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Journal
European Journal of Trauma and Emergency Surgery, 41(5)

ISSN
1863-9933

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Publication Date
2015-10-01

DOI
10.1007/s00068-015-0535-7

Peer reviewed

Eur J Trauma Emerg Surg
DOI 10.1007/s00068-015-0535-7

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REVIEW ARTICLE

Ultrasound in medical education: listening to the echoes of the past to shape a vision for the future

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Received: 30 January 2015 / Accepted: 18 April 2015

Abstract
Purpose Ultrasound in medical education has seen a tremendous growth over the last 10–20 years but ultrasound technology has been around for hundreds of years and sound has an even longer scientific history. The development of using sound and ultrasound to understand our body and our surroundings has been a rich part of human history. From the development of materials to produce piezoelectric conductors, ultrasound has been used and improved in many industries and medical specialties.
Methods As diagnostic medical ultrasound has improved its resolution and become more portable, various specialties from radiology, cardiology, obstetrics and more recently emergency, critical care and proceduralists have found the added benefits of using ultrasound to safely help patients. The past advancements in technology have established the scaffold for the possibilities of diagnostic ultrasound's use in the present and future.
Results A few medical educators have integrated ultrasound into medical school while a wealth of content exists online for learning ultrasound. Twenty-first century learners prefer blended learning where material can be reviewed online and personalize the education on their own time frame. This material combined with hands-on experience and mentorship can be used to develop learners' aptitude in ultrasound.
Conclusions As educators embrace this ultrasound technology and integrate it throughout the medical education journey, collaboration across specialties will synthesize a clear path forward when needs and resources are paired with vision and a strategic plan.

Keywords Ultrasound · Medical education · Technology · History

The focus issue of ultrasound in the *European Journal of Trauma and Emergency Surgery* highlights many uses of ultrasound in the prehospital and hospital setting. As ultrasound continues to impact medical care, training the next generation of clinicians to utilize ultrasound becomes imperative. This article highlights the history and present state of ultrasound in medical education.

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Introduction

Point-of-care ultrasound education is a rapidly expanding field within medicine. It is an exciting time to be involved in this ever evolving specialty that is entwined with the technological advancement of portable ultrasound. Since the inception of the integrated circuit in 1947, processor speed doubles in 18 months while also physically getting smaller by a half [1]. Since Gordon Moore first proposed it in 1965, its regularity has led to it being referred as "Moore's law", a technical metronome that has kept the computer revolution on track [2]. These increases in processor speed have allowed for smaller and faster ultrasound machines and probes. Those in the medical education community have to ask "How will we be able to keep up?" Diagnostically accurate ultrasound machines have already been made small enough fit into the white coat pocket. Educators must be proactive and stay ahead of this exciting and rapidly expanding technology to keep the 21st century students engaged and curious to learn more about ultrasound.

History of ultrasound education: traditional specialties

While point-of-care-focused ultrasound has rapidly expanded over the past 25 years, sonography is actually an ancient science. Traditional acoustics, considered the precursor to modern ultrasound dates back to the sixth century BC with Pythagoras introducing mathematical equations to describe the frequency of different stringed instruments [3]. In the 1500s, Galileo is credited with advancing the study of acoustics by identifying a correlation between pitch and frequency of sound. Major breakthroughs came in 1880 where French physicists brothers Jacques and Pierre Curie discovered the piezoelectric effect, describing the electrical charges accumulating in solid materials forming the foundation for studying sound waves and electrical frequency [4]. These concepts continued to expand in the early 1900s with the application of ultrasound to detect distant objects and measure these distances, termed "echolocation". Military advancements during World War I and II saw further refining of echolocation as a means to traverse long ocean distances by sending sound waves through water, which later became as "sonar" [5]. Further development of the reflectoscope with industrial uses to detect flaws helped the early sonography equipment used in medicine [6]. Not long after the discovery of sonar, ultrasound entered the world of medicine.

