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MEDICAL STUDENT ULTRASOUND EDUCATION: A WFUMB POSITION PAPER, PART I

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Abstract—The introduction of ultrasound into medical student education is well underway in many locations around the world, but is still in its infancy or has yet to begin in others. Proper incorporation of ultrasound education into medical training requires planning and resources, both capital and human. In this article, we discuss the state of the art of ultrasound in medical education throughout the world, as well as various methodologies utilized to improve student education and to incorporate ultrasound into every facet of training. Experiences from various educational systems and available evidence regarding the impact of ultrasound education are summarized. Representing multiple societies and specialties throughout the world, we discuss established modern as well as novel education structures and different successful approaches.

Key Words: Ultrasound, Education, Point of care, Medical students, Knobology.

INTRODUCTION

Ultrasound is recognized as an effective first-line imaging modality for a wide range of indications. Furthermore, ultrasound appears to facilitate an interdisciplinary imaging approach and may increase interspecialty collaboration (Herrmann et al. 2015). Lack of ionizing radiation, low cost, high portability and its non-invasive nature have made ultrasound a very attractive tool for medical student education. Ultrasound also has a unique ability to connect basic science with clinical applications and enhance direct student teacher interactions (Baltarowich et al. 2014; Hempel et al. 2016b). The aim of this position paper is to present the history of ultrasound in medical education and discuss its current status, future needs and various approaches taken throughout the world.

CONVENTIONAL ULTRASOUND AND POINT-OF-CARE-ULTRASOUND

Ultrasound use in medicine typically follows one of two general paths, as a standard comprehensive approach by traditional imagers or as point-of-care-ultrasound (POCUS) at the bedside by clinicians. The role ultrasound plays in patient care varies with region, health care system and setting type. Such diversity in application has arisen secondary to political, economic, regulatory, technological and other factors.

The use of ultrasound in medical education will depend on the type of ultrasound equipment available, selected educational approach and faculty skill sets. These will determine the type and quality of training delivered to students. Technological advancements have made ultrasound equipment more accessible and include development of hand-held ultrasound devices using personal smartphones (Barreiros et al. 2014; Gilja et al. 2014; Mirabel et al. 2015). These types of ultrasound devices are easily incorporated into student education and are an optimal form for carrying on clinical rotations (Gilja et al. 2003).

Typically, three levels of ultrasound equipment are used in student education:

- Level 1: hand-held devices, the size of mobile phones or tablets that are tailored to answer focused clinical questions.
- Level 2: point-of-care-ultrasound cart-based systems,

with expanded capability compared with level 1 devices.

- Level 3: larger and more expensive, high-resolution

ultrasound systems with advanced capabilities, enabling comprehensive patient evaluation (Gilja et al. 2003; Piscaglia et al. 2013).

Conventional ultrasound

For many clinical indications, ultrasound is the established first-line imaging modality worldwide. Conventional ultrasound (CUS) has been performed across multiple specialties for more than four decades. CUS equipment is generally more expensive and uses a broader variety of transducers across a wide range of imaging applications. Such systems are usually found in dedicated scanning rooms with the patients transported to the room for scanning. In a handful of countries, CUS education has long been incorporated into basic graduate medical education and postgraduate programs (Angtuaco et al. 2007; Bahner and Royall 2013; Cantisani et al. 2016; Prosch et al. 2015).

Point-of-Care Ultrasound

Point-of-care ultrasound can be performed using conventional ultrasound equipment or portable or hand-held devices. Although first-and second-generation devices offered highly limited imaging capabilities, handheld scanners are rapidly improving in resolution, offering adjunct imaging capabilities and becoming increasingly comparable to modern cart-based systems. Current gaps in capabilities between hand-held and larger cart-based systems are likely to continue to narrow and one day disappear altogether.

POCUS using conventional ultrasound equipment. Conventional ultrasound equipment is frequently used for POCUS by providers with extensive imaging experience, including clinicians, radiologists and sonographers. Limitations of conventional ultrasound imaging systems generally include prolonged boot-up time, poor battery life and limited mobility.

