Point-of-care ultrasound for deep venous thrombosis of the lower limb

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Abstract

The incidence and morbidity of deep venous thrombosis (DVT) and pulmonary embolus are high. Although efforts to increase screening for DVT have been recommended, this is limited by resources. Venous duplex ultrasound has replaced venography as the first-line investigation of choice for DVT, increasing availability and reducing patient exposure to radiation and intravenous contrast. Furthermore, an abbreviated ultrasound where DVT is inferred from incomplete venous compressibility has an equivalent accuracy to venous duplex, requiring less time and training enabling its widespread use by emergency, critical care and anaesthesia clinicians. In this review, the evolution and method of lower limb venous compression ultrasound is described along with evidence for its use in patients at high risk for DVT in these clinical settings.

Keywords: deep venous thrombosis, screening, point-of-care ultrasound, venous Doppler ultrasound, compression venography.

Introduction

Venous thromboembolism (VTE), which comprises deep venous thrombosis (DVT) and pulmonary embolus (PE), is the third commonest vascular disorder in Caucasian populations,[1] and in Australia, DVT alone (without concomitant PE) affects 52 persons per 100,000 annually.[2] Approximately 2 million patients are diagnosed with a deep venous thrombosis (DVT) annually in the United States,[3] resulting in estimated 600,000 hospitalisations and 200,000 deaths resulting from pulmonary embolism (PE),[4,5] and the short-term mortality rate from untreated pulmonary embolus probably exceeds 20%.[6] It is estimated that many more cases of DVT are not diagnosed and hence improvements in diagnosis of VTE is a priority.[7]

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doi: 10.1002/ajum.12188

In many regions, ultrasound has replaced venography as the first-line investigation of choice for DVT[8–13] due to its comparable (but slightly lower) accuracy[9,13] with the lack of exposure to staff and patients to radiation and lack of exposure to patients to intravenous contrast. Venography is now usually reserved for when ultrasound is not adequate or available.

The basic principles of ultrasound identification of DVT (known as ‘venous duplex’) are visualisation of a thrombus within vein lumen, which results in reduced or absent blood flow in the vein using colour flow and spectral Doppler. It has been realised that inability to completely compress the vein with the ultrasound probe has an equivalent accuracy (false-positive and false-negative predictive value) to venous duplex, and this technique can be easily taught to non-radiologists and non-sonographers, enabling point-of-care application and therefore potentially saving considerable time and cost of referring patients to the radiology department. This technique is usually referred to as lower limb venous two- or three-point compression ultrasound, depending on the number and site of compression points, and is becoming popular in emergency, critical care and perioperative medicine. In this review, the evolution and method of lower limb venous compression ultrasound is described along with evidence for its use in emergency medicine, critical care and the current evidence for its use in pre-operative screening in patients at high risk for DVT.

Sonoanatomy of the lower extremity deep venous system

Starting proximally, the highest vessels that are usually identifiable with linear probe ultrasound are the external iliac vessels (Figure 1). The external iliac vein becomes the common femoral vein as it passes under the inguinal ligament.

The common femoral vein is usually 2–4 cm in length, receiving three tributaries, being the great saphenous vein (superficial vein), profunda femoral vein and femoral vein (deep veins). The greater saphenous vein is a superficial vein, which receives venous blood from the anterior medial calf and the foot and runs up along the medial aspect of the thigh. It also usually has a valve in its terminal portion (terminal valve).[14] The femoral vein is a deep vein, which drains most of the lower limb and may contain a valve either proximal and/or distal to the junction with the greater saphenous vein. The femoral vein may be dual and can be either medial, lateral, deep or superficial to the femoral artery. The femoral vein continues through the adductor canal where it then forms the popliteal vein, which receives most of the venous drainage from the calf. The popliteal vein is usually superficial (lies on top) of the popliteal artery. The popliteal vein receives several branches including the anterior tibial veins (deep veins) and the small saphenous vein (superficial vein). The posterior tibial veins are in the posterior compartment of the leg and travel with the posterior tibial artery. The posterior tibial veins receive blood from the

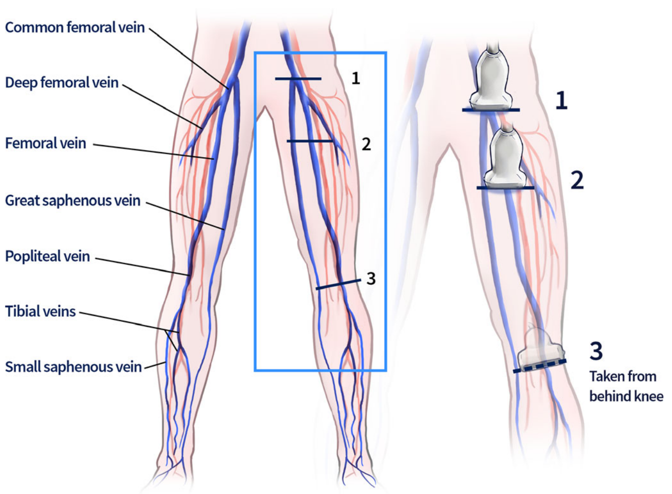

Figure 1: Sonoanatomy of the lower extremity venous system.

plantar surface of the foot and pass between the medial malleolus and Achilles tendon, then enter the posterior compartment of the calf. They run supero-medially along the lower leg. The soleal sinus is major storage for blood embedded in the soleus muscle. It empties into either posterior tibial or popliteal vein. The soleal sinus is a common site for thrombosis to originate.

