INTRODUCTION

The expanded use of ultrasound imaging—specifically, point-of-care ultrasound (POCUS)—has become a driving force for including ultrasound training in undergraduate medical education (UME) (Lambrecht et al., 2022). Point-of-care ultrasound examination can be defined as the use of ultrasound imaging by a health care provider at the patient’s bedside to answer a limited number of pre-determined clinical questions (Vignon et al., 2011; Dietrich et al., 2017). One key to the growing use of POCUS has been the development of ultrasound instruments that are portable, have high resolution, and are more affordable (Clevert et al., 2019).

DESCRIPTIVE ARTICLE

Adaptation of an anatomy graduate course in ultrasound imaging from in-person to live, remote instruction during the Covid-19 pandemic

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Abstract

Health concerns during the Covid-19 pandemic required the adaptation of a lecture-laboratory course in ultrasound imaging for graduate students from an in-person to a live, remote learning format. The adaptation of in-person lectures to live, remote delivery was achieved by using videoconferencing. The adaptation of in-person laboratory sessions to live, remote instruction was achieved in the first half of the course by providing a hand-held ultrasound instrument to each student who performed self-scanning at their remote locations, while the instructor provided live instruction using videoconferencing. In the second half of the course, the students transitioned to using cart-based, hospital-type instruments and self-scanning in the ultrasound laboratory on campus. The aim of this study was to measure the success of this adaptation to the course by comparing assessment scores of students in the live, remote course with assessment scores of students in the in-person course offered in the previous year. There were no statistically significant differences in the assessment scores of students in the two courses. The adaptation of a course in ultrasound imaging from an in-person to a live, remote learning format during the Covid-19 pandemic described here suggests that contrary to the prevailing view, ultrasound imaging can be taught to students without in-person instruction. The adapted course can serve as a model for teaching ultrasound where instructors and learners are physically separated by constraints other than health concerns during a pandemic.

KEYWORDS

Covid-19 pandemic, gross anatomy education, graduate education, hand-held ultrasound instruments, remote learning, self-scanning, ultrasound training
with sonography for trauma (FAST) protocol, performed on unstable trauma patients to identify free fluid in the abdominopelvic cavity, is an example of a widely used POCUS assessment (Scalea et al., 1999). The highly successful application of POCUS in emergency medicine and in critical care has made the broader medical community aware of its potential benefit to get immediate answers to clinical questions (Kendall et al., 2007), so that POCUS has been advocated in a wide variety of medical specialties (Moore & Copel, 2011; Nelson et al., 2019). It has even been suggested that POCUS be included in the physical examination (Dinh et al., 2016; Nardi et al., 2016; So et al., 2017; Wagner & Boughton, 2018).

With the growing use of POCUS in medical practice, there has been a corresponding steady increase in the number of medical schools that have added instruction in ultrasound to their undergraduate medical curricula. A survey conducted in 2012 of allopathic medical schools in the United States determined that 62% of schools included ultrasound training in their UME curriculum (Bahner et al., 2014). In a more recent survey of allopathic and osteopathic medical schools, an ultrasound presence in their UME curriculum was reported in 72% of responding schools (Nicholas et al., 2021). The inclusion of ultrasound training in UME is seen globally, though there is wide variation in how ultrasound is integrated and there remains a need for structured programs to teach ultrasound (Hoffmann et al., 2020).

Because of the increasing likelihood that medical students will encounter POCUS during their clinical rotations, it has been proposed that exposure to ultrasound should occur early in students' preclinical training (Bahner & Royall, 2013; Rempell et al., 2016; Khoury et al., 2020; Nicholas et al., 2021). More specifically, it has been suggested that training in ultrasound should coincide with the study of anatomy because ultrasound has the potential to provide a link between students' understanding of anatomy in the preclinical phase of their education and their eventual assessment of actual patient anatomy and pathology (So et al., 2017; Royer, 2019; Lufler et al., 2022).