POCUS using mobile ultrasound equipment. Point-of-care-ultrasound studies are performed at the patient’s bedside by the treating clinician. Ultrasound devices may have to fit into narrow spaces and require extended battery life. The range of examinations performed is broad and can span from ocular to cardiac, from musculoskeletal to pelvic or interventional (Dietrich et al. 2015a, 2015b, 2017). Typical settings include the emergency department (ED), the intensive care unit (ICU), hospital wards and outpatient clinical and even pre-hospital settings.

POCUS using small handheld devices. Hand-held ultrasound devices have the potential to extend the physical examination with focused ad hoc imaging, and can guide the selection of further investigations in real time (Hussain 2015).

A variety of terms have been created to describe such ultraportable ultrasound devices, including echoscopes (Barreiros et al. 2014; Dietrich et al. 2012, 2015a, 2015b, 2017; Gilja et al. 2014; Piscaglia et al. 2013), visual stethoscopes (Gillman and Kirkpatrick 2012) and sonoscopes (Greenbaum 2003; Hoffmann 2003).

The ability of POCUS to provide real-time visual, anatomic and functional information at the patient's bed-side is perhaps its greatest value in medical education. Abundant information, such as cardiac contractility, intestinal motility, and presence of a pneumothorax in a patient with chest trauma can be obtained rapidly, efficiently and with high accuracy (Bahner et al. 2008; Dietrich et al. 2015a). Real-time evaluation of anatomy and topographic areas allows the student to perform a virtual "in vivo dissection," improving understanding of anatomic relationships and physiology. A World Federation for Ultrasound in Medicine and Biology (WFUMB) position paper on POCUS expanding on this topic in greater detail has recently been published (Dietrich et al. 2017).

HISTORICAL PERSPECTIVE

Many advocates of ultrasound in medical education are surprised to discover how long ultrasound has been incorporated into medical curricula in some countries. "Anatomie am Lebenden" (which loosely translates to "hands-on," "peer to peer" teaching of anatomy") was an anatomy teaching experiment using ultrasound that was initiated more than 30 y ago at the Hannover Medical School (MHH, Hannover, Germany). In this program, selected medical students participated as subjects and peer teachers. Research revealed this to be an effective approach that led to improved student motivation and facilitated learning anatomy (Brown et al. 2012; Wicke et al. 2003). Several other German medical schools later adopted this approach, but hands-on exposure was limited to a narrow range of applications (Arger et al. 2005; Barloon et al. 1998; Brunner et al. 1995; Decara et al. 2005; Kobal et al. 2004, 2005; Shapiro et al. 2002; Teichgraber et al. 1996; Tshibwabwa and Groves 2005; Wicke et al. 2003; Wittich et al. 2002; Yoo et al. 2004).

Ultrasound in medical education outside of Europe has spread significantly and dates back nearly 20 y in some locations (Angtuaco et al. 2007; Fernandez-Frackelton et al. 2007; Gogalniceanu et al. 2010; Rao et al. 2008; Syperda et al. 2008; Tshibwabwa et al. 2007; Wright and Bell 2008). Standardization has been made particularly difficult, at least in part because of varied regulatory bodies (Dietrich 2012; Dietrich and Riemer-Hommel 2012). However, there is a global movement underway for adoption of ultrasound curricula in medical schools, as well as modernization and standardization led by the current evidence-based consensus conference organized by the Society of Ultrasound in Medical Education (SUSME) and World Interactive Network Focused on Critical Ultrasound (WINFOCUS) (Cantisani et al. 2016; Hussain 2015).

Perhaps the most comprehensive documentation of full ultrasound integration into a medical school curriculum came from arguably the most advanced ultrasound medical school program in the world, when in 2011 the University of South Carolina School of Medicine reported their experience in integrating an ultrasound curriculum for all students, across all 4 y of medical school (Hoppmann et al. 2011). The curriculum was based on a point-of-care ''focused'' ultrasound program that was originally developed for local postgraduate emergency medicine physicians and rotating medical students (Cook et al. 2007; Hoppmann et al. 2015).

