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REVIEW ARTICLE–MISCELLANEOUS AREA

Ultrasonography in undergraduate medical education: a comprehensive review and the education program implemented at Jichi Medical University

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Abstract

The concept of point-of-care ultrasound has been widely accepted owing to the development of portable ultrasound systems and growing body of evidence concerning its extensive utility. Thus, it is reasonable to suggest that training to use this modality be included in undergraduate medical education. Training in ultrasonography helps medical students learn basic subjects such as anatomy and physiology, improve their physical examination skills, and acquire diagnostic and procedural skills. Technological advances such as simulators, affordable handheld devices, and tele-ultrasound systems can facilitate undergraduate ultrasound education. Several reports have indicated that some medical schools have integrated ultrasound training into their undergraduate medical curricula. Jichi Medical University in Japan has been providing medical students with ultrasound education to fulfill part of its mission to provide medical care to rural areas. Vertical integration of ultrasound education into a curriculum seems reasonable to ensure skill retention and improvement. However, several issues have hampered the integration of ultrasound into medical education, including a lack of trained faculty, the need to recruit human models, requisition of ultrasound machines for training, and limited curricular space; proposed solutions include peer teaching, students as trained simulated patients, the development of more affordable handheld devices, and a flipped classroom approach with access to an e-learning platform, respectively. A curriculum should be developed through multidisciplinary and bottom-up student-initiated approaches. Formulating national and international consensuses concerning the milestones and curricula can promote the incorporation of ultrasound training into undergraduate medical education at the national level.

Keywords Undergraduate medical education · Ultrasound · Point-of-care ultrasound · Vertical curriculum

Introduction

With the increasing use of focused ultrasound at the bedside, which is called point-of-care ultrasound (POCUS), it is reasonable to suggest that training to use this modality be included in undergraduate medical education globally [1, 2]. A previous report described the initial introduction of ultrasound training into medical student education in a German anatomy class over 30 years ago [3]. The approach effectively improved student motivation and facilitated anatomy education [1]. In the 2000s, the concept of POCUS became widely accepted with the development of portable ultrasound systems and a growing body of evidence supporting its extensive utility at the bedside [4, 5]. Such systems facilitated the introduction of versatile ultrasound into medical student education. In 2010, the first class of students who had participated in a 4-year "vertical ultrasound curriculum" graduated from medical schools in the USA. The schools had envisioned their graduates gaining knowledge and skills to perform POCUS and utilize it in their residency, as well as in future practice [6–8].

The real-time visual information and feedback obtained with portable or handheld ultrasound devices as active learning tools expand the horizons of medical students and increase their motivation to learn [1, 9]. Training medical

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students to perform ultrasound is expected to facilitate the study of basic subjects such as anatomy and physiology, improve the efficiency of physical examinations, and aid them in acquiring diagnostic and procedural skills [1, 2]. More advanced technologies such as wireless handheld ultrasound devices, devices with artificial intelligence, and 5G-equipped tele-ultrasound systems are expected to further the development of undergraduate medical education.

We herein report a comprehensive review of ultrasound training in undergraduate medical education and the details of ultrasound education at Jichi Medical University (JMU) in Japan. We also describe outstanding issues to be resolved and the future outlook of undergraduate ultrasound education in Japan.

Ultrasound as a tool for learning basic sciences and physical examination skills

Classically, ultrasound knowledge and skills are imbued in trainees after they have studied basic science such as anatomy and physiology and learned to perform physical examinations. However, the education methodology is undergoing a paradigm shift thanks to advances in ultrasound technology as ultrasound has proven useful as a tool for learning basic science and acquiring physical examination skills.

Understanding anatomy

Ultrasound is an effective modality for enhancing students' understanding of anatomy or "living anatomy" from different perspectives. Many studies have reported positive student perceptions and a self-reported increase in knowledge of anatomy [10]. A comparative study using pre- and post-tests showed that ultrasound imaging and cadaveric prosection were equally effective in facilitating learning the gross anatomy of the heart [11]. However, Finn et al. [12] reported that there was no additive effect on increasing understanding when combining the two modalities. Furthermore, Canty et al. [13] found that an ultrasound simulator appeared as effective as human cadaveric prosection in facilitating an understanding of the cardiac anatomy.

Several issues must be considered when incorporating ultrasound into an anatomy curriculum, including the curricular time, availability of ultrasound machines for educational purposes, and availability of instructors to train in performing ultrasound [14]. To manage these issues, Jurjus et al. [15] demonstrated that anatomists with minimal training were as effective as clinicians in teaching anatomy using ultrasound. Smith et al. [16] reported significant improvements in student perceptions of the impact of ultrasound on anatomy education using a paired anatomy teaching assistant and clinician teaching model. Furthermore, handheld ultrasound devices for students' personal use outside of a structured class may be valuable tools for learning and understanding the three-dimensional anatomy structure, allowing students to scan themselves and each other [17].