Lower limb venous compression ultrasound

The conventional venous duplex examination performed includes ultrasound of the entire venous system of the lower leg. However, the sensitivity of detection of DVT below the knee with ultrasound has been reported as low as 38%.[14] In addition, the management of below-knee DVT is controversial, as the proximal propagation rate may be low, with some guidelines recommending serial ultrasound examinations to detect proximal propagation of thrombus before commencement of treatment.[15] For this reason, the compression ultrasound techniques have been restricted to above the knee. This practice was verified as appropriate in a report that found above-knee compression ultrasound to be comparable to whole leg venous ultrasound for the management of symptomatic outpatients with suspected lower extremity deep venous thrombosis.[16]

Lower limb venous compression ultrasound was initially reported as a two-point compression technique, where the two points compressed are (i) the common femoral vein, in the region where it communicates with the greater saphenous vein and profunda vein, and (ii) the popliteal vein. The sensitivity and specificity of two-point venous compression approach those of the comprehensive venous duplex scan (data presented below in the emergency and critical care medicine sections). However, as approximately 6% of DVTs are found in the femoral vein,[17] which is in between these two compression points, it is possible that a femoral vein thrombus may be missed using the two-point technique. A three-point compression ultrasound technique has since been reported, adding the femoral vein, and when compared to two-point compression and venography, the three-point technique was shown to be more sensitive than the two-point technique.[18] Although the compression ultrasound refers to compression points, it is probably better to compress the veins above and below the defined three points to reduce the chance of missing a thrombus, which has led some practitioners to use the term compression zone rather than compression point.

With regard to the safety of performing point-of-care lower extremity ultrasound, a literature review from 2007 revealed no articles demonstrating whether or not compression ultrasound results in progression of DVT.[19] However, in the presence of an acute and mobile clot in the femoral region, common sense dictates that excessive compression and manipulation should be avoided.

The method of lower limb venous compression ultrasound is described in Table 1 and Video S1 below, and the limitations of lower limb venous compression ultrasound are summarised in Table 2.

Table 1: Performing two- and three-point lower limb compression ultrasound for diagnosis of deep venous thrombosis.

Step	Description
Equipment	• High-frequency linear transducer (superficial) • Curvilinear transducer (deeper structure or if obese) • Colour flow (Video S2) or spectral Doppler may be required to confirm whether a vessel is an artery or a vein
Patient positioning	• Reversed Trendelenburg position with the bed tilted up to 20° to allow venous dilatation from blood pooling • Knee 20–30° bend and hip 30° externally rotated (frog's leg position) to allow full access to the medial part of the thigh and the popliteal fossa (Figure 2) • The popliteal vein can also be evaluated with the patient in decubitus position with the study leg side up
Examination technique	• Discrimination of arteries and veins is critically important, and the following features are useful: o Veins are easier to compress with external force from the probe than arteries, which is the most reliable technique. Only veins contain valves o Arteries have a more visible (thicker) wall, are pulsatile and may have atherosclerosis • The relationship of the artery to the vein is not a reliable method of discrimination between the two types of vessel • If any doubt, colour or pulsed-wave Doppler can be used (Video S2)
Examination technique	• Transverse 2-D ultrasound imaging with compression • Probe's indicator to the patient's right • Three-point technique examines the junction of the common femoral and greater saphenous veins, the femoral vein and the popliteal vein and GSV (Figures 1 and 3) • Two-point technique examines the junction of the common femoral and greater saphenous veins and the popliteal vein • The common femoral vein represents the most medial vessel inferior to the inguinal ligament, which connects the pubic symphysis to the anterior superior iliac spine. The common femoral vein usually extends 2 cm proximal and 2 cm distal to junction point between the common femoral and greater spahenous veins • Point 1 is defined at the junction of the common femoral and greater saphenous veins, which has a clinical significance where DVT at the junction point should be treated. In this view, the femoral and profunda femoral arteries are usually visualised (Figure 4) • Point 2 is defined at the femoral vein, which is essentially located in the adductor canal below the junction of profunda femoral and femoral veins (Figure 4) • Point 3 is defined at the popliteal vein and is located in the popliteal fossa (Figure 5) • With the indicator pointed to the patient's right, the PV is located in the near field of the image and is anatomically more posterior when compared to popliteal artery • Examiner will image the veins at the three described points, then will apply compression in an attempt to completely compress the vein (Video S1)
Assessment of deep venous thrombosis	• In the absence of DVT, the walls of the vein should coapt, completely obliterating the vein's lumen, and the adjacent artery may become deformed with compression (Video S3) • Non-compressible vein indicates the presence of DVT (Videos S3 and S4) • Note the degree of occlusion: irregular, heterogenous • Form, length and mobility • Acute thrombus: anechoic to hypoechoic, poorly attached, spongy texture, dilated vein • Chronic thrombus: hyperechoic or brightly echogenic, well attached, rigid texture, calcifications, contracted vein, large collaterals, thickened vein walls[48]
Associated features	• Raised D-dimers • Wells score[49] • Lung: subpleural infarcts[26] o Heart (in larger PE's): right ventricular dilatation and dysfunction and D-shaped septum,[50] dilated inferior vena cava, McConnell sign[a,51] mobile thrombus (rarely seen) o Unilateral limb desaturation with near-infrared spectroscopy

