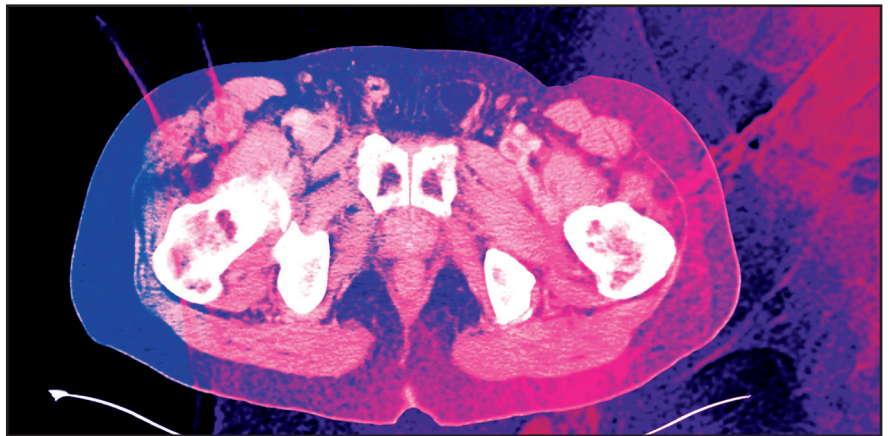


# Imaging of deep venous thrombosis: A multimodality overview

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**A**ccurate clinical diagnosis of deep venous thrombosis (DVT) is notoriously difficult, analogous to accurate clinical diagnosis of pulmonary embolism (PE). Both are part of the same process of venous thromboembolism (VTE). Most cases of DVT are believed to begin in the calves, and approximately 90% of PE cases are believed to originate from the deep veins of the lower extremities and/or the pelvis. DVT usually begins around the leaflets of venous valves, especially in the calves, and can propagate superiorly. Less commonly, DVT can form in the abdominal, pelvic, or upper thigh veins,

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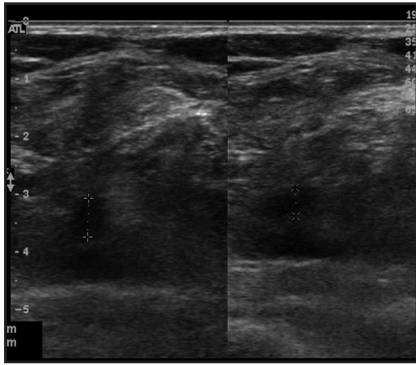


due to obstruction or other processes, and can then propagate inferiorly. DVT is related to stasis, hypercoagulability, and trauma to the venous wall; ie, Virchow's triad. Risk factors include various blood disorders, malignancy, estrogen administration, dehydration, recent surgery or trauma, prolonged immobility, heart failure, mass effect on the deep veins, obesity, pregnancy, age >40, and history of prior DVT.

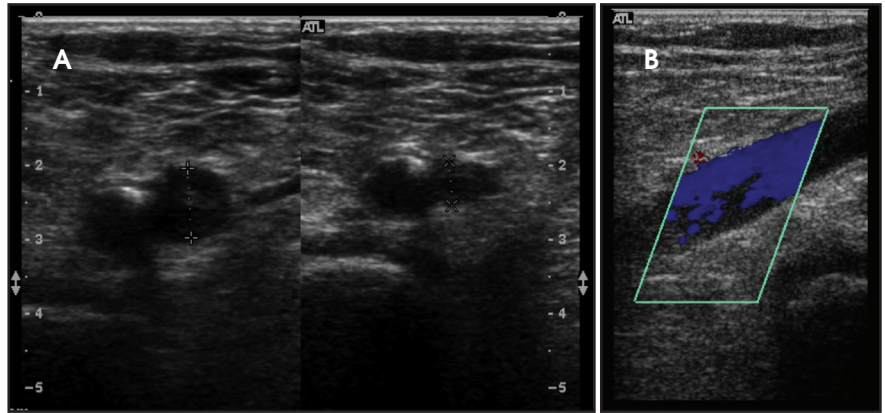
Up to two-thirds of patients with lower extremity (LE) DVT are asymptomatic, but this is very variable, depending on the specific reported series, the patient population, and the technique(s) used to identify or screen for DVT. A multicenter report of > 5000 patients with DVT on

ultrasound revealed PE in 14.5%, and 90% of these patients had signs and/or symptoms of DVT and/or PE. In this series there was unilateral LE DVT in 77%, bilateral LE DVT in 12% (with 15% of LE DVT isolated to the calf), and upper extremity (UE) DVT in 11%.<sup>1</sup> The prevalence of identifiable DVT in patients with PE is also very variable in the literature.<sup>2</sup> Acute DVT may embolize, resolve completely over time, or contract or scar with varying degrees of residual occlusion and obstruction, venous wall thickening, and damaged and incompetent venous valves.

For decades, conventional venography was the imaging test of choice for suspected DVT in the legs, pelvis, and



**FIGURE 1.** An 85-year-old woman with dementia, elevated D-dimer, and right lower extremity pain. Transverse gray scale images without (left) and with (right) compression show complete thrombosis (calipers) of the proximal right popliteal vein, which is only slightly compressible.



**FIGURE 2.** A 69-year-old man with acute left lower extremity edema. Lower extremity sonography from several months earlier (not shown) was normal. Transverse gray scale images (A) without (left) and with (right) compression show partial thrombosis and partial compressibility (calipers) of the left popliteal vein. Sagittal color Doppler image at this level (B) demonstrates partial thrombosis of the posterior portion of the vein.

inferior vena cava (IVC).<sup>3</sup> On conventional venography, clot is identified as a filling defect, or is implied by complete non-filling of a vein. Potential problems with conventional venography include the need for the patient to travel to a radiology department, difficulty in obtaining venous access, pain from the procedure, contrast reactions, interobserver disagreement, technical limitations, and paradoxical postprocedure DVT in a minority of patients.<sup>3</sup>

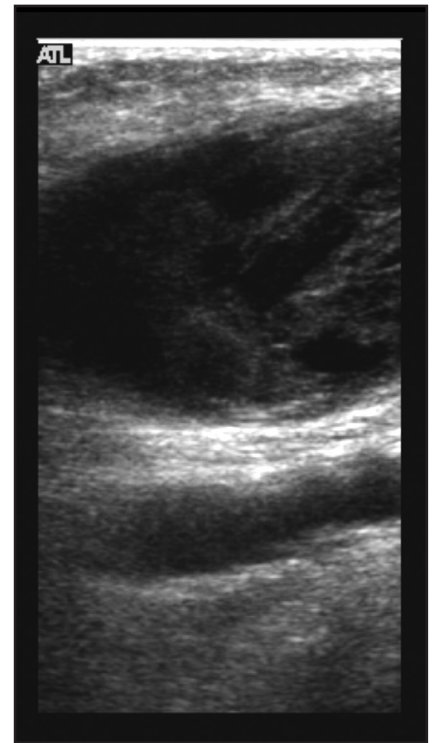
With the introduction of ultrasound (US) in the 1980s, and the subsequent universal adoption of US as the initial imaging examination of choice for suspected LE or UE DVT, LE venography is almost never done for diagnosis alone, but is used in conjunction with therapeutic procedures, and has occasional use for upper extremity and central thoracic DVT imaging.