Understanding physiology

Literature concerning the use of ultrasound to learn physiology is scarcer than that concerning anatomy. Ultrasound is an ideal imaging modality for observing the dynamic cardiovascular system in real time and learning about cardiovascular physiology. In a study using questionnaires, 74% of 301 medical students felt that a hands-on ultrasound course improved their understanding of cardiac physiology [18]. Paganini et al. noted that an ultrasound demonstration session in large classes was beneficial in conjunction with traditional methods for teaching cardiovascular physiology and specifically illustrated reflexes [19]. Bell et al. [20] provided objective evidence using pre- and post-tests that medical students could learn about cardiac physiology with the aid of a hands-on ultrasound laboratory. In the field of respiratory physiology, an ultrasound demonstration session may also be a useful didactic tool [21].

Learning physical examination skills

Ultrasound as an assistive technology can also be used to learn physical examination skills by visualizing the internal anatomy and providing real-time feedback on physical examination findings. Therefore, early ultrasound education using portable devices may help foster physical examination skills. Positive student perceptions or self-reported improvement in learning physical examination skills with ultrasound have been commonly reported in studies dealing with this topic [10, 22]. However, these positive responses do not necessarily equate to competency.

Butter et al. [23] conducted a randomized trial indicating that once students achieve basic proficiency in abdominal physical examination, the addition of ultrasound education may boost their physical examination skills. Regarding the estimation of liver size based on physical examination, Barloon et al. [24] reported that 30 min of ultrasound training helped medical students more accurately estimate the size than no such training. In contrast, other studies have demonstrated the limitations associated with a short training time for ultrasound in learning how to accurately estimate liver size during physical examinations [23, 25].

Ahn et al. developed a novel method of training students to evaluate the femoral vascular system by combining traditional physical examination instruction, ultrasound, and ink visible under ultraviolet light to map the femoral artery. The approach enhanced students' ability to accurately palpate the femoral pulse compared to traditional instruction alone [26].

In learning to perform physical examinations of the musculoskeletal system, Walrod et al. [27] demonstrated that ultrasonography appeared effective in helping students locate and identify soft tissue structures on palpation compared to bony structures. Subsequent research conducted by the same group has suggested that ultrasound assistance might improve students' abilities to correctly locate, palpate, and identify soft tissue structures in the limbs, provided they be allowed sufficient hands-on practice [28]. Ruiz-Curiel et al. [29] showed that medical students' skills in detecting joint inflammation on palpation significantly improved when using ultrasonography as an educational tool for feedback through a five-session training program over 13 weeks.

A research group in the USA performed a prospective observational study comparing mandatory Objective Standardized Clinical Examination (OSCE) scores of 1st-year medical students in the pre-ultrasound curriculum year to the scores in the year an ultrasound curriculum was introduced. The ultrasound curriculum students had better overall associated OSCE scores than the students without ultrasound training [30].

However, despite the widespread reported usefulness of ultrasound in learning physical examination skills, its addition as an educational tool may not actually help medical students learn if they are overwhelmed with information obtained via ultrasound. In addition, studying the handling of the transducers and manipulation of the machine may pose additional demands on learners [31]. Sweetman et al. found that a post-ultrasound cohort of medical students provided positive feedback on a 2-h session using ultrasound and reported increased confidence in clinical skills concerning the gastrointestinal tract. However, their clinical skills did not actually improve according to OSCE scores as compared with the pre-ultrasound cohort [32]. Jamniczky et al. [31] indicated that the cognitive load imposed by studying how to work ultrasound devices may be associated with a lower perceived utility when building abdominal physical examination skills using ultrasound. These findings suggest that medical students may need to be trained in basic ultrasound knowledge and skills before they can effectively learn physical examination skills using ultrasound [32, 33]. Alternatively, medical students may need to reach a minimum level of competence in performing physical examinations before they are able to benefit from the visual feedback offered by ultrasound [23].

Gaining an understanding of ultrasound and fostering technical skills

As described above, ultrasound is now regarded as a useful tool for learning anatomy, physiology, and physical examination skills. In this section, we will discuss the acquisition of knowledge concerning ultrasound and the fostering of technical skills in terms of the clinical utility.

Cardiac ultrasound

The utility of cardiac ultrasound has been evaluated most in the integration of ultrasound in medical education. Cawthorn et al. demonstrated that 3rd-year medical students in the USA were more readily able to master cardiac ultrasound image acquisition and interpretation after a novel training program than 1st-year students who had not yet undergone their core cardiology teaching block. They further demonstrated that electronic educational modules were as effective as traditional lectures for delivering such knowledge, although self-directed scan training on a high-fidelity simulator was not as effective as scan training by a sonographer [34]. Recently, several educational programs related to point-of-care cardiac ultrasound for undergraduate medical education were found to have positive outcomes, including eliciting improvements in confidence in obtaining proper images [35] and observed OSCE scores [36–40].