One of the factors limiting the expansion of ultrasound imaging both in clinical practice and in medical education is the need for qualified instructors to teach image acquisition and interpretation (Bahner et al., 2014; Nelson et al., 2019; Russell et al., 2022). Direct supervision by an expert is a core element in ultrasound instruction (Filippucci et al., 2007; Harrison, 2015; Schott et al., 2020). Indeed, it has been recommended that 50% of a workshop or course in ultrasound be devoted to supervised, hands-on training (Hoffmann et al., 2020). The need for qualified instructors is compounded by the recommendation to keep the instructor-to-student ratio low (1:4–1:5) in the hands-on part of a course so that instructors have sufficient opportunity to provide constructive feedback (Hoppmann et al., 2011; Palma, 2015; Landry et al., 2017; Dietrich et al., 2019).

Students in anatomy graduate programs are a potential pool of qualified instructors who can teach the fundamentals of ultrasound image acquisition and interpretation. However, few graduate programs in anatomy offer instruction in ultrasound imaging. The status of ultrasound integration in graduate programs in the anatomical sciences was determined using survey methodology (Royer, 2016). Data from this study reflected the state of ultrasound training in 77% (33 of 43) institutions in the United States that were identified as offering a graduate program in anatomical sciences. Of the 33 institutions that completed the survey, 36% (N = 12) reported having an exposure to ultrasound in their graduate curriculum that was characterized as "passive", which is, watching a live demonstration, viewing an online module, or studying pre-labeled ultrasound scans. Only 15% (N = 5) had an ultrasound experience that involved active, hands-on image acquisition and interpretation. In one graduate program that did offer an active ultrasound experience, a hands-on ultrasound curriculum was integrated into a graduate course in gross anatomy (Royer et al., 2017). This integration was successful in improving master's students' confidence in performing a range of ultrasound skills and in identifying normal anatomical structures using ultrasound. The students' success demonstrated the feasibility of teaching ultrasound to novices who were not pursuing a medical degree, and addressed the question of whether non-medical students would value the use of ultrasound to learn anatomy (Ivanusic et al., 2010). A second report has described the incorporation of ultrasound sessions into a graduate level gross anatomy course (Bullen et al., 2020). The goal of these sessions was to use ultrasound technology to create a supplemental, hands-on and engaging method of learning anatomy that would appeal to graduate students and possibly, reinforce the understanding of content. Students in this course overwhelmingly reported that the ultrasound sessions were beneficial and that ultrasound should be used for anatomical instruction in non-medical graduate programs.

Apart from adding to the pool of instructors for ultrasound in medical schools, there is another very attractive benefit of including instruction in ultrasound imaging in graduate programs in anatomy. Graduate students often serve as teaching assistants in medical anatomy courses, and if trained in the fundamentals of ultrasound, they are uniquely positioned to make correlations between the anatomy studied in the cadaver, and the anatomy—and physiology—visualized in the living body with ultrasound. Indeed, when anatomy graduate assistants were paired with clinicians in a novel model to teach ultrasound to first-year medical students, medical student perceptions of both the value of ultrasound in anatomy and the relevance of ultrasound in medical education improved over student perceptions when the teaching was provided by clinicians alone (Smith et al., 2018).

In the fall of 2019, a course in ultrasound imaging was created at The Ohio State University and offered for the first time in the anatomy graduate program. This course is unique in that it focuses on the knowledge and skills needed to acquire and interpret ultrasound images, and relied on a knowledge base of anatomy obtained in previous coursework. The primary goal of this course is to teach ultrasound imaging so that students can use this skill in future teaching and research. The course followed a typical design for ultrasound training that included in-person lectures covering the concepts of ultrasound imaging, followed by hands-on laboratory sessions during which the instructor demonstrated various techniques of image
acquisition. Students then attempted to replicate the imaging techniques under the supervision of the instructor, who critiqued the students’ performance.