### Ultrasound

The advantages of US include very high accuracy for thigh and arm evaluation for acute DVT, relatively low cost, portability, absence of ionizing radiation, and ready repeatability. Current techniques still rely primarily on compression sonography – if pressure from the US transducer completely collapses the vein, then DVT is absent, whereas DVT is present if the vein does not completely collapse. Depending on whether the thrombosis

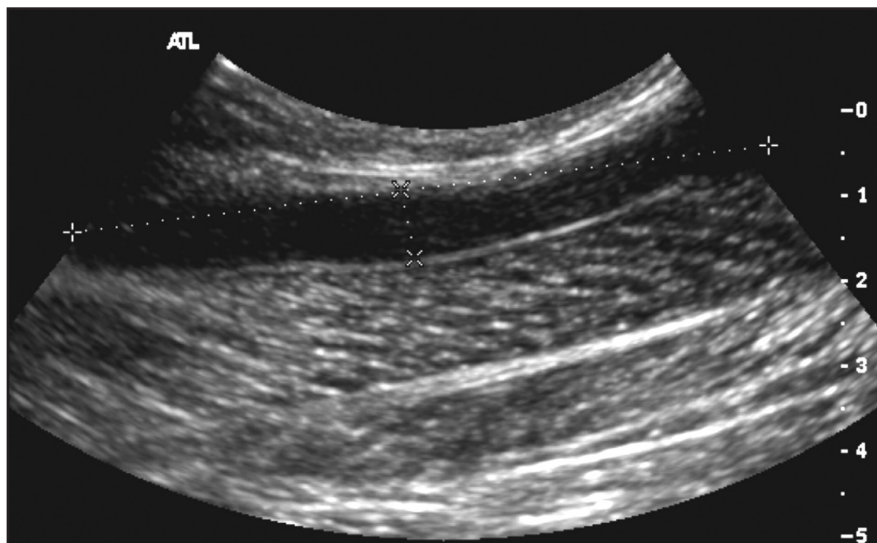
is incomplete or complete at a specific level, the vein may be partially collapsible, or not collapsible at all, respectively. In acute DVT, there may also be venous distention, which is variable, and the echogenicity and visibility of the clot is also variable.<sup>4</sup>

With US, transverse images are routinely obtained, without and with compression of the common femoral vein (CFV), the femoral vein (FV – formerly known as the ‘superficial’ femoral vein), and the popliteal vein (PV) along their course with a 5- or 7.5-MHz linear transducer. These images are supplemented with sagittal gray scale as well as color and spectral Doppler images (Figures 1 and 2). These latter images may be particularly helpful in obese patients, and when imaging deep areas, especially of the FV in the adductor canal.<sup>5</sup> Color and spectral Doppler images also provide indirect evidence of pelvic venous occlusion, as a monophasic waveform in the CFV is a reliable indicator of proximal venous obstruction.<sup>6</sup> Although routinely performed in our department and elsewhere, augmentation, where the calf is squeezed while simultaneously imaging more proximal deep veins with US, did not yield any additional diagnoses of DVT in a series of almost 2,000 examinations, so its utility is questionable.<sup>7</sup> If DVT is not identified, in a minority of patients an alternative diagnosis may be discovered (Figure 3), including

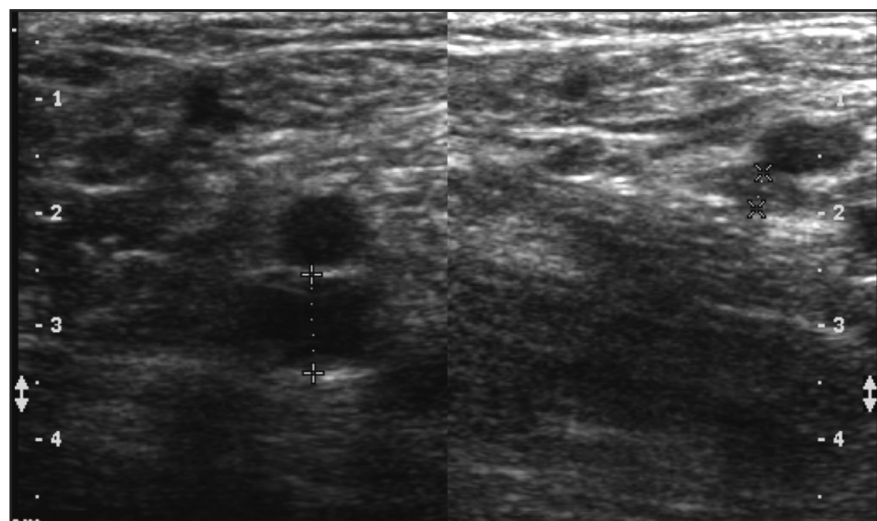


**FIGURE 3.** An 89-year-old woman with left lower extremity swelling. Sagittal gray scale image of the left popliteal fossa reveals a complex cyst, which was unchanged compared with previous sonographic examinations (not shown) and which did not demonstrate any flow on Doppler imaging (not shown). There was no evidence of DVT or evidence for rupture of the cyst.

hematoma and rupture of a popliteal fossa cyst (Figure 4).<sup>8</sup> The accuracy of US for DVT in the thighs of symptomatic patients approaches 100%.<sup>9</sup> However, US may be limited in obese patients, in



**FIGURE 4.** A 34-year-old man with acute left calf swelling. Sagittal gray scale sonographic image of the left calf shows an elongated, relatively hypoechoic collection with debris in the subcutaneous tissues, which is consistent with a hematoma. There was no evidence of either calf or thigh DVT (images not shown).



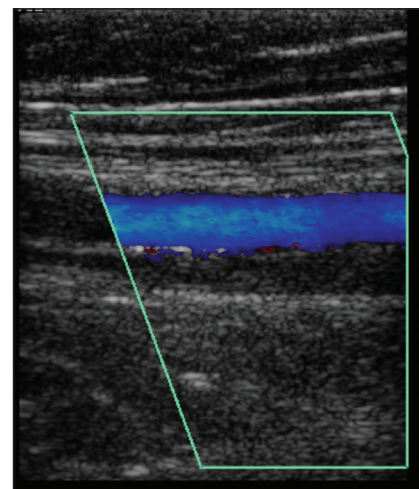
**FIGURE 6.** A 75-year-old woman with a history of DVT and inferior vena cava filter placement, now with lower extremity swelling. Transverse gray scale images of the left common femoral vein without (left) and with (right) compression show partial compressibility of the vein, and venous wall thickening (calipers), representing chronic DVT. Similar findings were present for the right common femoral and left popliteal veins (not shown).

patients with marked LE edema and in patients with overlying casts.

