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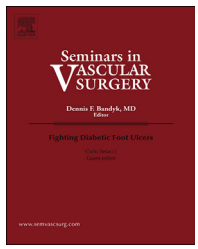

Vascular surgery resident education and hands-on training in vascular laboratory testing

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ABSTRACT

Diagnostic testing performed in the noninvasive vascular laboratory is a cornerstone of care for patients with suspected or known vascular disease. The Society for Vascular Surgery has mandated that vascular surgery resident training include mentored experience in performing vascular laboratory testing and interpreting its results. The trainee should be experienced with vascular laboratory instrumentation and testing protocols, be knowledgeable in ultrasound imaging of vascular anatomy, and be competent to classify disease severity relevant to the study indication. The scope of test interpretation should include peripheral arterial, peripheral venous, cerebrovascular, and visceral abdominal testing using duplex ultrasound supplemented by indirect physiologic testing for peripheral arterial and venous disease. The emergence of endovascular therapy has expanded duplex ultrasound applications in the areas of screening, procedural imaging, and surveillance following intervention. Pre-procedure testing to assess disease location and severity, and vein mapping for dialysis access or extremity bypass grafting provide important patient-specific information that can reduce the need for more invasive vascular imaging. It is recommended that trainees acquire the hand-on skills to perform duplex testing in vascular clinic and inpatient sites, such as the emergency department and operating room. Training programs should have a structured vascular laboratory curriculum that documents annual educational milestones that encompass both test interpretation aptitude and hands-on duplex scanning skills. Before completion of training, the resident should acquire documented experience in test interpretation sufficient to take the Physician Vascular Interpretation examination, which is required for American Board of Surgery certification as a vascular surgeon.

1. Introduction

The noninvasive vascular laboratory has evolved into an essential component in the evaluation of patients with arterial and venous disease. Vascular diagnostic testing and its interpretation form the basis for decisions regarding medical treatment, hospital admission, intervention, or need for additional testing. For vascular surgery residents and fellows in the United States and Canada, training in noninvasive vascular testing is a curriculum requirement. The educational milestones to be achieved during training should cover testing techniques, diagnostic accuracy, testing limitations, and criteria for test interpretation. Acquiring knowledge in this area of vascular medicine is beyond that learned in medical school or general surgery training, and thus a core curriculum

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is required to ensure competency in the clinical application of vascular testing and its interpretation during a 2-year 5+2 fellowship or the integrated 0+5 residency. In the June–September 2013 issue of *Seminars in Vascular Surgery* [1], an in-depth discussion of interpretation criteria in the areas of arterial and venous testing was provided, as well as a review of ultrasound instrumentation and physics. Vascular surgery trainees can use this primer of vascular laboratory test interpretation to assess their competence by reviewing the questions that accompany each article.

Acquiring hands-on duplex ultrasound imaging skill is an essential part of attaining vascular laboratory competence and should be an integral part of vascular surgeon training. Proficiency in hands-on ultrasound imaging is the standard-of-care skill required for peripheral artery cannulation and central venous catheter placement. The ability to perform duplex scanning is very useful for point-of-care patient evaluations to diagnose lower-limb deep vein thrombosis, assess bypass graft patency, dialysis access planning and fistula maturation, and femoral artery false aneurysm thrombin injection. Incorporation of hands-on duplex scanning experience during training is strongly recommended and judged by residents to be highly valued in surveys of vascular surgery training program experience [2].

2. Noninvasive vascular laboratory experience requirements

Vascular surgery resident training programs must include experience in the interpretation of noninvasive vascular laboratory studies. To interpret these studies, the trainee must demonstrate knowledge of vascular anatomy and physiology; ultrasound physics; and the application of ultrasound testing in the outpatient clinic, emergency department, operating room, and hospitalized patient. The Society for Vascular Surgery considers clinical experience and expertise in vascular laboratory test interpretation a mandatory component of vascular surgery training and of being a vascular specialist. As of 2014, initial board certification in vascular surgery by the Vascular Surgery Board of the American Board of Surgery is predicated on successfully passing the Registered Physician Vascular Interpretation, which is administered by the Alliance for Physician Certification and Advancement. Application for the Physician Vascular Interpretation (PVI) examination requires that the vascular surgery trainee document their vascular interpretation experience in a clinical diagnostic setting with a minimum of 500 cases interpreted during a minimum of 1 month within the 36 months preceding application submission [2]. No more than 100 of these cases can be didactic or simulated cases that are presented and interpreted in a format that is equivalent to cases encountered in a clinical diagnostic setting. Cases must be distributed over the following testing areas, with no more than 50% of the total coming from any one area:

- Carotid duplex ultrasound (extracranial cerebrovascular)
- Transcranial Doppler (intracranial cerebrovascular)
- Peripheral arterial and venous physiologic testing
- Peripheral arterial duplex ultrasound
- Venous duplex ultrasound
- Visceral vascular duplex ultrasound
- Screening

As of January 2018, the PVI examination can be taken on demand; application instructions and required documentation (medical license, Program Director letter, log of interpretation experience) are detailed at the Alliance for Physician Certification and Advancement's website (www.APCA.org). After completion of training, the vascular surgeon who plans to include vascular laboratory interpretation in their scope of practice must provide evidence of continuing medical education (CME) activity specific to noninvasive vascular diagnostic testing to retain the Registered Physician Vascular Interpretation certification.

3. Vascular laboratory education curriculum

A curriculum that provides the vascular surgery trainee with the technical knowledge and clinical application of diagnostic ultrasound should be based on the Accreditation Council for Graduate Medical Education's core competencies of resident education (Table 1). A detailed example of a vascular laboratory curriculum is provided in Appendix 2 of *Strandness's Duplex Scanning in Vascular Disorders*, 5th edition [3]. An instructional program is outlined for 10 areas of vascular laboratory operations with both learning objectives and mentor/teacher responsibilities detailed (Table 2). The vascular surgery trainee should be familiar with the core elements of interpretation in each area of testing and know the interpretation criteria of disease classification.

Competence in vascular laboratory testing requires specific knowledge in patient and disease states, physics and instrumentation, testing protocols, and interpretation criteria.

Table 1 – Accreditation Council for Graduate Medical Education core competencies.

Competency	Description
Patient care	Identify, respect, and care about patients' preferences, values, and differences Communicate, listen to, and inform patients using shared decision-making
Medical knowledge	Application of established and evolving biomedical sciences and clinical standards of care to patient care
Practice-based learning and improvement	Investigate and evaluate patient care provided with assimilation of clinical evidence to improve patient care
Interpersonal and communication skills	Effective information exchange with patients, families, and health professionals
Professionalism	Complete professional responsibilities with adherence to ethical principles and sensitivity to a diverse patient population
Systems-based practice	Awareness of the health care system to effectively use resources for optimal patient care

Table 2 – Vascular laboratory instruction areas for vascular surgery resident education.

Vascular laboratory operations and instrumentation
Extracranial cerebrovascular testing–carotid duplex ultrasound
Peripheral venous testing–deep vein thrombosis detection
Peripheral venous testing–lower limb venous insufficiency diagnosis
Peripheral arterial testing–indirect physiologic testing of upper and lower limbs
Peripheral arterial duplex ultrasound testing of native arteries, bypass grafts, and angioplasty
Abdominal vascular duplex ultrasound of abdominal aorta and iliac arteries
Abdominal vascular duplex ultrasound of renal and mesenteric arteries
Preoperative vessel mapping–upper and lower limb vein mapping, dialysis access planning
Vascular laboratory quality assurance and accreditation

Topics such as ultrasound physics, Doppler ultrasound principles, and operation of test instrumentation can be acquired from textbooks and a vascular laboratory rotation with hands-on training. During the vascular laboratory rotation, the trainee would acquire experience in transducer selection, image acquisition, duplex scanning, pulsed-Doppler waveform recording, and spectral analysis. A structured vascular laboratory experience of 40 hours or more observing and assisting in testing would provide a sufficient technical introduction to vascular laboratory operations. This fundamental knowledge is necessary to reviewing and interpreting patient-specific vascular laboratory studies. Test interpretation requires review of the indication for testing, evaluation of examination findings, recognition of artifacts, and providing a test summary that considers patient circumstances, for example, comparison with previous testing, other medical condition, and technical limitations.