[a]McConnell sign: global hypokinesis of the right ventricular free wall with sparing the right ventricular apex.

Comparison of focused compression venous sonography to 'gold standard' medical imaging

The two- and three-point venous compression techniques are simple and hence are able to be performed within 10 min, compared to the comprehensive radiological testing that usually requires 30–40 min. Although the reported rates of sensitivity and specificity are comparable (data presented below in the emergency and critical care medicine sections), it is possible

Table 2: Limitations of venous compression ultrasound.

Limitation	Description
Iliac veins	• Iliac veins are often not easily visualised or compressible, and although only 1–2% of DVT are isolated to the iliac veins, clinicians must be cautious if abnormal compression is encountered in the femoral region as this should raise suspicion for a DVT in the iliac vein • Although not within the normal scope of a compression study, an abnormal pulsed-wave Doppler pattern seen in the femoral vein can be used to exclude a complete (not partial) iliac vein thrombosis and an iliac vein thrombus may extend all the way to the inferior vena, which may be identified with echocardiography
Femoral veins	• Although the addition of the femoral vein compression point may assist in detection of the approximately 6% of DVTs that are not seen at the other two points,[52] some advocate imaging as much of the femoral vein as proximal as possible starting at the common femoral vein and translating the probe slowly distally towards the knee • Femoral vein duplication is common, and therefore, it is important to routinely look for a second femoral vein to avoid missing a DVT[53] • Compression may be difficult in obese or oedematous patients particularly in the adductor canal. Therefore, at the adductor canal, a 2-hand technique may be necessary where the examiner places his or her hand behind patient's leg and pushes the soft tissue up towards the transducer (Figure 6)
Calf veins	• The compression method excludes the calf veins and the iliac veins. Calf DVT's are difficult to identify with ultrasound, with a low sensitivity. Calf DVT's diagnosed by venography (previous gold standard) were only clinically important if found to progress proximally, which should be identified by the compression method in the popliteal area[54,55] • Although calf DVTs are often not treated, ultrasound examinations should be repeated as the propagation risk may be significant in high-risk patients[31]
General/pitfalls	• Non-compressible vein may be mistaken for an artery, which results in a false negative, and an artery may be mistaken for a non-compressible vein, which results in a false positive • Inability to see the vein due to large body habitus, hardware, bandages • Lymph nodes should not be mistaken for a venous thrombus (Figure 7) • No flow in Baker cysts • Arteriovenous fistula • Venous congestion (stasis) • Venous haematoma • Venous valve, a frequent site of clot formation (Video S1) • Intravascular catheter in lumen • Thrombus in only one limb of a duplicated vein • Deep venous segment (false negative)

DVT, deep venous thrombosis.

that there is a small false-negative rate for compression ultrasound. It is important to emphasise that the reliability of the compression technique is dependent on the operator training and experience and the false-negative rate may also be reduced by scanning more of the deep venous system than the two compression points, as described above.

However, an important limitation of the evidence for focused compression venous sonography is the assumption that the radiology scan is the gold standard. If there is a significant time difference between the two examinations – hours or a day or more – the findings can change. This is an issue with many focused ultrasound comparison studies. For example, what was a positive above-knee DVT at the time of the focused study from a small amount of popliteal thrombus can lyse/break off and be negative in radiology, a 'false positive', making the focused DVT study appear less specific. If the focused DVT is negative and later there is some thrombus seen with a

Figure 2: Positioning of the lower limb for compression ultrasound examination. Knee 20–30° bend and hip 30° externally rotated (frog's leg position) to allow full access to the medial part of the thigh and the popliteal fossa.

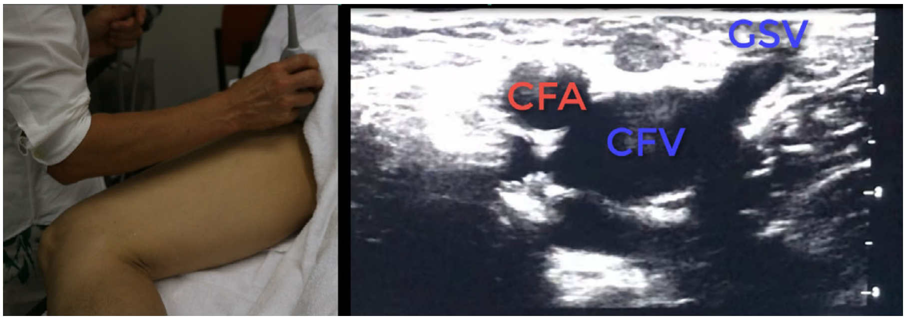

Figure 3: Compression point 1 – junction of common femoral vein and greater saphenous vein. CFA, common femoral artery; CFV, common femoral vein; GSV, greater saphenous vein.

