PART TWO: UPPER EXTREMITIES

Testing the Venous Circulation

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FIGURE 4.1. Diagram of the upper extremity venous system.

FIGURE 4.2. Representation of the phenomenon leading to compression and thrombosis of the subclavian vein at the thoracic outlet, which is seen in Paget-Schroetter syndrome or effort thrombosis.
General Concepts in Upper Extremity Venous Evaluation

- The upper extremity is anatomically split into three portions: the hands (most distal), the forearm (between the wrist and elbow/antecubital fossa), and the arm (between the elbow and shoulder).
- The upper extremity venous system is a complex system of interconnected superficial and deep veins with frequent anatomic variations.
  - The superficial dorsal venous network of the hands will form the cephalic (on the radial side) and basilic (on the ulnar side) veins. Both cephalic and basilic veins are considered superficial veins. They are not paired and are not associated with an artery.
  - Both cephalic and basilic veins will slightly course in the ventral aspect of the forearm. The cephalic vein will assume a lateral ascending course in the arm, before draining into the proximal portion of the axillary vein. The basilic vein will course along the medial aspect of the arm and drain into the brachial vein at various levels.
  - The median cubital vein and other accessory veins usually join the cephalic and basilic veins in the forearms.
  - The superficial palmar venous network of the hands will form the radial and ulnar veins. These veins are paired alongside the arteries of the same name and are considered deep veins. These veins join usually at the level of the antecubital fossa/elbow level to form the brachial veins (also paired). Once joined by the basilic vein, the brachial veins become a single axillary vein and then a single subclavian vein at the level of the outer border of the first rib. Past the confluence with the jugular vein, the subclavian becomes the innominate vein (right and left), which drain into the superior vena cava.
    - Veins of the upper extremities have valves, although less numerous than in the lower extremities. Most valves are located proximal to confluences of veins (i.e., in the axillary vein proximal to the junction with the cephalic vein, or in the subclavian vein proximal to the junction with the external jugular vein).
- The hemodynamics of the venous flow return from the upper extremities, in contrast with the lower extremities, is strongly dependent on the heart and therefore pressure gradient. There is little to no contribution of a muscle pump (role played by the calf muscles in the lower extremities).
- The pathology of the venous system of the upper extremity is most noticeable and clinically important for thrombosis of the major draining vessels such as the axillary, subclavian, and innominate veins.
- The etiology of thrombosis in the venous system of the upper extremity is often linked to external compression (such as Paget-Schroetter syndrome, also known as spontaneous or effort thrombosis, or venous thrombosis at the thoracic outlet) or iatrogenic factors (such as insertion of wires, such as from a pacemaker, or catheters/lines, such as peripherally inserted central catheter [PICC] lines).
Congenital narrowing of the subclavian vein and thrombosis due to hypercoagulability syndromes or tumors are relatively rare pathologies.

Only approximately 2% of documented deep venous thrombosis (DVT) occurring in human arose in the upper extremities.

The incidence of pulmonary embolism from upper extremity DVT varies tremendously in the literature from 1–3% to 9–11%.

Tips/Rationale

Know the patient’s medical history and occupational background.

- Paget-Schroetter syndrome, or its less severe form known as McLeery’s syndrome (intermittent compression at the thoracic outlet with symptoms but no thrombosis), are most often seen in very active, young, and otherwise healthy patients. Competitive athletes and workers using repetitive, forceful motions of the upper body and arms will be the most prone to these syndromes.

- Central, acute thrombosis requires immediate and aggressive treatment through thrombectomy or, more widely accepted, through catheter-directed thrombolysis.

Know the rationale for the test.

- The venous system of the upper extremity should be thoroughly evaluated before hemodialysis access creation or placement.

- The size of the veins that could be used for the graft would be important, but the condition of the venous drainage would be crucial.

- Superficial veins may also be harvested for lower extremity bypass graft and/or coronary bypass graft.

