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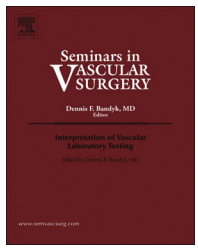

How vascular surgeons can learn ultrasound

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ARTICLE INFO

ABSTRACT

Vascular ultrasound has proven to be a cornerstone for the management of patients with vascular disease, and is utilized by vascular surgeons in the outpatient clinic, the operating room, and for follow-up after revascularisation. Today vascular surgeons are among the most frequent users of ultrasound apart from radiologists. Mastering the skills of vascular ultrasound and interpretation is best acquired under supervision and is more easily learned as part of the daily practice of vascular surgery. Separating vascular ultrasound into basic and advanced procedures is useful, and basic vascular ultrasound skills should be a part of a vascular surgical training program curriculum. In Europe, certification of vascular surgeons in basic vascular ultrasound via a pass-fail test is in its infancy, preceded by local and national initiatives. In the area of clinical vascular research, duplex ultrasound is superior to most other diagnostic modalities due to its availability and noninvasive nature and ultrasound-based research will in addition to improving patient care generate physicians highly experienced in vascular ultrasound.

1. Introduction

Fifty years ago, diagnostic ultrasound was introduced into clinical medicine in Scandinavia in close collaboration between urologists and welding engineers [1]. Many vascular clinics were quick to follow and vascular ultrasound has proven to be an invaluable part of the diagnostic armamentarium in every phase of treatments in nearly all vascular fields. In a study based on the Medicare population from 2004 to 2009, vascular surgeons were not only found to be the second highest users of nonradiologist-performed ultrasound, exceeded only by cardiologists, but also demonstrated the second highest growth (36%) in examinations per 1,000 beneficiaries [2]. Today, vascular ultrasound is used for multiple purposes—for screening (eg, in abdominal aortic aneurysms [AAA] screening programs) [3], preoperative workup (eg, before carotid thrombendarterectomy) [4], intraoperative quality control (eg, in carotid endarterectomy [CEA] and in situ bypass surgery [5–8]), and in postoperative follow-up (eg, after peripheral vein bypass surgery or for endovascular aortic aneurysm repair [EVAR] follow-up) [9,10].

The advantages of vascular ultrasonography are numerous for patients, vascular surgeons, and hospitals. Ultrasound performed during the primary consultation can identify the location of vascular disease in the vast majority of cases and, combined with history and physical examination, a treatment plan can be made in most cases [4,11–13]. If used appropriately, the patient can either be scheduled directly to treatment or, in some cases, referred for additional imaging. Besides

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https://doi.org/10.1053/j.semvascsurg.2019.01.007
0895-7967/$ - see front matter © 2019 Elsevier Inc. All rights reserved.

having the opportunity to spare the patients time, risk, and discomfort associated with additional imaging, vascular ultrasound is in general highly cost effective [14–18].

However, vascular ultrasound is a dynamic examination that requires both technical skills to produce the optimal images and interpretation skills to avoid false-negative and false-positive diagnoses. Highly competent ultrasound operators are essential to exploit the full potential of vascular ultrasound.

This article will describe, from a vascular surgeon's viewpoint, who should learn vascular ultrasound, how they should learn it, and for which patients it should be used. We will draw on experiences from vascular surgical departments, where vascular ultrasound has been integrated for more than 40 years.

2. Who should perform vascular ultrasound?

When defining curricula for vascular training, including development of educational programs in vascular ultrasound, it is important to map the actual needs for training, the "market segment," and not simply rely on available resources and equipment, reflecting convenience rather than a systematic educational plan. In a national needs assessment using a Delphi process among 33 predefined key persons in vascular surgery, Nayahangan et al [19] identified and prioritized the technical procedures that a newly qualified vascular surgeon should learn. Vascular ultrasound was identified to be among the 20 most important procedures to be included in a future training curriculum for vascular surgeons, emphasizing that the educational milieu finds that vascular ultrasound should be mastered within the specialty and not rely on radiologists. In a busy clinical practice, it is relevant to consider why vascular surgeons should allocate time to learn and perform vascular ultrasound. For the on-call staff, the ability to get ultrasound diagnoses immediately will soon become indispensable and thus reinforce its use by the vascular surgeon himself. Many surgeons will find it satisfactory to master new skills and combine ultrasound imaging with clinical findings but also to avoid some intraoperative surprises. When learning vascular ultrasound, the vascular surgeon is advantaged by his theoretical and practical understanding of the vascular anatomy, physiology, pathology, and pathophysiology—knowledge and experience that will compensate for his shortcomings in general ultrasound experience. This, in combination with his search for a surgical or endovascular treatment option, further improves understanding and mastering of the ultrasound technique as a useful tool in daily practice. In contradiction to the radiological approach, where the radiologist has to master all organ systems, vascular surgeons will focus more narrowly on the organ (vessels) and pathology in question.