The Covid-19 pandemic restricted in-person teaching and challenged educators around the world to rapidly adapt the methods they use to deliver content. Traditional, face-to-face lectures were readily converted from in-person to an online format, particularly at those institutions that had key electronic resources already blended into their curricula before the pandemic (Binks et al., 2021). However, online systems are not thought to be an effective substitute for an in-person, hands-on mode of instruction (Bowra et al., 2015; Alhasan & Al-Horani, 2021; Zavitz et al., 2021).

In its response to the constraints on social interaction required by the Covid-19 pandemic, the graduate course in ultrasound imaging at Ohio State was adapted from in-person to a live, remote format. To meet this challenge in the first half of the course, each student was provided a hand-held ultrasound instrument that they could use for self-scanning at home during live, video conferencing laboratory sessions. The larger challenge was how to convert the in-person laboratory experience to a live, remote format. To meet this challenge in the first half of the course, each student was provided a hand-held ultrasound instrument that they could use for self-scanning at home during live, video conferencing laboratory sessions. The larger challenge was to transform the content delivered in the two courses was, with few exceptions, identical. The key factors responsible for the students’ success in the adapted course are discussed and refinements to the adapted instructional mode of delivery and this report describes the adaptations that were made. In-person lectures were replaced with real-time video conferencing sessions. The larger challenge was how to convert the in-person laboratory experience to a live, remote format. To meet this challenge in the first half of the course, each student was provided a hand-held ultrasound instrument that they could use for self-scanning at home during live, video conferencing laboratory sessions. The larger challenge was to transform the content delivered in the two courses.

The aim of this study was to measure the success of this adaptation to the course by comparing assessment scores of students in the adapted, live, remote course with assessment scores of students in the in-person course offered in the previous year. There was no statistical difference between the scores of students in courses with the two different formats, despite the fact that the content delivered in the two courses was, with few exceptions, identical. The key factors responsible for the students’ success in the adapted course are discussed and refinements to the adapted course for future offerings are suggested. The observed success of the students in the adapted course shows that, contrary to the prevailing view, instruction in the acquisition of ultrasound images is not dependent on in-person teaching. This finding suggests that a live, remote format can be used to extend broader access to instruction in ultrasound imaging and to teach individuals who cannot attend in-person courses.

MATERIALS AND METHODS

This study (protocol #2022E0089) has been reviewed by The Ohio State University Office of Responsible Research Practices and determined to be exempt from Institutional Review Board review. All students gave their permission to use their ultrasound images for publication.

Description of students in the study

Students enrolled in the in-person course or the live, remote course were all graduate students pursuing either a master’s or doctoral degree in anatomy. All of the students had previously completed a graduate-level, dissection-based course in human gross anatomy (Anatomy 6900) and were now enrolled in this two-credit ultrasound imaging course (Anatomy 7500) as an elective to satisfy their degree requirements. None of the students had previous experience using an ultrasound instrument to acquire images. Six students (n = 6) were enrolled in the in-person course and six students (n = 6) in the live, remote course. The course was available to all students from graduate programs in the university other than anatomy, but to date, only anatomy graduate students have enrolled.

Ultrasound imaging course schedule and resources

Table 1 shows the topics covered in each teaching session and the placement of two summative assessments, a mid-term examination and a final examination. The course was divided into two halves by the mid-term examination. As described below, hand-held ultrasound instruments were used in the first half of the course (7 weeks), and cart-based, hospital-type instruments were used in the second half of the course (7 weeks). For each topic, the following resources were posted on the course website: (1) a reading assignment from the required text (Loukas & Burns, 2020) that provided a short review of relevant anatomy, a description of techniques used to acquire specific images, and clinical applications; (2) videos selected from the world-wide web that demonstrated imaging technique and/or clinical application; (3) lecture slides; (4) a list of image objectives, and (5) a laboratory handout with step-by-step instructions—adapted from the required text—for image acquisition. Importantly, the required text provided ultrasound images that served as references for student image acquisition. The syllabus for the live, remote course is available as a Supporting Information File: Syllabus ANATOMY 7500 Autumn 2020.

