

Compression Ultrasonography of the Lower Extremity With Portable Vascular Ultrasonography Can Accurately Detect Deep Venous Thrombosis in the Emergency Department

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Study objective: Compression ultrasonography of the lower extremity is an established method of detecting proximal lower extremity deep venous thrombosis when performed by a certified operator in a vascular laboratory. Our objective is to determine the sensitivity and specificity of bedside 2-point compression ultrasonography performed in the emergency department (ED) with portable vascular ultrasonography for the detection of proximal lower extremity deep venous thrombosis. We did this by directly comparing emergency physician-performed ultrasonography to lower extremity duplex ultrasonography performed by the Department of Radiology.

Methods: This was a prospective, cross-sectional study and diagnostic test assessment of a convenience sample of ED patients with a suspected lower extremity deep venous thrombosis, conducted at a single-center, urban, academic ED. All physicians had a 10-minute training session before enrolling patients. ED compression ultrasonography occurred before Department of Radiology ultrasonography and involved identification of 2 specific points: the common femoral and popliteal vessels, with subsequent compression of the common femoral and popliteal veins. The study result was considered positive for proximal lower extremity deep venous thrombosis if either vein was incompressible or a thrombus was visualized. Sensitivity and specificity were calculated with the final radiologist interpretation of the Department of Radiology ultrasonography as the criterion standard.

Results: A total of 47 physicians performed 199 2-point compression ultrasonographic examinations in the ED. Median number of examinations per physician was 2 (range 1 to 29 examinations; interquartile range 1 to 5 examinations). There were 45 proximal lower extremity deep venous thromboses observed on Department of Radiology evaluation, all correctly identified by ED 2-point compression ultrasonography. The 153 patients without proximal lower extremity deep venous thrombosis all had a negative ED compression ultrasonographic result. One patient with a negative Department of Radiology ultrasonographic result was found to have decreased compression of the popliteal vein on ED compression ultrasonography, giving a single false-positive result, yet repeated ultrasonography by the Department of Radiology 1 week later showed a popliteal deep venous thrombosis. The sensitivity and specificity of ED 2-point compression ultrasonography for deep venous thrombosis were 100% (95% confidence interval 92% to 100%) and 99% (95% confidence interval 96% to 100%), respectively.

Conclusion: Emergency physician-performed 2-point compression ultrasonography of the lower extremity with a portable vascular ultrasonographic machine, conducted in the ED by this physician group and in this patient sample, accurately identified the presence and absence of proximal lower extremity deep venous thrombosis. [Ann Emerg Med. 2010;56:601-610.]

Please see page 602 for the Editor's Capsule Summary of this article.

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INTRODUCTION

Rapid and accurate detection of deep venous thrombosis and the prevention of pulmonary embolism is a critical aspect of emergency medicine worldwide. Approximately 2 million patients are diagnosed with a deep venous thrombosis annually

in the United States,¹ with approximately 600,000 hospitalizations and another 200,000 deaths resulting from pulmonary embolism.^{2,3} Because none of the available imaging modalities have ideal test characteristics, the diagnosis of deep venous thrombosis remains challenging.^{2,4-6} Contrast venography exposes the patient to radiation and intravenous contrast material, has special technical

Editor's Capsule Summary*What is already known on this topic*

Radiology department ultrasonography is commonly used to detect lower extremity deep venous thrombosis. Studies of emergency physician-performed ultrasonography have shown mixed results.

What question this study addressed

Can emergency physicians who received 10 minutes of training use a low-resolution portable ultrasonographic machine and a 2-point (at common femoral and popliteal vessels only) compression technique to accurately diagnose proximal lower extremity deep venous thrombosis?

What this study adds to our knowledge

Forty-seven physicians examined 199 patients, achieving a sensitivity of 100% and a specificity of 99%, as judged by the official radiology ultrasonography.

How this might change clinical practice

Novice physicians using a simplified technique achieved remarkable accuracy. These findings, if confirmed, could result in practice changes that would expedite the emergency department care of patients with suspected deep venous thrombosis.

requirements that limit its availability, and has associated morbidity.^{2,6-9} For these reasons, duplex ultrasonography (compression ultrasonography, as well as color and flow Doppler ultrasonography) of the lower extremity, performed by a certified technician and interpreted by a radiologist, has emerged as an effective first-line method of detecting deep venous thrombosis, with a reported sensitivity of 91% to 96% and a specificity of 98% to 100%.^{5,6} It has replaced other diagnostic imaging methods in common practice and many now consider duplex ultrasonography of the lower extremity to be the standard of care in diagnosing proximal lower extremity deep venous thrombosis.^{2,5-7,10,11}