KEY COMPONENTS OF ULTRASOUND INTEGRATION INTO MEDICAL STUDENT EDUCATION

There are several key considerations in any attempt to integrate ultrasound into medical education that deserve specific discussion. These include:

- Motivating students to perform ultrasound
- Setting appropriate goals
- How should ultrasound be taught and by whom?

- What should be part of an ultrasound curriculum?
- Educational media, material and assessment
- Support of deans
- Support of module leaders
- Hands-on teachers
- Space
- Budget (US equipment, server to save images for each student, simulation)
- Funding

Motivation

Experience has indicated that ultrasound is a considerable motivating factor for medical students when introduced into the medical curriculum. The wide use of digital tablets, smartphones, computers and online resources has readied today's students to comfortably consume visual information and adapt to learning via visual and auditory media.

In addition, the process of scanning can be viewed similarly to palpation during patient examination. Students typically covet any increase in hands-on patient contact experiences, and POCUS satisfies this demand by increasing clinician patient interaction and contact time. The real-time visual information provided by ultrasound opens a new horizon for students regarding topography, morphology, hemodynamics and elasticity of organs, as well as the movement of anatomic structures in functional tests such as Valsalva.

Setting appropriate goals

Ultrasound should also be taught as an adjunct diagnostic tool to the physical examination. There is a natural pathway for transfer of knowledge from anatomy and physiology to sono-natomy/physiology and, then, pathology. Ultrasound hands-on skills should be practiced routinely throughout medical school to cement acquired knowledge. Additionally, students should be taught reasonable indications and limitations for ultrasound examinations, as well as appropriate use of other imaging modalities. Ideally, student training in ultrasound should be easily accessible, even outside of normal school hours. Most importantly, ultrasound education should be standardized, systematic, transparent and structured and allow students to easily acquire ultrasound clinical skills.

How should ultrasound be taught and by whom?

Ultrasound education can be delivered via classic methods such as didactic presentations for a large audience, or practical hands-on courses by professors or tutors who have been trained under a "teach-the-teacher" concept. Lectures are often appropriate for teaching fundamental principles of ultrasound, but cannot replace the essential hands-on training that is critical for obtaining the visuospatial and visuomotor skills necessary for handling a transducer and acquiring images. The "teach-the-teacher" approach relies on recruitment of experienced students as tutors, who then teach their peers.

Inspiring students while they are learning ultrasound is critical. One of the most fascinating teaching methods, and often the best received, is to connect clinical data and represented anatomy/pathophysiology to the ultrasound image in real time. Once students have an appreciation for these relationships, they can then relate all of the findings to clinical management decisions. The educational content has to be tailored to concurrent education topics.

Classic training methods. Medical student education is traditionally based on “classic” training methods such as presentations, lectures, courses and workshops. However, new technologies and web-based sources of information have opened novel educational applications in medical practice (Konge et al. 2015). Some of the newer educational strategies will be discussed in an upcoming WFUMB article focusing specifically on that topic.

The pros of classic teaching approaches are as follows:

- Already established methodology
- Ability to utilize established infrastructure
- Requires no teacher retraining on newer education methods
- Allows teaching of large groups

Delivery of ultrasound education using classic teaching methods is well established and does not require the expense of adopting new educational methodology, which may require greater institutional investment. This is especially relevant for senior educators, with no requirement for them to adapt to new technology or new training methods. Such a change typically requires a nearly complete retooling of traditional lectures. However, classic teaching methods may be suboptimal for delivery of visually intense educational material such as ultrasound, especially when interwoven with clinical information. Furthermore, even traditional lecture delivery may still require additional education for clinician lecturers who are new to ultrasound but will be required to participate when ultrasound is introduced into a medical school curriculum.