Controversy remains over whether to routinely image both lower extremities with US, or whether to image only the symptomatic LE.<sup>7,10,11</sup> Isolated contralateral DVT was rare in the series of almost 2,000 examinations,<sup>7</sup> and a negative unilateral LE US was associated with a low subsequent DVT and PE risk in a relatively recent meta-analysis.<sup>11</sup> However, many centers, including our

own, routinely scan both LEs in most patients. Additionally, some authors have advocated a limited US examination, with imaging at the inguinal region and behind the knee only.<sup>12</sup> However, up to 20% of patients with DVT isolated to the thigh have the thrombus only in the FV,<sup>13-15</sup> so the literature does not support this practice of 'limited' US.

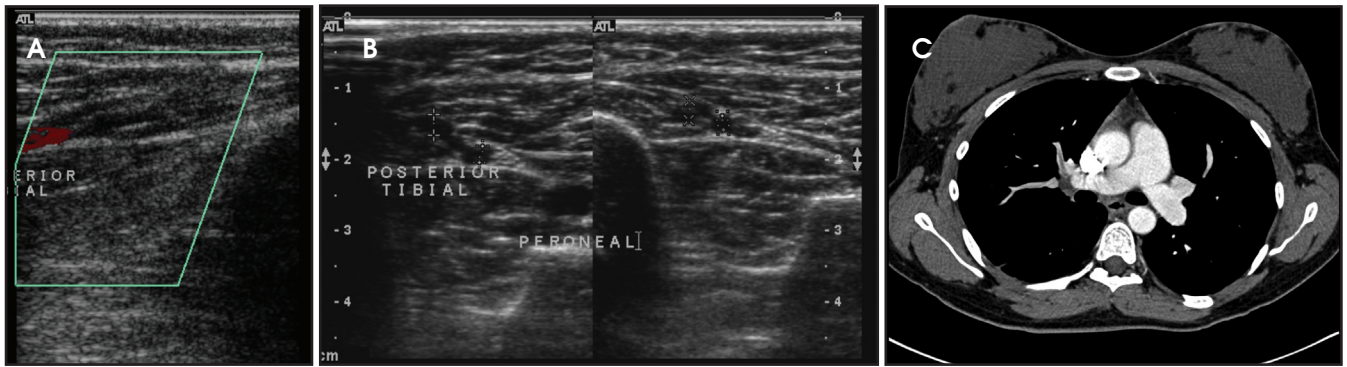
Potential pitfalls of US imaging for DVT include duplication of the FV, which occurs in upwards of 50% or



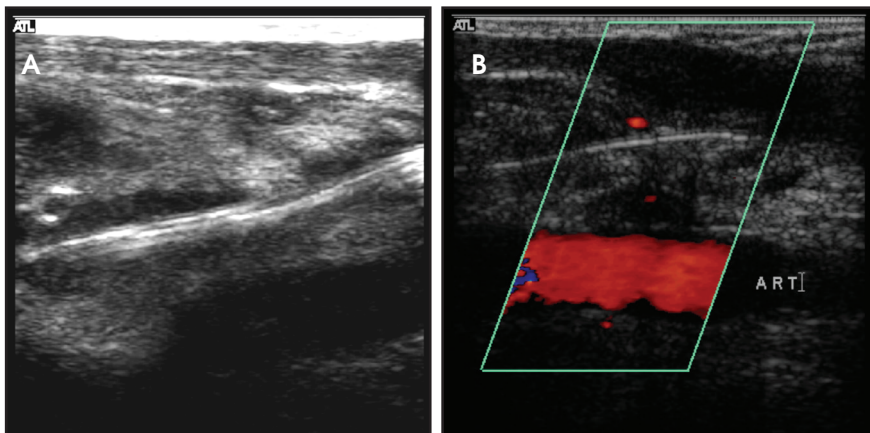
**FIGURE 5.** A 76-year-old woman with thrombosis of the medial limb of a duplicated left femoral vein. Color Doppler image in the coronal plane shows flow in the anterior limb (ie, lateral limb), but no flow in the posterior limb.

more of individuals, so if DVT is present in only one limb, US may be falsely negative if only the patent limb is identified (Figure 5).<sup>16,17</sup> Also, the IVC and iliac veins are challenging to routinely evaluate with US. In addition, correctly recognizing chronic DVT – and acute superimposed on chronic DVT – is problematic with all noninvasive imaging modalities, including US. Up to 50% of patients on follow-up US for acute DVT may have residual abnormalities.<sup>18</sup> Findings of chronic DVT on US include increased clot echogenicity, irregularly thickened venous walls, small-caliber veins, and collateral veins (Figure 6).

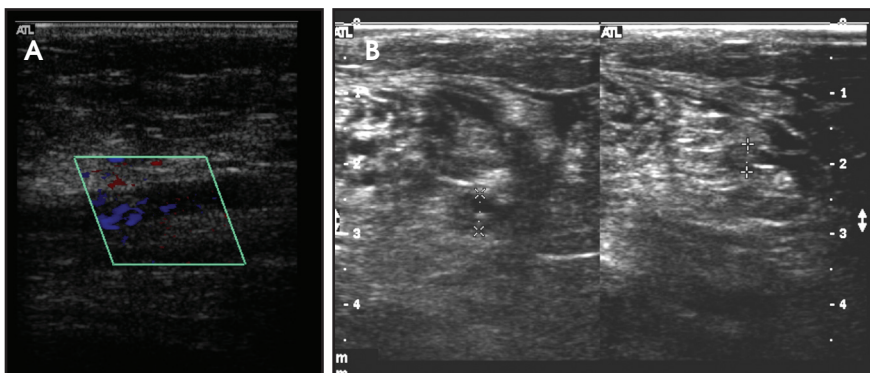
However, these findings may not necessarily be present, the echogenicity of chronic DVT is variable, and chronic DVT may not be readily distinguishable from acute DVT, particularly if there are no previous imaging examinations for comparison.<sup>18,19</sup> It is important to attempt to distinguish post-phlebotic syndrome from chronic DVT in symptomatic patients, and repeat US is very useful in this situation. Additionally, some authors have recommended that the US be repeated in DVT patients who become asymptomatic after initial treatment, to obtain a new baseline for future evaluation, and



**FIGURE 7.** A 34-year-old post-partum woman with fever and oxygen desaturation. Initial lower extremity sonography demonstrated no DVT in the thighs, but DVT was present in branches of the posterior left tibial vein, a deep calf vein. Sagittal Color Doppler image (A) and transverse gray scale images (B) without (left) and with (right) compression reveal no flow in the veins and lack of compressibility (calipers, B). CT pulmonary angiography (without venography) was then performed, which shows a right upper lobe embolism (C). There were also right middle lobe emboli (not shown).