Despite these advances in ultrasonographic research, a standard protocol for ultrasonographic evaluation of lower extremity deep venous thrombosis is not universally accepted.^{4-6,12,13} Whereas some hospital radiology laboratories image the proximal lower extremity only, others perform whole-leg duplex imaging of the entire venous system.¹³⁻¹⁵ Although the former investigates the proximal lower extremity only, the whole-leg approach is able to detect isolated calf deep venous thrombosis, in addition to proximal lower extremity deep venous thrombosis. Although some consider whole-leg

ultrasonography superior because of its ability to diagnose calf and proximal lower extremity deep venous thrombosis, the evidence for this is based on the thought that detecting isolated calf deep venous thrombosis is clinically important.^{6,13,14} A recent study randomized patients to radiologist-performed serial 2-point compression ultrasonography plus serum D-dimer or whole-leg color duplex ultrasonography and found the 2 diagnostic strategies to be equivalent for the management of symptomatic outpatients with suspected lower extremity deep venous thrombosis.¹⁶ The long-term outcome was similar, even though the 2-point compression group missed several calf deep venous thromboses. However, the ability to obtain a radiologist-performed (or technician-performed and radiologist interpreted) duplex ultrasonography of the lower extremity in the emergency department (ED) can be difficult after hours or on weekends because some hospitals do not have duplex ultrasonography available to the ED at all times.

In 2006, the American College of Emergency Physicians (ACEP) released a clinical compendium outlining the use of emergency ultrasonography, in which bedside compression ultrasonography was described as an appropriate method for evaluating lower extremity deep venous thrombosis in the ED.¹⁷ ACEP published an emergency ultrasonography policy statement in 2009 that listed deep venous thrombosis as one of the 11 core emergency ultrasonography applications, yet deep venous thrombosis was identified as a less established application that was only recently adopted because of utility and research.¹⁸ Furthermore, the emergency medicine community has not universally accepted a standard protocol for ED ultrasonographic evaluation of lower extremity deep venous thrombosis.¹⁹ Whole-leg ED duplex ultrasonography of the entire lower extremity venous system by emergency physicians trained with a 30-hour ultrasonographic course had a sensitivity and specificity potentially high enough to be used as a stand-alone test for ED patients (>95%), but this requires a significant ED time commitment (greater than 13 minutes) and a higher level of training than general ED practice.²⁰ A recent study using a large heterogeneous group of emergency clinicians with various levels of ultrasonographic experience demonstrated that ED-performed ultrasonography with a 3-point compression technique was 70% sensitive (95% confidence interval [CI] 60% to 80%) and 89% specific (95% CI 83% to 94%) compared with radiology-performed ultrasonography, raising concern about the widespread use of ED ultrasonography for deep venous thrombosis.¹⁹

Although the methods used to detect deep venous thrombosis range from 2-point compression of the femoral and popliteal vessels to whole-leg duplex imaging of the entire venous system, numerous studies have used different compression sites along the femoral and popliteal vessels, with reported sensitivities ranging from 70% to 100% and specificities of 76% to 99%.^{13-16,19-31} This research was also performed in various settings, such as radiology laboratories, EDs, and inpatient wards, and by various operators

(radiologists, physicians, technicians, midlevel providers). Several studies showed that investigation of the proximal lower extremity veins by 2-point compression applied to the common femoral vein at the groin and the popliteal vein at the popliteal fossa can be effective in identifying proximal lower extremity deep venous thrombosis.^{16,22-25,27,28} Furthermore, this method is thought to be adequate and reproducible when performed with almost any year and model of ultrasonographic machine, despite the resolution or frequency of the vascular probe.^{16,23}

Portable vascular ultrasonographic machines are used in many hospitals for vascular access and are smaller than conventional machines.^{35,36} They are lightweight, battery powered, and relatively inexpensive and became popular as a result of emphasis on ultrasonographically guided central line placement for patient safety core measures.³²⁻³⁶

This study sought to assess whether bedside 2-point compression ultrasonography of the lower extremity at the common femoral and popliteal vessels only, performed by physicians in the ED with a portable vascular ultrasonographic machine, could detect the presence or absence of proximal lower extremity deep venous thrombosis with acceptable test characteristics.

MATERIALS AND METHODS

Study Design

This was an institutional review board–approved, prospective, cross-sectional study and diagnostic test assessment of a convenience sample of ED patients with a suspected lower extremity deep venous thrombosis. All patients enrolled in the study presented to the ED with a suspected lower extremity deep venous thrombosis and underwent 2-point compression ultrasonography with portable vascular ultrasonography in the ED before formal Department of Radiology evaluation (Figure 1).

Setting

This study was performed at a single-center, urban, university-affiliated public hospital with an emergency medicine residency program and an annual ED census of 60,000.