Note: The postevaluation of hemodialysis access will be covered in a separate chapter.
**Protocol Algorithm**

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**FIGURE 4.3.** Algorithm for examination of the upper extremity venous system.

**Evaluation of Clinical Symptoms, Medical History, and Referral**

- Disseminated edema of the upper extremity and/or face
- Localized redness and pain in superficial veins
- Preoperative evaluation for coronary or other bypass graft
- Preoperative evaluation for hemodialysis access

**Duplex Ultrasound**

- For evaluation of thrombosis, a complete exam should include:
  - Internal jugular, innominate and SVC, subclavian and axillary veins of the arm and forearm including the superficial veins (cephalic and basilic veins)
- For evaluation of localized symptoms, a full exam may be warranted, but a special focus will be placed on the symptomatic area (aside from superficial thrombophlebitis, incidental findings of infection and/or infiltration at puncture sites may be seen and the cause of the symptoms).
- The exam can focus on measuring the superficial veins (cephalic and basilic veins) as well as the radial and ulnar arteries in some cases. Although examining the deep veins in addition may be a wise and prudent choice too.
- Preoperative evaluation for positioning of a hemodialysis access in the arm or forearm have received more specific guidelines. The arterial inflow and venous outflow need to be examined, as well as the patency of the arterial palmar arches, and the size of the veins and arteries which will receive the bridge graft or constitute the main access. Because of the extent of the exam, preop assessment for hemodialysis have received a separate billing code.
Duplex Exam of Upper Extremity Venous Circulation

Test Preparation

- The test preparation’s main challenge is ensuring that the patient’s position is conducive to the best visibility of the vessels and comfortable for the patient and sonographer. The patient may be supine or sitting.
- The particular situation surrounding the request for the test will often dictate the most appropriate equipment setting and positioning.
- The examination should preferably be bilateral, particularly if effort thrombosis or Paget-Schroetter syndrome is suspected. The problem has been reported to be bilateral in 60% of cases with or without apparent symptoms at the time of the examination.
- Preoperative evaluation for hemodialysis access graft is also recommended to be performed bilaterally. The rationale here is that even when the surgery is well planned and the patient and physician have elected to place the access in the nondominant arm, evaluating the other arm may save time. An inadvertent placement of an intravenous (IV) line in the arm to receive the access may trigger a change of plan at the last minute.

Testing Sequence

FIGURE 4.4. Start (or end) the exam by visualizing and evaluating the internal jugular vein (IJV). It may be valuable to visualize the portion of the internal jugular vein located at the junction with the innominate, the innominate vein, and the superior vena cava. These veins are difficult to access by duplex ultrasound. Using a transducer with a smaller footprint (such as a phased array) with a lower frequency, placed in the suprasternal notch may offer an adequate technique and window.
FIGURE 4.5. Arm resting on a pillow or arm rest if available can help the patient maintain an adequate position for evaluation of the arteries or veins, here for transverse views.

FIGURE 4.6. Arm resting on a pillow or arm rest if available can help the patient maintain an adequate position for evaluation of the arteries or veins, here for longitudinal views.

FIGURE 4.7. This position allows for the examination of the subclavian artery and vein (useful for a pre-operative evaluation for hemodialysis access) as well as for following the vessels toward the arm in a longitudinal approach.
FIGURE 4.8. These positions allow for viewing the veins and arteries (useful when performing a pre-operative exam for future placement of a hemodialysis access) in longitudinal, and evaluating the flow physiology by PW and/or color Doppler. (A) Evaluation of the distal axillary, proximal brachial. (B) Evaluation of the brachial and basilic. (C) Evaluation of the distal brachial and basilic, as well as confluence of radial and ulnar.

