Ultrasound in the detection of venous thromboembolism

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Venous thrombosis is a common disease process leading to tens of thousands of deaths per year. Despite prophylactic efforts, venous thromboembolic disease is a common and serious complication in critical care patients. Difficulty and delay in obtaining diagnostic imaging studies to rule out deep venous thrombosis is exacerbated by increased susceptibility that critically ill patients have to thromboembolism. Lower extremity venous ultrasound use by clinicians has been well studied and has proven both reliable and efficient. Evaluation of the upper extremities can be more challenging and requires a higher degree of technical skill. However, both can be integrated into an overall scheme of prevention, screening, and rapid diagnosis of thromboembolic disease and its complications. This article delves into available literature and describes performance of both applications in a critical care setting. (Crit Care Med 2007; 35[Suppl.]:S224–S234)

Key Words: critical care ultrasound; deep venous thrombosis; thromboembolism; venous ultrasound; emergency ultrasound

Although it is simplistic to say that ultrasound suddenly or recently arrived on the critical care scene, its use by clinicians providing critical care has fairly recently become a major topic. The seeds for ultrasound applications in critical care patients have been sewn over the last two decades by a variety of specialists in Europe, Asia, and North America. One of the most accepted uses of bedside ultrasound is assessment for venous thromboembolic disease. In contrast to venography, ultrasound avoids delivery of intravenous contrast to patients who may have transient renal dysfunction or have underlying renal disease. Although the dose of radiation delivered during venography is not immediately threatening, the process can actually cause formation of deep venous thrombosis (DVT) (1). Further, because venography is typically performed in a radiology suite rather than at bedside, in the critical care setting, patient transportation may be a considerable drawback.

Common practice in many facilities is to have an ultrasound or vascular technologist travel to the intensive care unit (ICU) with a large but mobile ultrasound machine, perform an examination, and then have a radiologist interpret the results at a later point. The development of lighter and smaller machines has made this job much easier but has not changed the underlying need of clinicians to obtain rapid diagnostic imaging results in critically ill patients. In most clinical situations, venous ultrasound studies will not be available without delay, and clinicians performing the examination themselves will not find only improved efficiency, as the time to definitive diagnosis decreases, but also high accuracy.

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Thromboembolic Disease

The true prevalence of venous thromboembolic disease in ICUs is unknown. Different specialty ICUs will contain patients with somewhat different underlying and predisposing factors and obstacles to anticoagulation prophylaxis that will lead to a variable prevalence of venous thrombosis. Nonspecific symptoms and patients who may not be able to communicate complaints, such as pain and a sensation of swelling, complicate diagnosis of venous thromboembolism (2). However, many ICU patients have potential risk factors predisposing them to development of venous thromboembolism, including a multitude of premorbid conditions, prolonged immobility, vascular injury from indwelling venous catheters, and activation of inflammatory and procoagulant pathways.

Most models for predicting DVT based on symptoms and history are derived from ambulatory patients, and there is little evidence that they are applicable in the critical care setting. In addition to possible premorbid conditions leading to DVT formation, a number of specific factors exist during a patient's ICU stay that contribute to venous thromboembolism. These include mechanical ventilation, immobility, femoral venous catheterization, sedative use, and paralytic drugs (3). In all likelihood, these factors have a synergistic effect not only with each other but also with preexisting conditions such as hypercoagulability disorders that may not be previously recognized.

Prevalence of DVT in ICU patients seems to vary widely from study to study but is typically thought of as 10% and may be higher or lower in certain populations (4–8). When DVT does develop in ICU patients, it tends to do so in the first week of admission. Although DVT prophylaxis does help to decrease the rate of DVT development, it is used only in approximately 60% of at-risk patients (7, 9). Many patients who are at risk for DVT development are also at an increased risk from anticoagulation, making the clinician choose between two potential evils.

There are a number of different sequelae of lower extremity DVT, the most common of which is chronic venous stasis; however, the most dangerous in the ICU is pulmonary embolism (PE). PE is generally thought to be among the most common preventable causes of death in hospitalized patients (10). The majority of PEs, approximately 95%, originate in the lower extremities (3). Whereas PE can be physiologically challenging to healthy young patients, ICU patients typically have even less cardiopulmonary reserve to compensate for the increased physiologic stress of a PE. PE prevalence among ICU patients is less certain than in the general population. Studies suggest rates of up to 13% in patients without thromboembolic prophylaxis (11). However, many PEs are unsuspected and may be revealed only at autopsy (12). Postmortem studies indicated that PE is identified in 20–27% of ICU patients (6, 13). Several studies suggest that unsuspected PE may be present in up to 70% or 80% of patients dying in hospital (14, 15).

Surprisingly, there is some suggestion that none of the risk factors for venous thromboembolism that would typically be established at ICU admission are actually associated with development of a DVT or PE during the ICU stay (3). These potential risk factors included age, sex, Acute Physiology and Chronic Health Evaluation II score, admitting diagnosis, history of venous thromboembolism, malignancy, or anticoagulant use. Unfortunately, even when heparin prophylaxis is undertaken, the risk of DVT does not disappear (16). One study, in which ICU wide screening was performed twice weekly, identified the presence of DVT in a larger portion of patients receiving heparin or mechanical prophylaxis than patients receiving no DVT prophylaxis (7).

Conventional wisdom once indicated that thromboembolism was a disease of adult ICU patients. However, pediatric ICU studies indicate the rates of DVT can be as high as 23% to 40% in infants and children (17, 18). The prevalence of PE in children with documented DVT has been estimated to be as high as 30% to 60%, and mortality from PE is approximately 10% in pediatric ICU patients (19, 20). Despite these statistics, thromboembolic disease is suspected in less than half of all fatal cases of PE (21). One of the explanations offered by a group of authors is that not enough imaging studies are performed to catch the large number of DVTs that go unnoticed and embolize (3). Although the obvious solution would seem to be simply ordering more imaging studies to evaluate for thromboembolism, this may not be practical for several reasons. In many institutions, even large academic centers, ultrasound services from traditional imaging providers may be limited or unavailable during evenings, nights, and weekends. Even if available, the addition of several extremity ultrasound studies on a daily basis may overtax a system that is frequently stressed. Of course, it should be of little surprise that this article advocates clinician-performed ultrasound examinations to rule out thromboembolic disease. Performing such examinations on a regular basis will not place an additional burden on traditional imaging providers and holds potential for improved efficiency in the ICU setting for assessment of patients with suspected thromboembolism.