Selection of Participants

Eligible patients were aged 18 years or older, suspected of having a lower extremity deep venous thrombosis, and undergoing Department of Radiology ultrasonography of the lower extremity. There was no distinction made between patients suspected of having a proximal lower extremity deep venous thrombosis or an isolated calf deep venous thrombosis for enrollment purposes. Any patient with a suspected lower extremity deep venous thrombosis was eligible. Patients with a known deep venous thrombosis, a previous deep venous thrombosis in the past 6 months, or a recent duplex ultrasonography (within the past month) were excluded from the study.⁶ There were no exclusions made according to sex,

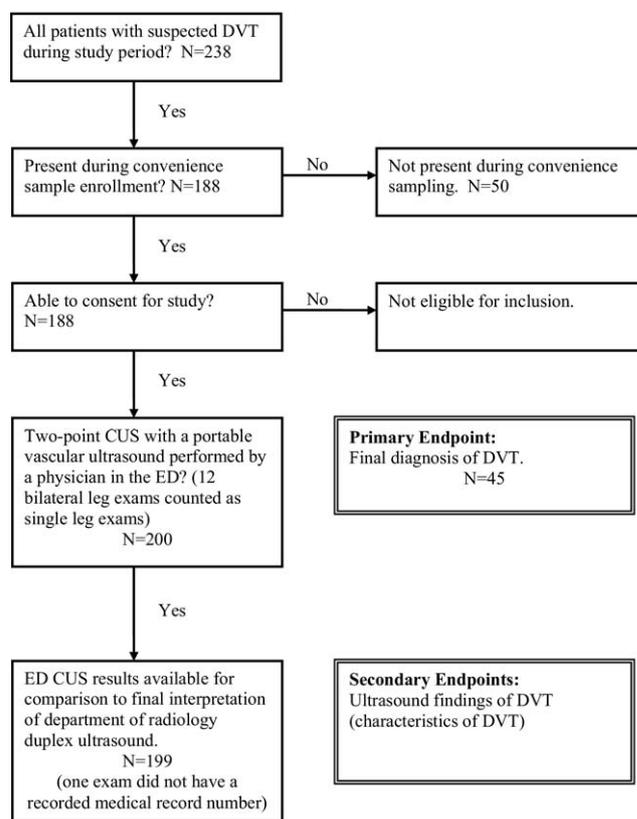


Figure 1. Flow diagram of study design and endpoints. DVT, Deep venous thrombosis; CUS, compression ultrasonography.

race, or weight. Our convenience sample was defined as those enrolled at the convenience of the treating physician. Enrolling physicians were given a \$5 gift card to a local outdoor equipment store for each completed enrollment form and were encouraged to enroll every patient that qualified for and consented to the study. Physician subjects were board-certified emergency medicine attending physicians and postgraduate residents working in the ED: years 2 to 4 emergency medicine residents, rotating years 2 to 3 internal medicine residents, years 1 to 5 combined emergency medicine/internal medicine residents, and year 2 family medicine residents.

Interventions

Before enrolling patients, all participating physicians had a 10-minute bedside training session. Previous data have shown that emergency medicine residents can perform a detailed multiple-point proximal lower extremity deep venous thrombosis compression ultrasonographic examination in less than 12 minutes²⁵ and a 2-point compression examination in less than 4 minutes.²⁶ Because our study involved 2-point compression ultrasonography of only the common femoral and popliteal vessels, the training session did not require more than 10 minutes. A uniform training session was agreed on by the 3 study investigators and was given to all levels of physicians

involved in this study. Only the 3 study investigators conducted the training sessions, which took place during any shift worked by one of the 3 investigators during the enrollment period. Each training session involved familiarization with study criteria and verbal instruction on how to identify normal anatomy, incompressibility, and thrombus. Instruction also included bedside use of the portable vascular ultrasonographic machine, with identification of the popliteal vein and common femoral vein on a normal volunteer patient, chosen at random by the instructing study investigator. The enrolling physicians had to demonstrate their ability to find the femoral and popliteal veins, measure their compressibility, and describe how both an incompressible vein and a thrombus would appear on ultrasonography. This was done before enrolling patients and before the conclusion of the training session. If physicians were not sure whether they had identified the correct vein, or if they could not tell whether a vein was compressible or whether a thrombus was present, they were instructed to select the “other” option on the data sheet and indicate which vessel gave them problems. Common mistakes, such as having the incorrect depth setting or positioning the probe incorrectly, were reviewed during the training session. Physicians were free to enroll patients after completion of the training session. A study investigator was not required to be present during enrollment by a trained physician after completion of a training session.

Methods of Measurement

Physician subjects performed compression ultrasonography with the Bard Site-Rite IV portable vascular ultrasonography (Salt Lake City, UT), using the standard 7.5-MHz linear probe supplied with the machine. This probe allows a depth of 2 or 4 cm, with limited contrast and gain capabilities. Compression ultrasonographic evaluation involved identification of only the common femoral vessels at the level of the groin and the popliteal vessels in the popliteal fossa, with subsequent compression of the common femoral and popliteal veins. The minimum number of times that each vessel would be compressed was one single attempt, and the maximum number of compressions at each site was not specified. After the patient consented to enrollment, enrolling physicians followed a study protocol that first involved finding the common femoral vessels and documenting the compressibility of the femoral vein or presence of thrombus on a standardized data sheet. Next, the popliteal vessels were identified, and the compressibility or presence of thrombus was documented on the same standardized data sheet. If the physician was unable to identify one or both of the vessels, or if the results of compression or thrombus were indeterminate, this was documented by an “other” option on the data sheet.