The development of low-priced handheld ultrasound devices enables physicians and medical students to easily perform ultrasound as an extension of a physical examination at the patient's bedside. DeCara et al. [41] demonstrated in 2005 that student-performed cardiac ultrasound examinations, when used as an extension of a physical examination, yielded a significantly more accurate bedside diagnosis than a physical examination alone, even when a focused effort to review traditional examination skills was made beforehand. Another study concerning the utility of pocket-sized ultrasound devices in a large group of medical students showed that students detected mitral regurgitation significantly more effectively than with a physical examination after brief group training, although the detection rates of aortic regurgitation and aortic stenosis did not improve [42]. Yan et al. [43] showed that focused cardiac ultrasound performed by ten medical students was better than a physical examination for identifying clinically significant mitral stenosis, aortic stenosis, and tricuspid regurgitation. Notably, the diagnostic accuracy of 1st-year medical students using bedside cardiac ultrasound examinations after brief training was significantly superior to that of cardiologists performing cardiac physical examinations to detect and evaluate select valvular and nonvalvular cardiac abnormalities [44].

When a pocket-sized ultrasound device was used by medical students who had been briefly trained, it demonstrated acceptable diagnostic value for detecting basic structural and functional findings with a notable learning curve effect [45]. However, the added value as a screening tool to detect clinically relevant valvular lesions was limited among medical students [42]. In contrast, an interesting study showed that well-trained medical students using portable ultrasound devices were able to effectively screen for hypertrophic cardiomyopathy in 2332 young athletes [46].

Abdominal ultrasound

Abdominal ultrasound is a core application in medical ultrasound and thus merits inclusion in educational curricula to facilitate students' rudimentary understanding of ultrasound details and skills. Training in abdominal ultrasound was proven valuable for pre-clerkship medical students in terms of familiarizing them with the ultrasound technique and sonographic anatomy [37, 47–49].

Cheng et al., from Taiwan, described interesting teaching strategies. They simplified the process of learning to perform upper abdominal ultrasound, including the liver, using andragogy to enhance learning, mnemonics to help memory, and a pin-badge reward system as incentives [50]. First- and second-year medical students early in their training at the University of South Carolina were able to obtain liver size measurements with ultrasound that were more accurate and had less variability than those obtained by internal medicine clinicians using physical examination in six patients from a gastroenterology clinic [51]. A small randomized controlled trial then revealed that 1st-year medical students were able to use ultrasound to diagnose hepatomegaly and ascites after brief instruction, with findings comparable to those obtained with a physical examination [52].

In renal and bladder ultrasound, integration of ultrasound training focusing on flank pain and voiding difficulty into a clinical skill course allowed medical students to learn a new set of clinical skills. The method did not distract them from their traditional curriculum education [53]. In assessing the abdominal aorta, 62% of medical students with no prior experience in ultrasound who participated in a short training program were able to accurately measure the maximal diameter of the abdominal aorta, reaching a professional standard of skill [54]. Interestingly, ultrasound performed by a medical student trained sufficiently was highly accurate and more effective in detecting aortic abdominal aneurysms than a physical examination performed by vascular surgeons in 57 patients (disease prevalence: 28%) [55].

In another clinical situation, six minimally trained 1st-year medical students enrolled at the UC Irvine School of Medicine in California used basic abdominal ultrasound to successfully identify sonographic markers of chronic parasitic infections in rural Tanzania [56].

Lung and pleural ultrasound

Point-of-care lung ultrasound is now widely used to assess pneumothorax and cardiogenic pulmonary edema at the bedside, especially in the fields of emergency and critical care medicine [57, 58]. Furthermore, the application of lung ultrasound to the assessment of pneumonia has been increasingly studied over the past decade [59, 60]. However, despite these advancements, lung ultrasound seems to be uncommon in undergraduate curricula.

An initial study on lung ultrasound showed that, among medical students without ultrasound experience, limited education to improve their knowledge and image acquisition and interpretation skills was successful [61]. However, another study showed that medical students struggled to translate knowledge of lung ultrasound into performance in a simulated clinical scenario [62]. In detecting pleural effusion in hospitalized patients, Steinmetz et al. demonstrated that the odds of medical students correctly identifying the presence versus absence of pleural effusion was five times greater when using ultrasound as an adjunct to a physical examination than with a physical examination alone [63].