The cons of classic teaching approaches are as follows:

- A lack of motivation for practical training because of insufficient time and high resource requirement
- Scheduling needs for classroom lectures followed by

hands-on training

- Insufficient practical training leaving students with poor image acquisition skills
- Burdening of students with acquiring hands-on skills

on their own and students’ low confidence in their practical skills and ultrasound clinical decision making

- Highly limited real-time feedback opportunity in

practical training

- Fewer opportunities for students to cement lecture knowledge during real-time ultrasound use

New teaching and training methods optimize delivery of visual information. In fact, rather than sitting in lectures, students desire short and focused aliquots of information delivery. As a reflection of this, many medical schools around the world are adapting their curricula to match these new approaches to medical student education and are realizing that ultrasound crosslinks basic science and clinical management. Ultrasound incorporation allows students to relate more closely to anatomy and physiology and to understand how they apply in practice.

Peer teaching. Practical skills are best learned during hands-on exercises taught in small, closely supervised groups. However, this makes training students to perform and interpret ultrasound both labor-and time-intensive (Heinzow et al. 2013). Teaching faculty may not have the time to accommodate a new commitment when ultrasound is introduced into the curriculum. The problem may be overcome by choosing teaching formats that have a multiplier effect, such as having senior staff train peer tutors who, in turn, teach peers practical ultrasound skills (Hoppmann et al. 2011).

The efficacy of peer teaching has been compared with that of traditional faculty teaching in several randomized controlled trials by assessing the post-training performance on objective structured clinical examinations (OSCEs). Performance among peer-tutored students was not inferior to that of students taught by a traditional faculty approach (Celebi et al. 2012; Kaine et al. 2016; Knobe et al. 2010), indicating that both formats are suitable for teaching basic ultrasound techniques (Celebi et al. 2012). Students might also connect more easily with their peers, creating a better working atmosphere (Garcia-Casasola et al. 2016). Peer tutors may benefit from peer teaching by improving their own knowledge and skills (Knobe et al. 2010). Training high-quality peer tutors requires an ongoing effort with regular teaching opportunities (Ahn et al. 2014).

Examples of peer teaching initiatives. In 2007, a pioneering project began at the University of Vienna: the students' initiative "sono4 you." In sono4 you, students organized themselves to provide basic training in ultrasound of the abdomen, head and neck, heart, emergency applications, musculoskeletal system and simulation of US-guided interventions to peers (Prosch et al. 2015). Peer teachers received regular training from faculty to maintain and expand their skills. Similar initiatives were later introduced at other German-speaking medical schools. Peer teaching offers opportunities to involve highly motivated trainees and should be guided by faculty to guarantee high-quality instruction (DesJardin et al. 2017).

A section of the Swiss Society of Ultrasound in Medicine (SGUM) called the "Young Sonographers" collaborated with local student groups and the Institute of Primary Health Care in Bern to develop a national curriculum for teaching basic ultrasound skills to medical students. The curriculum used blended learning, consisting of four 1-h e-learning modules with 4 h of peer-taught practical lessons per module. Student progress was assessed with a final examination conducted by SGUM ultrasound experts.

In summary, peer teaching as an avenue for making undergraduate ultrasound training available to a broad base of students is well established and tested. It is essential that students be encouraged to create initiatives for close collaboration with local experts, faculty and national ultrasound societies, to expand learning opportunities. Additionally, ultrasound societies should oversee and guide educational content, teaching format and skill assessment to guarantee high-quality ultrasound education.

Teaching the teachers. The "teach-the-teacher" approach can be very helpful when there is a lack of educational resources in a busy clinical setting. Experienced clinical faculty are recruited to learn ultrasound relevant to their settings and improve existing ultrasound skill and, in turn, provide education to students. "Teach the teachers" often focuses on improving existing ultrasound skills, but some educators are taught from scratch. Blended learning methods have proven highly effective in ultrasound education (Gogalniceanu et al. 2010; Hempel et al. 2016a) and are especially well adapted for busy faculty who are volunteering to learn ultrasound. It must be noted that not every clinical faculty or ultrasound practitioner makes a good teacher. Potential teachers require good ultrasound technique as well as good communication skills and the willingness to teach.