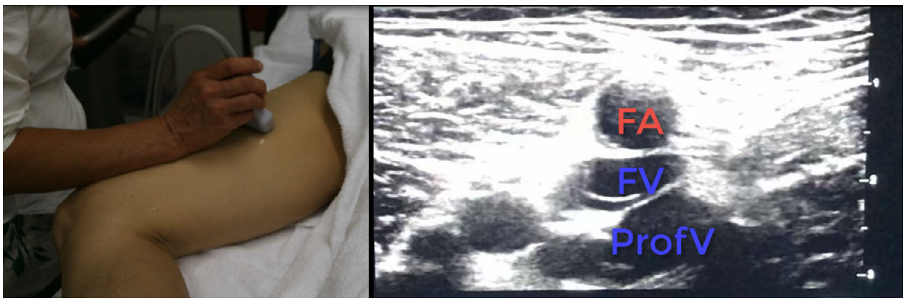

Figure 4: Compression point 2 – femoral vein; FA, femoral artery; FV, femoral vein; ProfV, femoral profunda vein.

radiology scan in the popliteal vein from progression of calf DVT, it becomes a false negative and the focused DVT looks less sensitive. This can happen in planned follow-up after formal imaging both ways as well. Finding out that your focused scan may have missed a DVT may be disconcerting to the focused ultrasound practitioner, who has likely made treatment decisions on the basis of the first scan.

Compression venous sonography for deep venous thrombosis in emergency medicine

Compression venous sonography is a core application for emergency medicine and is supported by the American College of Emergency Physicians (ACEP).[20] Much of the validation work for compression venous sonography has been performed by emergency physicians. In a systematic review of 1162 patients in 6 studies with patients presenting to the emergency department who had clinically suspected DVT, 2-point compression ultrasound performed by emergency physicians had an overall sensitivity of 95% (87–99%) and specificity of 96% (87–99%) for diagnosis of DVT compared with radiology ultrasound.[21] But of course, ultrasound is operator-dependent and the true test performance depends upon the skill and experience of the individual performing the scan. Compression venous sonography is used in the emergency medicine setting for two indications, suspected DVT and suspected PE. For suspected DVT, compression venous sonography performed by the emergency

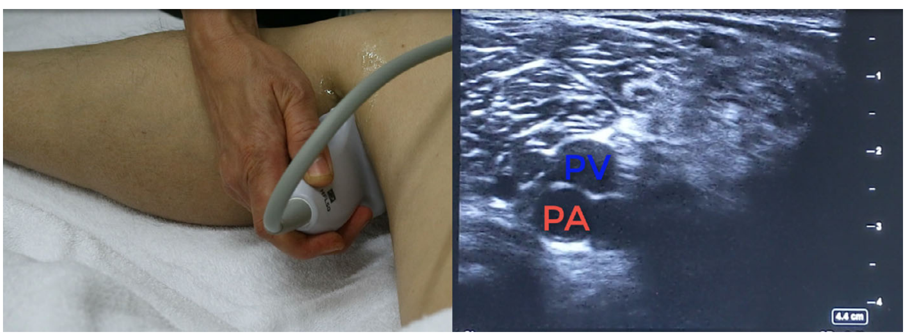

Figure 5: Compression point 3 – popliteal vein; PV, popliteal artery; PA.

Figure 6: Two-hand technique used when obesity limits venous compression.

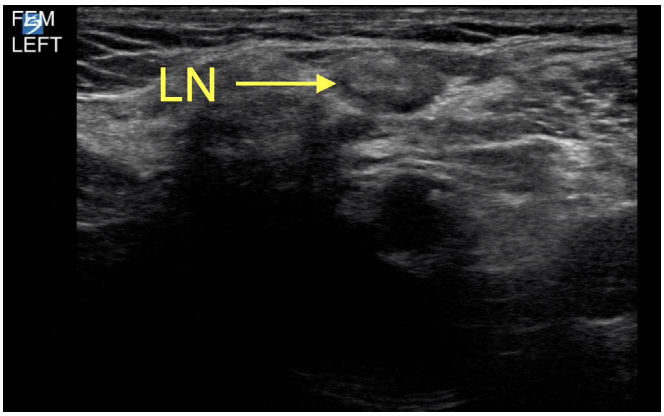

Figure 7: Femoral lymph node. LN, lymph node.

physician at the point of care is clinically useful and decreases time in the emergency department, usually by several hours.[22,23] If a DVT is found, it will usually trigger treatment, exclude other differential diagnoses and may initiate consideration for disposition and follow-up depending on symptom severity. A negative study is likely to exclude proximal DVT at that point in time. But caution should be advised with inadequate studies and lesser skilled operators. Isolated below-knee DVT is still possible, but given this is much less likely to propagate or result in PE, shared decision-making regarding empiric treatment, and planning for a comprehensive formal leg ultrasound as an outpatient can be pursued. This could be in the next few days and followed up by their primary care provider, facilitating an early decision for discharge, reducing the time spent in the emergency department. The second important scenario, often underappreciated, is the haemodynamically unstable or hypoxemic patient or a patient who has a high pre-test concern for PE. Even in the absence of leg symptoms, a proximal DVT study can be very helpful, as a positive DVT ultrasound makes the presence of PE extremely likely.[24–26] This can influence immediate decisions regarding treatment, including thrombolysis, and timing of confirmatory PE imaging.