The instruction program in each area of testing should include learning objectives that detail indications for testing, protocols of testing, and the elements of test reporting. The vascular surgery resident is not expected to be an expert in performing duplex ultrasound testing, but should be familiar with B-mode imaging and color Doppler, and be able to demonstrate transducer use and acquisition of duplex images for interpretation in peripheral arterial, peripheral venous, and extracranial carotid testing. In the area of test reporting, the trainee should be familiar with physician requirements and differences between a preliminary and a final report.

I recommend trainees read the following two textbooks on the topic of vascular laboratory testing: *Strandness's Duplex Scanning in Vascular Disorders*, 5th edition, and *The Vascular System*, 2nd edition [3,4]. Both of these textbooks provide the basics of ultrasound physics, fundamentals of ultrasound scanning, examples of normal and abnormal vascular anatomy, and detailed discussions of testing protocols and interpretation criteria of common vascular laboratory studies. This reading assignment should be completed early in vascular surgery training and learning augmented by attending a multi-day CME course devoted to vascular laboratory testing. In developing a vascular laboratory curriculum, trainees and program directors should review Appendix 2 in *Strandness's Duplex Scanning in Vascular Disorders* [3] for instructional methods and learner milestones in each testing area. The goal of self-directed study is to obtain cognitive experience for normal and abnormal ultrasound imaging. Direct supervision by a faculty educator is required for test-report generation and acquiring independent judgment in each testing area.

Table 3 – Essential components of a vascular laboratory curriculum.

Components
Faculty mentor with hands-on skills in duplex ultrasound
Faculty mentors for test interpretation and dictation proficiency
Technologist mentor for instrumentation and imaging assistance
Duplex scanner in the vascular surgery clinic and operating room
Assigned vascular laboratory education time early in training
Attend a vascular laboratory interpretation review course or similar continuing medical education conference on vascular laboratory testing
Annual education milestone review of vascular laboratory interpretation and hand-on skills

Ensuring vascular laboratory competence in a trainee requires a number of successful components (Table 3). Most

Table 4 – Example of vascular laboratory education milestones.

Level	Milestones
1	Demonstrates basic knowledge in vascular anatomy and physiology expected of a medical school graduate Understands basic ultrasound physics and instrumentation Shows ability to acquire ultrasound images of arteries and veins and record pulsed Doppler spectrum with appropriate angle correction for velocity measurement
2	Demonstrates knowledge in testing protocols and interpretation in cerebrovascular, peripheral arterial, and peripheral venous testing areas Has acquired hand-on skills with duplex ultrasound for artery and venous catheter access
3	Demonstrates interpretation skill in all vascular laboratory testing areas Has hands-on skills for operative planning and patient evaluation in the emergency department, intensive care unit, and vascular clinic
4[a]	Meets prerequisites for Registered Physician Vascular Interpretation credential (>500 interpretations) Demonstrates hand-on skills for the diagnosis and management of common vascular conditions (dialysis access planning, endovenous ablation of lower limb veins, and intraoperative duplex imaging)
5	Demonstrates advanced interpretation skills for uncommon vascular conditions Teaches test interpretation and hand-on skills to other learners Has the PVI credential and interpretation skills necessary to be medical staff of an accredited vascular laboratory

Abbreviation: PVI, Physician Vascular Interpretation.
[a]Recommended proficiency at the completion of vascular surgery training.