Focused assessment with sonography for trauma (FAST) and extended FAST (EFAST)

FAST is an integrated, goal-directed, bedside examination to detect hemorrhaging in trauma patients. EFAST further includes an examination of the chest to detect pneumothorax. FAST and EFAST incorporate the fundamentals of bedside examinations in acute care settings. An initial study conducted in the UK suggested that, in the absence of any prior experience, most medical students achieved basic competency in FAST scanning after a 5-h training course based on a comprehensive curriculum [64]. Several studies subsequently demonstrated that various training courses in FAST or EFAST with human models increased the knowledge and skills in undergraduate medical education [40, 65–69]. Supervised FAST and EFAST examinations in patients in addition to a brief didactic presentation and one hour of hands-on practice on normal models was effective in teaching medical students basic skills [70, 71]. Shokoohi et al. [71] demonstrated an increase in the rate of successfully obtaining high-quality FAST images after inputting just ten scans from patients. Medical students who receive basic ultrasound training early in their medical education may acquire competency in performing a FAST examination effectively during their clerkship [71].

Obstetric and gynecological ultrasound

Ultrasound is a cornerstone in the diagnosis and management of obstetric diseases and conditions. However, little attention has been paid to undergraduate ultrasound education in obstetrics [72]. Computer-aided strategies for teaching medical students prenatal ultrasound diagnostic skills were introduced in 2008 [73]. Hamza et al. [72] from Germany reported the utility of a well-designed student tutor-based obstetrical and gynecological ultrasound course including scanning of patients. In rural Panama, 1st-year medical students from the USA with minimal training were able to use obstetric ultrasound examinations to identify complications in second- and third-trimester pregnant women [74].

Head and neck ultrasound

Due to the rapid integration of POCUS into clinical practice, an introduction to ultrasound-guided procedures in addition to knowledge of both normal and pathological findings will soon be an important part of undergraduate medical education. In head and neck learning sessions, multimodal ultrasound instruction including a didactic presentation, live-model demonstration and practice, computerized simulation cases, and simulated ultrasound-guided fine-needle aspiration using phantom models have proven beneficial for increasing medical students' confidence in their skills [75]. An inexpensive handmade thyroid phantom model allows medical students to practice measuring lesions and performing fine-needle aspiration using ultrasound [76]. In emergency medicine, a point-of-care head and neck ultrasound curriculum using live models with or without phantoms resulted in an improvement in students' knowledge and skills concerning head and neck ultrasound applications [77, 78].

Ultrasound-guided procedures

In addition to procedures in the head and neck, several ultrasound-guided procedures in other regions have also been introduced to undergraduate medical education.

The use of ultrasound guidance for central venous catheter (CVC) insertion increases procedure success rates and decreases mechanical complications, so this procedure is strongly and broadly recommended [79, 80]. In education on ultrasound-guided CVC insertion, understanding the anatomy and physiology of the vessels along with their surrounding structures using ultrasound is the first step, and it is crucial to differentiate arteries and veins to ensure accurate and safe procedures [40, 81–83]. There are a number of commercial ultrasound training models available for CVC insertion; however, they may not be cost effective or logistically feasible for distribution to a large number of medical students [84]. An inexpensive homemade training phantom [84] and a life-like, reproducible model using a fresh cadaver [85] for ultrasound-guided CVC insertion training have therefore been introduced in undergraduate medical education.

With the growing body of evidence supporting the use of ultrasound for CVC insertion, observational and randomized controlled studies demonstrated improved success rates with the use of ultrasound guidance for peripheral intravenous access in patients with difficult access [79, 80]. A prospective randomized trial including 69 medical students in 2008 demonstrated no marked difference in the success of peripheral intravenous cannulation of other medical students between traditional and ultrasound-guided techniques, suggesting that the psychomotor skills required for performing ultrasound need to be properly developed over time [86]. Another randomized trial using a phantom for the assessment showed that the group receiving traditional face-to-face education on ultrasound-guided vascular access performed significantly better than those not receiving the education [87]. A pilot study demonstrated the utility of an interprofessional approach to learning to perform peripheral intravenous access with ultrasound by medical students with experience in ultrasound training and experienced nurses. This approach allowed both groups of participants to learn from each other and interpret ultrasound images, identify the vein for venipuncture, and perform the procedure on their partner [88].

Ultrasound-guided peripheral nerve blocks have been performed for decades and have spread beyond pain specialists. Therefore, educators need to integrate these advanced applications into medical education [89]. A few studies have shown that medical students were able to learn the sonographic anatomy of peripheral nerves and gain skills in ultrasound-guided techniques using handmade phantoms [89, 90].

Technological advances in educational tools

Technological advances in educational tools can facilitate undergraduate ultrasound education.

Simulators

Responding to changing practice environments requires new training models. A systematic review and meta-analysis revealed that technology-enhanced simulation for healthcare professional education alone or when added to traditional practice was associated with improved learning outcomes compared with no intervention [91].