The ED compression ultrasonographic result was considered positive for proximal lower extremity deep venous thrombosis if either vein was not compressible or a thrombus was visualized. All ED compression ultrasonographic measurements were followed by immediate (within 3 hours) duplex ultrasonographic evaluation by the Department of Radiology to

assess for proximal lower extremity deep venous thrombosis, performed in the ultrasonographic suite. All Department of Radiology duplex ultrasonography was performed with either a Phillips IU 22 (Bothell, WA) with an L9-3 linear array probe or a Phillips HD 5000 ATL with an L7-4 linear array probe. According to our Department of Radiology protocol, only the proximal lower extremity venous system was evaluated. The calf veins distal to the popliteal veins were not imaged. Still images were recorded 24 hours a day, 7 days a week, by one of 10 full-time ultrasonographers, 5 of whom were credentialed as registered diagnostic medical sonographers. Images were electronically transmitted to one of 5 attending board-certified staff radiologists from the Division of Ultrasonography and Mammography who routinely read ultrasonographic images at our hospital. The Department of Radiology ultrasonographic technicians and attending radiologists were blinded to all ED compression ultrasonographic results. The name and medical record number of each patient were used by study investigators or research assistants trained in data abstraction to archive the final dictated interpretation of each Department of Radiology–performed duplex study.

Outcome Measures

The primary outcome measure was the identification of a proximal lower extremity deep venous thrombosis through the use of bedside ED 2-point compression ultrasonography. The final attending radiologist interpretation of the Department of Radiology–performed study was considered the criterion standard for study purposes. Secondary outcome measures were the characteristics of the deep venous thrombosis observed on ED compression ultrasonography: compressibility, thrombus visualization, and location of deep venous thrombosis.

Primary Data Analysis

Data collected for this study were maintained in a Microsoft Excel (Version 11 and 12.0, Microsoft, Redmond, WA) worksheet, with subsequent analysis using Stata³⁷ (Version 10, Statacorp, College Station, TX) and VassarStats.³⁷ According to a 2005 quality assurance project conducted as part of the ultrasonography education program for the emergency medicine residency at our hospital, 30% of patients sent for lower extremity duplex ultrasonography from the ED were found to have a proximal lower extremity deep venous thrombosis. A priori power calculation estimated that 186 patients were needed to detect a minimum sensitivity for ED compression ultrasonography such that the lower-bound limit of the 95% CI would be greater than 85%.

RESULTS

From June 2006 through July 2007, 47 physicians enrolled 188 patients, resulting in 200 total examinations. Twelve patients were enrolled separately for bilateral lower extremity ultrasonography. The total number of patients who had a formal duplex Department of Radiology study ordered from the

Table 1. Sensitivity and specificity of ED two-point compression ultrasonography, using Department of Radiology ultrasonography as the gold standard.

ED Ultrasonography Category	Positive DOR Ultrasonographic Results	Negative DOR Ultrasonographic Results
Positive ED compression ultrasonography	45	1
Negative ED compression ultrasonography	0	153
Sensitivity, %	100 (95% CI 92–100)	
Specificity, %	99.4 (95% CI 96–100)	

DOR, Department of Radiology.

ED to assess for lower extremity deep venous thrombosis during this time was 248, 10 of which were cancelled before the study was performed by the ordering clinician or ED clerk for unknown reasons (ordered in error, wrong patient, change of mind, etc). This accounted for 238 total duplex ultrasonography examinations (unilateral and bilateral) ordered by the ED and performed by the Department of Radiology. Our convenience sample enrolled 188 of the 238 total patients evaluated for the presence of a lower extremity deep venous thrombosis during the enrollment period.

Of the 200 examinations performed by the physician subjects in the ED and enrolled in the study, 199 had complete data and were included in the final data analysis. One examination was excluded because the patient name and medical record number were not recorded. No other examinations were excluded from those collected, and none of the enrolled examinations or the excluded examination was found to have indeterminate results.

Beside 2-point compression ultrasonography of the lower extremity, performed by physicians in the ED with a portable vascular ultrasonographic machine for the evaluation of proximal lower extremity deep venous thrombosis, had a sensitivity of 100% (95% CI 92% to 100%) and a specificity of 99% (95% CI 96% to 100%) (Table 1). There were 45 deep venous thromboses observed on Department of Radiology evaluation, and all were correctly identified by ED 2-point compression ultrasonography (Table 2). There were 154 patients without a deep venous thrombosis on Department of Radiology ultrasonography, all of whom had a negative ED 2-point compression ultrasonography result except for one, in which compression ultrasonography by the enrolling emergency physician showed decreased compressibility of the popliteal vein, suggesting the presence of a deep venous thrombosis by our study criteria. In this subject, the decreased popliteal compression was also noted in the attending radiologist reading of the Department of Radiology study, but a definite deep venous thrombosis was not diagnosed and the study result was dictated as negative by the attending radiologist. Repeated

duplex evaluation result by the Department of Radiology at 1 week was positive for a popliteal deep venous thrombosis. This was considered a false-positive result according to the study protocol, and there were no false-negative results. Deep venous thrombosis characteristics are summarized in Table 3.