3. How can vascular surgeons learn vascular ultrasound?

When an imaging technique is introduced, it is vital to address how the technique is learned and when the technique is mastered. Although vascular ultrasound has been used for years, the matter of appropriate training is still unsubstantiated. In one of the few available recommendations, the European Federation of Societies for Ultrasound in Medicine and Biology suggests that, besides attending an appropriate theoretical course, the practical training for an ultrasound novice should involve at least two half-day ultrasound clinics per week over a period of 3 to 6 months and a minimum of 100 supervised examinations of each type (eg, carotid, lower limb, venous) [20,21]. These numbers are in line with guidelines from the American Association for Vascular Surgery and the Society for Vascular Surgery [22]. Besides being more or less impossible to fulfill such a number for vascular trainees that need to learn other things besides vascular ultrasound, such recommendations do not take into account that some vascular ultrasound examinations are "easy" and others are "difficult"; in addition, it does not consider the importance of preceding clinical experiences besides preexisting ultrasonic skills. Finally, it is important to acknowledge that all trainees learn at their own pace and it is impossible to define a number of procedures that will guarantee competency for all. Optimally, competency in each procedure should be ensured by valid assessments of the individual trainee by experienced supervisors. However, an estimated minimum number of performed procedures can be valuable to guide the training and certification programs.

We acknowledge that the risk of missed pathology is sometimes cited as a potential disadvantage of point-of-care or nonradiologist-performed ultrasound imaging [23], but the magnitude of the minimum number of supervised vascular ultrasound examinations needed to perform vascular ultrasound are debatable. Most vascular surgeons will find that the ultrasound examinations most often needed are the easiest to learn [24], and the experience from Denmark, where mastering all of the "easy" vascular ultrasound examinations is part of the National Health Service–approved curriculum, supports this assumption. From an educational point of view, it is reasonable to divide vascular ultrasound into basic and advanced procedures, as recommended here.

3.1. *Basic vascular ultrasound*

In our experience, the majority (>75%) of all vascular ultrasound examinations needed by a vascular surgeon are basic and can be learned after a 2½-day practical and theoretical workshop (ESVS.org), followed by about a dozen supervised scans of each procedure [24]. However, it requires that ultrasound, after this introductory course, is used continuously in the clinic and that ultrasonic mentorship is possible. Therefore, ultrasound equipment needs to be available to the trainee 24/7. What to consider as "basic vascular ultrasound" depends not only on how difficult the procedure is, but also on the consequences of a diagnostic mistake, as well as on national and international differences in how patient care is organized. For example, if carotid ultrasound is used as the only preoperative examination before CEA, it should be considered an advanced procedure, but if used to select stroke/transient ischemic attack patients for computed tomography angiography, it can be considered basic. In Denmark, basic vascular ultrasound covers infrarenal aorta aneurysms, screening for aorto-iliac disease by visual

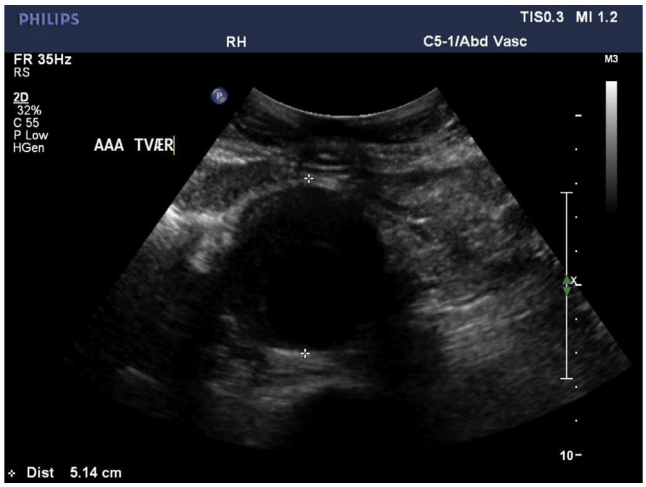

Fig. 1 – Abdominal aortic aneurysm (AAA) ultrasound. Ultrasound scanning of the infrarenal aorta reveals an AAA (51 mm) as part of surveillance program and the patients will be referred for computed tomography in preparation for AAA repair.

interpretation of the flow curve in the femoral artery, suprageniculare arteries, peripheral bypass (stenoses and occlusions), and venous insufficiency (superficial and deep).

