or has ongoing bleeding (4,68).

Other HD Access Complications

US readily helps to distinguish fluid collections (avascular) from aneurysm and pseudoaneurysm (vascular) with color Doppler imaging. History and clinical symptoms are helpful in differentiating infected from noninfected collections, as hematoma and abscess can appear as heterogeneous hypoechoic avascular fluid collections (Figs 25–27, S8). The presence of air, seen as echogenic foci with dirty shadowing, within the collection can be seen with infection but may also be related to a recent vascular access or needle aspiration. Hematoma is a posttraumatic blood collection located outside of the vessel and does not have continuity with the lumen (68). If the posterior (deep) portion of the HD access is punctured, bleeding from this area is less well controlled and can lead to development of hematoma.

Seroma is an uncommon complication of AVG but can occur in 2%–4% of cases within the 1st month after graft placement owing to transudation of sterile and clear serum from connective tissue that surrounds the prosthesis. At US, seroma is a simple anechoic avascular fluid collection that is often near the arterial anastomosis (68). Large seromas may require aspiration or other treatment if they are causing compression of the anastomosis (54).

Conclusion

Preoperative US used to map vascular anatomy, variations, patency, and size helps determine the suitability for HD access and helps identify candidates for percutaneous AVF creation. Postoperative US helps evaluate vascular access maturity and

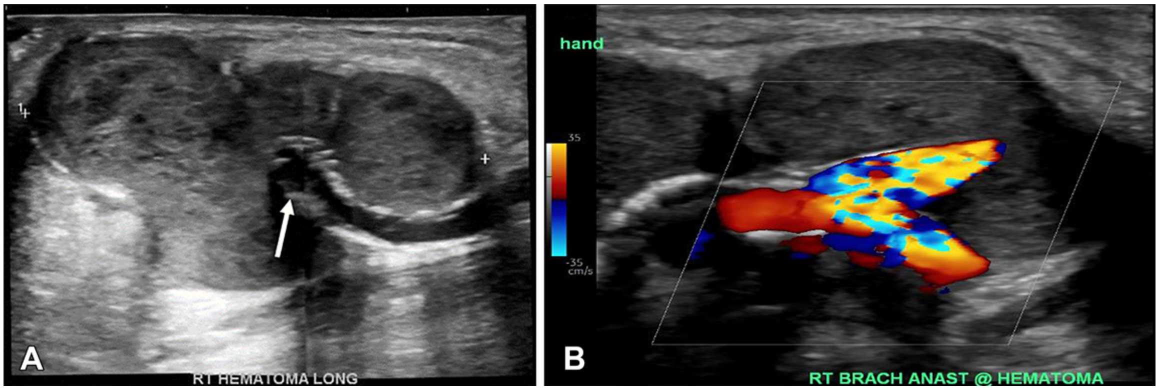


Figure 27. HD access graft–associated fluid collections. **(A)** Gray-scale US image of a perigraft hematoma shows a lobular collection with internal echoes partly surrounding the graft (arrow). **(B)** Color Doppler US image shows that there is no blood flow in the collection. A hematoma can appear similar to an abscess, but this patient had no clinical signs of infection.

can help identify stenosis and thrombosis, which is important in triaging endovascular or surgical intervention to assist maturation. Postoperative complications such as steal syndrome, aneurysm and pseudoaneurysm, high output failure, and localized complications can be readily diagnosed at US.

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