If the results of ED compression ultrasonography are compared directly with Department of Radiology duplex ultrasonography for equivalence, Cohen's κ coefficient is 0.99 (95% CI 0.958 to 1).

A histogram displaying the results of the 199 examinations by 47 operators is shown (Figure 2). The median number of patients enrolled per physician was 2 (range 1 to 29 patients; interquartile range 1 to 5 patients). Of the enrolling physician subjects, there were 2 attending physicians and 45 residents. One attending physician had completed an ultrasonographic fellowship and previously performed more than 1,000 ultrasonographic examinations, including 50 previous compression ultrasonographic examinations for deep venous thrombosis. This attending physician was also a study investigator and performed 29 of the 199 examinations. The other attending physician previously performed 2 compression ultrasonographic examinations for deep venous thrombosis, and 1 resident had previously performed 2 as well. The remaining 44 enrolling physicians had not performed compression ultrasonography for deep venous thrombosis before this study. The average experience level of the enrolling emergency physicians (excluding the ultrasonographically trained attending physician) was 14.5 previous ultrasonographic examinations (median 5 examinations; mode 5 examinations; range 2 to 98 examinations), including all indications of ED ultrasonography.^{17,18}

LIMITATIONS

This study has limitations that are important to consider when the results are interpreted. The first limitation is the use of a convenience sample of patients and enrolling physicians rather than studying all consecutive patients sent for a Department of Radiology evaluation. It was not feasible for us to enroll consecutive patients because of the time constraints of maintaining adequate patient flow in a busy ED. This sampling method therefore could involve a patient selection bias in which certain patients (ie, difficult or equivocal patients) may not have been enrolled, which if present could have led to an overestimation in the sensitivity and specificity of ED 2-point compression ultrasonography. We did not collect data on patient demographics, such as body mass index, sex, or ethnicity, which may affect the comparison of patients enrolled in our study to other populations. Our convenience sample did enroll 188 of the 238 total patients who had a formal Department of Radiology duplex ultrasonographic examination, indicating that we captured 79% of the total patients evaluated for lower extremity deep venous thrombosis in the ED during the study period.

The limited depth, contrast, and gain abilities of the portable vascular ultrasound make it attractive for vascular procedures

Table 2. Comparison of ED 2-point compression ultrasonographic results to the final reading of the Department of Radiology ultrasonography.*

Subject (N=45)	Thrombus on ED CUS (N=28)	Incompressible on ED CUS (N=39)	DOR Ultrasonography Final Reading (N=45)	Final Diagnosis (N=45)
1	0	1	Femoral thrombus not observed but less compressible	Common femoral DVT
2	1	1	Femoral thrombus observed with decreased compressibility	Common femoral DVT
3	0	1	Distal femoral thrombus with decreased compressibility	Distal femoral DVT
4	0	1	Distal femoral thrombus with decreased compressibility	Distal femoral DVT
5	1	0	Superficial femoral DVT	DVT
6	1	0	Popliteal DVT	DVT
7	1	0	Superficial femoral DVT	DVT
8	1	1	Midfemoral and popliteal DVT	DVT
9	1	1	Nonocclusive DVT in proximal and midfemoral vein	DVT
10	0	1	Nonocclusive DVT in midfemoral vein	DVT
11	1	0	Partial occlusion of popliteal DVT	DVT
12	1	1	Common femoral DVT with popliteal DVT	DVT
13	0	1	Popliteal DVT	DVT
14	1	1	Common femoral DVT with popliteal DVT	DVT
15	0	1	Popliteal DVT	DVT
16	0	1	Popliteal DVT	DVT
17	1	1	Midfemoral and popliteal DVT	DVT
18	1	1	Nonocclusive DVT in proximal and midfemoral vein	DVT
19	0	1	Nonocclusive DVT in midfemoral vein	DVT
20	1	1	Common and superficial femoral vein, popliteal vein	DVT
21	1	0	Superficial femoral DVT	DVT
22	1	1	Common and superficial femoral vein, popliteal vein	DVT
23	1	1	Common femoral DVT	DVT
24	0	1	Nonocclusive DVT in proximal and midfemoral vein	DVT
25	1	0	Superficial femoral DVT	DVT with cellulitis
26	1	1	Popliteal DVT	DVT with PE
27	1	1	Popliteal DVT	DVT with PE
28	0	1	Distal femoral and popliteal thrombus with decreased compressibility	Femoral to popliteal DVT
29	1	1	Femoral thrombus observed but decreased compressibility, popliteal thrombus observed	Femoral to popliteal DVT
30	1	1	Distal femoral, popliteal thrombus with decreased compressibility	Femoral to popliteal DVT
31	0	1	Femoral/popliteal thrombus not observed but decreased compressibility	Femoral to popliteal DVT
32	0	1	Femoral/popliteal thrombus not observed but decreased compressibility	Femoral to popliteal DVT
33	1	1	Femoral thrombus	Femoral DVT
34	1	1	Femoral thrombus	Femoral DVT
35	1	1	Thrombus in right femoral vein	Femoral DVT and ARF
36	1	1	Thrombus in right femoral vein	Femoral DVT and ARF
37	0	1	Occlusive common femoral vein	DVT
38	0	1	Occlusive common femoral vein	DVT
39	1	1	Popliteal thrombus and decreased compressibility	Popliteal DVT
40	0	1	Popliteal thrombus not observed but had decreased compressibility	Popliteal DVT
41	1	1	Popliteal thrombus, decreased femoral/popliteal compressibility	Popliteal DVT and PE
42	1	1	Popliteal thrombus, decreased femoral/popliteal compressibility	Popliteal DVT and PE
43 [†]	0	1	Initial: decreased popliteal compressibility, repeat: popliteal DVT [†]	DVT
44	1	1	New Femoral DVT	Femoral DVT
45	0	1	Popliteal DVT	Popliteal DVT