**FIGURE 8.** A 90-year-old man with left upper extremity erythema and swelling, 9 days following pacemaker placement. Gray scale (A) and color Doppler (B) coronal sonographic images demonstrate thrombosis of the left mid and distal subclavian vein around the pacemaker wire.



**FIGURE 9.** A 75-year-old man with chronic lymphocytic leukemia and acute left upper extremity swelling. (A) Sagittal color Doppler image shows thrombosis of most of the left basilic vein, although there is a small amount of flow. (B) Transverse gray scale images without (left) and with (right) compression demonstrate incomplete compressibility of the left basilic vein (calipers).

to determine whether therapy should be continued or not.<sup>18,20</sup> Finally, the results of US in asymptomatic patients when compared with conventional venography (eg, in patients after

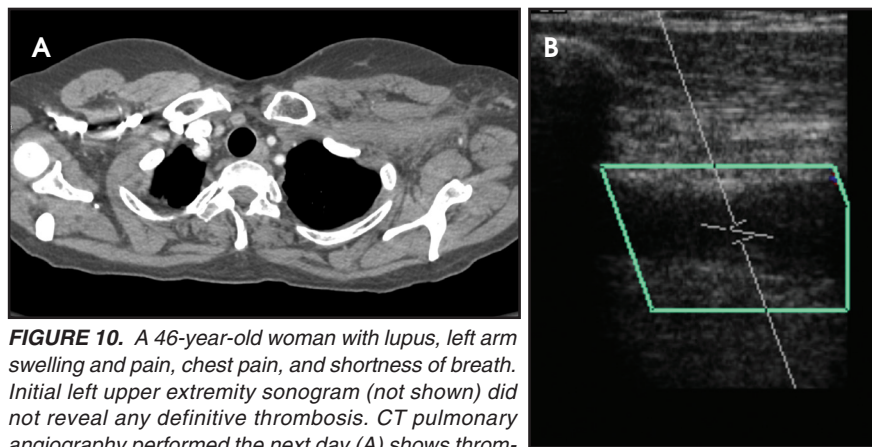
joint replacements) has been reported as poorer compared with symptomatic patients, as the clots are usually smaller and nonocclusive, and the incidence of calf DVT is much higher –

although these results are from older reports in the literature.<sup>21</sup>

The utility of US in patients with suspected PE but without signs or symptoms of DVT is controversial.<sup>15</sup> Proposed algorithms include performing US after an indeterminate ventilation-perfusion scan, or after a nondiagnostic CT pulmonary angiography (CTPA) examination, or as the initial imaging examination, but the incidence of DVT is variable in such patients.<sup>14,22,23</sup> If US is done first in patients with suspected PE, but with negative results, then PE is not excluded, while positive results assume—but do not prove—the presence of PE. If actually present, the extent of PE is not known based on US alone.

The deep calf veins are typically paired structures that accompany the arteries, but there are also soleal and gastrocnemius veins. The posterior tibial and peroneal veins are located between the calf muscles and are more susceptible to thrombosis, whereas thrombi are less frequent in the anterior tibial veins. US of the calves is not routinely performed at most centers because of the relatively low accuracy and the high incidence of nondiagnostic examinations.<sup>24</sup> However, if a patient specifically reports focal pain in the calf, then an attempt should be made by the sonographer to image this region.

The incidence, significance of, and therapy for isolated calf DVT remains controversial.<sup>25-28</sup> There are reports of up to 32% of patients with calf DVT



**FIGURE 10.** A 46-year-old woman with lupus, left arm swelling and pain, chest pain, and shortness of breath. Initial left upper extremity sonogram (not shown) did not reveal any definitive thrombosis. CT pulmonary angiography performed the next day (A) shows thrombosis of the left subclavian vein, extending from the axillary vein, but there was no evidence of pulmonary embolism. Because of the discrepancy, repeat sonography was performed (B), which confirmed left upper extremity deep venous thrombosis. There is no color or spectral flow on this representative coronal image through the left subclavian vein.

propagating on serial US, and up to 30% with recurrence of isolated untreated calf DVT within 3 months.<sup>29</sup> Both symptomatic and asymptomatic calf DVT appear to propagate superiorly with equal frequency.<sup>29</sup> Calf DVT has also been associated with the post-phlebotic syndrome. The incidence of DVT isolated to the calf is also not trivial; in one series, DVT isolated to the calves was reported in 57% of patients, and some patients with DVT isolated to the calf have concurrent PE (8% in one series) (Figure 7).<sup>14,30,31</sup> In a recent series of 137 patients with LE DVT who underwent CT venography, the most common site was in a muscular calf vein.<sup>32</sup>

Some authors recommend follow-up thigh US at one week, particularly if patient symptoms continue, but the initial US examination is negative for the thighs, so as to not miss calf DVT propagating to the thighs.<sup>12,24</sup> However, this recommendation is usually not followed by most practices.<sup>33</sup>

The incidence of UE DVT has increased in recent years, due to the more widespread use of central venous catheters, pacemakers, automated implanted defibrillators, and other devices (Figure 8). UE DVT may also occur as a result of hypercoagulability, malignancy, low-flow states, and ‘effort’ thrombosis in young athletes (especially in men with underlying thoracic outlet syndrome).<sup>34-36</sup> Signs and symptoms of UE DVT include

pain and swelling, but are, as with LE DVT, not particularly specific.

The exact association of UE DVT with clinically significant PE is not known to our knowledge, although the risk has been estimated at 15%.<sup>37</sup> However, in a recent series of 300 patients with UE DVT, most of whom were symptomatic, there was a low (2%) incidence of documented pulmonary embolism.<sup>38</sup> The initial test of choice for suspected UE DVT as noted is US, which is up to 95% accurate.<sup>39</sup> Only the symptomatic side is evaluated, in contrast to LE US. The axillary, brachial, basilic, and internal jugular veins are imaged with compression, supplemented with color and spectral Doppler (Figure 9). The subclavian vein is not easily compressed due to the overlying clavicle, and the central portions of the brachiocephalic veins are not routinely visualized, so reliance is made on color Doppler and on secondary signs, including absence of pulsatility and respiratory variation in positive cases.<sup>37</sup> CT and MR are useful for imaging suspected central venous thrombosis where initial US is equivocal or nondiagnostic (Figure 10).