What should be part of an ultrasound curriculum?

Ultrasound education should begin with classic ultrasound basics such as physics, knobology, image optimization and safety. Examination techniques, along with anatomy, physiology and important pathologies, follow naturally within the curriculum. Pre-clinical ultrasound teaching should be introduced into anatomy and physiology courses, as this allows students to learn sonographic anatomy and improves their understanding of live human anatomy and physiology. Because ultrasound relies on practical skills, e-learning platforms and high-fidelity simulators are playing an ever-increasing role in student education. Initial studies have shown good results for e-learning and high-fidelity ultrasound simulator platforms. Simulation-based point-of-care ultrasound training is a matter of competency rather than volume.

Anatomy, physiology. Ultrasound may improve students' acquisition of anatomic knowledge (Mouratev et al. 2013; Tarique et al. 2018). Students are able to better understand the topography, function, relations of adjacent organs and their real-time movements when examining using ultrasound. Similarly, anatomy and physiology instructors have found ultrasound to be an exciting addition to their teaching armamentarium and have recognized its value in reaching the modern medical student. Anatomy and physiology ultrasound education should be presented to the students in a tailored way that relates to topics being covered in the course and should, whenever possible, be related to basic clinical scenarios.

Examination technique. Examination techniques should be well defined and scaffolded (from simple to complex and then to more focused) so that students are able to adapt to different scanning settings such as a primary care office setting versus scanning a critically ill patient in the resuscitation bay. Patient positioning (and any necessary changes in position), transducer placement and manipulation and machine operation should all be covered as part of examination techniques. However, this prefacing knowledge should not be taught at the same time as the psychomotor skills that are required to perform the scan. This is because there is limited literature to suggest that adopting this instructional practice may place the learner into cognitive overload. Working memory has a finite and limited capacity. Therefore, it is important not to teach multiple skills at the same time, for example, demonstrating how to scan the thyroid, performing image optimization and instrumentation and how to use color Doppler imaging (Nicholls et al. 2016a). Doing so would overload the finite capacity of the working memory. Therefore, it is suggested when teaching multipart, or complex, skills that the educator should first break down the task into subparts, and then teach each subpart. Whole-task practice is achieved when the skill subparts are reconstructed and practiced with the correct sequencing and timing. Students should attain a good understanding of standard orientation and movements of the transducer. Standard image orientation and any measurement norms should be followed.

Introduction to "knobology". Knobology refers to machine operations and controls. These controls, conceptually similar from one machine to another, are designed to achieve the same image modification and activation of adjunct ultrasound techniques, such as color Doppler activation. However, in practice, keyboards and instrument interfaces can differ greatly from one machine to another in location and actual functionality and, on some machines, do not exist.

Examination-dependent pre-sets are integrated into most machines and provided by the vendor to simplify technical adjustments. Similarly, there are essential buttons for image acquisition that exist in every machine and need to be identified. Ideally, students would become acquainted with a variety of ultrasound machine types, making it easier for them to adjust to different equipment in future educational and practice settings.

Terminology. Knowledge of standard ultrasound terminology is important to allow communication between students and teachers, as well as colleagues in clinical practice. Additionally, students should be able to read scholarly articles and understand ultrasound terminology used in diagnostic reports.

Safety. Sonographic applications are considered safe according to the guidelines of the British Medical Ultrasound Society (BMUS), European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) and WFUMB. However, depending on application and device, thermal effects could theoretically occur in the tissues being scanned, particularly in the case of Doppler ultrasound (BMUS 2016). Ultrasound education should include discussion of possible effects of ultrasound on human tissue, mainly through thermal and non-thermal (or mechanical) mechanisms (ter Haar et al. 1989). These relate to tissue heating, cavitation and mechanical overload (O'Brien 2007). The as low as reasonably achievable (ALARA) principle (Fowlkes et al. 2008), potential thermal effect as described by the thermal index (TI) and mechanical effect by the mechanical index (MI) can be included as part of safety in ultrasound student education (Nelson et al. 2009).