3.1.1. AAAs

Nonradiologist-performed ultrasound diagnosing of AAAs has been shown to reduce the time to diagnosis of AAA, potentially improve survival, and achieve acceptable to very high sensitivity and specificity for the diagnosis of AAAs [25–28]. Several studies have shown that with little formal training and supervised examinations, it is possible to perform reliable ultrasound diagnoses of AAAs [26,28,29] (Fig. 1).

3.1.2. *Lower limb infrainguinal vein bypass*

Duplex ultrasound surveillance programs of infrainguinal vein bypass grafts are widely practiced as a noninvasive and low-cost modality [30]. The lower limb vein bypass is superficial and easily accessible in most of its course, and duplex ultrasound is normally not difficult to learn. In a study comparing ultrasound novices with highly experienced vascular sonographers, novices showed good agreement and even better when focusing on the most relevant grafts at risk [31].

3.1.3. *Iliac arteries*

Assessment of the aorto-iliac arterial segment is crucial in the diagnostic workup of patients with peripheral arterial disease having the potential to rationalize further diagnostics and plan treatment. However, a full duplex scan of the iliac segment is time-consuming and may be difficult due to the deep course and angulation of the iliac vessels. Simple visual interpretation of the Doppler waveform in the common femoral artery can be considered a basic ultrasound procedure and has been proven to be both a sensitive and an accurate technique for prediction of significant aorto-iliac lesions [32,33] (Fig. 2).

3.1.4. *Femoral-popliteal arterial segment*

The femoral and the popliteal artery is, in most of its course, superficially situated and therefore relatively easy to insonate adequately, showing good agreement with digital subtraction arteriography in patients with peripheral arterial disease [34–36] and should be considered a basic ultrasound examinations [24].

3.1.5. *Venous insufficiency*

Duplex ultrasound scanning of the superficial and deep veins of the lower limb is well described, although there is considerable variation as to who actually undertakes the investigation [37,38]. The evidence on minimum training is lacking but uncomplicated cases can be considered basic. It seems reasonable that the vascular surgeon responsible for treating the patient performs his own ultrasound examinations after theoretical and practical ultrasound education (Fig. 3).

3.2. *Advanced vascular ultrasound*

Vascular ultrasound procedures not covered in the basic curriculum can be designated as "advanced" and will be more difficult to master requiring more training and supervision. Advanced vascular ultrasound covers: carotid arteries (as only preoperative examination before CEA), vertebral and subclavian arteries, post-EVAR surveillance in patients with growing sac or suspicion of endoleak, renal and mesenteric arteries, iliac arteries and infragenicular arteries, contrast-enhanced ultrasound, ultrasound-guided thrombin injection of pseudo-aneurysms, arteriovenous fistula for dialysis, transcranial ultrasound, and three-dimensional ultrasound. These more advanced ultrasound procedures should be reserved to fewer dedicated physicians or vascular technologists in high-volume departments with interest in and dedication to ultrasound, as illustrated in the examples that follow.

3.2.1. *Extracranial carotid arteries*

Carotid ultrasound was among the first to be "evidence based" in replacing arteriography for identifying and quantifying carotid stenosis. It soon became the preferred screening method to select for arteriography and later the sole method for identification of those who should have CEA performed. Clearly an area where the sonographer needs extensive training, however, numerous studies in the 1980s and 1990s found accuracy and reproducibility similar to digital subtraction arteriography for assessment of degree of stenosis [39–41]. Quantification of carotid artery stenosis with duplex ultrasound may be associated with a considerable variation, which could lead to a different clinical conclusion and emphasizes that carotid ultrasound, as the only preoperative measure before CEA, should be considered "advanced ultrasound" [42,43]. However, when using ultrasound only for screening for carotid pathology (normal or diseased), a much lower number of training cases may be needed.