The first formal use of ultrasound as a medical diagnostic tool was in the 1930s by Dr. Karl Dussik who studied Neurology and Psychiatry at the University of Vienna in Austria. Dr. Dussik was experimenting with using cranial ultrasound as a diagnostic tool attempting to visualize cerebral ventricles by measuring sound wave transmission of ultrasound beams through the head [7]. This was done using a through-transmission technique by placing transducers on both sides of a patient's head while partially submerged under water. These echo waves created images of the ventricles called "hyperphonography" that were recorded on paper in an attempt to identify brain tumors. In 1942, Dr. Dussik [7] authored the first ever published literature on the use of ultrasound in brain imaging. These initial crude acoustic reflections and different attenuation patterns, later thought to be artifact, are widely considered the first medical diagnosis made with ultrasound.

Meanwhile in the United States, the integration between sonography and medicine continued. George Ludwig, in 1946, began experimentation on animal tissue to detect foreign bodies and implanted gallstones. Ludwig documented the impedance mismatch of sound waves between various tissues of different reflection coefficients, extrapolating that transmission coefficients could be used to differentiate neoplasm from normal tissue [8]. Published reports of these findings were delayed by the United States Department of Defense due to the use of sonar in the military. Shortly thereafter, John Julian Wild, a Cambridge-trained American Surgeon practicing during World War II developed a "Wild tube" to identify patients suffering from bowel injury in combat [9]. His device used sound waves bouncing off tissues of different thickness as a non-invasive method to distinguishing injuries from healthy tissue. Eventually gaining access to higher frequency equipment, he was able to use ultrasound to diagnose malignancies in breast, rectal and vaginal tissues. Working together with Dr. John Reid, their landmark paper describes using "immediate application of echography to the detection of tumors in accessible sites in the living intact human organism" was published in the *Lancet* in 1951 [10]. These significant advances resulted in physicians, engineers and scientists creating over 6000 sonographic publications by the end of the 1950s.

Although medical ultrasound had its beginnings in Neurology, outside specialties began to find utility for sonography in their respective fields. By the end of the 1950s, Dr. Inge Edler, head of the Cardiology Department in Lund, Sweden began exploring techniques to visualize cardiac valves. His team in coordination with, graduate nuclear physicist student, Carl Hertz [11] was able to record the first two-dimensional cardiac images in 1953 and the first pediatric echocardiography in 1971 [12]. These findings gave Dr. Edler the title of "father of echocardiography". Concomitantly, the discovery that sonography was safe in pediatric and fetal studies led to a surge of Obstetric and Gynecologic sonographic research with the first ultrasonographic detection of early pregnancy in 1963 [13]. Significant advances were made by Obstetrician and Gynecologist, Alfred Kratochwil, who took sonographic equipment initially intended for ophthalmologic use and began visualizing pelvic size, placental location and measuring fetal heart tones before delivery [14]. By 1969, the first World Congress on Ultrasound Diagnostics in Medicine was held in Vienna with international contributions from Obstetrics and Gynecology, Cardiology, Ophthalmology and Internal Medicine.

Further advancements of computer electronic equipment allowed the original analog printed images to be viewed through digital converters. Hitachi Corporation in Japan claimed to be the first digital ultrasound scanner with a 512 by 512 pixel image storage capability [15]. Many of the large transducers used had become thinner, lighter and smaller creating a smaller contact surface with the skin. Microprocessor improvements allowed increased processing speed to improve data acquisition algorithms, produce higher resolution images, and decrease the lag time between the probe and image. With new scanning options, manufacturers began producing probes with specific uses. In 1986, Philips marketed the first vaginal probe and a reduced size abdominal probe [16]. Given the explosion of ultrasound in medicine, multiple published studies showed no definite adverse effects from long-term sonography [17]. In 1982 and again in 1997 the American Institute of Ultrasound in Medicine produced a statement indicating "Although the possibility exists that such biological effects may be identified in the future, current data indicate that the benefits to patients of the prudent use of diagnostic ultrasound outweigh the risks, if any, that may be present". This generalized acceptance of ultrasound by the medical community led to multiple publications and textbooks which became templates for standards of care in medical ultrasound [18].

History of ultrasound in undergraduate medical education

With advances in ultrasound technology creating more portable, affordable, and high-quality ultrasound machines, the use of point-of-care ultrasound by physicians has significantly increased. Focused ultrasonography has been incorporated by a wide array of medical specialties including emergency medicine, internal medicine, critical care, anesthesia, and trauma surgery. The increased utility among a broad range of medical specialties and the myriad applications of focused ultrasonography has encouraged the integration of ultrasound education into medical school curricula.