PE, Pulmonary embolism; ARF, acute renal failure.

*In ED-compression ultrasonography columns, "0" indicates no thrombus or normal compression (negative result) and "1" indicates either a visualized thrombus or an incompressible popliteal or femoral vein (positive result).

[†]Study 43 had a DOR examination result that was initially negative, yet a repeated DOR study result 6 hours later was positive for DVT. (This was considered a positive DVT for study purposes.)

Table 3. ED compression ultrasonography DVT characteristics.

	Total Number	Popliteal	Femoral	Both (Popliteal+Femoral)
Total DVT	45	11	20	14
Incompressible with thrombus	22	3	8	11
Incompressible only (no thrombus)	17	6	8	3
Thrombus only	6	2	4	0

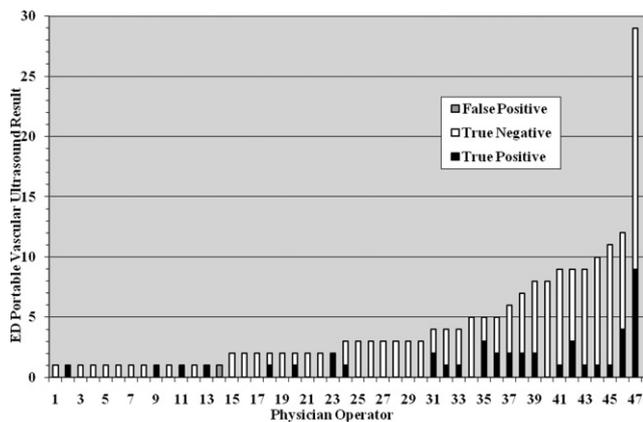


Figure 2. Histogram demonstrating results by operator. The 47 enrolling physicians are plotted on the horizontal axis, with the 199 ED compression ultrasonographic results shown. The single false-positive result occurred as the only enrolled examination for 1 physician operator, and 1 operator enrolled a total of 29 patients.

because the resolution allows for easy identification of vessels. However, the high-resolution linear array vascular probes (13 to 6-MHz, 10 to 5-MHz) used by the newest ED ultrasonographic machines have a greater resolution than the 7.5-MHz probe of the Bard Site-Rite. The higher resolution may make it easier to visualize multiple small vessels, which may in turn confuse the operator and make it difficult to correctly identify the popliteal vessels. This raises the question about reproducibility of this study with a high-frequency probe. As operators become more fluent with ultrasonographic technology and as the technology itself evolves, temporal changes can affect the diagnostic test characteristics in this situation. It is likely the results of this study will apply to conventional ED ultrasonographic machines, but this was not tested here.

Furthermore, the Bard Site-Rite IV only has 2 depth settings, 2 or 4 cm, which limits the patients who can be evaluated. Despite the prevalence of obesity at our public hospital, our study surprisingly did not have any indeterminate results. One possibility for this is that the limited contrast and gain abilities of the Bard Site-Rite IV may have improved the ED ultrasonographer's ability to identify the vessels, thus reducing the confusion with other smaller vessels that can occur with high-resolution ultrasonography. It is also possible that difficult (ie, obese) patients were avoided. We did not find any evidence to support this bias, and giving the enrolling physician a \$5 gift card for each submitted examination encouraged inclusion of all potential subjects.

The ease of use and ability to quickly find the femoral and popliteal vessels with the portable ultrasonographic machine used in this study was not compared with that of a high-resolution ultrasonographic machine, and a study that answers this question could be helpful in explaining the lack of indeterminate results encountered here. Although the minimum number of compressions for each vessel was one single attempt, the actual number of compressions a provider performed was not recorded. Because the study reproducibility could be affected by the compression attempts needed for adequate visualization, subsequent studies may benefit from using a standard number of compressions at each vessel. Despite these limitations, our findings are consistent with those of previous studies,¹⁶⁻²⁹ with the exception of our low rate of indeterminate results, and we believe that ED 2-point compression ultrasonography for deep venous thrombosis will be accurate and reproducible, provided the vessels are adequately visualized.