Ultrasound in the Evaluation of Venous Thromboembolism

Ultrasound use for diagnosis of DVT dates back to the early 1960s when audible Doppler was utilized for detection of venous thrombus (22–24). No images were created by these early Doppler machines, and it was not until the 1980s that B-mode ultrasound started to become popular for venous studies. By the end of the decade, ultrasound images were improving rapidly, and highly accurate diagnosis of venous thrombosis was becoming possible. In the early 1990s, ultrasound was already established as the new gold standard for detection of DVT. Venography, although more accurate, was becoming more and more of a distant second-choice study. Venography was time consuming, potentially nephrotoxic, and delivered a dose of radiation to patients. The process of intravenous injection of a somewhat caustic contrast actually resulted in DVT formation in 2% of patients undergoing venography (1).

Over the years, other modalities have been adapted for diagnosis of thromboembolism. Plesthymography seemed to hold promise and did not require imaging specialists to perform the study (25, 26). However, poor sensitivity and specificity and the inability to actually visualize venous thrombosis have significantly cooled initial excitement over the technology. Computed tomography (CT) of the lower extremities with contrast is becoming more common, despite as yet unclear sensitivity and specificity. Although having the advantage of imaging pelvic vessels, the CT scanner cannot travel to the patient's bedside, radiation doses are unavoidable, nephrotoxic intravenous contrast is typically used, and the modality is considerably more expensive.

Ultrasound evaluation of venous thrombosis consists of verifying vein patency or the lack thereof. The gold standard for venous patency is the ability of a vein to collapse completely under pressure, with the lumen disappearing entirely under direct visualization with ultrasound (Fig. 1). A thrombus cannot exist, at least directly under the transducer, or the venous lumen would not disappear and the walls of the vein would not appear to meet each other.

Other additional techniques have been used to support or refute the diagnosis of

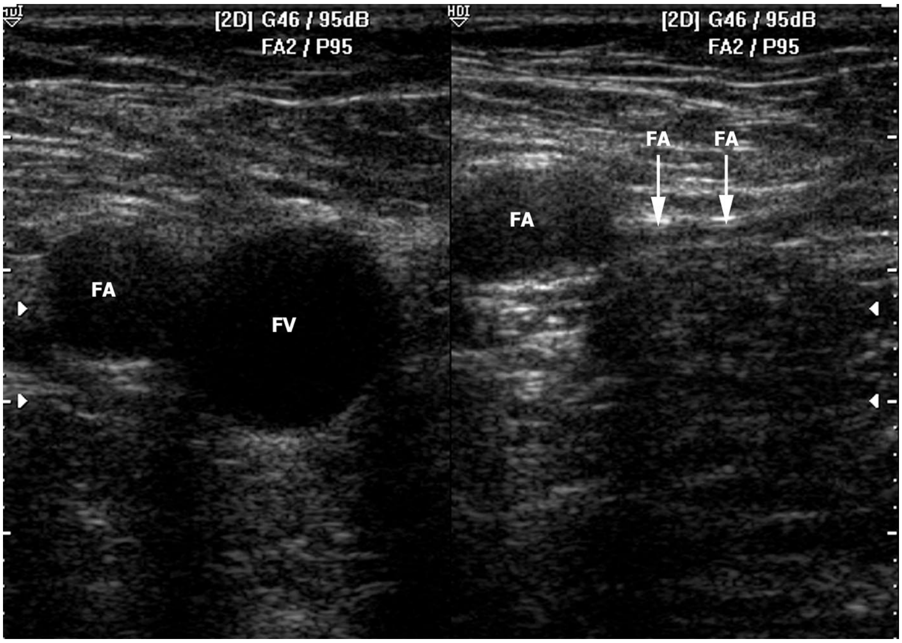

Figure 1. Side-by-side comparison of femoral vein (*FV*) and artery (*FA*) is seen. *Right*, transducer pressure is being applied, leading to femoral vein collapse.

DVT. Although it has become apparent that they offer little in the majority of examinations of the lower extremities, these techniques are still utilized by most vascular and ultrasound laboratories. Color Doppler and pulse-wave Doppler give the traditional venous ultrasound examination its name, "duplex." The examination utilizes not only images of veins but also interrogation of blood flow with color and pulse-wave Doppler. Color Doppler represents flow within a vein with a specific color map of different color shades assigned to a variety of speeds and one of two directions (either toward or away from the ultrasound transducer). The color map may be selected by the sonologist from a variety of options or by the ultrasound machine manufacturer. Pulse-wave Doppler is a graphical depiction of blood flow direction and speed. It must be noted that this is an extreme oversimplification of the topic, which typically takes entire books to describe in detail.

Augmentation is a technique utilizing either pulse-wave or color Doppler to confirm blood flow through a section of the extremity. Typically, blood flow is evaluated in a proximal portion of the venous segment, for example, the common femoral vein. The sonologist then squeezes the calf, sending a rush of venous blood past the transducer held over the proximal portion of the extremity. A sudden increase of blood flow is seen on either color or pulse-wave Doppler and is thought to indicate that no completely occlusive thrombus is present between the operator's hand on the calf and the ultrasound transducer. The absolute diagnostic nature of this maneuver has been disproved as patients with venous disease, thick legs, and other co-morbidities may lack positive augmentation, despite having no venous thrombus. Similarly, patients with DVT may still show augmentation due to partially occluding thrombi or previously established collaterals (27). The greatest utility of this technique is locating inconspicuous vascular structures that are not immediately obvious with just gray-scale imaging.