Initially ultrasound education was incorporated as limited sessions in preclinical medical school curricula as an adjunct to teaching the basic sciences. As early as 1996, at Hannover Medical School in Germany, focused ultrasonography was used as an effective educational aid in teaching anatomy to medical students [19–24]. In a 4-year review, Tshibwabwa et al. [21] described that first-year medical students at McMaster University in Ontario, Canada were able to enhance their understanding the anatomy of the cardiovascular and renal system through three 90-min 'ultrasound anatomy' session provided by a radiologist in conjunction with integrated clinical skills, anatomy and radiology sessions. A study at the Mayo Clinic demonstrated that first-year medical students who participated in 3 weeks of echocardiography training with handheld ultrasound devices were highly effective at obtaining a standard para-sternal long axis image and described increased satisfaction and understanding of cardiovascular anatomy [19].

Additionally, focused ultrasonography in the medical school curricula has been shown to augment the development of physical examination skills [24–26]. In 2010, Afonso et al. [25] showed that second-year medical students at Wayne State University felt that the incorporation of ultrasound into the physical diagnosis course improved their skills in both the physical exam and in sonography. In a study from the University of Chicago, Decara et al. [26] showed that ten fourth-year medical students enrolled in a 4-week course used focused echocardiography in cardiac examinations with improved detection of cardiac conditions and higher accuracy in cardiac auscultation skills.

With increasing evidence that discrete sessions of focused ultrasound education were highly effective as an educational adjunct, easily understood, and well received by medical students, medical schools began to fully incorporate ultrasound education into the entire 4-year medical school curriculum [27]. The first medical school to establish a fully integrated 4-year ultrasound curriculum was the University of South Carolina in 2006. Their ultrasound curriculum is based on a model used to train emergency medicine physicians and residents and is divided into preclinical and clinical applications [28]. Preclinical use of ultrasound focuses on bolstering student understanding of topics related to anatomy, physiology, and pathology. In these first 2 years of medical training, students are instructed in various modalities including lectures, laboratory sessions, web-based learning modules, problem-based learning sessions, and small groups [24]. The clinical use of ultrasound focuses on problem-solving applications of ultrasound in various clinical scenarios. Assessments of ultrasound understanding and sonographic proficiency are made each semester in the first 2 years and after each clerkship in the form of objective structured clinical examinations (OSCEs) [24].

Since 2006, several more medical schools have similarly incorporated ultrasound education into the entire medical school curricula and studies have described these curricula as effective, feasible, and highly regarded by medical students [24, 26, 28, 29]. In a review of University of South Carolina's integrated ultrasound curriculum, Hoppmann et al. [24] demonstrated that over 90 % of students felt that the integration of ultrasound education in the medical school curriculum enhanced their understanding of the basic sciences in their preclinical education.

Perhaps the newest development with undergraduate ultrasound education is the formation of ultrasound interest groups. In institutions where a complete vertical 4-year curriculum has yet to been established, ultrasound interest groups such as the one established at the Ohio State University College of Medicine in 2008 provide medical students an alternative, extracurricular opportunity to gain ultrasound exposure and develop skills in sonography [30].

History of ultrasound in graduate medical education

The professional medical societies for many specialties have written specialty-specific guidelines for ultrasound use [31–36] which has encouraged the inclusion of ultrasound training in residency. In 1990, the American College of Emergency Physicians (ACEP) published a position statement supporting the use of ultrasound by appropriately trained physicians [37]. The following year, the Society for American Emergency medicine (SAEM) endorsed this statement and recommended the establishment of a training curriculum as well as the development of ongoing research in emergency ultrasonography [38].