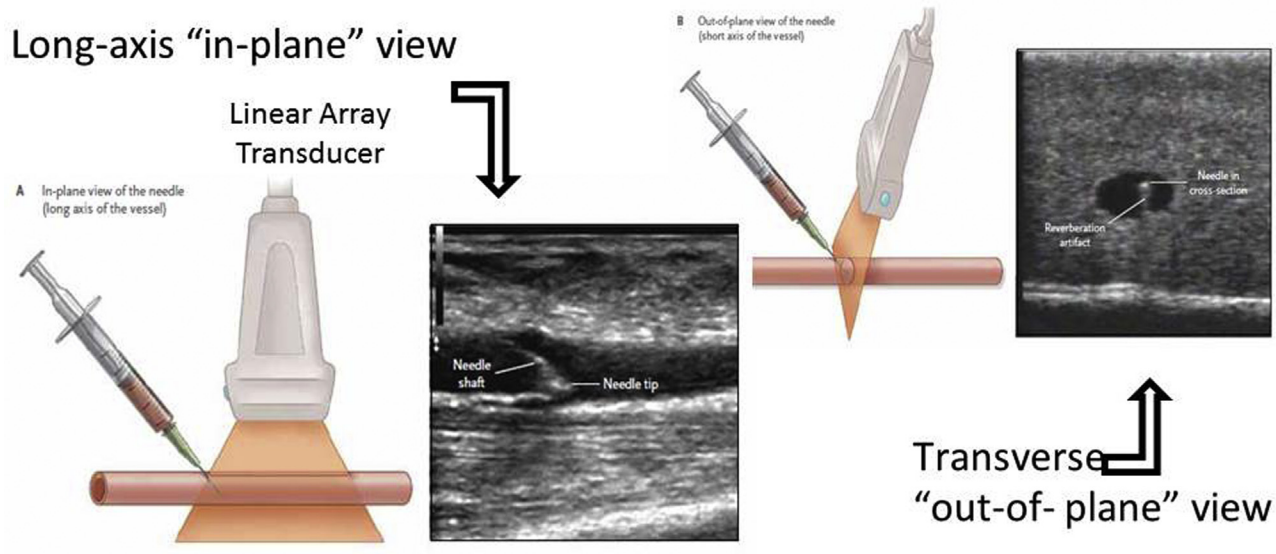

Fig. 1 – Technique of B-mode ultrasound imaging for needle cannulation of a vessel in long-axis and transverse views.

important is vascular surgery faculty mentors with hands-on skills in duplex ultrasound imaging and experience in test interpretation and dictation. The presence of a duplex scanner in the vascular surgery clinic and operating room is key to developing hands-on skills and acquiring imaging experience under mentorship. An assigned vascular laboratory rotation with a vascular technology mentor should occur early in training. During this 1- to 2-week period, experience using duplex instrumentation is acquired and the basics of vascular imaging are mastered. The trainee should observe and perform carotid testing; peripheral arterial and venous testing; and postoperative testing after angioplasty, bypass grafting, and endovascular abdominal aneurysm repair.

A vascular laboratory curriculum should specify what is expected of the trainee during and at the completion of their vascular surgery training. I recommend using five educational