Lower Limb DVT

An ultrasound examination of the leg is indicated whenever the intensivist is suspicious for a proximal DVT. Proximal DVTs are those located in the popliteal vein or higher in the leg. As opposed to distal or calf DVTs, these are thrombi that are much more likely to embolize and pose a significant danger for PE (28). Historically, venous ultrasound examinations of the lower extremity were a lengthy process, taking up to 37 mins per leg (29). This could be even longer if the calf veins were interrogated and the extremity was obese or edematous. Many facilities no longer include the calf veins in their evaluation because calf DVTs are frequently not treated and are simply followed up with a repeat ultrasound examination in 5 to 7 days to detect proximal propagation (30). The complete lower extremity ultrasound study involves a painstaking interrogation of every centimeter of deep vein segment in the leg. Periodic blood flow measurements are also taken using color and pulse-wave Doppler. Such an approach in the clinical ultrasound setting is not feasible due to time pressure on physicians.

A number of studies over the last two decades have made it clear that a complete examination of every centimeter of the deep venous system is not necessary. Accuracy and safety can be maintained with a more rational and focused approach. This focused approach makes use of the phenomenon that small, isolated segments of thrombus, such as a 3-cm segment of occlusive clot in the middle of the superficial femoral vein, is extremely rare. Thus sonologists can survey key vein segments to rule out proximal DVT in the lower extremity. The examination can always be extended if questions about specific vein segments arise. In addition, blood flow evaluation with pulse-wave and color Doppler are generally not employed, further decreasing the amount of time required.

The scientific basis for a focused approach is sound, and the practice of a simplified examination is well studied. An early postmortem study evaluating the distribution of venous thrombosis in the lower extremities revealed that proximal DVTs were never found in small isolated segments (31). They were most likely to take up significant portions of the common femoral, deep femoral, superficial femoral, or popliteal veins. Later studies took advantage of this knowledge and focused their gray-scale ultrasound examinations on specific regions of the deep venous system, utilizing venous compression as the only criteria for refuting or diagnosing the presence of DVT. A head-to-head comparison of a focused technique (evaluating vein compression at the common femoral and popliteal veins only) with contrast venography in 220 consecutive patients revealed that the focused ultrasound technique had a sensitivity of 100% for detection of proximal DVT (32). Not surprisingly venography was superior at detecting calf DVTs because the ultrasound examination did not include a search of the calf. However, adding in lone calf thrombi, the technique's sensitivity and specificity for the presence of overall DVT only dropped to 91% and 99%, respectively. This was followed by other studies evaluating a focused, compression-only technique that examined hundreds of patients and added support to the technique, with high sensitivities and specificities (29, 32–34).

Criticism has come from the traditional imaging community for the focused extremity ultrasound evaluation but suffered from poor retrospective study design and a misunderstanding of what the focused examination actually entails (35). In the last decade, multiple studies performed in clinical settings compared the focused compression technique with gold-standard testing and clinical outcome. They have all provided even more support for the safety and accuracy of this ultrasound examination, refuting the assertion that small, segmental DVTs would be frequently missed by clinicians (30, 36–38).

The key benefits of a clinician-performed ultrasound examination of the lower extremities are the accuracy, convenience, and efficiency that it offers. Convenience comes from the potential round-the-clock access afforded to a properly trained and credentialed clinician to an important diagnostic imaging study. The process of ordering a study from traditional imaging providers and waiting for an ultrasound technologist to arrive, perform the examination, send images to a interpreting physician, and then finally receiving an interpretation can be completely eliminated, and this improves efficiency. A study of clinicians new to the examination revealed that even with a probable learning curve still in effect, the median time for a focused examination was only 3 mins and 28 secs (37). Although not studied in an ICU setting, use for patient evaluations in other clinical scenarios indicates that clinicians are able to make a significant effect on the time to diagnosis and decision making regarding treatment when utilizing the focused ultrasound examination themselves (38).

Performing the Examination

The examination effectively begins with preparation of the equipment. A high-resolution linear array transducer is required. Most modern systems, especially compact ones that function best in the confines of an ICU setting, will have broadband ultrasound transducers, allowing the sonologist to make use of a range of frequencies with just one ultrasound probe. Typical frequency ranges will be from 5 to 10 or even 12 MHz. The lower frequency will play a larger role in thick edematous legs, and the higher frequency will be helpful for visualizing subtle details for which good resolution is required. Although not mandatory for the lower extremity examination, color and pulse-wave Doppler are also likely to be available on such equipment. As suggested earlier, color Doppler can be quite useful in discerning vascular structures such as the vein or nearby artery in a difficult gray-scale picture. The vessels can then be focused on and examined closer. The pulse-wave Doppler generates tracing that will help the sonologist differentiate between artery and vein. Although it may initially seem that vessel identity would be obvious based on anatomic knowledge, this is frequently far from the truth. The ability to obtain a venous or arterial blood flow tracing can be helpful in confusing situations.

Similar to most procedures or examinations, patient positioning and access are important considerations. Despite this, there are few settings in which a lower extremity ultrasound examination could not be performed. The patient's proximal inner thigh near the inguinal ligament and several centimeters distal to it should be exposed. If bandages are present, such as in a burn patient, they may be temporarily moved, and the examination can even be performed in a sterile fashion by using the commonly available packets of sterile gel and a sterile glove to cover the ultrasound transducer. The second location that will have to be exposed is the popliteal fossa, behind the knee. Ideally a 4- to 5-cm length will be available for interrogation, as anatomy can vary from patient to patient. If the patient cannot tolerate this movement due to injury or for other reasons, the entire torso may have to be rolled on the side.

Veins in the lower extremity are best visualized when distended as much as possible. In an ambulatory setting, patients' beds are inclined to 30 or 45 degrees at the head. This allows venous pooling and the examination is made easier. In patients with spinal precautions, the bed may need to be placed in reverse Trendelenburg position to achieve the same effect. The knee will need to be turned out slightly so the transducer can access the popliteal fossa.