In postgraduate medical education, POCUS is sometimes taught in conjunction with low- and high-fidelity simulators. Low-fidelity simulators are usually anatomically static, like the aforementioned vascular phantoms. Several commercial products are available for training in ultrasound-guided procedures. However, these models are costly, and the friability with repeated punctures remains a major limitation, resulting in the need for the frequent purchase of replacements given the large number of students involved in such training. Low-cost homemade gelatin-based phantoms facilitate the development and assessment of basic ultrasound skills, such as transducer movement, vessel cannulation, aspiration, and biopsies [84, 92, 93]. A cheap and interesting simulator using a Kunafa knife and playdough was developed to train students in hand movements with a probe and corresponding cross-sections or two-dimensional images [94]. Three-dimensional printed models may also be promising for cost-effectively training medical students in procedural skills [95].

High-fidelity simulators, by contrast, are high-tech and dynamic devices, such as computerized mannequins [96]. When providing initial cardiac ultrasound training to physicians, training using a high-fidelity simulator was found to be not inferior to that using a human model [97]. When training medical students in cardiac ultrasound, Cawthorn et al. [34] demonstrated that self-directed simulation training using the same simulator alone was not as effective as practical small-group instructions under the supervision of experienced sonographers. In contrast, Hempel et al. [98] showed that supervised cardiac ultrasound training using a simulator was not inferior to supervised training using human models in allowing medical students to acquire appropriate knowledge and skills. A randomized study also demonstrated that using a simulator to facilitate the acquisition of skills in cardiac ultrasound in addition to conventional educational approaches was feasible and useful, with improved examination scores, shortened examination times, and improved student satisfaction [99]. Simulation-based ultrasound training programs using other kinds of high-fidelity simulators were found to be useful for helping medical students train in cardiac ultrasound and other applications of POCUS [100, 101]. Ultrasound simulators can also be useful self-directed tools that help previously trained students retain and improve their scanning skills [102].

Handheld ultrasound devices

Compared with standard ultrasound devices, the accessibility and lower cost make handheld devices attractive educational tools for both faculties and medical students. Along with the dissemination of handheld devices, an increasing number of studies have reported the use of such devices for educational purposes, indicating their potential utility as an adjunct in teaching anatomy and training to perform clinical examinations, especially for cardiac conditions [9, 103–105]. Furthermore, in a hands-on session, a live image on a handheld device can be projected onto a large monitor to allow the view to be easily shared among attendees.

Notably, self-learning using a personal or rental device is feasible, regardless of location or timing. Students can learn by scanning each other, family members, or themselves at their own pace. Such self-learning may be as effective as traditional courses [36, 106, 107].

Tele-ultrasound

Tele-ultrasound and tele-mentoring have been successfully introduced for guiding didactic education, hands-on training, and patient management [108]. Preliminary research has shown that medical students as novice ultrasound users are able to obtain adequate cardiac views using a handheld device through a tele-mentored approach [109, 110]. Poland et al. [111] demonstrated that both traditional in-person ultrasound training and telepresent ultrasound training resulted in significant increases in knowledge, confidence, and performance of a FAST examination.

The cutting-edge portable ultrasound devices available these days enable users to share live ultrasound images and videos directly with remote colleagues on their own mobile device, tablet, or personal computer. The user can also project both a live ultrasound movie from a handheld ultrasound device and a probe-handling movie from an external web camera that can both be uploaded and saved on the same personal computer. The screen can then be shared remotely through a video-based conference platform. Of note, however, online security concerning protected health information data is an important factor in the development of real-time teaching with tele-ultrasound [2].

In the COVID-19 era, many medical schools have converted both preclinical and clinical sessions to asynchronous e-learning, small-group sessions, and distanced learning [112]. Tele-ultrasound with screen sharing seems to be one way of mitigating the loss of bedside scanning sessions and face-to-face live demonstrations [113].

Peer teaching (peer-assisted learning)

Traditionally, ultrasound knowledge is taught in lectures, and practical hands-on courses are then held in small groups under the supervision of a physician or faculty staff experienced in ultrasound. In association with growing demand for ultrasound education and international interest in peer teaching, where students help each other learn and learn by teaching [114, 115], many reports have been published in the past decade concerning the utility of peer-assisted ultrasound teaching.

In basic education, sonographic anatomy and a physical examination with ultrasound can be taught effectively by peer tutors with extensive training in ultrasound clerkship [116, 117]. Peer teaching also proved effective in education concerning cardiac ultrasound [118–121], abdominal ultrasound [92, 122], cardiac and abdominal ultrasound [123, 124], obstetrical and gynecological ultrasound [72], musculoskeletal ultrasound [125], and comprehensive ultrasound [126, 127]. Kühl et al. [118] showed in a randomized controlled study that hands-on training supervised by student tutors led to a significant gain in cardiac ultrasound skills among novices, although it was inferior to teaching by an expert sonographer. However, other randomized controlled trials demonstrated that students' ultrasound competence and clinical skills did not differ markedly between trainees who were taught by faculty and those taught by peer tutors [116, 121, 124, 125]. Being closer to tutees in their experience and understanding of ultrasonography, peer tutors may be able to provide a more focused approach to teaching how to perform ultrasound and quickly troubleshoot any difficulties tutees may encounter [121].