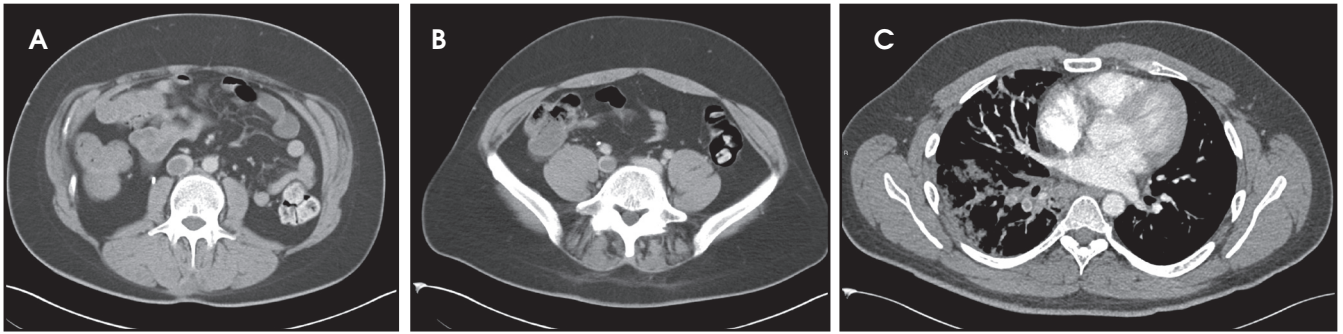
### CT venography

CT pulmonary angiography is the noninvasive imaging examination of choice for suspected PE in most situations. Since PE and DVT are both as-

pects of VTE, imaging the deep veins with CT immediately after imaging the thorax for suspected PE can demonstrate the presence or absence of DVT, as well as the overall burden and distribution of DVT. Combined CT venography and pulmonary angiography, a.k.a. CTVPA, is a “one-stop examination,” requiring only a few additional minutes—although the overall radiation dose is higher, there are more images to review, and the dose of IV contrast needs to be higher for optimal venous enhancement compared with CTPA alone.<sup>14,40</sup> CT venography (CTV) is useful even if CTPA is positive, for identification of co-existent DVT in the thighs, calves, abdomen, and pelvis, serves as a baseline for future comparison, and occasionally may influence patient management. CTV may also salvage the occasionally nondiagnostic or limited CTPA examination, and serves as a road map for therapy.<sup>14</sup> CTV permits routine evaluation of the deep veins of the calves, the iliac veins/IVC, and the profunda femoral vein, none of which are routinely well evaluated with US (Figures 11 and 12). CTV also occasionally demonstrates the reason for VTE, such as compression from adenopathy or a mass in the pelvis, as well as alternative diagnoses. A clearly positive or negative CTV component of the CTVPA examination may improve confidence in interpretation of the CTPA component if it is less conclusive one way or the other, in our experience. CTVPA is still routinely performed on most of our patients undergoing CTPA—unless the patient: a) is pregnant; b) had a recent negative or positive leg ultrasound examination (occasionally we will still perform CTV, depending on the specific situation); c) is a child or young adult (we also consider these on a case-by-case basis, but often do not perform CTV); or d) there is a low clinical index of suspicion for VTE, but CTPA is still requested.<sup>14</sup>

CTV images are acquired at 3 to 3.5 minutes from the start of IV contrast administration for CTPA.

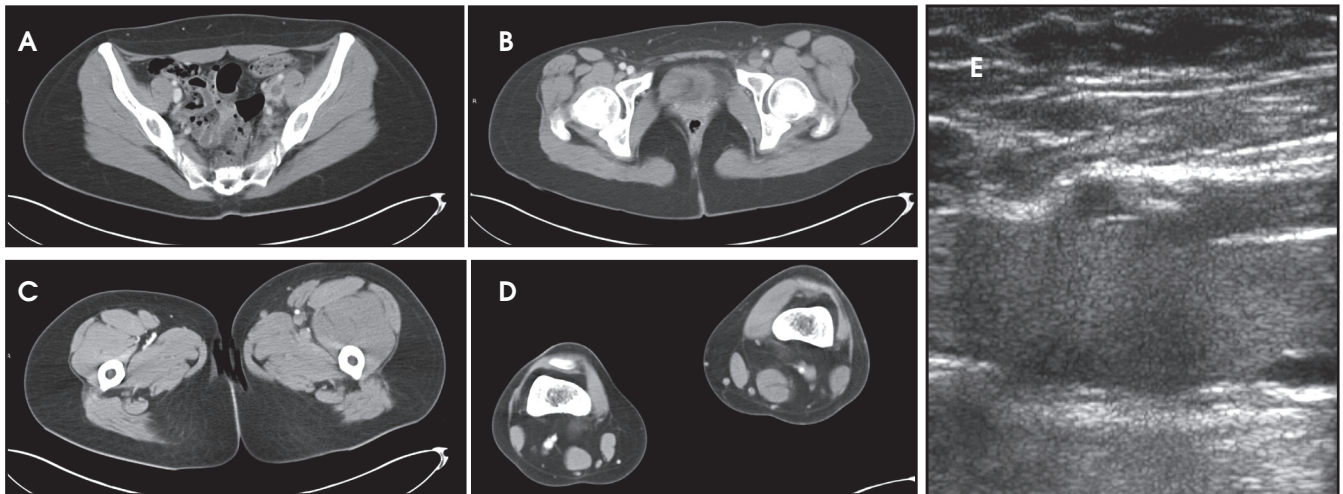
We previously obtained consecutive 5-mm images in groups of four, with 2- to 3-cm gaps, from the diaphragm to the



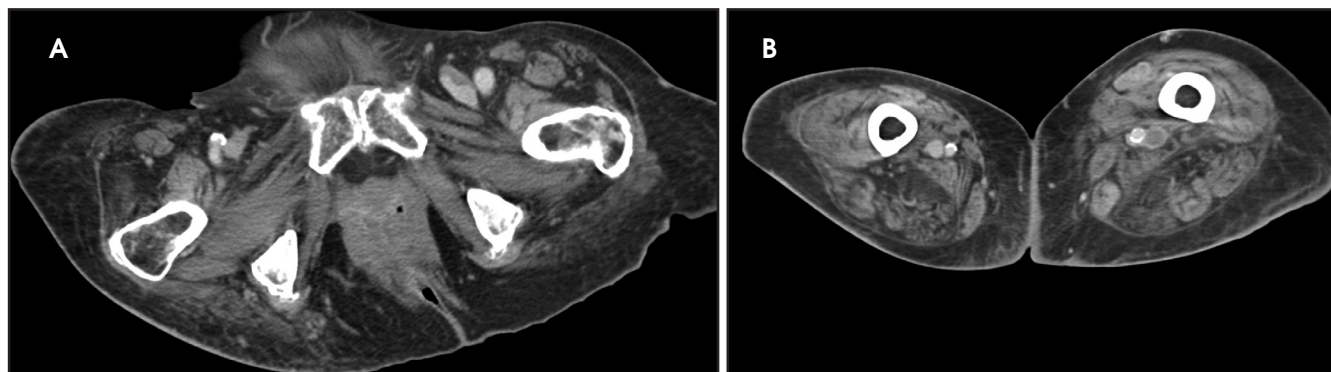
**FIGURE 11.** A 31-year-old man with acute pleuritic chest pain, dyspnea, and tachycardia following recent mid-lumbar laminectomy and fusion. Combined CT venography and pulmonary angiography demonstrated inferior vena cava and right iliac venous thrombosis, as well as right pulmonary emboli and associated infarctions, but no lower extremity DVT. (A) Transverse CT venography (CTV) image shows thrombus filling most of the lumen of the inferior vena cava (arrow). (B) Transverse CTV image demonstrates thrombus in the right common iliac vein, which is contiguous with the caval thrombus. (C) Transverse CT pulmonary angiography image shows emboli in two right lower lobe segmental arterial branches, as well as multiple areas of peripheral pulmonary infarction.