3.2.2. *Infragenicular arteries*

Lower limb arterial mapping has, since the beginning of the century, emerged as an alternative to angiography in preoperative workup of patients with claudication or critical limb ischemia [36,44–46]. It is a demanding examination that

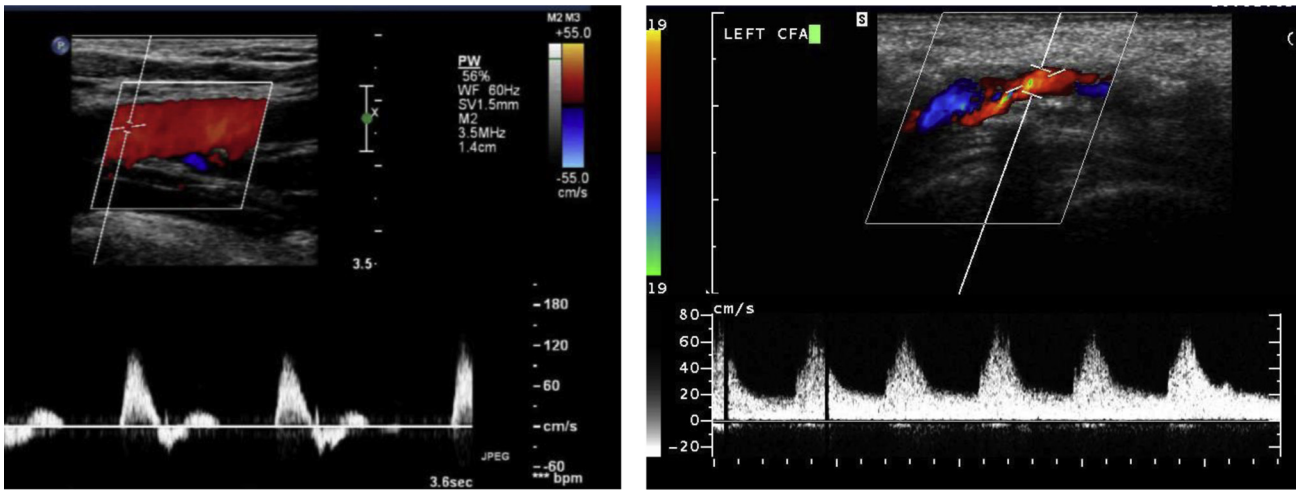

Fig. 2 – Normal and abnormal flow in the common femoral artery. Normal (left) and abnormal (right) flow curve recorded in the common femoral artery. Visual interpretation of the flow curve is a fast and reliable way to rationalize the use of angiography and other diagnostic measures in peripheral arterial disease patients as an normal curve excludes significant upstream lesions where else an abnormal curve require further diagnostics if clinical relevant.

requires extensive training, but that can be used as the sole preoperative modality before lower limb revascularization [47,48], showing good agreement with intraoperative findings [46]. Vascular surgeons have the ability to direct the examinations towards revascularization, that is, identification of appropriate inflow and outflow in case of bypass surgery or establishing the best access site for endovascular intervention. In selected patients, contrast-enhanced ultrasound can help to overcome some inherent drawbacks of the ultrasound technique: calcification and low flow [49].

3.2.3. *Ultrasound surveillance after endovascular aortic aneurysm repair*

Ultrasound is increasingly used in surveillance after endovascular aortic aneurysm repair (EVAR) and has been shown to be a reliable alternative to computed tomography angiography after uncomplicated EVAR in patients with a stable residual sac [50]. Under such conditions, the ultrasound examination is, in most cases, easy and comparable with follow-up of small AAAs. In contradiction, ultrasound-based follow-up of EVAR patients with growing sac, complicated anatomy, or suspected endoleak is a demanding examination and will, in many cases, require additional ultrasound contrast administration [10,49] (Fig. 4).