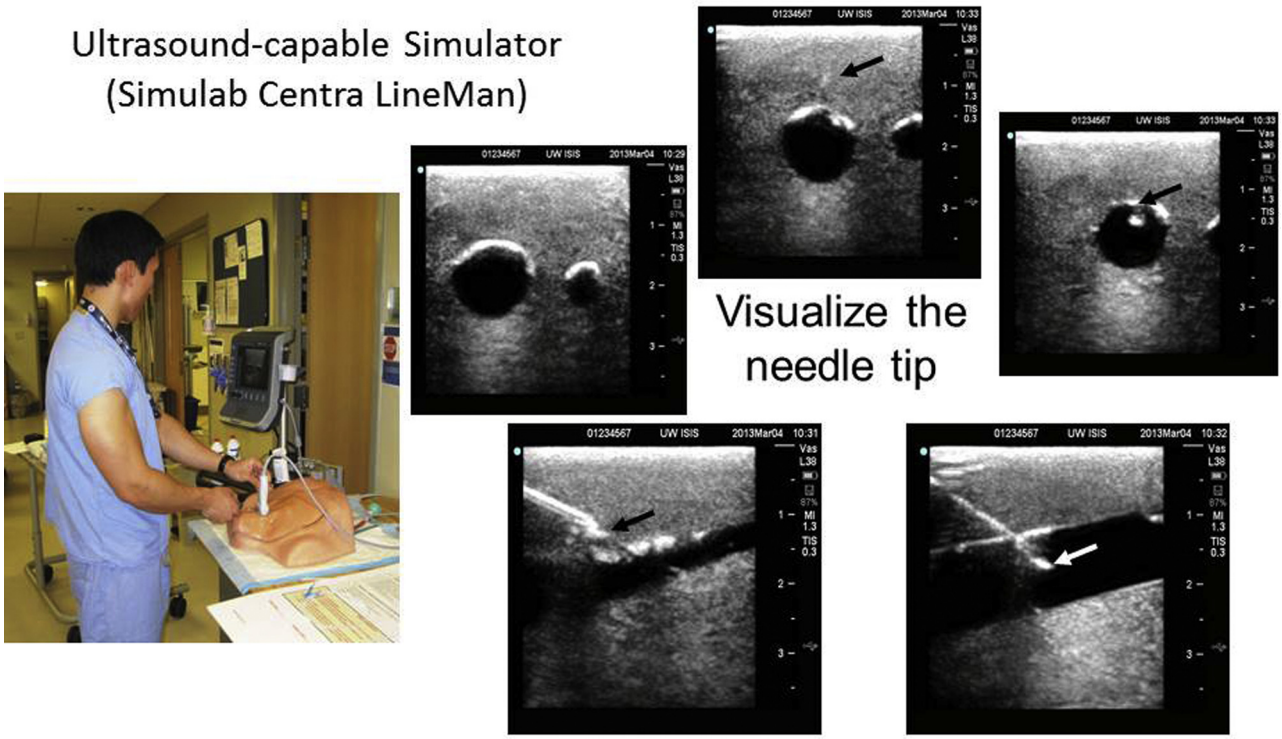

Fig. 2 – Images depicting a trainee using a model simulator to perform real-time ultrasound imaging of needle tip insertion into a vessel.

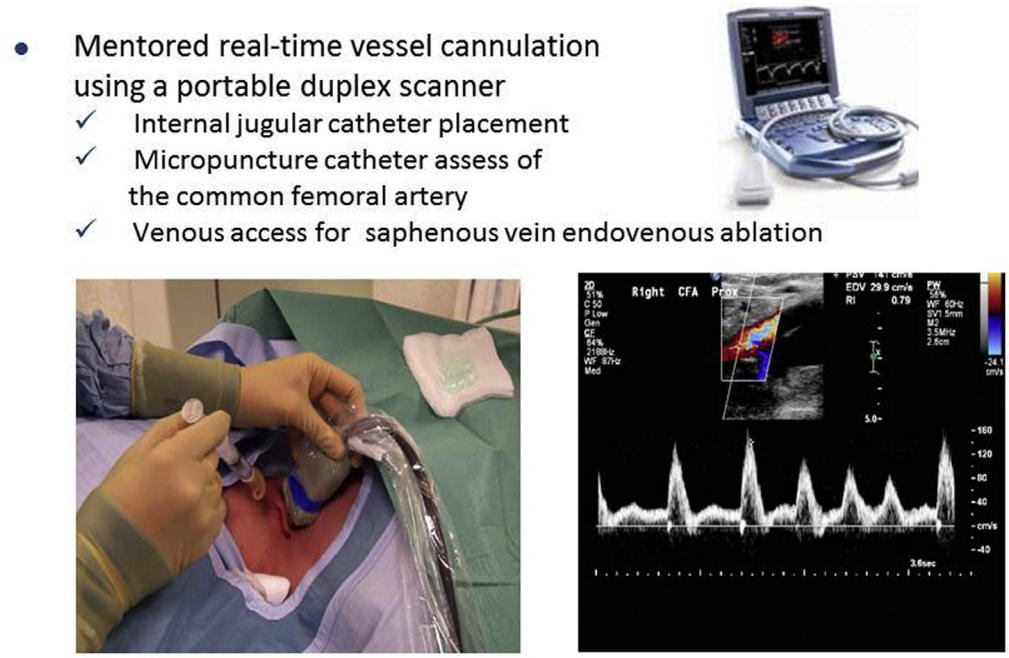

Fig. 3 – Images of mentored real-time duplex imaging in the operating room for vessel imaging and Doppler flow analysis.

milestones to document resident competence during training (Table 4). It is expected that the trainee will achieve level 4 competence during their training—preferably by the end of the third year in a 0-5 integrated residency and during the second year of a 5+2 fellowship. Ideally, all trainees should aspire to level 5 competence by the end of training because participation as medical staff in an accredited vascular laboratory is a desirable part of vascular surgery practice.