Compression venous sonography for deep venous thrombosis in critical care

Deep vein thrombosis is a common cause of preventable mortality and morbidity in the ICU, and compression venography is supported by the Society of Critical Care, who recommend scanning using the two-point compression method.[27] A 3-point compression technique performed by an intensivist in the ICU found a 20% prevalence of DVT, 86% sensitivity and 96% specificity when compared with radiology. Median time delay between the ordering and execution of the examination was 13.8 h.[28] A multicentre retrospective study compared matched intensivist-performed focused ultrasound with those performed by certified vascular technicians. The sensitivity and specificity of the intensive care unit (ICU)-performed studies compared with the technician studies were 88% and 98% vs. 85% and 100%, respectively. Furthermore, ICU studies were available real-time compared with a median time delay of nearly 14 h for the vascular laboratory studies.[28]

Compression ultrasound for deep venous thrombosis in anaesthesia

Deep vein thrombosis is a common cause of preventable mortality and morbidity in patients hospitalised for surgery, as DVT's are implicated in up to 90% of PE.[29–31] Most data are on screening for patients for DVT after surgery. Pre-operative thromboprophylaxis for in-patient surgery is recommended in moderate- to high-risk patients[31] with prophylactic dose anticoagulation and venous compression stockings. However, there have been some reports on screening before surgery where the incidence of above-knee pre-operative DVT was reported before surgery for excision of brain tumour (3[32] to 23%[33]), spinal metastasis (1.5–25%[34–36]), and surgery for hip fracture (18.9%[37]) and trauma (10%[38]). Unfortunately, the quality of evidence for patient benefit remains poor, with the bulk of the literature being observational and a lack of any randomised trials (Table 3). If a DVT is identified pre-operatively, the decision whether to treat is tied to the anticipated risks of haemorrhage during and after surgery, as pre-operative anticoagulation has been reported to be associated with a clinically important increased risk of bleeding.[37,39] In several centres, pre-operative therapeutic anticoagulation was stopped prior to neurosurgery and an inferior vena cava filter inserted to prevent proximal migration of the DVT during the perioperative period when anticoagulation was ceased.[40–46] Although it is logical that earlier detection and treatment of DVT may result in less morbidity and mortality from PE, there is some doubt,[47] but due to the lack of adequately powered randomised trials, this research question is yet to be proven either way. The guidelines from the

Table 3: Summary of reported evidence for management of pre-operative, above knee, deep venous thrombosis.

Reference	Study design	Screening	Management	Summary of findings
		Neurosurgery		
Zacharia *et al.*[45]	Retrospective observational	232 patients undergoing spinal metastasis removal	IVC filter	232 of 314 (73.9%) patients screened, of whom 22 (9.48%) had a DVT.
Pandey *et al.*[46]	Prospective observational	115 patients scheduled for craniotomy for brain tumour	Anticoagulation and IVC filter	Seven (6%) of the 115 screened patients had DVT. Of these patients, one developed post-operative PE, and another had bilateral DVT post-operatively.None of the patients without pre-operative DVT developed VTE post-operatively.There were no deaths and no complications from the anticoagulation or IVC filter insertion.
Dickerson *et al.*[47]	Retrospective before and after policy change from routine screening to targeted screening	All neurosurgery485 patients undergoing routine screening and 504 patients targeted screening	IVC filter	The DVT rate was higher in the routine screening group (10% vs. 3%, $P < 0.01$) and IVC filter rate (6% vs. 2%, $P < 0.01$).There was no difference in the PE rate (2% in both groups, $P = 0.72$) or all-cause mortality at discharge (7% vs. 6%, $P = 0.49$).
		Hip fracture surgery		
Xia *et al.*[37]	Retrospective case–control	301 consecutive hip fracture surgery patients	Anticoagulation	Pre-operative DVT was found in 18.9% (57/301) and pulmonary embolism (PE) in 1%. Of the DVTs, 22.8% (13/57) were above knee and 77.2% (44/57) below kneeIn below-knee DVT, anticoagulation did not significantly reduce the rate of DVT progression and, however, did had a significantly lower post-operative haemoglobin concentration than those who did not receive pre-operative therapeutic anticoagulation

Table 3. Continued

Reference	Study design	Screening	Management	Summary of findings
Zahn *et al.*[56]	Prospective	61 consecutive hip fracture patients	IVC filter	Of 61 patients screened, 21 patients had a delay of >48hr in surgery in whom 13 had a pre-operative DVT (62%)

Anticoagulation; therapeutic anticoagulation before surgery recommenced at a variable time after surgery, DVT; deep venous thrombosis, IVC filter; inferior vena cava filter inserted before surgery.