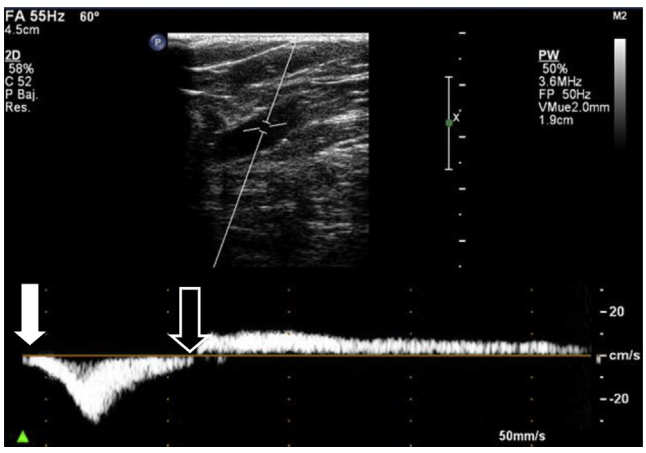

Fig. 3 – Ultrasound scanning for superficial venous insufficiency. Venous valve reflux at the saphenofemoral junction after calf compression (solid white arrow) and release of compression (white arrow outline).

3.2.4. *Duplex ultrasound of the mesenteric arteries*

Increased peak systolic velocities above well-defined thresholds have been found to be a reliable measure of significant mesenteric artery stenosis. Normal velocities can safely exclude significant disease, whereas a significant velocity increase will require an additional computed tomography arteriography before planning eventual revascularization [51]. Proper visualization of severely diseased mesenteric arteries, and especially the celiac trunk, is difficult even in experienced hands. Besides the usual constraints due to bowel gas, heavy calcifications, and inconstant collaterals, the velocity measurements need to be relative to respiratory phases and performed both standing and supine [52].

3.3. *Theoretical education of vascular ultrasound*

The training of practical skills should be accompanied with theoretical education covering ultrasound physics and methods, ultrasound anatomy, ultrasound pathology, and safety according to the European Federation of Societies for Ultrasound in Medicine and Biology recommendations. In Europe, Continuing Medical Education–accredited workshops in both basic and advanced vascular ultrasound focusing on vascular surgeons and vascular surgeons in training are arranged by the European Society for Vascular Surgery (www.esvs.org), among others.

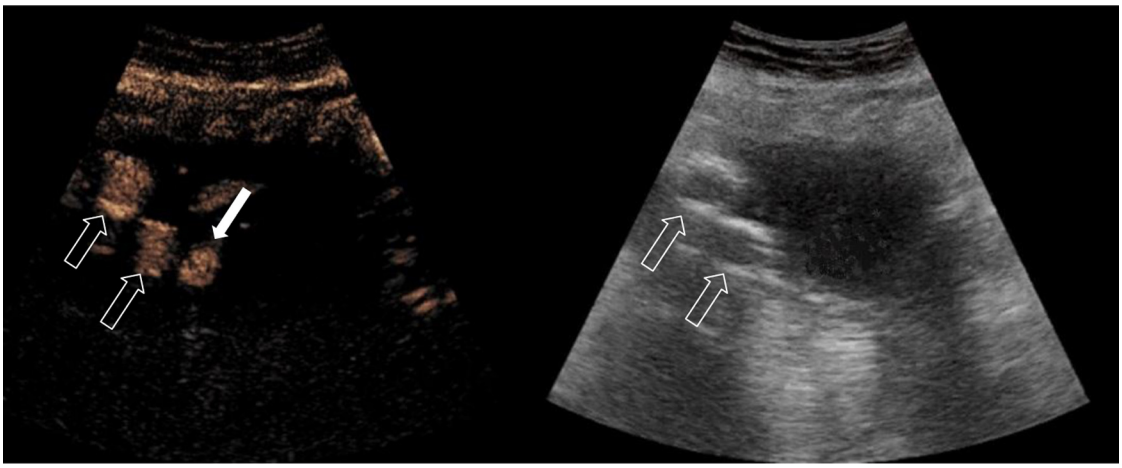

Fig. 4 – Contrast enhanced ultrasound after endovascular aortic aneurysm repair. Endoleak after endovascular aortic aneurysm repair only seen with contrast enhanced ultrasound (solid white arrow) on the left image. The Iliac components (white arrow outline) are contrast filled as well. Courtesy of Kim Bredahl.

3.4. *Training practical ultrasound skills*

Diagnostic vascular ultrasound can be trained without any risk for the patient. In a large vascular outpatient clinic, there will be many opportunities for practicing the majority of vascular ultrasound examinations under supervision. The challenge is to ensure the trainees have enough time to practice and ensure availability of skilled supervisors. Initially, this will mean double staffing in the outpatient clinic but quite quickly the trainee can scan alone and then consult a supervisor for a short demonstration before finalizing the examination.