The actual examination begins just below the inguinal ligament with the common femoral vein (Fig. 2). The common femoral vein is visualized in cross section, above its junction with the saphenous vein (Fig. 1). Although the greater saphenous is a superficial vein, a thrombus found in the immediate vicinity of the saphenofemoral junction is considered a DVT. A thrombus in such a location will quickly seed the common femoral and move up and down from there. Similar to virtually all ultrasound examinations, this one depends on adequate amounts of gel between the transducer and skin surface. Once the common femoral vein and artery are located in cross section, verification of vein patency can begin (Fig. 1).

Downward pressure is applied to the ultrasound transducer until the vein collapses completely on the ultrasound monitor. If the vein is not collapsing and the artery is starting to deform, consideration must be given to the possibility of thrombus within the vein's lumen. The amount of pressure required to collapse the vein will differ from patient to patient, and with experience, the sonologist will be able to ascertain if enough pressure has been applied. Care must be taken because downward pressure at the wrong angle or down the wrong vector can greatly decrease the actual pressure felt by the vein and make it appear uncollapsible.

As the vein lumen disappears and walls meet each other, pressure on the transducer is relaxed and the vein allowed to take its original shape. The transducer is then moved down the leg approximately the width of the transducer, typically about 1 cm. Downward pressure is again applied, and the vein is observed for complete collapse. Within 2 or 3 cm, in this proximal to distal progression, the sonologist should reach the entry point of the greater saphenous vein into the common femoral. Both should collapse under transducer compression. This is a point of difficulty in many patients, as the saphenous may be difficult to compress accurately at this junction. For documentation purposes, it is helpful to use the dual-image feature found on most ultrasound machines and place the image without pressure applied on the left side and image with pressure applied on the right. This clearly illustrates that the vein appropriately collapsed or, alternatively, that it did not (Fig. 1).

The process of compression then relaxation follows by moving 1 cm distally and continues until the common femoral vein splits into the deep femoral and superficial femoral veins. After the saphenofemoral junction is compressed and the transducer is moved distally, the femoral artery will typically split into the deep femoral and superficial femoral arteries, if it did not already occur. The junction of the deep femoral and superficial femoral veins is almost always 1 or 2 cm distal to the split of the common femoral artery. An unnamed perforator frequently comes into the common fem-

Figure 2. Linear transducer is held in transverse, across the common femoral vein.

oral vein just proximal to the junction of the deep femoral and superficial femoral veins. Although anatomic relationships vary, the deep femoral vein typically disappears deep into the thigh shortly after it is first identified on a proximal to distal descent. The superficial femoral vein continues just under or occasionally next to the superficial femoral artery.

The junction of the deep femoral and superficial femoral veins can be surprisingly confusing. In a proximal to distal descent, the deep femoral vein may appear to quickly switch locations with the deep femoral artery in cross section. This can lead to doubt as to which vessels are expected to remain open with transducer pressure (arteries) and which should collapse (patent veins). Pulse-wave Doppler can be exceedingly helpful in identifying each of the four vessels. This may be a moot point in a thin extremity with good veins, but it can salvage an examination in the typical obese or edematous leg, in which clinical suspicion is high. After collapse of the deep and superficial femoral veins for the first 1 or 2 cm is verified, the examination moves to the popliteal region.

To examine the lower leg, the transducer is placed behind the knee, and the popliteal artery and vein are located in cross section (Fig. 3). There should be no smaller vessels around the two or the transducer is too distal (Fig. 4). Occasionally, the trifurcation of the popliteal vein occurs very proximal, high behind the knee. The examination should capture the last 2 cm of the popliteal vein and end just distal to the trifurcation. Just as in the upper leg, compression of the vein, or veins, is followed by sliding the transducer distally for 1 cm, where compression is repeated again. Although calf DVTs are relatively less important and frequently not treated, it may be helpful to be aware of them, especially when one is close to entering the popliteal vein. Scanning through the trifurcation by 1 or 2 cm allows the sonologist to ensure all three vessels that make up the popliteal collapse. If one of the branches is thrombosed proximally, it is likely to seed the popliteal shortly, turning into a proximal DVT. The calf DVT should be treated or watched very carefully with serial ultrasound examinations if anticoagulation is contraindicated in the particular patient.

There is some controversy regarding the routine scanning of the contralateral leg, and although it may be a wise financial decision in some settings, two large studies examining >3,200 patients suggested that in patients with unilateral symptoms, scanning the contralateral leg is neither indicated nor cost effective (39, 40). However, neither study focused on ICU patients, and in those cases in which both legs are suspect, both legs should be scanned as indicated, based on the clinical picture. Obviously, if a DVT is diagnosed in one leg, the other is less likely to be scanned unless complete venous occlusion by thrombus is suspected. Treatment will typically be the same for unilateral and bilateral DVTs unless an inferior vena cava filter is planned but femoral access points are blocked by thrombi on both sides.

If a DVT is identified, locating the most proximal portion of the thrombus may be more important in the ICU patient than in the ambulatory setting. Locating and noting or marking the proximal end will allow the sonologist to evaluate for possible progression and treatment failure at a later time. If anticoagulation is failing, other interventions such as a Greenfield filter may be indicated. Noting exactly where the thrombus was 2 days previously compared with the latest ultrasound examination may aid in decision making. In the case of a popliteal DVT, when no common femoral, deep femoral, or superficial femoral thrombus was noted during the first portion of the examination, it is helpful to examine the distal superficial femoral vein just before it dives through the obturator canal. Locating thrombus in that portion of the vein should lead to a proximal tracing of the clot and documentation of how high the thrombus extends.

As discussed briefly, documentation of the ultrasound examination is helpful for the medical record, billing, and for colleagues. Utilizing the dual-image feature,

Figure 3. Linear transducer is held in transverse, across the popliteal vein.