American College of Chest Physicians recommend against routine use of ultrasound to screen for DVT's, but they do recommend treatment with either anticoagulant medication or inferior vena cava filter placement in patients diagnosed with an asymptomatic proximal DVT.[31]

Conclusion

Point-of-care application of ultrasound for detection of DVT using the two- and three-point compression technique by non-radiology medical personnel is equivalent in accuracy to conventional venous duplex ultrasound performed by radiology and is becoming incorporated into the curriculum of acute care medical specialties. This practice may result in saving time and cost for referral to radiology and may result in more widespread screening of patients and an earlier detection and treatment of DVT.

Acknowledgements

There are no finding disclosures. We acknowledge the significant contributions to performing this study from the administrative staff of the Ultrasound Education Group, the University of Melbourne.

Authorship declaration

The authorship listing conforms to the journal's authorship policy, and all authors are in agreement with the content of the submitted manuscript.

Funding

No funding information is provided.

Disclosure statement

David Canty is an employee of the University of Melbourne. Educational content is available for sale in Australia.

References

1 Næss IA, Christiansen S, Romundstad P, Cannegieter S, Rosendaal FR, Hammerstrøm J. Incidence and mortality of venous thrombosis: a population-based study. *J Thromb Haemost* 2007; 5(4): 692–9.
2 Ho WK, Hankey GJ, Eikelboom JW. The incidence of venous thromboembolism: a prospective, community-based study in Perth, Western Australia. *Med J Australia* 2008; 189(3): 144–7.
3 Weinmann EE, Salzman EW. Deep-vein thrombosis. *N Engl J Med* 1994; 331(24): 1630–41.
4 Hirsh J, Hoak J. Management of deep vein thrombosis and pulmonary embolism: a statement for healthcare professionals from the council on thrombosis (in consultation with the council on cardiovascular radiology), American Heart Association. *Circulation* 1996; 93(12): 2212–45.
5 Silverstein MD, Heit JA, Mohr DN, Petterson TM, O'Fallon WM, Melton LJ. Trends in the incidence of deep vein thrombosis and pulmonary embolism: a 25-year population-based study. *Arch Intern Med* 1998; 158(6): 585–93.
6 Calder KK, Herbert M, Henderson SO. The mortality of untreated pulmonary embolism in emergency department patients. *Ann Emerg Med* 2005; 45(3): 302–10.
7 Courtney DM, Kline JA. Identification of prearrest clinical factors associated with outpatient fatal pulmonary embolism. *Acad Emerg Med* 2001; 8(12): 1136–42.
8 Langsfeld M, Hershey FB, Thorpe L, Auer AI, Binnington HB, Hurley JJ, *et al*. Duplex B-mode imaging for the diagnosis of deep venous thrombosis. *Arch Surg* 1987; 122(5): 587–91.
9 Lensing AW, Prandoni P, Brandjes D, Huisman PM, Vigo M, Tomasella G, *et al*. Detection of deep-vein thrombosis by real-time B-mode ultrasonography. *N Engl J Med* 1989; 320(6): 342–5.
10 Heijboer H, Buller HR, Lensing AW, Turpie AG, Colly LP, ten Cate JW. A comparison of real-time compression ultrasonography with impedance plethysmography for the diagnosis of deep-vein thrombosis in symptomatic outpatients. *N Engl J Med* 1993; 329 (19): 1365–9.
11 Hirsh J, Hoak J. Management of deep vein thrombosis and pulmonary embolism. A statement for healthcare professionals. Council on Thrombosis (in consultation with the Council on Cardiovascular Radiology), American Heart Association. *Circulation* 1996; 93(12): 2212–45.
12 Andrews EJ Jr, Fleischer AC. Sonography for deep venous thrombosis: current and future applications. *Ultrasound Q* 2005; 21(4): 213–25.
13 Gaitini D. Current approaches and controversial issues in the diagnosis of deep vein thrombosis via duplex Doppler ultrasound. *J Clin Ultrasound* 2006; 34(6): 289–97.
14 Zhang Y, Xia H, Wang Y, Chen L, Li S, Hussein I, *et al*. The rate of missed diagnosis of lower-limb DVT by ultrasound amounts to 50% or so in patients without symptoms of DVT: a meta-analysis. *Medicine* 2019; 98(37): e17103.
15 Masuda EM, Kistner RL. The case for managing calf vein thrombi with duplex surveillance and selective anticoagulation. *Dis Mon* 2010; 10(56): 601–13.