Ultrasound simulators are recognized as valuable when learning surgical and endovascular skills and might play a role in vascular ultrasound training. Interventional ultrasound can be both uncomfortable and potentially risky to the patient, which is why learning the most basic skills in a safe simulation-based environment seems obvious. In a computer-based carotid artery duplex ultrasound simulator providing real-time color Doppler images and Doppler spectral waveforms, preliminary studies determined its potential use for training and assessment of skills in vascular ultrasound [53]. In a lower limb arterial duplex simulator, it was possible to demonstrate transfer of ultrasound skills to real patients in a prospective study of 17 ultrasound novices and was considered valuable when teaching vascular ultrasound [54].

In the future, advanced and validated simulators with Doppler functionality may play an important role as a standardized platform for testing ultrasound competences using a validated test tool, although such simulators, to the best of our knowledge, are not commercially available yet.

4. Certification in vascular ultrasound

As mentioned, a fixed number of ultrasound studies or a fixed term of training does not guarantee a sufficient level of competence, and should only be used to guide the training and certification program. The only way to ensure individual competency is to test each trainee using dedicated assessment tools with solid evidence of validity [55,56]. These tests have important consequences: Failing competent trainees delays or jeopardizes their careers and passing incompetent trainees puts patients at risk. Therefore, it is essential that the pass/fail cutoffs are established using credible standard settings methods [57] (Fig. 5).

There are few established certification programs for vascular surgeons in Europe, despite that half of the vascular trainees in Spain considered ultrasound training insufficient in a national survey [58], and a recent general needs assessment in Denmark identified vascular ultrasound to be among the most important procedures for future training programs for vascular surgeons in training [19]. The European Society for Vascular Surgery is currently initiating a European certification program in vascular ultrasound designed for vascular surgeons, but several challenges need to be considered. The Spanish Society for Vascular Surgery has an established certification program of competences in noninvasive evaluation of vascular disease, including vascular ultrasound. The program includes training courses and theoretical and practical examinations in basic vascular ultrasound (www.cdvni.es). Less than two decades after the introduction, most Spanish vascular surgeons have passed the program and the number of vascular ultrasound examinations has nearly doubled from 31 to 54 examinations per 10,000/year [59].

5. One stop vascular clinic

A very important aspect is the synergy of diagnosis and planning of a potential operation when vascular surgeons perform vascular ultrasonography. Rather than first speaking to and examining the patient, followed by referral for imaging or functional studies, the vascular surgeon who at the same