Figure 4. Popliteal vein (*PV*) is seen in cross section just superficial to the popliteal artery (*PA*).

the sonologist can print thermal pictures of compression results at the common femoral and greater saphenous junction (Fig. 1). The next point can be just distal to the junction of the superficial femoral and deep femoral veins, where two arteries and two veins can be seen (Fig. 5). Finally, a side-by-side image at the popliteal fossa can be obtained. Such documentation results in three thermal prints that can be easily scanned into an electronic record or attached to a page in a physical chart and adequately convey results of the examination.

Acute DVT Features

A fresh or acute thrombus may be directly visualized within the lumen, even without compression (Fig. 6). This is not always the case and depends on the echogenicity of the thrombus and the clarity of the image obtained, a patient-dependent factor. If not seen before compression as echogenic material, the thrombus will typically be apparent after transducer pressure is applied and the vein fails to collapse. Although it may seem that if echogenic material is noted in the venous lumen, compression is obviated, that is not the case in many patients. Echogenic appearance within the lumen can occur due to artifacts from increased gain or even from slowly sludging blood within the vein. Compression in these cases leads to lumen collapse and proof that no thrombus is present. If the vein seems to be only partially filled, a long-axis view is warranted to see if the thrombus is running along one wall or floating, or perhaps the walls are thickened from an old DVT (Fig. 7). Free-floating thrombus is thought to be particularly dangerous, as these types of DVTs readily break off and embolize. Reported cases of embolization during a lower extremity ultrasound examination are difficult to find. Anecdotally, it is an extremely rare occurrence, with several large vascular laboratories privately reporting one instance in 30, 25, and 20 yrs, respectively.

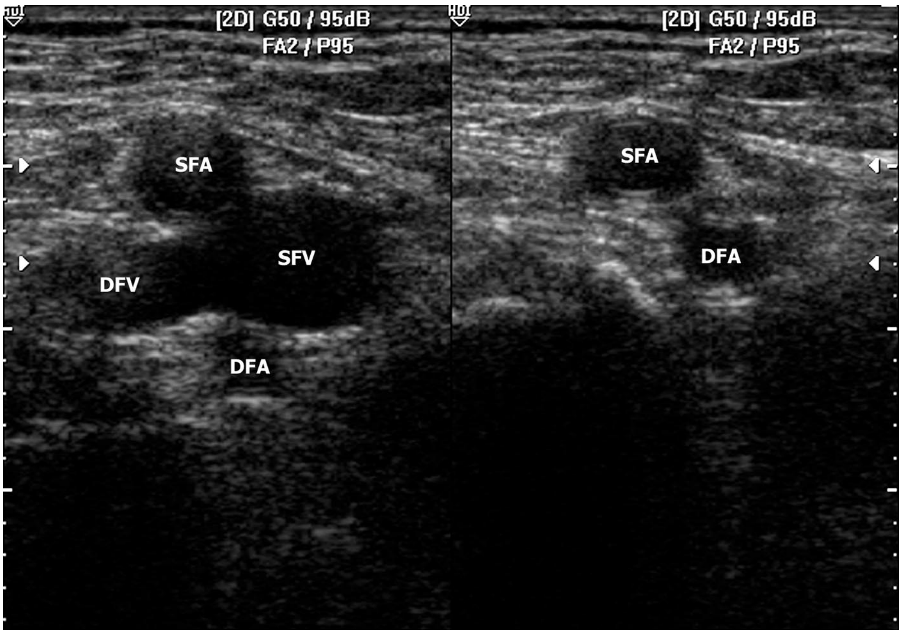

Figure 5. Side-by-side image of the superficial femoral (*SFA, SFV*) and deep femoral (*DFA, DFV*) artery and veins is shown (with transducer compression shown at *right*).

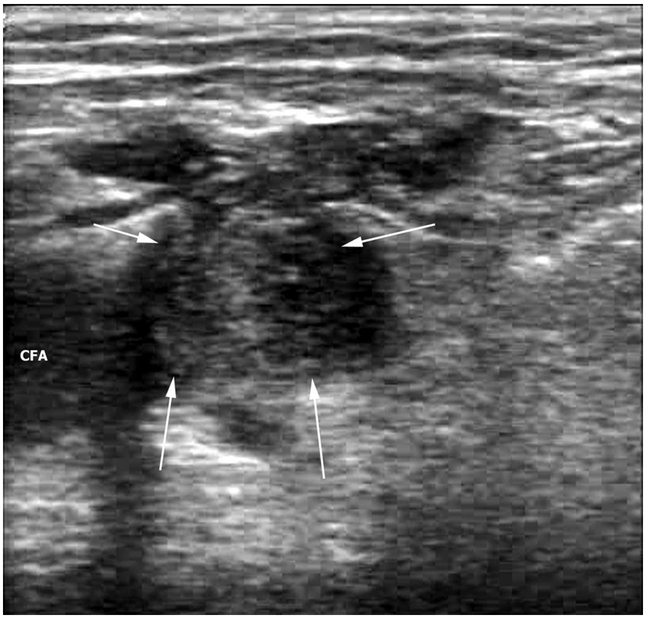

Figure 6. Obvious thrombus is seen in the common femoral vein (*arrows*). The thrombus actually extends into the greater saphenous vein and may have originated there. *CFA*, common femoral artery.

Chronic DVT Features

A chronic DVT refers to an organized thrombus as opposed to a soft, fresh clot. Organization is thought to occur between 5 and 10 days in most cases (41). Aging thrombi generally recannulize centrally, and blood flow can be seen through or around the old thrombus. Occasionally, only a small trace of the DVT is left in the form of scarred and thickened venous walls. Complete collapse of the vein under transducer pressure is not possible, although near-complete collapse frequently occurs. In general, as thrombus ages, its echogenicity increases, and chronic DVTs will tend to be brighter on the screen. However, multiple factors affect how bright a thrombus appears on any individual ultrasound examination, and there is overlap in the appearances of some chronic and acute DVTs. Reviewing the patient's medical record and any previous studies may be helpful to determine whether a chronic DVT is present or if a thrombus is acute.