4. Acquiring hands-on vascular laboratory and ultrasound imaging skills

An initial and critical hands-on scanning skill is ultrasound-guided vascular access. The trainee needs to demonstrate using B-mode ultrasound to image vessels in transverse and long-axis views and in "real-time" cannulate the lumen with a

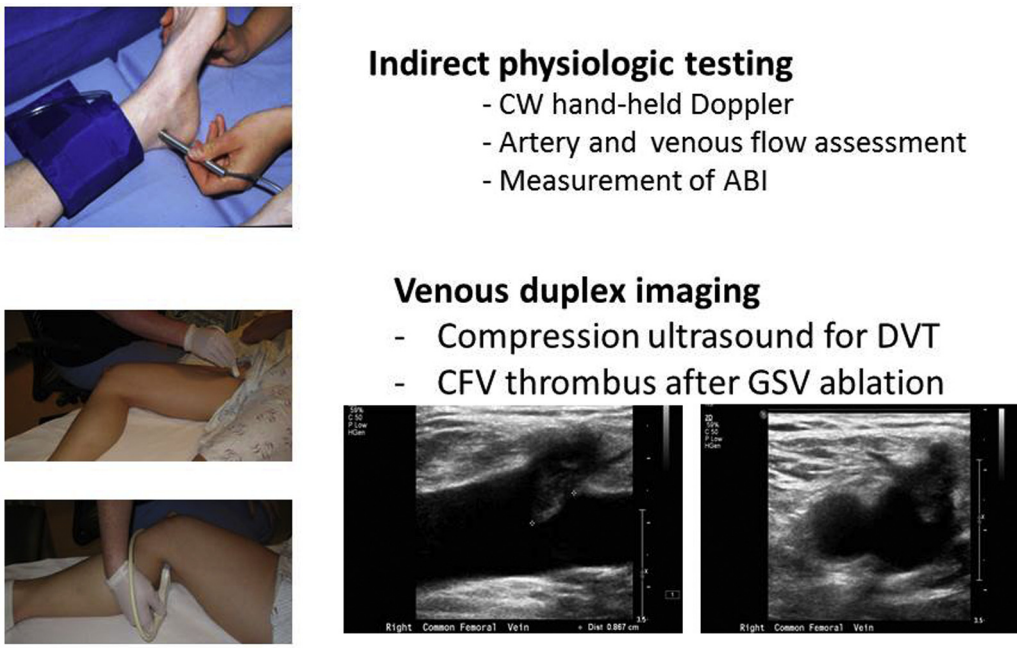

Fig. 4 – Images of indirect physiologic testing and venous duplex imaging depicting basic hands-on trainee skills. ABI, ankle-brachial index; CFV, common femoral vein; CW, continuous wave; DVT, deep vein thrombosis; GSV, great saphenous vein.