16 Bernardi E, Camporese G, Büller HR, Siragusa S, Imberti D, Berchio A, *et al*. Serial 2-point ultrasonography plus D-dimer vs whole-leg color-coded Doppler ultrasonography for diagnosing suspected symptomatic deep vein thrombosis: a randomized controlled trial. *JAMA* 2008; 300(14): 1653–9.
17 Adhikari S, Zeger W, Thom C, Fields JM. Isolated deep venous thrombosis: implications for 2-point compression ultrasonography of the lower extremity. *Ann Emerg Med* 2015; 66(3): 262–6.
18 Zuker-Herman R, Dangur IA, Berant R, Sitt EC, Baskin L, Shaya Y, *et al*. Comparison between two-point and three-point compression ultrasound for the diagnosis of deep vein thrombosis. *J Thromb Thrombolysis* 2018; 45(1): 99–105.
19 Nunn KP, Thompson PK. Towards evidence based emergency medicine: best BETs from the Manchester Royal Infirmary. Using the ultrasound compression test for deep vein thrombosis will not precipitate a thromboembolic event. *Emerg Med J* 2007; 24(7): 494–5.
20 ACEP Policy Statement. Approved October (2008) Emergency ultrasound guidelines. https://www.emra.org/uploadedFiles/EMRA/committees-divisions/ultrasound/ACEP-2008-EUSGuidelines.Pdf (Accessed 4th July 2019).
21 Burnside PR, Brown MD, Kline JA. Systematic review of emergency physician–performed ultrasonography for lower-extremity deep vein thrombosis. *Acad Emerg Med* 2008; 15(6): 493–8.
22 Blaivas M, Lambert MJ, Harwood RA, Wood JP, Konicki J. Lower-extremity Doppler for deep venous thrombosis—can emergency physicians be accurate and fast? *Acad Emerg Med* 2000; 7(2): 120–6.
23 Seyedhosseini J, Fadavi A, Vahidi E, Saeedi M, Momeni M. Impact of point-of-care ultrasound on disposition time of patients presenting with lower extremity deep vein thrombosis, done by emergency physicians. *Turk J Emerg Med* 2018; 18(1): 20–4.
24 Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest* 2008; 134(1): 117–25.
25 Nazerian P, Vanni S, Volpicelli G, Gigli C, Zanobetti M, Bartolucci M, *et al*. Accuracy of point-of-care multiorgan ultrasonography for the diagnosis of pulmonary embolism. *Chest* 2014; 145(5): 950–7.
26 Nazerian P, Volpicelli G, Gigli C, Becattini C, Sferrazza Papa GF, Grifoni S, *et al*. Diagnostic performance of wells score combined with point-of-care lung and venous ultrasound in suspected pulmonary embolism. *Acad Emerg Med* 2017; 24(3): 270–80.
27 Frankel HL, Kirkpatrick AW, Elbarbary M, Blaivas M, Desai H, Evans D, *et al*. Guidelines for the appropriate use of bedside general and cardiac ultrasonography in the evaluation of critically ill patients-part I: general ultrasonography. *Crit Care Med* 2015; 43 (11): 2479–502.
28 Kory PD, Pellecchia CM, Shiloh AL, Mayo PH, DiBello C, Koenig S. Accuracy of ultrasonography performed by critical care physicians for the diagnosis of DVT. *Chest* 2011; 139(3): 538–42.
29 Browse N, Thomas ML. Occasional survey: source of non-lethal pulmonary emboli. *Lancet.* 1974; 303(7851): 258–9.
30 Danish SF, Burnett MG, Stein SC. Prophylaxis for deep venous thrombosis in patients with craniotomies: a review. *Neurosurg Focus* 2004; 17(4): 1–8.
31 Guyatt GH, Akl EA, Crowther M, Gutterman DD, Schuünemann HJ. Executive summary: antithrombotic therapy and prevention of thrombosis: American College of Chest Physicians evidence-based clinical practice guidelines. *Chest* 2012; 141(2 Suppl): 7S.
32 Chaichana KL, Pendleton C, Jackson C, Martinez-Gutierrez JC, Diaz-Stransky A, Aguayo J, *et al*. Deep venous thrombosis and pulmonary embolisms in adult patients undergoing craniotomy for brain tumors. *Neurol Res* 2013; 35(2): 206–11.
33 Dermody M, Alessi-Chinetti J, Iafrati MD, Estes JM. The utility of screening for deep venous thrombosis in asymptomatic, non-ambulatory neurosurgical patients. *J Vasc Surg* 2011; 53(5): 1309–15.
34 Flinn WR, Sandager GP, Silva MB Jr, Benjamin ME, Cerullo LJ, Taylor M. Prospective surveillance for perioperative venous thrombosis: experience in 2643 patients. *JAMA Surgery* 1996; 131(5): 472–80.
35 Tominaga H, Setoguchi T, Tanabe F, Kawamura I, Tsuneyoshi Y, Kawabata N, *et al*. Risk factors for venous thromboembolism after spine surgery. *Medicine* 2015; 94(5): e466.
36 Yoshioka K, Kitajima I, Kabata T, Tani M, Kawahara N, Murakami H, *et al*. Venous thromboembolism after spine surgery: changes of the fibrin monomer complex and D-dimer level during the perioperative period. *J Neurosurg* 2010; 13(5): 594–9.
37 Xia Z-N, Xiao K, Zhu W, Feng B, Zhang B-Z, Lin J, *et al*. Risk assessment and management of preoperative venous thromboembolism following femoral neck fracture. *J Orthop Surg Res* 2018; 13(1): 291.
38 Napolitano LM, Garlapati VS, Heard SO, Silva WE, Cutler BS, O'Neill AM, *et al*. Asymptomatic deep venous thrombosis in the trauma patient: is an aggressive screening protocol justified? *J Trauma Acute Care Surg* 1995; 39(4): 651–9.
39 Dickinson LD, Miller LD, Patel CP, Gupta SK. Enoxaparin increases the incidence of postoperative intracranial hemorrhage when initiated preoperatively for deep venous thrombosis prophylaxis in patients with brain tumors. *Neurosurgery* 1998; 43(5): 1074–9.
40 Natsumeda M, Uzuka T, Watanabe J, Fukuda M, Akaiwa Y, Hanzawa K, *et al*. High incidence of deep vein thrombosis in the perioperative period of neurosurgical patients. *World Neurosurg* 2018; 112: e103–e12.
41 Patel AP, Koltz MT, Sansur CA, Gulati M, Hamilton DK. An analysis of deep vein thrombosis in 1277 consecutive neurosurgical patients undergoing routine weekly ultrasonography. *J Neurosurg* 2013; 118(3): 505–9.
42 Powell M, Kirshblum S, O'Connor KC. Duplex ultrasound screening for deep vein thrombosis in spinal cord injured patients at rehabilitation admission. *Arch Phys Med Rehabil* 1999; 80(9): 1044–6.
43 Ray WZ, Strom RG, Blackburn SL, Ashley WW, Sicard GA, Rich KM. Incidence of deep venous thrombosis after subarachnoid hemorrhage. *J Neurosurg* 2009; 110(5): 1010–4.
44 Swanson E. Ultrasound screening for deep venous thrombosis detection: a prospective evaluation of 200 plastic surgery outpatients. Plastic and Reconstructive Surgery. *Global Open* 2015; 3(3): e332.
45 Zacharia BE, Kahn S, Bander ED, Cederquist GY, Cope WP, McLaughlin L, *et al*. Incidence and risk factors for preoperative deep venous thrombosis in 314 consecutive patients undergoing surgery for spinal metastasis. *J Neurosurg* 2017; 27(2): 189–97.
46 Pandey A, Thakur B, Hogg F, Brogna C, Logan J, Arya R, *et al*. The role of preoperative deep vein thrombosis screening in neurooncology. *J Neurosurg* 2018; 130(1): 38–43.