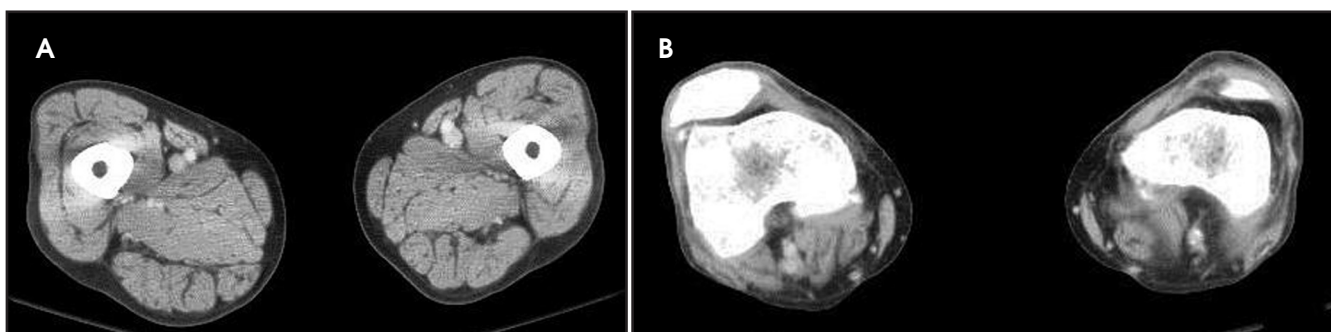
**FIGURE 12.** A 79-year-old man with suspected 'breakthrough' pulmonary embolism, presenting with new shortness of breath and right lower extremity swelling. Combined CT venography and pulmonary angiography confirmed right central pulmonary embolism (not shown) and diffuse pelvic and upper thigh DVT, right greater than left, as well as right calf DVT. (A) Transverse CTV image reveals thrombosis within the caval filter. (B) Transverse CTV image at level of the symphysis pubis reveals expansile thrombosis of the right common femoral vein, with venous wall enhancement and perivenous edema, as well as partial thrombosis of the left common femoral vein. (C) Transverse CTV image demonstrates thrombosis of a proximal left calf vein. Note the soft-tissue edema.



**FIGURE 13.** A 29-year-old woman with acute chest pain, acute left leg edema and discoloration, and history of birth control pill use. CT venography (A, B, C, and D) was initially performed in conjunction with CT pulmonary angiography (not shown), which demonstrated bilateral pulmonary emboli and pulmonary infarctions. (A) Transverse image through the pelvis shows thrombosis of the left external iliac vein, with enhancement of the venous wall and perivenous edema. (B) Transverse image of the lower pelvis shows thrombosis of the left common femoral vein and perivenous edema. (C) Transverse image of the upper thighs shows left muscular swelling and thrombosis of the left femoral and left profunda femoral veins. (D) Transverse image through the distal thighs shows thrombosis of the left popliteal vein. Note expansion of all of the thrombosed veins (A-D). (E) Follow-up sonography performed later the same day confirmed diffuse thrombosis of the left lower extremity deep venous system. This representative sagittal gray scale image demonstrates echogenic thrombus expanding the left common femoral vein.



**FIGURE 14.** A 78-year-old woman with suspected pulmonary embolism. CT pulmonary angiography (not shown) revealed pulmonary edema and pleural effusions, but no evidence for pulmonary embolism. The CT venography portion of the examination (A,B) showed left inguinal and thigh deep venous thrombosis. (A) Transverse CTV image at the level of the symphysis pubis shows partial thrombosis of the left common femoral vein. (B) Transverse CTV image of the mid thighs shows expansile thrombosis of the left femoral vein, which is consistent with acute DVT. Note venous wall enhancement, and generalized edema and swelling of the left thigh.



**FIGURE 15.** A 79-year-old woman with tachycardia and findings of chronic DVT on CT venography. There was no evidence of pulmonary embolism on CT pulmonary angiography (not shown), nor was there evidence for acute DVT. (A) Transverse CTV image through the mid thighs reveals subtle posterior wall thickening and focal calcification along the left femoral vein. (B) Transverse CTV image through the distal thighs demonstrates a shrunken left popliteal vein.

ankle. We administer between 120 and 150 mL of iodinated contrast, depending on patient weight. Clot is identified as a filling defect within a deep vein. Acute DVT often expands the vein, and has associated perivenous edema and enhancement of the venous wall.<sup>41,42</sup> We previously preferred this “survey” technique to continuous images, to reduce overall radiation burden and the number of images to review. The goal was to identify potentially important clot burden, but not every short-segment DVT. However, with our newest CT scanners, we determined that obtaining continuous images actually results in a lower overall radiation dose than with our previous protocol, and also permits creation of 3-dimensional and other reformations, so we have recently switched to routine acquisition of continuous images for CT venography. One can also lower the kVp to improve

vascular enhancement and lower radiation exposure.<sup>42-45</sup>

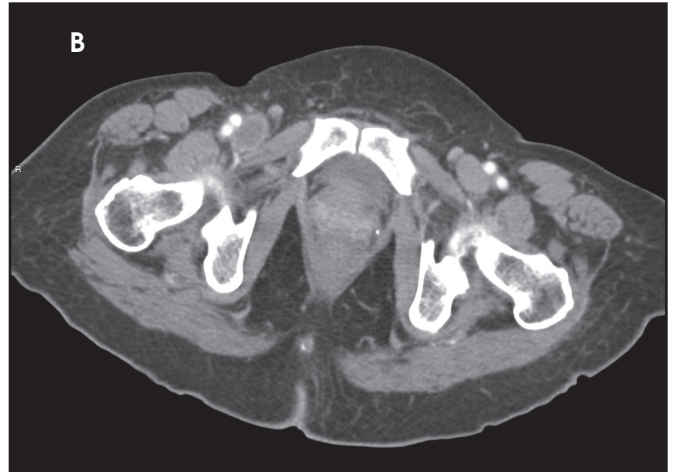
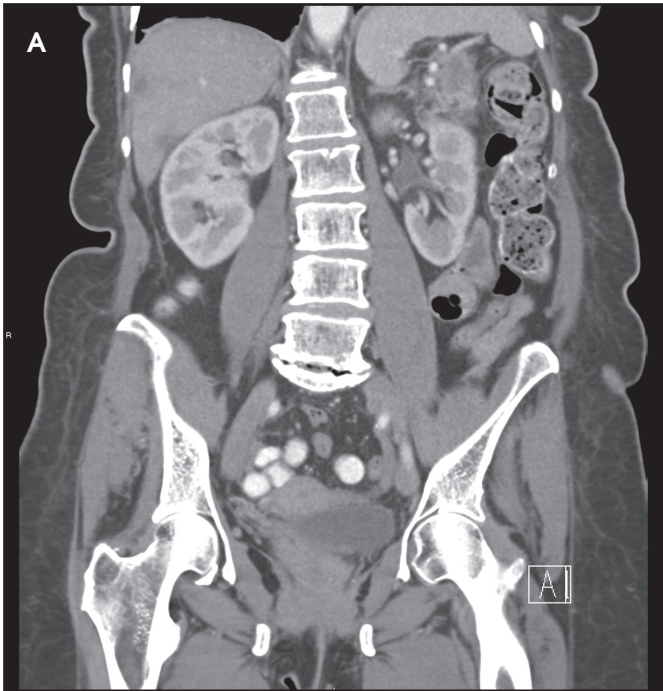
High accuracy has been reported for CTV for thigh DVT identification or exclusion, using US as the reference standard, and the addition of CTV to CTPA has increased the overall diagnostic yield of VTE by 20% to 27% in several series.<sup>41,46-48</sup> When CTV was added to CTPA, the sensitivity for VTE increased from 83% to 90% in the PI-OPED II study, although the absolute increase in VTE was small.<sup>49</sup> The PI-OPED II study also supported the use of discontinuous CTV images, as there was little difference between them and contiguous images in the same 150 examinations. There was 89% agreement and equivalent accuracy to lower extremity sonography for these patients.<sup>50</sup>