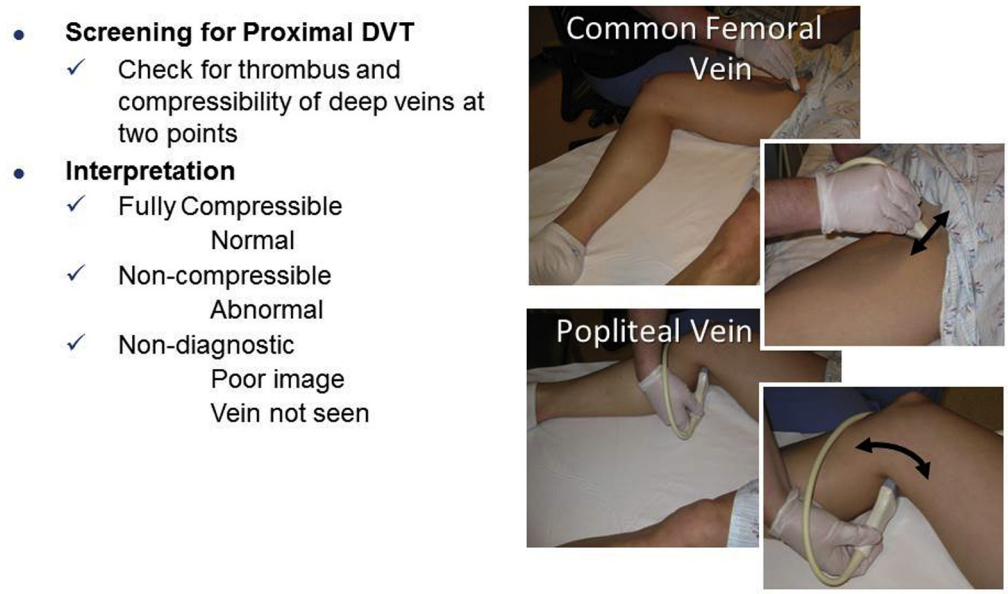

Fig. 5 – Point-of-care ultrasound imaging to screen for lower limb deep vein thrombosis (DVT) based on common femoral and popliteal vein imaging and probe compression.

needle (Fig. 1). This skill can be learned using a simulation model (Fig. 2). The commercially available CentraLineMan (Simulab, Seattle, WA) allows trainees to practice performing venous catheterization using ultrasound-guided approaches at the subclavian, supraclavicular, and internal jugular vein sites. The learner images the vessel in transverse and long-axis planes and visualizes the needle tip as it is inserted into the lumen. Training for femoral artery and vein access is also available using the FemoraLineMan system (Simulab).

In a procedure or operating room, ultrasound-guided vascular access should by mentored initially by a faculty vascular surgeon. The trainee, using a portable duplex scanner, can be assisted in vessel imaging, determining suitability for vessel cannulation, and monitoring the technique of micropuncture needle cannulation. When accessing the common femoral artery, duplex ultrasound imaging is used to confirm the presence of a minimally diseased artery segment for micropuncture needle and guide-wire insertion (Fig. 3). Mastering ultrasound-guided access is a basic scanning skill and indicates level 2 milestone competency. Proficiency in this hands-on imaging skill is mandatory because it is used routinely for internal jugular vein cannulation, common

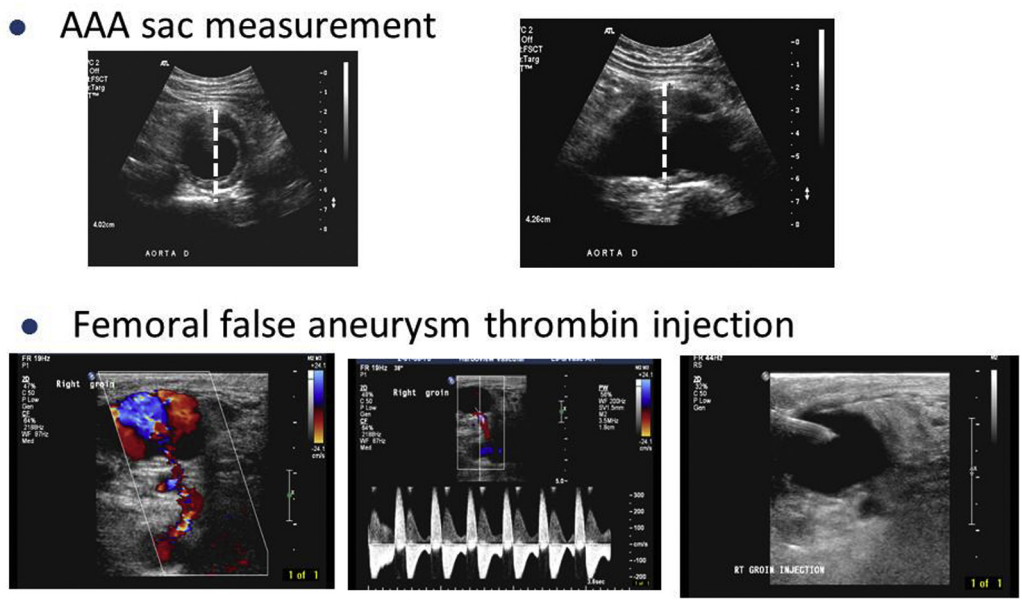

Fig. 6 – Duplex ultrasound images illustrating abdominal aortic aneurysm (AAA) sac measurement and femoral false aneurysm thrombin injection.