Relevant pathology. The clinical practice situation and setting dictate the likely pathology that will be encountered by an operator. Relevant pathologic states that apply to point-of-care ultrasound and the binary nature of decision making regarding these pathologies have been codified (Dietrich et al. 2017). Medical students should be familiar with a breadth of pathologies, reflective of their general knowledge, not of future specialty choices (Dinh et al. 2016a, 2016b). Important pathologies introduced should be curriculum driven and include findings related to trauma and surgical specialties, as well as medical diseases and emergencies.

From the teachers and students' perspective it is fundamental to understand which common pathologies can be identified by ultrasound and which require additional investigation. The early introduction of extensive repositories of pathologies risks overextending student's learning capacities. Ultrasound educators should present an overview of common pathologies and then prioritize them based on clinical situation and setting. To prepare students for their first contact with difficult or emergent clinical situations, basic emergency pathologies should be emphasized to enable adequate emergency treatment and to understand the diagnostic and therapeutic power ultrasound brings to those clinical situations.

Educational media, material and assessment

Ideally, educational tools for ultrasound should be easily accessible, standardized, systematic, easily reproducible, and transparent for structured teaching and learning purposes. Educational media and material include course books (dedicated to students), e-books, apps, interactive e-learning tools, examination technique videos, webinars and case repositories (atlas) with examples of very important pathologies (VIPs).

Hands-on ultrasound education. Hands-on education is a critical component of ultrasound training in medical school. Not only does it increase students' motivation as they perform scans on simulated or real patients, appreciating anatomy and physiology in real time, but it is also important for developing spatial coordination required for scanning. However, most importantly, hands-on training is the most vital factor in becoming a skilled doctor that is familiar with the scanner and accurate in ultrasound diagnostics.

There are no conclusive published data on the optimal tutor/trainee ratio for hands-on ultrasound training sessions. The logical answer would always be that during a 1/1 training session, the one trainee has the undivided attention of the tutor and the most intense and effective learning.

However, currently there is no generally accepted recommendation on the teacher-to-student ratio during the ultrasound education process. We propose a ratio of 1/4 as a generally accepted rule of thumb that has been working well in various hands-on courses around the world for basic training. This allows for greatest efficiency in using human resources, balanced against quality instruction. In the clinical setting later on in the educational process, one-to-one shadowing with hands-on time for the trainee is suggested until it changes to the fully supervised, then partially supervised and finally independent stage.

Currently there is no generally accepted recommendation on the minimum time for trainees having the transducer in their hand before training is completed. The European Common Course (ECC) for abdominal ultrasound asks for 21 h of basic training, and 14 of the 21 h are spent on practical training with the ultrasound machine. Further research is needed to determine minimal training and hands-on exposure milestones for medical students.

Simulators. The use of low- and high-fidelity ultrasound simulation has found to be a useful tool for ultrasound education, mainly via improvement in trainee competence in post-course-simulated environments and improved skill in post-training assessments (Lewiss et al. 2014). For instance, learning ultrasound through the use of simulators was evaluated in a pilot study with 240 medical students at the University of M€unster (Metzger and Flanagin 2011). The study reported significant improvement in students' technical knowledge and confidence post-simulation. Investigators found that pre- and post-course assessments when using ultrasound simulation are crucial to improving knowledge, motivation and skill retention (Kromann et al. 2009; Todsen et al. 2015). Research has also indicated that simulator-based ultrasound training in pairs ("dyad practice") is effective in the transfer of specific skills (Tolsgaard et al. 2015).

Ultrasound simulators using real ultrasound data are being used with increasing frequency, making the assessment of simulation-based training a crucial component of some training programs. The use of OSCE stations with a clear grading scale has been reported to reduce subjectivity in those training sessions (Konge et al. 2014; Swannick 2010). One disadvantage of ultrasound simulators is that virtual-reality sonography simulators can become an expensive educational tool; some purchase prices can go well above USD 100,000 and the lower end of pricing being 2.500 20.00, not including the costs associated with maintenance, software updates and tutor training (Konge et al. 2014; Lewiss et al. 2014). However, given the increasing use of this technology and associated costs, studies reporting the translation of ultrasound simulation training into a significant clinical benefit and improved clinical outcomes are still needed.