Only 47 of 60 eligible physician subjects at our institution enrolled patients, with the majority of those being resident physicians. This may introduce a subgroup or "ultrasonographic interest" bias on the part of the operators, which could inflate estimates of sensitivity and specificity. The operator with the most ultrasonographic experience, a study investigator with ultrasonographic fellowship training but not credentialed as a registered diagnostic medical sonographer, enrolled 9 of the 43 patients with positive deep venous thrombosis examination results and 20 of the 149 patients with negative examination results. Although this accounts for some clustering of data around a single provider, a histogram broken down by operator has been reported so that the reader may interpret these results with clarity (Figure 2). The limited experience and diverse background of the other 46 operators (emergency medicine residents, full- and part-time emergency medicine faculty, and internal medicine and family medicine rotating residents) suggest that any physician with limited ultrasonographic experience can easily acquire the skills necessary to perform ED 2-point compression ultrasonography for proximal lower extremity deep venous thrombosis.

DISCUSSION

Our results demonstrate good diagnostic accuracy of ED 2-point compression ultrasonography for proximal lower extremity deep venous thrombosis with a portable vascular ultrasonographic machine. In contrast to that of a recent study conducted at an urban academic ED with a heterogeneous group of ED clinicians (attending physicians, residents, and

midlevel providers), the sensitivity and specificity of single-visit ED-performed compression ultrasonography was found to be lower, 70% (95% CI 60% to 80%) and 89% (95% CI 83% to 94%), respectively.²¹ There was also a difference in the number of indeterminate results. Two methodological differences exist between this study and ours. The first involves the use of a 3-point compression (common femoral, superficial femoral, and popliteal) as opposed to 2-point (common femoral, popliteal). The addition of another measured variable increases the chance of error and may partially account for the lower sensitivity and specificity. The second difference involves the use of a 14 to 5-MHz linear format broadband probe compared to the 7.5-MHz linear probe equipped with our machine. One possible explanation is that the higher frequency probe, which gives much greater detail, may cause the ultrasonographer to focus on superficial veins, lymph nodes, or other fluid-filled areas and misidentify the common femoral or popliteal vessels entirely. We did not measure the opinion of the ultrasonographer, nor did we compare identification of the vessels between high- and low-frequency probes. To our knowledge, this has not been studied before. The study most similar to ours is one that performed an ultrasonographic image quality comparison between an inexpensive handheld ED machine and a large mobile ED system, in which a significant difference was observed between image quality and resolution but not detail.³⁸ The degree to which improved image quality affects diagnostic accuracy has been questioned, such that a reader's ability to interpret an image correctly may not always improve with increased image quality, resolution, and detail.³⁹ On conclusion of our study, we did have the general impression that it was easier to identify the vessels with the low-frequency probe, which may have affected our diagnostic accuracy. Although this finding is subjective and was not studied here, we have included this statement to suggest areas of additional research and development. This may be more evident in the hands of inexperienced operators or with the use of color Doppler flow and certainly warrants further investigation.

One of the 43 deep venous thromboses identified as a positive result in our study (because of incompressibility) (patient 43, Table 2) was initially read as negative by the attending radiologist, despite having abnormal flow augmentation on the Department of Radiology examination. Given the concern of the emergency physician about the decreased compressibility of the femoral vein on ED compression ultrasonography, the emergency physician ordered a second Department of Radiology ultrasonography that was conducted 6 hours after the first. The second examination showed a thrombus of the popliteal vein, as well as decreased compressibility of the femoral vein. This result was classified as positive for study purposes because the second ultrasonography occurred during a single ED visit and was the one used for the final diagnosis for the patient, even though the second Department of Radiology duplex ultrasonography was conducted 6 hours later. This was different from the single false-

positive result mentioned above, in which the final Department of Radiology ultrasonography result was read as negative and a repeated Department of Radiology duplex result at 1 week was positive. Theoretically, conventional venography may have identified the above deep venous thromboses initially and, if studied here, could have led to a lower sensitivity of ED 2-point compression ultrasonography for deep venous thrombosis. In our study, however, ED compression ultrasonography was more accurate than Department of Radiology duplex evaluation.

In a recently published meta-analysis of emergency physician-performed ultrasonography,¹⁹ the studies analyzed were found to have the following methodological problems: a small number of experienced emergency physician operators (range 2 to 8 operators), few registered diagnostic medical sonographer credentialed radiology-based sonographers (less than 25%), limited details about patient enrollment methods and demographics, limited information about anatomic location of deep venous thrombosis, and the potential for missed calf vein deep venous thrombosis. Although we did not address patient demographics, we do mention that our patients are a sample of those of a typical public hospital in southern California. Detailed information is provided about patient enrollment methods. We provide specific information about the deep venous thrombosis location, and 50% of our radiology-based sonographers were credentialed as registered diagnostic medical sonographers. The large sample of physician operators and limited previous ultrasonographic experience of physicians performing ultrasonography (internal medicine residents with no previous ultrasonographic experience and emergency medicine residents with minimal experience) suggest that the physician operators in our study are similar to those in general community practice.