In 1994, Mateer et al. [39] published the "Model Curriculum for Physician Training in Emergency Ultrasonography," which outlined emergency ultrasound examination as a guide for emergency medicine training programs. By 1996 the emergency medicine core content curriculum required emergency ultrasonographic competence for residency graduates of Emergency Medicine [40]. In 1999, the American Medical Association passed resolutions that recommended that hospitals follow specialty-specific guidelines for credentialing decisions related to ultrasound by the physicians [35, 36]. By 2001, ACEP established its first guidelines on Emergency ultrasound, which discussed the range of practice and clinical indications for emergency ultrasound [41]. These guidelines were subsequently revised in 2008 and now represent the most comprehensive specialty-specific guidelines to date as a standard for emergency ultrasonography [42]. These 2008 guidelines recommend that residents of emergency medicine have a minimum of 80 h or 2 weeks of an introductory ultrasound rotation, 20 h of scheduled educational sessions, and time spent acquiring 150 ultrasound scans [42]. In 2013, ACGME incorporated new core competencies for bedside ultrasound in emergency medicine resident training. See Tables 1 and 2 as an adaptation of this framework with a medical student focus.

The American College of Surgeons (ACS) formed the ultrasound users group in the mid 1990s, which established the concept of surgeon-performed ultrasound on a national platform [43]. In 1995, the ACS Committee on Emerging Surgical Technology and Education created the ACS National Ultrasound Faculty, whose objective was to develop of surgical ultrasound courses and educational material. In 1997, the ACS Board of Regents published a statement regarding verification of a surgeon's ultrasound qualifications [44].

Future challenges for integrating ultrasound into medical education

The first major challenge in the integration of ultrasound into medical education is resistance by senior educators who fear that it will replace the physical exam in an already overwhelming curriculum. This resistance has repeated itself several times in history. In the 1760s when Austrian Leopold Auenbrugger invented the medical technique of percussion that originated from the testing of wine casks he was largely ignored by the medical community [45, 46]. Thirty years later in the late 1790s it slowly started to gain acceptance when Jean-Nicolas Corvisart who later was Napoleon's personal physician started teaching it to his medical students in France. Percussion was again revived by Joseph Skoda in Vienna in the 1830s and in 1837s as an assistant physician he was transferred to work in the inpatient psychiatric ward as punishment by his superiors because they felt that his technique was "annoying" to patients [47]. Eventually percussion made its way into mainstream medical education nearly 100 years after its discovery. It is a different world today and ultrasound education has started to gain widespread acceptance at a relatively rapid pace.

In reality it is not conscientious to compare a $40,000 dollar ultrasound machine that requires $10,000 in software and servers to a finger used in percussion. Point-of-care ultrasound education is a resource intensive undertaking. Image interpretation can be taught in traditional lecture format but effective ultrasound image acquisition education requires many hours of hands-on teaching by experts. Ultrasound machines, servers for image archives, and quality assurance work flow solutions are also costly to purchase and maintain. Setting up a system for bedside ultrasound requires buy-in not just from academic faculty

Table 1 The ACGME (American College of Graduate Medical Education) has delineated a competency scale based from Miller's pyramid of knows, knows how, shows how, does

Milestone	Domains	GME	Medical student
1	Indications for ultrasound	Intern	Advanced competency path
2	Skills lab scans	Resident	Digital portfolio
3	Multiple clinical scans	Resident	Clinical competencies
4	# Of exams (e.g. 25 per application)	Graduation	Advanced competency for specialty
5	Expert scans/advanced scope	Fellow	Expert in medical student ultrasound

This framework can be delineated with a 5 point graded system that could be used to guide medical student progression of skills. Since the medical hierarchy delineates the attending physician with privileges, the medical student ultrasound experience will have to be integrated into the residency experience as the learner continues to expand their ultrasound skill

Table 2 Traditional medical school curriculum employs learning anatomy and pathology in the first 2 years while the clinical years in 3 and 4 are spent on rotations

Medical school year	Traditional medical school topic	Topic area	Domain	Ultrasound skill	Degree of difficulty
1	N/A	Knobology	Acquisition	Machine orientation	Hard
1	Anatomy	Cardiovascular	Acquisition	Subxiphoid view	Moderate
1	Anatomy	Abdomen	Acquisition	FAST scan	Moderate
1	Anatomy	Musculoskeletal	Acquisition	Joint. Bone, muscle, tendon image	Hard
2	Pathology	All areas	Interpretation	Reviewing pathologic cases	Hard
2	Introduction to clinical medicine	Vascular access	Performance	Guiding a needle to a target on a phantom	Moderate
3	Clinical rotations	Multiple	Rotation specific	Specialty specific	Moderate
4	Acting intern	Specialty specific	Indications/acquisition interpretation/medical decision making	Saving, recording ultrasound exams	Moderate to hard

As the student progresses from understanding sonographic signatures in the preclinical setting, with appropriate supervision, the students can learn how to use ultrasound practically during the clinical rotations. By the end of medical school, students could be prepared to use ultrasound in their specialty of choice and refine these skills during residency training

Fig. 1 Students scanning in an ultrasound lab on a student "model"

Fig. 2 Students getting hands-on experience using ultrasound

but also from hospital administrators who will be approving the large budgets required to make it successful. Ultrasound must be seen as valuable by all parties involved to invest in the necessary resources to implement it into an educational system. See Figs. 1, 2 and 3.