The traditional methods of ultrasound training are still not completely standardized, especially in departments with large numbers of trainees and practitioners. A simulator-enriched curriculum may allow for greater standardization in early training and permit objective comparison of trainees as well as tutors. Additionally, high-fidelity simulators can offer exposure to ultrasound cases that are rarely encountered by students or are difficult to expose students to, such as cardiac arrests and critical ultrasound-guided procedures. Incorporating an assessment tool into the program would provide an objective measure of competency. To this end, many simulation companies are pursuing development of built-in competency assessment tools to aid educators in assessing progress made by their students. One potential disadvantage is that funding for simulation equipment might compete with funding for traditional hands-on tutors, potentially limiting student exposure to this additional teaching tool.

E-learning, interactive teaching methods. E-learning can be a solution for training in areas with limited educational resources. E-learning often takes the form of video lectures, teleconferences and webinars. Other e-learning tools, such as webcasts and e-books, represent a cheaper solution for teaching ultrasound. The advantages of e-learning include students' ability to tailor their learning pace, duration and location. Because ultrasound expertise is highly dependent on pattern recognition, easily accessible image archives are important. Such e-learning resources are offered by WFUMB and multiple national and regional societies among others.

Massive open online course (MOOC) is an open-access online teaching approach allowing for unlimited trainee participation while providing interaction among students and faculty. It has been successfully applied in a wide variety of disciplines and is currently a focus in education research. The MOOC may also be integrated into a medical student ultrasound educational program (Tolks et al. 2016).

Webinars. The use of web-based seminars or "webinars" can help disseminate information and illustrate practical applications when no direct supervision is possible. Using web conferencing technology overcomes geographic isolation and decreases costs (Metzger and Flanagin 2011). This format allows live and interactive presentations by experts that can be accessed online from any location with an internet connection. Webinars accelerate the learning process by increasing communication with experts and by using text chats and voting and drawing tools and sharing comments and contributions (Chiswell et al. 2018).

Social media. Social media such as YouTube, Facebook and Twitter can support dissemination of knowledge but also allow interactive communication via chats and private messaging in defined groups. Students already use these social platforms on a daily basis for educational purposes such as in anatomy (Barry et al. 2016; Hempel et al. 2016b). Lack of quality control and significant potential for misinformation are an ongoing concern with social media as well as some other online educational modalities.

Need for standardized assessment. There is a growing demand to standardize ultrasound training, establish structured clinical courses and assess competency according to well-defined and reproducible criteria. The goal is a widely applicable approach to enhance local initiatives and standardize quality as well as predictability of outcomes across all educational programs. Training programs should follow quality assurance standards and develop criteria for centers of excellence, in which effective high-quality ultrasound is performed and also high-quality teaching is provided.

Assessment of ultrasound competency can be performed using different methods (Todsen et al. 2015), including written exams, clinical observation, video review or clinical simulation. Regular direct observation of procedural skills (DOPS) with formal feedback can be documented in the trainee's portfolio. Unstructured observations have inter-observer variability and are less reliable. To overcome this issue, structured observation of technical skills and performance using checklists or global rating scales have been introduced (Martin et al. 1997; Nielsen et al. 2013).

Ideally, a series of DOPS and other structured appraisal forms would present a summary of the trainee's progress before a final assessment and document the trainee's competence in each domain of ultrasound education. Although suboptimal for numerous reasons, until competency assessment for ultrasound procedures becomes adequate, it may be necessary to suggest threshold numbers of procedures that must be performed to obtain competency, although a logbook cannot guarantee quality of performance or safety. National training databases can produce valuable information for setting such threshold numbers (Ward et al. 2017). Simulator developers are also providing solutions to competency assessment using artificial intelligence or other tools to intricately assess a student's performance while scanning or performing procedures on a simulator. Some of these systems can also test how the students integrate findings into clinical decision making. These tools are likely to be of greater utility in the future.