CTV readily reveals complex anatomy and pathology; eg, superficial venous thrombosis with or without

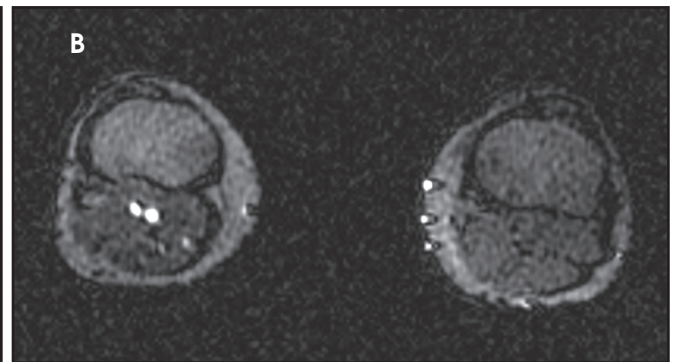
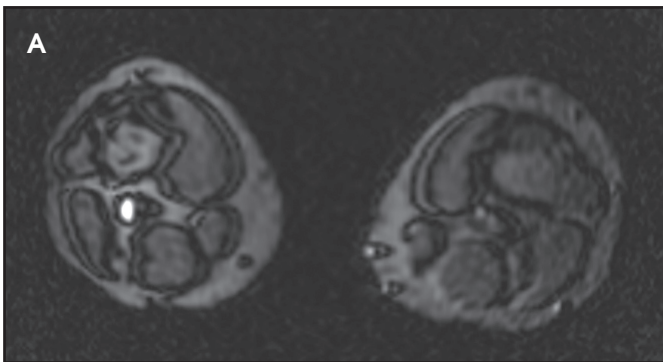
concurrent DVT, associated soft-tissue abnormalities, DVT in the profunda femoral vein, which is an area not usually imaged with US; iliac DVT, and calf DVT—although, as noted, the clinical importance of calf DVT remains controversial. But in contrast to its appearance on US, calf DVT is usually obvious on CTV in our experience (Figure 13).

### Issues with DVT

There are various controversies regarding CTV: whether to do it at all, when to do it, how to do it (eg, with or without the calves and/or the abdomen and pelvis); whether it is cost effective; and how much evidence supports its use in different scenarios.<sup>51-54</sup> Recent literature has been mixed, but is still overall more positive than negative towards the utility of CTV. This reflects the decreased yield of CTV, as CTPA



**FIGURE 16.** A 79-year-old woman with elevated liver function tests. Sonography of the right upper quadrant (not shown) demonstrated liver lesions consistent with metastases, prompting CT of the abdomen and pelvis, which showed a pancreatic tail mass (A, coronal reformatted), representing previously unknown pancreatic adenocarcinoma. Transverse image at bottom of the CT examination (B), at the level of the symphysis pubis, demonstrates expansile thrombosis of the right common femoral vein.



**FIGURE 17.** A 45-year-old man with known left lower extremity DVT related to acute knee injury. Noncontrast MR venography was performed in conjunction with routine MR of the left knee, for short-term follow-up of the DVT as well as for evaluation of suspected patellar tendon injury (which was present, not shown). (A) Transverse gradient recalled-echo image (bright-blood MR venography technique) of the lower thighs demonstrates normal flow in the right proximal popliteal vein (left portion of image), and thrombosis of the left proximal popliteal vein (right portion of image). A transverse image through the proximal calves from the same sequence (B) shows flow in deep right calf veins, but no flow in the deep left calf veins.

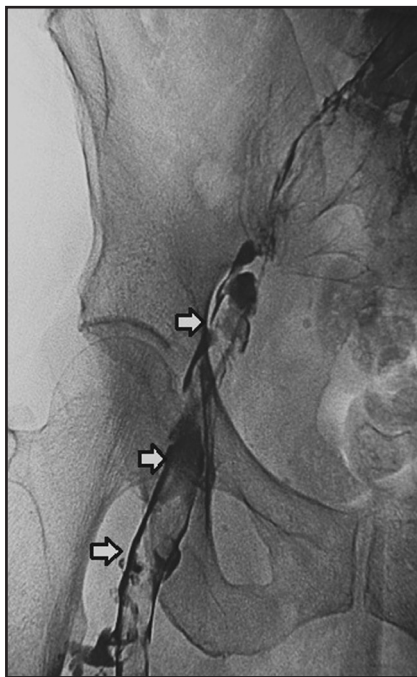
has become more widely used in recent years, as a result the positive rate of CTPA has decreased, and correspondingly the yield of CTV has decreased. There is also concern regarding the increased radiation exposure of combined CTPA and CTV, compared with CTPA alone.<sup>55-61</sup> The most recent literature shows a lower but nontrivial increase of 3% to 11% in the diagnosis of VTE when CTV is added to CTPA (Figure 14).<sup>55,56,60-62</sup> The yield of CTV for pelvic DVT identification was higher in the older literature<sup>46</sup> and is also greater in high-risk patients,<sup>57</sup>

whereas more recent series have shown a much lower yield for pelvic DVT.<sup>59</sup> The recent focus in the literature on CTV in general has been mainly on this lower additional yield, as well as on the high negative predictive value of CTPA alone if negative for subsequent PE. But there are other benefits of performing CTV as noted above, even when CTPA is positive, and there is relative consensus regarding the appropriateness of adding CTV to CTPA in high-risk patients.<sup>56-58</sup> We believe the focus should be on reducing unnecessary CTPA examinations to begin with,

rather than on the complete elimination of CTV from CTPA protocols.