Student tutors generally have the same learning goals as their tutees. However, "tutors' education" must be extended. Several modalities have been proposed to train student tutors, such as course-based training and clerkship in an ultrasound laboratory [128]. Course-based training covers the contents necessary to train tutor candidates, but they have limited opportunities to perform ultrasound and acquire practical scanning skills. With a clerkship, these candidates have ample opportunity for scanning practice. According to previous studies, medical students seem able to acquire sufficient knowledge and skills as effectively as faculty members by undergoing course-based training and a clerkship over a few weeks to teach POCUS skills. However, a quasi-randomized study demonstrated that student tutors trained with a course, clerkship, or course followed by a clerkship were able to teach scanning skills to 5th-year medical students very effectively and with a similar degree of success between the groups. Faculty may be able to train tutors in a way that optimally suits their specific conditions [126].

Many German medical faculties have established peer teaching systems for undergraduate medical education in their skills lab [129]. Nourkami-Tutdibi et al. [129] demonstrated that an existing peer teaching concept with highly motivated and well-trained student tutors could be adjusted to sustain ultrasound skill training even in the face of the global COVID-19 pandemic.

Vertical curriculum

Several reports indicate that medical schools in North America [107, 130, 131], Europe [132, 133], and Asia [134] continue to integrate ultrasound into undergraduate medical curricula. A survey conducted in 2019 showed that 74% of 64 responding US medical schools had integrated ultrasound into basic science courses, 66% into practice of medicine/clinical skills courses, and 35% into clinical rotations [130]. Many schools have likely incorporated or are trying to incorporate ultrasound into 1 or 2 years of undergraduate medical education. However, vertical or longitudinal 4-year curricula are being integrated gradually among North American medical schools [8, 131].

As described above, ultrasound has potential utility as an efficient educational tool that enhances traditional learning of anatomy, physiology, and physical examination skills. Furthermore, continued ultrasound practice is likely effective for encouraging skill retention and improvement. Thus, the vertical integration of ultrasound education across all years seems reasonable [8]. However, the curriculum implementation processes vary among medical schools due to differences in local resources and contexts [107]. Based on the models introduced or proposed in several papers, an illustration of the vertical ultrasound curriculum is shown in Fig. 1.

Ultrasound education at JMU

JMU is a unique medical school in Japan that aims to produce doctors able to engage in rural remote practice. JMU provides a 6-year undergraduate education program, the

Fig. 1 A vision of a vertical ultrasound curriculum in undergraduate medical education. *PBL* problem-based learning, *HHD* handheld device, *MCQ* multiple-choice question, *OSCE* objective structured clinical examination

Contents	Delivery methods	Assessment methods
Introduction to ultrasound Physics, terminology, machine use Basic sciences Anatomy Physiology Clinical lectures and PBL Pathology and diagnosis Physical examination course Clinical rotations Mandatory Elective Ultrasound elective course	Lecture Flipped classroom approach e-learning Self-skill training with HHD Hands-on training with human models high-fidelity simulators phantoms Peer teaching Tele-ultrasound Practical training on patients	Formative and summative Knowledge MCQs Pictorial questions Case-based questions Skills Image review OSCE Diagnostic accuracy Attitude Observation Curriculum evaluation Questionnaire Online survey

length of which is standard in Japan. In most cases, the graduates work as general practitioners in rural areas for about 6 years after they finish their residency training, an obligation they must fulfill in exchange for exemption from medical school tuition [135]. Ultrasound education has been provided to these medical students since 1978. Several background factors should be considered on early implementation of the ultrasound education. The majority of younger JMU graduates must work independently with limited medical resources at rural clinics. Fortunately, Japan has had ample medical ultrasound resources since the 1980s, so ultrasound machines, which were not very portable in those days, were able to be used at many rural clinics at the time.

Historically, ultrasound education has been mainly provided by the Department of Clinical Laboratory Medicine at JMU. Uniquely, clinical laboratory medicine includes ultrasound under the Japanese medical system. For 4th- or 5th-year medical students, the precedent department started extracurricular seminars, which included cardiac and abdominal ultrasound with other applications. In those days, the faculty taught students ultrasound knowledge and helped them interpret ultrasound images, including B-mode movies and M-mode images, to determine the size of the cardiac cavity and its movement. Hands-on training was integrated into those seminars 20 years ago. The students practiced their skills on each other, receiving assistance and feedback from faculty. In recent years, 10–20 5th-year medical students join the extracurricular seminars each year. The current program conducted over 6 months consists of 18 seminars, in which students have the opportunity to learn the basics of ultrasound as well as abdominal, cardiac, neck, and emergency ultrasound.