FIGURE 4.9. These positions allow for viewing the major deep veins and the basilic vein in transverse to perform compression and exclude thrombosis. (Continued)
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FIGURE 4.10. These positions allow for viewing the cephalic vein in transverse to perform compression to exclude thrombosis, as well as to measure the vein diameter for use as a conduit for bypass graft or hemodialysis access.
Results and Interpretation

FIGURE 4.11. Evaluation of the IJV could be done by compression (just like most other accessible veins). However, thrombosis of the jugular vein often results from indwelling catheter or other lines and compression may not be very comfortable for the patient or even possible (due to surgical dressing, edema, etc.). Evaluating the IJV for patency with color Doppler in transverse and/or longitudinal views is an alternative to compression. Color should fill the entire lumen.

FIGURE 4.12. Suprasternal approach for visualization of the superior vena cava (SVC). Vein compression at this level is not possible to exclude thrombosis. Other techniques such as color Doppler, power Doppler, or pulse Doppler, in addition to visualization in gray scale, should be used to evaluate the presence or absence of thrombus (always correlating observations to history).

FIGURE 4.13. Example of evaluation of patency of upper extremity veins with guided compression. Normal compression of the basilic and brachial veins with the ultrasound transducer excludes the presence of thrombosis.
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FIGURE 4.14. Evaluation of veins patency in transverse using color Doppler. Here both brachial veins (arrows) are patent (evident by complete color fill of the vessels).

FIGURE 4.15. Proximal subclavian vein with typical slightly pulsatile but phasic pulsed wave Doppler waveforms. The pulsatility is due to the closeness of the heart; the phasicity corresponds to the phases of respiration and the changes of pressure in the thoracic cavity that increase (during inspiration) or decrease/stop (during expiration) the venous return from the upper extremities and head. The subclavian vein and part of the axillary vein in most individuals are not amenable to ultrasound-guided compression to evaluate for the presence or absence of thrombosis. As cited earlier, color Doppler, power Doppler, and pulse Doppler are the techniques used for such evaluation.

FIGURE 4.16. Another typical example of pulse Doppler waveforms in a vein of the upper extremity. Here the basilic vein displays pulsatile and phasic flow.

FIGURE 4.17. Longitudinal view of the brachial bifurcation with arteries and veins. Evaluation of the veins in a longitudinal view would allow for understanding the anatomic and relative positions of the artery and veins. Adding color or pulse Doppler will allow for assessment of flow pattern and direction.
FIGURE 4.18. Depiction of valve closure in the proximal subclavian vein. Valves in the upper body are less numerous than in the lower extremity veins. (1) Subclavian vein with open valve leaflets. (2) Subclavian vein with valves closed. (3) The rouleaux effects proximal to the closed valve show that the valve is completely closed.

FIGURE 4.20. Sample of thrombosis in the internal jugular vein with either recanalization or non-completely occluding thrombus. Partial thrombus in an internal jugular vein in grayscale (1). Note: Depending on the age of the thrombus it may be difficult to evaluate the extent of the thrombus in B-mode alone. Partial thrombus in the internal jugular vein (2) with some flow (3) and the diameter of the vessel. Note that the pulsed wave Doppler waveform shows continuous (yet still slightly pulsatile) flow around the thrombus (4), which may indicate a more proximal extension of the thrombus to the brachiocephalic vein and/or superior vena cava (SVC). If Dopplers of both internal jugular veins are similar, the thrombus probably involves the SVC.

FIGURE 4.21. Complete thrombosis of the internal jugular vein seen by mixed echogenic materials (arrow) within the vessel lumen but also by absence of color on color Doppler and absence of signal on PW Doppler.
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FIGURE 4.23. Vein with indwelling catheter but no evidence of thrombosis. However the vein should also be examined in a transverse view to perform ultrasound guided compression and exclude the presence of anechoic thrombus with color or power Doppler to demonstrate flow around the catheter. Courtesy of Philips.