Interrogating the suspect vein in long axis (lengthwise) can also be helpful to determine whether a chronic DVT is present. Vessel walls may appear to be thickened, with no actual thrombus seen

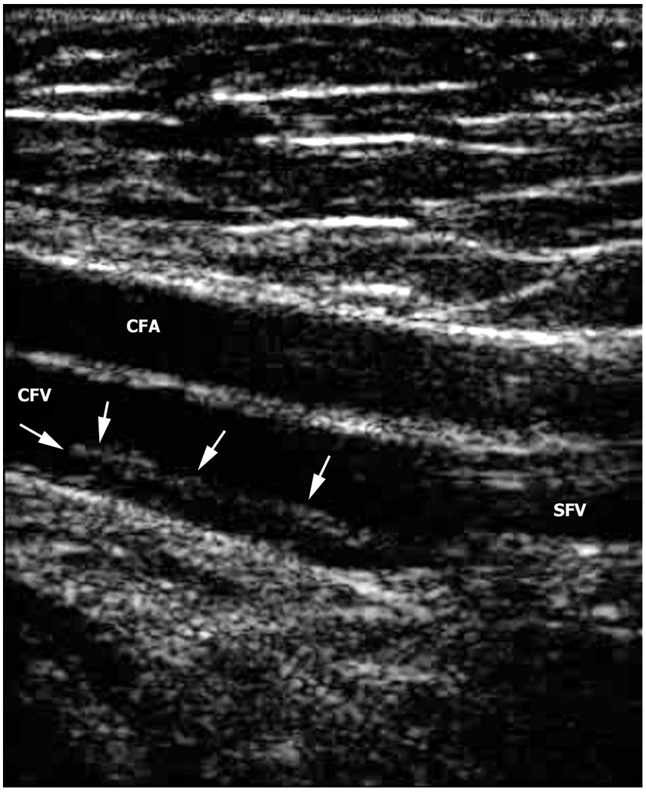

Figure 7. Long-axis view of a common femoral vein (*CFV*) thrombus (*arrows*), partially occlusive, running along the posterior wall. The thrombus arises from the deep femoral vein, which is difficult to differentiate in this image. *CFA*, common femoral artery; *SFV*, superficial femoral vein.

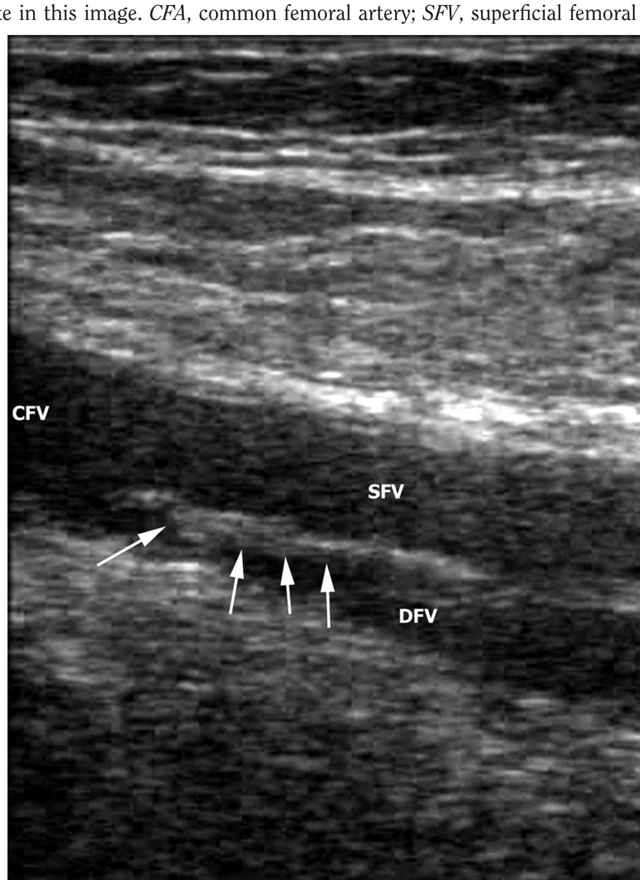

Figure 8. Chronic deep venous thrombosis is shown in long axis. The vein wall appears thickened (*arrows*). *CFV*, common femoral vein; *SFV*, superficial femoral vein; *DFV*, deep femoral vein.

(Fig. 8). Conversely, a long, thin, acute thrombus may be encountered that is, in effect, the tail of a fully occlusive thrombus downstream (Fig. 7). The proximal tip of a chronic DVT tends to become thinner and blend into the venous wall. Acute DVTs will have more of a rounded tip, but this is not always the case. Chronic DVTs may be more irregular in appearance. Unlike chronic DVTs, acute thrombus will compress visibly under transducer pressure. Collaterals may be found in the presence of a chronic DVT, and a search should be made for these. Although uncommon with careful evaluation and moderate experience, the sonologist may still be left unsure if the thrombus is chronic or acute. Although the rate of such encounters is not well reported, anecdotal evidence suggests it to be just 1% or 2%.

Superficial Vein Thrombus

Swelling and redness of the lower extremity may be caused by superficial vein thrombosis and by DVT. It is not rare to encounter superficial thrombi on an otherwise negative ultrasound examination of the lower extremity. Superficial vein thrombosis is not cause for anticoagulation in most patients, with the exception of the most proximal portion of the greater saphenous vein, as described. However, superficial thrombi can progress to involve the deep venous system from time to time. If superficial thrombi are identified in an ICU patient, monitoring, at least clinically, is warranted. Serial ultrasound examinations and marking the progress of a superficial thrombus on the patient's skin with a pen or marker may be helpful. If progression occurs, anticoagulation may become necessary, if not already employed, or prophylaxis methods may need to be reassessed.