In the formal curriculum, ultrasound has not been utilized for teaching basic science and physical examination skills. An overview of basic ultrasound knowledge and representative normal and abnormal images is presented in lectures provided by the Department of Clinical Laboratory Medicine. Pathophysiology and diagnostics are taught, including recorded ultrasound images if needed, in organ-based lectures provided by other clinical departments.

In bedside learning or clinical rotations from the fourth to fifth year, mandatory hands-on ultrasound training courses are provided by some departments. In the fifth and sixth years, some students can take elective courses, where they perform abdominal ultrasound on patients and then write up reports under the supervision of medical doctors on a daily basis over one to two months in a laboratory setting. These students acquire advanced knowledge and skills with a steep learning curve. Some of them go on to serve as peer tutors in a mandatory hands-on training course. Table 1 shows the details of the ultrasound education in the curriculum at JMU in 2021 [136].

As described above, JMU has a long history of providing ultrasound education in Japan. However, scientific evidence on the effect of education on practices after graduation is limited. A study based on questionnaires distributed to graduates may be an option for elucidating these effects.

Issues to be resolved in curriculum development

There are several issues facing the introduction of ultrasound into medical school curricula. First, the incorporation of new modalities and technologies, such as POCUS and handheld devices, into medical education requires a rigorous evaluation [9, 137]. As stated above, many articles have demonstrated the practical use of ultrasound in undergraduate medical education. Further research is needed to demonstrate the effects of such education, such as the retention of knowledge and skills [138, 139], clinical performance in residency [140], and ultimately patient care [141].

A shortage of trained faculty for teaching ultrasound remains a barrier to the implementation of training sessions. Faculty development sessions are essential for building a capacity for ultrasound education. Peer mentors can contribute as teaching staff, helping themselves retain their ultrasound knowledge, brush up on their skills, and build confidence in teaching. Artificial intelligence and augmented reality can also be used to assist faculty, providing novice medical students with real-time guidance on probe placement in order to optimize the image quality [142].

It can be challenging to find human models willing to participate in hands-on training, as recruiting volunteers or actual patients can be unreliable. When medical students scan each other, some concerns must be considered. For example, some may feel pressured to allow their bodies to be used for education, and there is a risk that abnormal ultrasound findings could come to light in front of their peers [104]. When students volunteer to serve as ultrasound models, it must be confirmed that they have wholly consented to the act [131, 143]. To mitigate these concerns, Ohio State University introduced an extracurricular program in which 2nd-year students served as trained simulated patients, gaining educational incentives [144].

In addition to the above issues, a sufficient number of ultrasound machines for educational purposes must be secured. The advent of more affordable handheld devices with advanced technologies may help improve the availability in educational settings [130]. When students are able to own an ultrasound device of their own at a reasonable price, like a stethoscope, hands-on training is facilitated, allowing education to be delivered to large groups of students at the same time [104].

Table 1 Details of US education in the curriculum at Jichi Medical University in 2021 [136]

Year	Courses, specialties	Contents of ultrasound education	US skill training
2–4	Basic clinical lectures		
	Clinical laboratory medicine	Introduction, knobology, interpretation of US images	
	Organ-based lectures	Interpretation of US images	
4–5	BSL (specialty rotations, each 2–3 weeks)		
	Clinical laboratory medicine	Knobology, terminology, artifacts, reporting	
		Cardiac, abdominal, and carotid US	Human model (students)
	Cardiology	Cardiac US	Simulator
	Gastroenterology	Gastrointestinal US	Human model (students), simulator
	Nephrology	Renal US	Human model (students)
	Neurology	Carotid US	Human model (students)
	Orthopedics	Musculoskeletal US	Human model (students)
	Obstetrics	Obstetrical US	Simulator
	Emergency medicine	FAST, abdominal, and lung US	Human model (students)
5–6	Elective compulsory BSL (each 4 weeks)		
	Clinical laboratory medicine	Abdominal US	Patients in the lab
	Gastroenterology	Gastrointestinal US, US-guided procedures	Human model (students), simulator
	Nephrology	Renal US, blood access	Human model (students), patients
	Neurology	Carotid US	Human model (students)
	Emergency Medicine	Focused cardiac US	Human model (students)
6	Free courses (customized by students)		
	Clinical laboratory medicine	Abdominal US	Patients in the laboratory
	Other courses		

Students have the opportunity to observe and perform US on patients in each BSL rotation

US ultrasound, *BSL* bedside learning, *FAST* focused assessment with sonography for trauma

Given the limited curricular space allocated for ultrasound education, providing students with excessive information all at once should be avoided in order to avoid exacerbating their cognitive load [8, 31]. Thus, the timing of ultrasound introduction and the application of an innovative educational method play roles in the success of curriculum development. A flipped classroom approach with access to an e-learning platform is a reasonable approach [138] as an ultrasound session can be incorporated into an existing course, such as a physical examination skill course, using this approach [104].