Although we did not have the ability to study isolated calf-vein deep venous thrombosis, recent evidence¹⁶ questions the relevance of detecting calf deep venous thrombosis and the need for long-term anticoagulation. Of 2,098 patients randomized to 2-point ultrasonography and whole-leg duplex ultrasonography (which included detection of isolated calf vein deep venous thrombosis), 2-point ultrasonography had a lower prevalence of deep venous thrombosis compared with whole-leg duplex ultrasonography. The entire difference was accounted for by 65 missed cases of isolated calf deep venous thrombosis. Because the long-term outcome of the 2 groups was found to be similar, the need for detection and treatment of isolated calf deep venous thrombosis may warrant further investigation and thus may not be as critical as previously thought.^{6,13,14,16} However, current opinion suggests that duplex ultrasonography of the proximal lower extremity only, when combined with either a normal D-dimer result at presentation or a repeated duplex examination at 1 week (to detect a calf deep venous thrombosis that extended to the proximal veins) in those with negative initial duplex examination results, is thought to be sufficient for exclusion of a calf deep venous thrombosis.¹⁶ In addition, a recent meta-analysis has shown that withholding

anticoagulation after a single negative whole-leg compression ultrasonographic examination is associated with a low risk of deep venous thrombosis in a 3-month follow-up period.⁴⁰

The use of ultrasonographic guidance for ED insertion of central lines has been shown to increase success rates and reduce complications,^{32,35,36} prompting the Department of Health and Human Services Agency for Healthcare Research and Quality to advocate the use of ultrasonographic guidance for central venous catheter placement.^{33,34} For these reasons, portable vascular ultrasonographic machines may experience increased availability in US hospitals. This may also apply to the ICU setting, in which portable vascular ultrasonographic machines continue to be popular. Given the rate of change with ultrasonographic technology, portable vascular machines may ultimately be replaced in the ED and ICU by larger, higher-resolution, complex machines with widespread applications. If a low-frequency, simpler machine can produce superior or equivalent results, perhaps the emergency medicine community should investigate the use of this technology or modification of more complex machines to have simpler settings. This may increase the potential use of 2-point compression ultrasonography as an ED proximal lower extremity deep venous thrombosis screening tool.

Despite the emerging opinions that duplex ultrasonography has become the standard, acceptable modality for evaluating the venous system for deep venous thrombosis,^{9,10,13} contrast venography is still considered the true criterion standard for diagnosing deep venous thrombosis.^{7,8} Because it was prohibitive and potentially dangerous to use contrast venography in all subjects in this study, and especially because it is not currently accepted practice in the ED, we considered the final radiologist interpretation of the Department of Radiology–performed study sufficient and practical to use as a criterion standard. We recognize that compression ultrasonography is thus a central aspect of both our criterion standard (the Department of Radiology duplex) and our test in question (ED 2-point compression ultrasonography). Because both of these could theoretically miss a deep venous thrombosis and thus miss the actual disease, it would have been ideal to compare this with another imaging modality or provide adequate long-term follow-up. In addition, the argument could be made that we should not be interested in comparing our results to a controversial criterion standard (because this will be contrast venography by convention), but should rather test to see whether ED compression ultrasonography is equivalent to Department of Radiology duplex ultrasonography. Cohen's κ (0.99) shows that there is near-perfect agreement between the 2 tests. In our patient sample as tested by this physician group, ED compression ultrasonography was therefore equivalent to Department of Radiology duplex ultrasonography. Therefore, irrespective of how the results are analyzed, our data show that compression ultrasonography of the lower extremity with portable vascular ultrasonography can accurately detect proximal lower extremity deep venous thrombosis in the ED.

Physician-performed 2-point compression ultrasonography of the lower extremity with a portable vascular ultrasonographic machine, conducted in the ED by this physician group and in this patient sample, accurately identified the presence and absence of proximal lower extremity deep venous thrombosis.

Although our findings support the ACEP policy statement and ACEP clinical compendium's statement that bedside compression ultrasonography is an appropriate method for evaluating lower extremity deep venous thrombosis in the ED,^{17,18} the lower diagnostic accuracy found in recent studies may reflect differences in equipment, training, and study methodology. This suggests that more data are needed before a standard protocol for ultrasonographic evaluation of lower extremity deep venous thrombosis is accepted by the emergency medicine community and applied to general ED practice. Future research should include investigation into the specific anatomic site and number of compressions needed, the role of D-dimer in 2-point compression ultrasonography, the follow-up needed after ED ultrasonography, and the type of ultrasonographic machine, settings, and probe resolution required for optimal diagnostic accuracy.

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