Other Causes of Leg Pain and Swelling

There are other causes of acute unilateral leg pain and swelling that may be readily identifiable in a portion of ambulatory patients. These typically include Baker cysts, muscle tears, and hematomas. Rupture of a Baker cyst or hemorrhage into a Baker cyst can be clinically indistinguishable from a lower extremity DVT. Although rupture is less likely in an immobilized ICU patient, hemorrhage into a Baker cyst or muscle may still occur, especially with anticoagulation.

Pelvic DVT

Pelvic vein thrombi carry a high risk of embolization. When not found in conjunction with femoral vein thrombosis, the presence of a pelvic DVT may be missed and the patient not treated. Identification of an external or common iliac vein DVT is not as critical when a femoral vein DVT is diagnosed and treated. However, in a small percentage of patients, isolated thrombosis of the pelvic veins may be encountered (42). Ultrasound interrogation of the pelvic veins may be quite challenging. In an ideal patient, who is thin and has little bowel gas, the visualization and sequential compression of the external and common iliac veins can be performed easily. However, such patients are fairly rare and are becoming more so in western society, where obesity is an increasing problem. Thus, if suspicion for isolated pelvic vein thrombosis exists and the iliac veins cannot be clearly seen on ultrasound, indirect evidence regarding the presence of absence of pelvic DVT must be sought.

Under normal conditions the blood flow through the common femoral vein exhibits phasic variation with breathing. The flow pattern graphed on a pulse-wave Doppler tracing will have peaks and troughs reflecting the increasing flow through the vein with decreasing intrathoracic pressure on inspiration (Fig. 9). However, if an obstruction (such as a common or external iliac DVT) exists between the changing intrathoracic pressure centrally and the common femoral vein, then no respiratory variation will be transmitted to the common femoral vein. With the transducer held longitudinally over the common femoral vein and pulse-wave Doppler activated, variation in the venous flow suggests the absence of a common or external iliac DVT. Alternatively, if no respiratory variation is seen, an iliac DVT should be strongly considered.

If possible, the inferior vena cava should be evaluated as well. A thrombus in the inferior vena cava may be seen directly in a cross-sectional view, and in many patients, the inferior vena cava can actually be compressed with moderate pressure on the transducer (Fig. 10). Otherwise, color Doppler and pulse-wave Doppler interrogation may be necessary. The inferior vena cava evaluation will be performed with a curved linear array transducer in all but the thinnest patients.

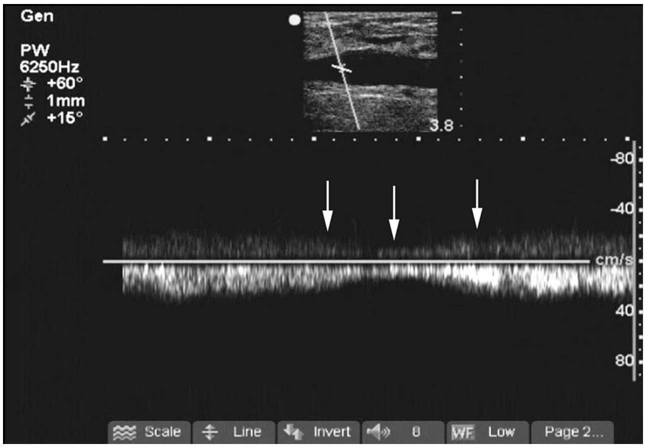

Figure 9. *Arrows* indicate phasic variation in this venous flow pattern as a result of changing thoracic pressure from respiration.

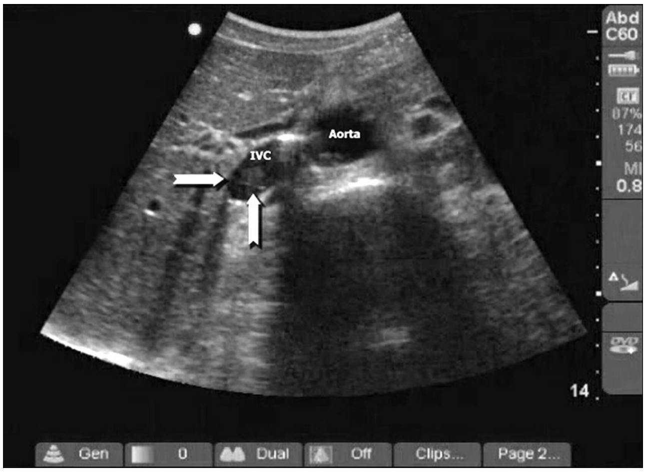

Figure 10. Inferior vena cava (*IVC*) is seen in cross section next to the aorta and has thrombus in it (*arrows*).

Upper Limb DVT

The deep venous system of the upper extremities starts distally at the palmar venous plexus, which gives rise to the radial and ulnar veins. The radial and ulnar veins travel along the radial and ulnar arteries and join in the antecubital fossa to form the brachial vein. The brachial vein in turn travels proximally, up the arm, on either side of the brachial artery. The basilic vein, a superficial vein, joins the brachial vein to make the axillary vein, which flows into the thorax and becomes the subclavian vein when it crosses under the clavicle. The basilic vein actually caries more blood in the arm than the deep venous system and is typically much larger in cross section. The subclavian vein is joined by the internal jugular as it drains the head and becomes the innominate vein. This summary of the upper extremity deep veins is deceptively simple.

Historically, upper extremity venous thrombosis was thought to be quite rare, and even when identified, few physicians worried about embolization risk. Up to the mid-1970s, most physicians believed that upper extremity DVT made up <2% of all DVT cases (43). Since that time, it has become evident that upper extremity DVTs make up a much higher percentage of all DVT cases. Recent work indicates as many as 18% of all DVTs are now upper extremity thrombi (44). In fact, up to 0.18% of all adult admissions to hospitals are upper extremity DVTs. Regardless of the exact prevalence, upper extremity thrombi are becoming more common than once thought. The most likely cause for this apparent increase is an increase in the utilization of central venous catheters and pacemaker wires and an increase in treated malignancy. The other misconception about upper extremity DVTs that is being refuted is a nearly nonexistent rate of embolization. In fact, some authors have suggested that 7% to 9% of upper extremity DVTs will lead to an acute PE (45, 46).