Considering these issues, it is recommended that the curriculum be developed using a phased approach [8, 143]. Educational modules need to be created by a multidisciplinary working group [104]. Importantly, the initiation of a formal ultrasound education program requires a bottom-up student-initiated approach in addition to a top-down administrative approach [145]. Many of the aforementioned studies have shown that medical students enjoy ultrasound courses and express interest in receiving further ultrasound training. An active ultrasound interest group initiated by students with the support of faculty can help further the curriculum development [8, 131]. Many programs advocate the involvement of medical students in the design and subsequent modification of ultrasound curricula [8, 145]. Formulating national and international consensuses concerning the milestones and curricula can promote the incorporation of ultrasound training into undergraduate medical education at the national level. [104, 107, 146].

Future perspectives concerning undergraduate ultrasound education in Japan

In Japan, the concept of POCUS has been widely accepted, and many training courses of POCUS for doctors were provided by several societies and institutions pre-COVID-19. Formal educational programs with certification systems are now being developed by some medical societies. Such standardization is also necessary to train clinicians who may become instructors in undergraduate medical education. Regarding undergraduate ultrasound education, each department in medical schools like JMU presumably provide training programs to students in clinical years. A nationwide survey will be required to grasp the precise situation [107].

Each university in Japan has a medical education development center or a related department dedicated to medical education and to the promotion of collaboration between basic science and clinical departments. Such departments may be used to implement systematic ultrasound education if they contain key individuals who realize the potential of ultrasound in medical education. In such departments, multidisciplinary working groups can be formed to develop a systematic ultrasound educational program with a group of medical students who are interested in ultrasound.

It is necessary to disseminate the notion that ultrasound has utility for teaching anatomy and physiology, and that its inclusion in medical education can help bridge basic science and clinical medicine [8]. In this sense, faculty from basic science departments need to be included in the multidisciplinary working group, and then the faculty development has to be planned with the support of clinicians or sonographers. Another solution is that clinicians or sonographers have time dedicated to teach some parts of basic sciences using ultrasound, collaborating with faculty in basic science departments during class.

Sonographers are currently responsible for the greater part of clinical ultrasonography in Japan. Therefore, they are capable of teaching ultrasound skills to medical students with proper teaching methods and skills. However, several issues have to be considered when medical schools ask them to provide teaching on ultrasound. The concept of POCUS is one of the key factors for incorporating ultrasound in medical education. Sonographers, who are usually engaged in comprehensive ultrasound examinations in laboratory settings, are also requested to deepen their understanding of the concept of POCUS. Furthermore, they must be compensated for teaching with time relief at their laboratories.

The Japan Society of Ultrasonics in Medicine, which consists of multidisciplinary specialists, generalists, and sonographers, should help foster a national culture of undergraduate ultrasound education and formulate a national consensus. National or domestic congresses, symposiums, and gamification events can help medical students from different schools and faculty from different specialties exchange ideas and share difficulties and success stories, thereby fostering the creation of interesting and effective content in ultrasound education [145, 147].

The rapid advance of telemedicine and tele-education in the COVID-19 era can help students gain knowledge and skills [113]. At JMU, we have found that novice medical students were able to acquire knowledge and skills for focused cardiac ultrasound through a flipped classroom approach consisting of e-learning and self-training with a handheld device followed by telepresent hands-on training (unpublished data).

The integration of POCUS in clinical fields will undoubtedly continue to increase as handheld devices become more affordable, with a higher quality and lower cost. This will positively influence the expansion of POCUS education for decades to come. However, the further increase of already high health care costs remains a major issue in Japan. Ways to integrate POCUS into clinical practice and medical education in an economically responsible manner will need to be discussed.

Conclusion

Training with ultrasound helps medical students learn basic subjects, improve their physical examination skills, and acquire diagnostic and procedural skills. Technological advances, such as the advent of simulators, handheld ultrasound devices, and tele-ultrasound systems, can facilitate undergraduate ultrasound education. However, several issues have hampered the integration of ultrasound into medical education, including a lack of trained faculty, the need to recruit human models, requisition of ultrasound machines for training, and limited curricular space; proposed solutions include peer teaching, students as trained simulated patients, the development of more affordable handheld devices, and a flipped classroom approach with access to an e-learning platform, respectively. A curriculum should be developed through multidisciplinary and bottom-up student-initiated approaches.

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Declarations

Conflict of interest Toru Kameda has received a presentation honorarium from GE Healthcare unrelated to the submitted work. The other authors declare that there are no conflicts of interest.

Ethical statements As this is a review article based on published literature, no ethics approval was required.

Informed consent Written informed consent was not required.

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