Development of psychomotor skills in ultrasound performance.

The competent performance of an ultrasound examination requires the user to have a broad range of knowledge and skills, including both communication and psychomotor. These skills are acquired through practical learning opportunities. Skill practice is required to develop the visuomotor and visuospatial skills that enable the learner to perform the exam in the correct planes, to obtain the diagnostic information. Many of the skills that are used to perform a focused or long ultrasound examination are complex. A complex skill is multidimensional and comprises many subparts. Therefore, the small and nuanced motor movements that are required to perform the task may not be noticed and appreciated by the learner; they are often evident only through clinical skill demonstration (Nicholls et al. 2014, 2016a, 2016b) and the use of physical guidance. The core skills needed to perform an ultrasound examination must be learned over time through supported clinical and then independent practice. The objective is to be able to execute the skill to a pre-determined or demonstrated standard. End-task and limited in-task feedback is essential to develop the foundation scanning skills required for clinical practice. Using an instructional approach that is evidence-based and aligned with the precepts of the motor learning domain is suggested when teaching a complex psychomotor skill (Nicholls et al. 2016a, 2016b).

ULTRASOUND CURRICULA INTEGRATION

Ultrasound education for medical students is among the most recently introduced subjects in medical curricula (Fodor et al. 2012). Ultrasound can be effectively used to teach clinical applications and augment physical examination skills, as well as improve anatomy and physiology knowledge (Arger et al. 2005; Bahner and Royall 2013; Bahner et al. 2013; Griksaitis et al. 2014; Hoppmann et al. 2011; Metzger and Flanagin 2011; Swamy and Searle 2012). The implementation of curricula depends on multiple factors including regulations, resources and other setting-specific factors. Traditional methods followed a siloed, organ- and topic-based approach, for example, musculoskeletal, cardiovascular, respiratory and gastrointestinal (Dahle et al. 2002; Dochy et al. 2003; Frank et al. 2010; Schmidt et al. 1996).

At the time of this article's writing, an international consensus guidelines process was underway on ultrasound in medical education. The process, organized by SUSME and WINFOCUS, is a rigorous evidence-based approach using GRADE (Grading of Recommendation, Assessment, Development and Evaluation) and modified Delphi technique to establish recommendations on ultrasound in medical education curriculum. It includes approximately 60 voting panel members from multiple specialties and more than 150 consultant advisors with expertise in ultrasound in medical education. Modern curricula of ultrasound education should meet established criteria on ultrasound education standards (Garcia-Casasola et al. 2015; Hempel et al. 2014; Kondrashov et al. 2015). Curricula incorporating medical ultrasound education also need to satisfy regulatory bodies.

Complete integration of ultrasound throughout (both vertically and horizontally) a medical education curriculum has been documented in a number of locations as proof of concept. Typically, in the pre-clinical portion, ultrasound is used to enhance student understanding of anatomy, physiology and pathophysiology. Ultrasound is also ideally taught as part of the physical assessment. In the clinical portion, students learn how to use ultrasound effectively as a problem-solving tool to diagnose a disease and pathology. Optimally, topics are related between courses, and ultrasound is used to reinforce what is learned from one course to the next. The horizontal and vertical integration of ultrasound into courses and rotations cannot be accomplished without a multidisciplinary approach. The vertical approach was characterized by assigning specific hours to ultrasound imaging for didactic sessions and workshops to cover the complete pre-clinical curriculum (Bahner and Royall 2013; Baltarowich et al. 2014; Brunner 1966; Chiem et al. 2016; Dinh et al. 2016a, 2016b; Flick 2016; Gillman and Kirkpatrick 2012; Hussain 2015; Millington et al. 2016; Prats et al. 2016; Smalley et al. 2016).

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