Patients in the ICU setting are especially vulnerable to developing upper extremity DVT. Many patients have central venous catheters, and internal jugular and subclavian access is frequently preferred. Pacemakers and presence of cancer or other procoagulant conditions are more common that in most clinical settings that would utilize venous ultrasound. Although, after mastering the lower extremity venous examination, the upper extremity one will come more easily, the examination itself covers more challenging anatomic territory. The subclavian and axillary veins do not lend themselves particularly well to compression as opposed to the lower extremity veins. Similar to the common femoral vein when it dives into the obturator canal, the proximal portion of the axillary vein may not be visualized at all, let alone compressed. Therefore, the upper extremity venous examination depends on indirect confirmation of vein patency more so than in the lower extremities. The examination is less accurate than in the lower extremities, with sensitivity and specificity as low as 82% and 82%, respectively (47). Both false-positive and false-negative findings are more common in upper extremity ultrasound examinations. Proper evaluation of proximal upper extremity veins, especially the innominate vein, depends on good pulse-wave Doppler techniques and requires not only differentiating appropriate from inappropriate venous wave patterns commonly seen at the vein level being examined, but also keeping track of blood flow direction. Reverse in the venous flow direction may be the only hint of a more proximal thrombosis.

Figure 11. Transducer is held in cross section over the internal jugular vein.

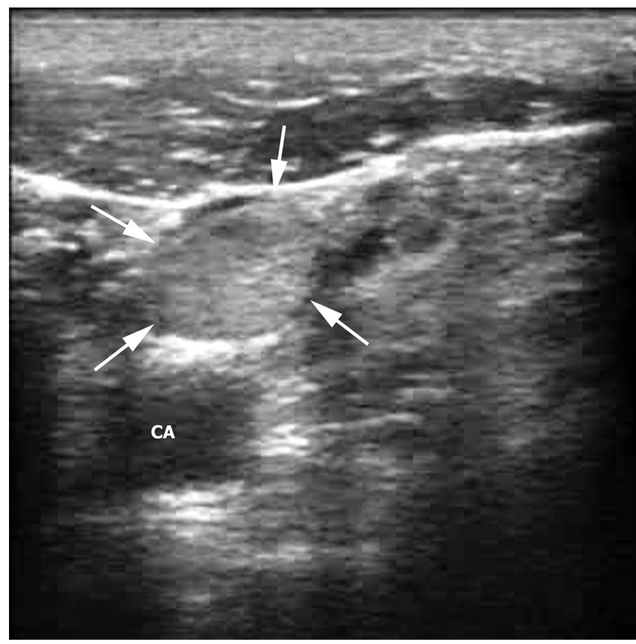

Figure 12. Echogenic thrombus is seen in the lumen of the internal jugular vein (*arrows*), just above the carotid artery (*CA*).

Performing the Examination

The venous ultrasound examination of the upper extremity is preferentially performed with the patient supine, to maximize venous distention. Many sonologists choose to start evaluating the jugular vein first, at the most distal point possible (Fig. 11). The jugular vein is superficial and best found in cross section, next to the carotid. In patients with normal central venous pressure, and especially those who are hypovolemic, the jugular will tend to be largely collapsed until the more proximal portion is reached. Asking the patient to perform a Valsalva maneuver or setting the ventilator to perform a sigh will lead to jugular engorgement. A thrombus is typically readily seen as an echogenic entity in the venous lumen (Fig. 12). Compression of the jugular vein with the transducer can be performed, but care must be taken to avoided carotid sinus massage in elderly patients. In the presence of upper extremity DVT, collateralization occurs rapidly and can aid in the diagnosis. For instance, the anterior jugular vein, which is normally easy to miss as it travels toward the thyroid, may be significantly enlarged if an occlusive innominate vein thrombus is present.

In the majority of cases, the jugular vein can be traced to its entry point into the innominate vein. Compression at this point is not possible, and visualization of the lumen in gray-scale along with Doppler interrogation will be required. Color or power Doppler windows should be placed along the visible portions of vein not covered by the clavicle. Blood flow, indicated by color, should fill the lumen from wall to wall. Pulse-wave Doppler can also confirm normal venous flow. An area of absent flow, despite appropriate settings, or no flow at all is indicative of a

DVT. Respiratory variation in the venous flow should also be noted, and comparison can be made with the contralateral side if necessary.

The subclavian vein is traced toward the shoulder with Doppler interrogation throughout its visible length. Anatomy can be confusing if suboptimal images are obtained. Pulse-wave Doppler will not only help with confirming flow in the vein but also in differentiating vein from artery. Although flow in the proximal upper extremity veins will show some pulsations, it will be less distinct than in the arteries. Further, arterial flow typically does not have respiratory variation. The proximal portion of the axillary vein is not seen due to overlying clavicle; just past the disruption, Doppler interrogation is resumed. If the distal subclavian and axillary veins are not visualized, they may be collapsed by the chest wall, and elevating the arm and rotating it outward will help fill the veins. Once the axilla is reached, the brachial vein can be directly compressed to confirm absence of DVT. Inability to compress and echogenic material in the lumen indicate the presence of thrombus. In the antecubital fossa, the radial and ulnar veins split to either side of the forearm and are typically easily compressible.

SUMMARY

The ability to perform venous ultrasound examinations in the intensive care setting without delay can and does increase overall efficiency of patient management. The tools required for performing the examination, both from an equipment standpoint and the clinician's skill side, are readily available and are utilized by many clinicians. Clinicians may not only perform these bedside ultrasound examinations on an around-the-clock basis but also have fewer limitations on repeating studies as frequently as required on at-risk patients. Integrating bedside ultrasound for thromboembolic disease into an ICU-based protocol for DVT prophylaxis, screening, and diagnosis holds promise for decreasing deadly sequelae such as PE.

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