As with other cross-sectional imaging examinations, accurate detection of chronic DVT is also problematic and not well studied on CTV. However, reported findings of chronic DVT on CTV parallel those on US—small veins, partial filling defects, absence of perivenous edema and venous wall enhancement, and venous wall/thrombus calcification (Figure 15).<sup>14,63</sup>

A relatively small percentage of CTV examinations are nondiagnostic, particularly in patients with poor cardiac



**FIGURE 18.** Frontal image from a catheter venogram shows diffuse thrombosis of the right iliac and upper thigh central venous system (arrows).

function and/or substantial lower extremity atherosclerosis.<sup>14,64</sup> Opacification of the deep veins may be suboptimal in these patients, and/or mixing artifacts may be difficult to differentiate from true DVT, although the latter usually has well-defined margins, especially when viewed with narrow windows. In general, if CTV is equivocal or nondiagnostic and/or additional information is needed regarding the lower extremities, US should then be performed. We believe that in this situation and in others that US and CTV are complementary in a subset of patients, and may help to resolve problematic findings encountered on either examination.

Contiguous multidetector CT venography, with corresponding multiplanar reformations, can be performed to provide detailed information in select patients (eg, those with iliofemoral DVT) or in patients with complex known or suspected venous pathology (eg, in chronic venous insufficiency, where the vascular surgeon is deciding what therapy, if any, is possible).<sup>65</sup> In a series of 56 patients with iliofemoral DVT (44 left-sided), volumetric CT venography

revealed anatomic abnormalities (particularly compression of the left common iliac vein by the right common iliac artery, which was exaggerated by a bony spur in 9 patients) in 45 patients.<sup>66</sup> We use such acquisitions for occasional problem solving – eg, after a nondiagnostic US, without concurrent CTPA.

The radiologist should also be aware that, just as patients undergoing contrast-enhanced CT examinations of the chest and/or abdomen will occasionally demonstrate unanticipated PE, periodically they will encounter an unanticipated DVT on abdominal and pelvic CT, which could be missed if not included in the search pattern (Figure 16). In some cases, the diagnosis will be apparent even though delayed images were not specifically obtained (to optimize opacification of the systemic veins and to simultaneously decrease mixing artifacts, as with CTV), whereas in other cases the diagnosis may be difficult, and if the patient has already left the CT suite, confirmatory US may be indicated to resolve the issue.

### MR venography (MRV)

MR venography has high accuracy compared with conventional venography for the pelvic and thigh veins, but is less accurate for the calves. A variety of sequences can be utilized, including spin-echo, gradient-recalled echo, and gadolinium-enhanced images.<sup>67-69</sup> MRV is also advantageous for imaging suspected central thoracic venous thrombosis: The veins are readily evaluated, in contrast to US, and the cause of thrombosis—eg, a central mass—can be identified. Central thoracic DVT can also be identified on CTPA/routine contrast-enhanced chest CT, although evaluation may be difficult on the former due to the arterial phase of image acquisition.

DVT findings on MRV include absent venous flow/filling defects, and perivenous inflammation, analogous to those on CTV (Figure 17). MRV may be superior to US for determining the chronicity of DVT, although this has not been well studied.<sup>19</sup> MRV is occasionally used as a problem-solving tool, especially for pelvic vein imaging

(particularly in pregnancy, when pelvic DVT may be an issue), and to avoid radiation exposure. The true frequency of pelvic DVT is underestimated with US—and in patients whom are pregnant, or patients who have had recent surgery or have a known or suspected pelvic malignancy, DVT may begin in the pelvis and propagate inferiorly into the thighs.<sup>70-72</sup>

In patients with a contraindication to iodinated contrast who can receive gadolinium, combined MR pulmonary angiography and MR venography can be performed. Axial T1-weighted/GRE images can be obtained after MR pulmonary angiography (MRPA), analogous to CTVPA, with the gadolinium augmenting the MR signal in patent veins. A combined MR pulmonary angiography and venography protocol increased the yield by 16% compared with MRPA alone in one study.<sup>73</sup> In a recent report using a blood pool MR contrast agent, simultaneous MR arteriography and venography performed in 245 patients (undergoing 295 MR examinations) with suspected arterial disease, there was an 11% incidence of unsuspected DVT in the lower extremities.<sup>74</sup>

### Conventional venography

Conventional catheter diagnostic venography (Figure 18) is now limited to specific scenarios: prior to placement of IVC filters; evaluation of central DVT in the proximal arms and thorax; as a prelude to interventions, such as thrombolysis, thrombectomy, and stent placement; with indeterminate US in obese patients or patients with a markedly swollen leg; and when other modalities do not or cannot solve a specific problem (eg, in suspected calf DVT in patients with negative or indeterminate US, where the findings would potentially change management, although this scenario can be also evaluated with CTV or MRV).

When portions of the subclavian and innominate veins and superior vena cava cannot be visualized, which as noted is a common situation with US, reliable evaluation can be performed

with catheter venography, with a contrast injection into the antecubital vein or via basilic or brachial vein access, with catheterization of the subclavian vein, under fluoroscopic control.

Conventional venography is performed routinely immediately prior to IVC filter placement, to evaluate for thrombosis in the path of the filter deployment, to search for an underlying venous anomaly, and also to measure the IVC to determine the type and size of filter to place. At our institution, we routinely hand inject into the ipsilateral iliac vein when planning to place an IVC filter via the femoral approach, to evaluate for iliac DVT. We then perform an "IVC gram" via a left iliac venous injection to look for congenital anomalies. We then perform a selective left renal venogram to check for a circumaortic renal vein, which can serve as a collateral pathway for emboli around the IVC.

## Conclusion

Ultrasound is the imaging examination of choice for suspected lower- or upper-extremity deep venous thrombosis. Ultrasound has high accuracy in symptomatic patients for evaluation of the deep thigh veins and the central arm veins. Ultrasound is less accurate for the calf and pelvic veins and in asymptomatic patients. Combined CT pulmonary angiography and CT venography permits comprehensive assessment for pulmonary embolism and deep venous thrombosis, and serves as a road map for therapy, although the reported yield of CT venography has decreased substantially in recent years as CTPA has been increasingly utilized/over-utilized, and CTV is not routinely performed in conjunction with CTPA at most institutions/practices, although there is still evidence to support its use, especially in high-risk patients. MR venography is a helpful problem-solving examination, and can be combined with MR pulmonary angiography. Conventional venography is mostly of historical interest when used solely as a diagnostic examination for the lower extremities, although venography via an inguinal

approach is still performed at some centers, including ours, as a road-mapping technique immediately prior to IVC filter placement. Venography of the lower and upper extremities is also routinely performed as part of a variety of therapeutic procedures for DVT, including thrombolysis, percutaneous thrombectomy, angioplasty, and stent placement.

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