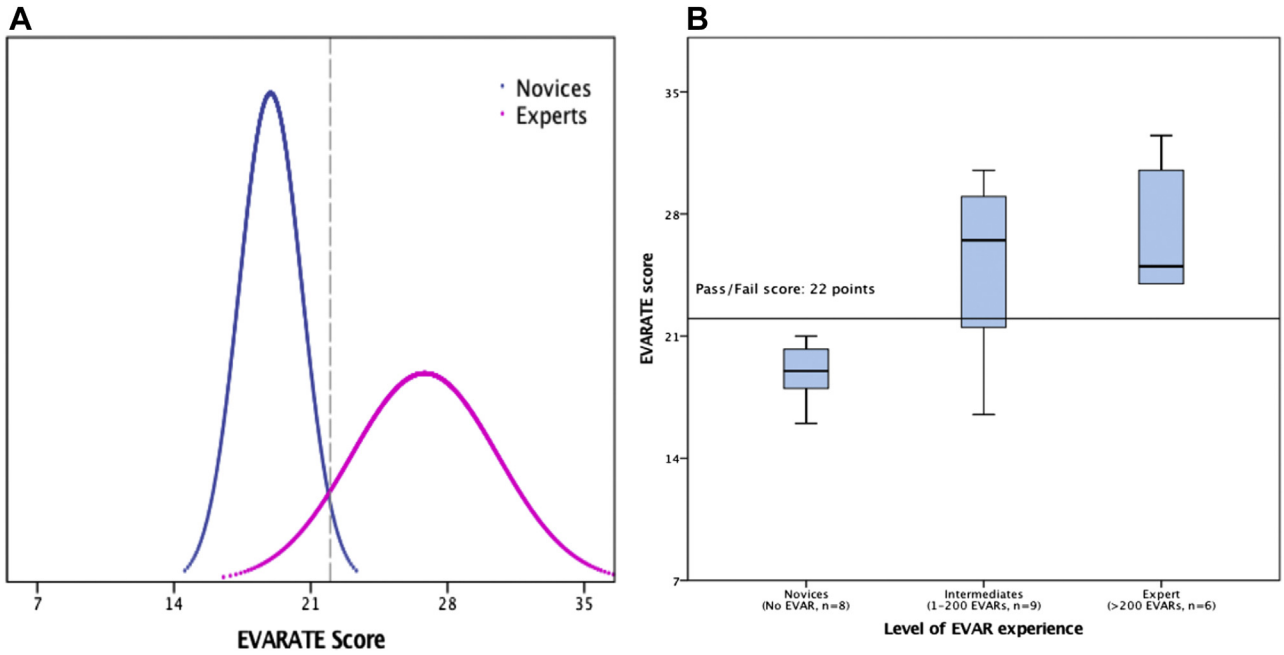

Fig. 5 – Example of skills-testing using a pass/fail standard. (A) Shows how a credible pass/fail standard can be defined using an established standard setting methods - the "contrasting groups" method. (B) Shows the consequences for doctors taking the test: In this example, none of the novices pass (no false positives) and none of the experts fail (no false negatives). From Strøm et al [66], reprinted with permission.

time performs the ultrasound examination will be able to draw conclusions about which therapy is relevant for the patient. This not only saves the patient an extra visit, but it most certainly also improves the quality of decisions made, because all relevant history and pathological findings of the physical examination are fresh in the memory of the surgeon performing the scan. Finally, this improved efficiency will not only be beneficial for patients with critical disease, but also for the funding source, as the "one-stop" clinic principle with ultrasound scanning at the first visit, combined with specialist examination by the vascular surgeon, is clearly cheaper than more visits at different clinics [12,13].

6. Vascular ultrasound for quality assessment and clinical research

Because ultrasound is accurate, noninvasive, harmless, and cost-effective, it is ideal for quality assessment and follow-up of vascular conditions and treatments. It is simply not accurate to rely on a clinical examination only. In order to assess size of an aneurysm, progression of disease, or patency of a stented area or a peripheral bypass, imaging modality combined with opportunities for measurement of blood flow variable is crucial. Similarly, the opportunities for research into diseases of the blood vessels, or organs that they supply, are endless because of the nature of vascular ultrasound. Consider the development of new treatment methods, such as drugs and devices used in vascular disease [60]. Without vascular ultrasonography, a lot of the evidence would not exist.

7. Ultrasound training in other specialities

Optimally, the curriculum for doctors in training should be evidence-based, just as the treatment of patients. An example from respiratory medicine is endobronchial ultrasound, for which the European Respiratory Society runs a complete curriculum based on solid evidence [61]. Endobronchial ultrasound was identified as a highly prioritized procedure in a general needs assessment using the Delphi methodology [62] and measurable objectives for theoretical knowledge, simulator performance, and clinical performance were defined based on validation studies [63–65]. The educational methods include e-learning, international theoretical courses including live demonstrations, centralized simulation-based training, and clinical shadowing at an expert center. When participants have completed the theory and the simulator training by passing validated tests, they can proceed with supervised clinical training and finally become European Respiratory Society–endorsed endobronchial ultrasound operators by uploading videorecordings of independently performed procedures for assessment by blinded endobronchial ultrasound experts. This approach aligns with the newest international guidelines regarding endosonography and training [66]. The program has now been implemented in Western Europe and evaluation is ongoing before further dissemination.

8. Conclusions

Due to its availability, low price, and noninvasive nature, vascular ultrasonography is the most important diagnostic

modality for managing patients with arterial or venous disease. It can be taught to every physician who wishes to learn it and, depending on enthusiasm and skills, many vascular surgeons have become excellent sonographers - in part, aided by their existing knowledge of vascular anatomy, pathology, and pathophysiology. In many conditions, treatment plans can be made solely on a single vascular ultrasound examination and monitoring of disease, quality control during procedures, and postoperative surveillance most often rely on vascular ultrasonography. Supervised scanning, mentorship, and quality assessment are vital to ensure high-quality vascular ultrasonography and certification seems to be a useful tool to reach this across countries, nations, and regions of the world.

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