Ultrasound skills are perishable without constant use and reinforcement. A medical student trained well in the preclinical first 2 years of medical school will have significant atrophy of their skills during their clinical clerkships in the latter 2 years if they do not use them. Maintaining those skills requires ultrasound competent supervisors in the clerkships or ultrasound threads in the clinical clerkship years. Either option requires significant resources and training of both students and attending physicians. Of course a medical student cannot possibly have a supervisor looking

Fig. 3 Hands on experience is rated highly by medical students

over their shoulder for every exam that they perform. They will likely perform many ultrasound scans unsupervised as they progress through their training. The ultrasound videos can be reviewed immediately or perhaps in a few days, or even a few weeks. Determining the appropriate timeliness of feedback and meeting those guidelines with finite resources will be challenging in the coming years. A fair degree of independent learning is a part of the ultrasound learning experience. This must be supplemented with mentorship interaction and availability of ultrasound educational resources.

As ultrasound education gains acceptance and is seen as valuable, turf wars between specialties could hinder its growth. Who is the expert and who is financially compensated for appendix ultrasound for example? Radiology, emergency medicine, pediatrics, and surgery could all legitimately claim it under traditional fee for service models. Will one particular accreditation entity set the universal standard for point-of-care ultrasound competency? There will be power struggles to make that ultimate determination but ideally all specialties involved will come together.

Effective ultrasound education for future generations

It is important to remember that a large portion of ultrasound learners will be adults that have already embarked on their careers. These adults have little patience or time for long lectures in a large classroom. Additionally the newer generations of physicians are becoming more tech-savvy and can use modalities previously unavailable for learning. These new modalities of blended learning include podcasts accessible 24 h per day, e books, Youtube videos, and direct “hands-on” instruction via Google Glass [48].

Traditionally, medical subjects are taught in lecture format. However, research shows that medical students and residents learn best when studying a subject that applies to a clinical situation. Self-directed learning at home after a student sees a patient with acute pulmonary edema with a 10 min podcast or even a short textbook chapter specifically on that subject will likely be more effective than an hour long lecture on general pulmonary ultrasound done 2 weeks removed from that clinical encounter. In a survey of 401 US emergency medicine residents in 2012, podcasts (70.3 %) have bypassed textbooks (54.3 %) as the most beneficial modality. The majority (80 %) selected topics based on a recent clinical encounter [48]. Self-directed education is effective and must be considered when building an ultrasound curriculum [49]. The use of social media and free access online medical education or FOAMed has recently been a way to have relevant information pushed to the end user’s device or smartphone. The use of simulation and multimedia to help deliver curricula has increased as point-of-care ultrasound evolves [50] and more innovative uses for connected learners and educators are sure to come.

Conclusion

Point-of-care ultrasound in medical education is engrained and will grow exponentially in the coming years. To nurture this growth and overcome future challenges we must be prepared to allocate appropriate resources to this worthy cause. All subspecialties must recognize each others expertise and come together as a cohesive unit to keep up with the educational needs of our future generations.

Conflict of interest Dr. Nate Lane has no financial conflicts of interest to disclose. Dr. Shadi Lahham has no financial conflicts of interest to disclose. Dr. Linda Joseph has no financial conflicts of interest to disclose. Dr. David P. Bahner has no financial conflicts of interest to disclose. Dr. J. Christian Fox has received speaker honorarium and equipment from FujiFilm/Sonosite and has stock options with SonoSim.

Ethical standard The authors state compliance with the ethical guidelines in the creating of this manuscript. This is a review of the literature and no experiments or patients were involved in the writing of this article and thus no institutional review board approval was applicable in the creation of this document.

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