FIGURE 4.24. Another sample of pulse Doppler waveforms in an upper extremity vein that is suspicious for more proximal thrombosis, compression, or another form of obstruction. Brachial vein with pulse Doppler shows loss of pulsatility and phasicity (arrow; i.e., continuous flow still responding to distal augmentation). This finding probably indicates thrombosis or compression of more proximal veins.
FIGURE 4.25. Sample of a vein with a PICC line. (A) Right axillary vein with PICC line in a longitudinal view of the vein. (B) Right axillary vein with PICC line, shown here with B flow. B flow showing flow filling the lumen of the vessel around the catheter excludes here the presence of thrombus.

FIGURE 4.26. Superficial vein in the right forearm with a line present in the lumen. Manual compression with the transducer was performed to evaluate for the presence or absence of thrombus around the line. The vein does not compress completely around the line in this picture, suggesting acute thrombosis around the line. Confirmation with color or power Doppler should be performed.
FIGURE 4.27. View and position of the basilic vein in the upper arm. The basilic vein is medial to the brachial artery and veins. It can be used for bypass or dialysis access.

FIGURE 4.28. Sample of measurements of the cephalic vein (arrows) in transverse view for either a preoperative exam for a lower extremity bypass or a hemodialysis access. The measurements are: (A) 4.2 mm (or 0.42 cm) and (B) 3.1 mm (or 0.31 cm), which was taken distally.
FIGURE 4.29. Example of incidental findings when evaluating the upper extremity venous system. The patient presented with redness and swelling at the site investigated. (1) Lateral aspect of the arm. A large fluid collection is noted in the symptomatic area. This could represent infiltration from an IV or an inflammation of infection in the subcutaneous tissue. (2) Note also the posterior enhancement due to the acoustic window created by the fluid collection.

Concluding Tips

Upper extremity venous evaluation can be a challenging exam because most large draining veins are difficult to access and assess with conventional methods for evaluation of the main pathology of veins (i.e., thrombosis). Indeed because of their anatomic positions, the innominate, subclavian, and most of the axillary veins cannot be evaluated by manual compression with the ultrasound transducer. Thoroughly examining the flow patterns with pulse Doppler, but also color and/or power Doppler, will provide invaluable information and can confirm clinical suspicion. Unless the symptoms are localized, it will always be good practice to evaluate both upper extremities and the draining system as close as possible to the most central vein—the superior vena cava (SVC). The following section will cover the evaluation of hemodialysis access.
General Concepts in Examining Hemodialysis Access

This section will be slightly different in concept and scope than most others in this manual. This section will cover the use of ultrasound technology for the examination of a treatment procedure created not to relieve vascular problems but to supplement or replace the functions of a failing organ. In this case, the failing organs are the kidneys, and the treatment procedure is the creation of a hemodialysis access. The basic idea is to create a conduit with a high volume of blood that can be filtered through an external and artificial kidney, therefore replacing the daily filtration normally occurring through the kidneys.

- Hemodialysis is one of the methods (with peritoneal dialysis) used to replace one of the important functions of the kidneys (i.e., the continuous filtration of blood to remove electrolytes and other waste metabolites).
- Dialysis is usually required when the kidneys have lost approximately 90% of their function.
- Several conditions, such as diabetes, hypertension, and inflammation of the filtration system of the kidneys or small vessels within the kidneys, can cause the kidneys to fail. However, diabetes is the leading cause of kidney failure, followed closely by hypertension.
- Hemodialysis requires the creation of a conduit within the body for:
  - Easy access, so the technicians can easily find the conduit and the patient can be comfortably connected to the dialyzer for several hours
  - High volume of blood to be delivered and thus filtered within a few hours (and usually every other day)
  - For the former point, the most common sites are the wrist or forearm.
  - For the latter point, the best solution is to connect an artery to a vein, either directly or through the interposition of a synthetic graft.
- Arteriovenous fistula (AVF) is used when the access is a direct connection between the artery and vein, and looped graft or graft is used when the connection involves the interposition of a synthetic graft.
- Connecting a high-pressure system (the artery) to a low-pressure system (the vein) will force the blood to be rerouted toward the vein and thus raise the volume of blood through that conduit. Although the effect is immediate once the connection between the artery and vein is done, using the conduit for dialysis purposes requires some time for what is called “maturation.” This process of maturation includes:
  - A vein conduit that has sufficiently dilated (ideally to ≥ 0.5 cm in diameter) to accommodate the cannula used with the dialyzer
  - An adequate volume of flow (at least ≥ 350 mL/min and ideally around 400–500 mL/min)
  - A matured conduit of approximately 10 cm long in the draining vein for optimal rotation of puncture site
- AVFs usually require a longer time to mature than looped grafts.
Tips/Rationale