47 Dickerson JC, Harriel KL, Dambrino RJ, Taylor LI, Rimes JA, Chapman RW, *et al*. Screening duplex ultrasonography in neurosurgery patients does not correlate with a reduction in pulmonary embolism rate or decreased mortality. *J Neurosurg* 2019; 1–9.
48 Pellerito J, Polak J. Introduction to vascular ultrasonography, 6th ed. London, UK: Elsevier Health Sciences; 2012.
49 Wells PS, Anderson DR, Rodger M, Ginsberg JS, Kearon C, Gent M, *et al*. Derivation of a simple clinical model to categorize patients probability of pulmonary embolism: increasing the models utility with the SimpliRED D-dimer. *Thromb Haemost* 2000; 83(3): 416–20.
50 Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, *et al*. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr* 2015; 28(1): 1–39.e14.
51 McConnell MV, Solomon SD, Rayan ME, Come PC, Goldhaber SZ, Lee RT. Regional right ventricular dysfunction detected by echocardiography in acute pulmonary embolism. *Am J Cardiol.* 1996; 78(4): 469–73.
52 Zuker-Herman R, Ayalon Dangur I, Berant R, Sitt EC, Baskin L, Shaya Y, *et al*. Comparison between two-point and three-point compression ultrasound for the diagnosis of deep vein thrombosis. *J Thromb Thrombolysis* 2018; 45(1): 99–105.
53 Screaton N, Gillard J, Berman L, Kemp P. Duplicated superficial femoral veins: a source of error in the sonographic investigation of deep vein thrombosis. *Radiology* 1998; 206(2): 397–401.
54 Kakkar VV, Howe CT, Flanc C, Clarke MB. Natural history of postoperative deep-vein thrombosis. *Lancet* 1969; 2(7614): 230–2.
55 Moser KM, LeMoine JR. Is embolic risk conditioned by location of deep venous thrombosis? *Ann Intern Med* 1981; 94(4 pt 1): 439–44.
56 Zahn HR, Skinner JA, Porteous MJ. The preoperative prevalence of deep vein thrombosis in patients with femoral neck fractures and delayed operation. *Injury* 1999; 30(9): 605–7.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Video S1. Performing two- and three-point lower limb compression ultrasound for diagnosis of deep venous thrombosis.
Video S2. Using colour flow Doppler to discriminate between an artery and a vein.
Video S3. Absent deep venous thrombosis using compression ultrasound.
Video S4. Deep venous thrombosis in the popliteal vein using compression ultrasound.