Table 5 – Common point-of-care vascular clinic duplex ultrasound examinations.

Examinations
Vein mapping for dialysis access fistula: anatomic variants of basilic vein and radial artery origin
Dialysis access volume flow estimate from brachial artery
Venous reflux testing of the saphenous and deep veins: new patient with varicose veins and no prior venous insufficiency duplex testing
Venous thoracic outlet syndrome evaluation: assess for axillary vein collapse with inspiration with arm in neutral and abduction positions
Abdominal aortic aneurysm sac diameter measurement: prior to and after endovascular abdominal aneurysm repair
"Selected patients": lower limb bypass graft imaging–distal anastomosis; femoral-popliteal angioplasty site
Confirmation of high-grade internal carotid artery stenosis in asymptomatic patient

femoral artery and brachial artery access, and endovenous ablation of the great and small saphenous veins.

Trainees should acquire familiarity with point-of-care hands-on ultrasound testing for patient evaluation in both the vascular clinic and hospital setting. This would include indirect physiologic testing using a hand-held continuous-wave Doppler with measurement of ankle-brachial systolic pressure index, duplex venous imaging for lower limb deep vein thrombosis, and common femoral vein imaging after endovenous ablation of the great saphenous vein (Fig. 4). These point-of-care examinations comprise an abbreviated version of complete study performed in the vascular laboratory. The goal of testing is to answer a specific clinical question or guide a vascular procedure using interpretation criteria that are clear and dichotomous (yes/no; present/absent). For example, compression ultrasound at the common femoral and popliteal vein level for the diagnosis of DVT is an imaging skill that can be taught in less than 1 hour, and in the emergency department setting has reported sensitivity of 100% and specificity of 99% (Fig. 5) [5]. Audible interpretation of peripheral artery and venous flow using a continuous-wave Doppler is a mandatory skill used on a daily basis for assessment of limb ischemia severity, detection of arterial embolus, diagnosis of venous occlusion, monitoring results of arterial intervention, and assessment of dialysis access function. Proficiency in point-of-care vascular testing indicates level 3 milestone competency.

I recommend trainees also acquire more advanced hands-on scanning skills, including visceral duplex testing for measurement of abdominal aortic aneurysm sac diameter and endovascular abdominal aneurysm repair endoleak detection, intra-operative duplex scanning of carotid endarterectomy and lower limb bypass grafts, and ultrasound-guided thrombin injection of femoral false aneurysm (Fig. 6). The trainee should demonstrate imaging skills to assess abdominal aortic aneurysm sac for endoleak detection and sac diameter measurement and use of duplex imaging to perform ultrasound-guided procedures, for example, saphenous vein endovenous ablation and false aneurysm thrombin injection. The ability to perform advanced duplex testing is particular useful in the clinic. Table 5 lists examples of point-of-care duplex ultrasound testing performed routinely in my clinic. The ability to obtain vascular laboratory testing during an outpatient clinic evaluation is preferred, but often this is not possible. I perform point-of-care duplex testing in selected patients to answer a specific clinical question or to evaluate a new patient for whom prior testing was not performed or results of a recent examination are not available. My most common examinations are for dialysis access planning and assessment of dialysis access maturation based on measurement of brachial artery volume flow. Every training program should have faculty adept at hands-on duplex ultrasound testing to educate the resident about its role in patient evaluation and interpreting test findings.

5. Summary

The education of vascular surgery residents/fellows requires a combination of mentored interactive experience in an established vascular laboratory, self-directed study, and CME programs. In the United States, vascular laboratory training is a curriculum requirement, and to be considered for certification by the Vascular Surgery Board of the American Board of Surgery, the trainee must obtain the PVI credential offered by the Alliance for Physician Certification and Advancement. Each vascular surgery training program should have a structured curriculum that exposes the trainee to all clinical areas of noninvasive vascular laboratory testing, with participation in study interpretation and supervised hands-on duplex ultrasound imaging. The trainee must document experience in supervised interpretation in at least 500 studies that run the gamut of vascular testing and pathology. The use of written educational milestones can assist the trainee in achieving the necessary proficiency to be a successful vascular specialist.

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