- Despite an increase in the incidence and use of hemodialysis, reimbursement for evaluation does not include (as of 2008) regular follow-up, as it does with bypass grafts.
- Request for assessment of function of dialysis accesses (and reimbursement) needs to be based on signs of clinical dysfunction or indications, such as:
  - Loss or decreased strength of thrill felt over the access. The thrill, which is palpable over the access on a normally functioning access, is due to the high-flow volume
  - Problems with cannulation, circulation time, or flow volume rate found at the time of dialysis
  - Long maturation time after the surgical procedure
  - Edema of the extremity housing the access
  - Suspicion of pseudoaneurysm or aneurysm
  - Pain in the hands or fingers during or after dialysis or ulceration of the fingers
- Before undertaking ultrasound assessment, it is crucial that:
  - The sonographer obtains a detailed description of the type of access performed
  - The sonographer obtains a detailed description of the signs and symptoms prompting the request for evaluation. The rationale for this point will be discussed in the Testing Sequence and/or Results and Interpretation sections.

FIGURE 4.30. Dialysis technique.
FIGURE 4.31. Common configuration of hemodialysis accesses using veins. (A) Also known as Brescia-Cimino fistula. (B) Usually referred to as transposed basilic vein fistula.

FIGURE 4.32. Most common configuration of hemodialysis access with synthetic material. As with arterial bypass grafts, the name used to refer to the access usually is composed of the inflow artery, outflow vein, and type of graft used. Shown here is a brachial artery to basilic vein loop graft.
Protocol Algorithm

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Review procedure performed and clinical symptoms, and/or perform a visual evaluation of the dialysis access (presence of thrill, dilatation, edema, puncture sites, etc.)

Clinical symptoms involving dialysis process (poor maturation, loss or diminish thrill, inadequate re-circulation time, etc.)

Extrinsic signs and symptoms (edema suspected pseudoaneurysms, etc.)

Symptoms related to distal circulation (pain in the hand or fingers, ulceration of fingers)

In gray scale (B mode and with Doppler)
1- Examine the inflow to the AVF or graft (starting as high as the subclavian artery)
2- Identify the anastomosis to the vein and/or proximal anastomosis of the loop graft
3a- examine the outflow vein throughout its length
3b- examine the body of the loop graft and the anastomosis with the vein, then the outflow

And:
• Pay special attention to potential sites of stenosis (at anastomosis, but also kinks in loop graft)
• Measure diameter of outflow vein (for maturation)
• Measure volume flow (should be 500 ml/min)
• Examine central veins (IJ, proximal subclavian vein) as well as signs of dilated venous branches

And:
• Examine puncture sites for area of pseudoneurysms or arterio-venous fistula from puncture/cannulation

And:
• Examine arterial flow to the hand (distal to the AVF or arterial anastomosis of loop graft for flow direction)
• The examination can be performed by compressing the AVF to determine changes in flow direction
• Evaluate presence of branches

FIGURE 4.33. Examination algorithm. Algorithm based on information provided by the Society for Vascular Ultrasound (Vascular Professional Guidelines) and the American Institute of Ultrasound in Medicine (Practice Guideline).
Duplex Exam for Examining Hemodialysis Access

Test Preparation and Hand Test Sequence

**FIGURE 4.34.** Patient’s arm is comfortably resting on a pillow.

**FIGURE 4.35.** The dialysis access, whether AVF or loop graft, should include all sections outlined in the protocol algorithm (Fig. 4.33). Views can alternate between transverse and longitudinal as seen here to obtain the data. The scanning approach will vary based on the position of the access. It is therefore important if not crucial to obtain operative notes to understand the position of the access.
Results and Interpretation

FIGURE 4.36. Sample of evaluation of a matured dialysis access created between the brachial artery and cephalic vein. The waveform is taken at the brachial artery proximal to the access (site I on diagram in Fig. 4.32).

FIGURE 4.37. Measuring flow volume. Note: This feature is available in calculation package on most equipment; when it is not, the calculation can be done manually as long as the ultrasound equipment has a feature to calculate mean flow velocities through one cardiac cycle. To measure the flow volume (or volume flow), (1) measure diameter of the conduit (calculate the surface area $\pi r^2$), and (2) obtain mean flow velocities throughout one cardiac cycle with a Doppler sample volume set to the diameter of the vessel. Volume flow = surface area $\times$ mean velocities (unit will be cm$^3$/s), then multiply by 60 to get units in milliliters per minutes. Courtesy of Philips.
Figure 4.38. AVF between brachial artery and cephalic vein, with the Doppler sample taken in the brachial artery distal to the dialysis access. High-resistance flow should be noted (and resumed) in the artery distal to the AVF or loop graft take off, since that flow now feeds the distal territories in the forearm, hand, and fingers. The direction of flow should be directed toward these territories. When or if the flow appears reversed and the symptoms correlate with lack of flow to the territories distal to the AVF or loop graft, a steal phenomenon from the forearm by the dialysis access should be suspected. To confirm, the AVF or venous outflow from loop graft could be manually compressed (shut down) while the artery distal to the graft is evaluated by Doppler; a change of flow direction (to normal direction) should be observed.
FIGURE 4.39. AVF between brachial artery and cephalic vein, with the Doppler sample taken in the proximal aspect of the dialysis access (site VI1 on diagram in Fig. 4.32). Assess velocities, structural changes (dilatation, pseudoaneurysms), and sites of narrowing are seen throughout the conduit and at anastomoses. Caution: There is no recorded consensus on truly acceptable velocities within a dialysis access (although velocities < 100 cm/s are suspicious of poor function or poor maturity), but know that velocities will normally increase within a well-functioning access with maturity of the access. It is not unusual to have increased flow velocities at the anastomoses, particularly with synthetic graft, due to kinking of the graft. Clinical signs and symptoms should be strictly considered with these results before revision is undertaken. Criteria for stenosis usually follow the rule for bypass grafts and peripheral arteries, such as a doubling of velocity from a more proximal and nondiseased segment suggests 50% stenosis and a tripling of velocity suggests a 75% stenosis. Courtesy of Philips.
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FIGURE 4.41. Complications in autogenous dialysis access: (A) narrowing of a part of the vein graft, (B) stenosis often followed by decreased flow velocities and turbulence leading to thrombosis, and (C) slow flow itself (from multiple causes) can lead to thrombosis of the access.
Concluding Tips

Evaluation of dialysis accesses is a challenging exam. More than ever, a thorough understanding of basic hemodynamics and flow direction is needed, along with an open mind and critical thinking to anticipate and understand the changes in anatomy and, most importantly, physiology that the creation of the access will trigger. Communication with the surgeon who created the access, the dialysis center that treats the patient on a regular basis, and the patient (or caregiver) is also crucial for a successful and meaningful evaluation of this treatment option. Finally, and as for many if not all other exams in the vascular laboratory, the examination of a dialysis access should be tackled as a new challenge each time, even on returning patients. The vascular system is truly a dynamic system, and one should always consider every piece of information available as an integral part of the exam, every time.