Format of the teaching sessions

Each teaching session had two parts: a lecture and a laboratory exercise, and student attendance was required for both. The lectures focused on concepts and clinical applications, and emphasized the correlation between the anatomy studied in dissection-based courses and the anatomy that can be visualized using ultrasound imaging. All lectures were presented in real-time using a videoconferencing platform (Zoom Video Communications, Inc., San Jose, CA) with the instructor and all students in separate locations.

After a ten-minute break, a laboratory exercise followed each lecture. In the first half of the course, the instructor and each student had the KOSMOS™ Torso and Bridge hand-held ultrasound instrument (EchoNous, Inc., Redmond, WA) for personal use in their
| Session number | Title                                      | Lecture topics                                                                 | Laboratory topics                                                                 |
|---------------|--------------------------------------------|-------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| 1             | Course overview and introduction to ultrasound imaging | • Echogenicity  
• Transducer movements  
• “Window” versus “view” | • Correlate transducer position on body with image on the screen |
| 2             | Basic ultrasound physics | • Ultrasound image production  
• Acoustic impedance  
• Artifacts  
• Biosafety | • Orientation to the hand-held device  
• Acquire an image of the hepatorenal recess |
| 3             | Abdomen | • Indications for right upper quadrant exam  
• Liver segmentation  
• Color flow Doppler | • Acquire selected images of the liver, gall bladder and pancreas |
| 4             | Kidney and retroperitoneum | • Anatomy-physiology correlates of spleen, kidneys, urinary bladder, inferior vena cava, abdominal aorta  
• M-mode | • Acquire selected images of the spleen, left kidney, and urinary bladder  
• Use color flow Doppler to visualize ureteral jets  
• Use M-mode to measure changes in inferior vena cava diameter during respiration |
| 5             | Thorax: Chest wall, pleura, and lung | • Secondary pulmonary lobule  
• A- and B-lines  
• Pleural line  
• Lung point  
• Lung pulse | • Acquire selected images of the thoracic wall and the pleural line  
• Demonstrate lung sliding, the “seashore sign”, and the “barcode sign” |
| 6             | Thorax: Heart | • Indications for performing echocardiography  
• Planes used to image the heart  
• Differences in transducer orientation in echocardiography and in general sonography | • Acquire the following images of the heart: parasternal long axis (PLAX), parasternal short axis (PSAX), apical 4-chamber (A4C), apical 2-chamber (A2C), and subxiphoid |
| 7             | Mid-term Written Examination and Laboratory Examination | | |
| 8             | Upper Limb | • Echotexture of normal muscle, tendon, ligament, and peripheral nerve  
• Anisotropy | • Follow instructions in laboratory notes for scanning and image acquisition using the cart-based, hospital-type ultrasound instrument |
| 9             | Back | • Anatomy of the lumbar spine  
• Application to lumbar puncture and epidural anesthesia | • Acquire selected images of the lumbar spine |
| 10            | Lower Limb | • Translate understanding of upper limb to lower limb  
• Use power Doppler to evaluate muscle perfusion | • Acquire selected images of the knee and ankle |
| 11            | Vascular Imaging | • Basic physics of Doppler ultrasound  
• Different modes of Doppler imaging  
• Spectral waveforms  
• Coaptation of veins  
• Augmentation of venous return | • Demonstrate coaptation and augmented venous return in the popliteal vein  
• Obtain spectral waveforms of the popliteal vein and artery |
| 12            | Anterior Neck | • Review surface anatomy of the neck and relate to vertebral levels  
• Review key visceral relationships in the neck | • Acquire selected images of the thyroid gland, the internal jugular vein, carotid artery, and the trachea |
| 13            | Focused Assessment with Ultrasound for Trauma (FAST) | • Describe the FAST examination  
• Review various transducers | • Acquire selected images associated with the FAST examination  
• Compare images of the respiratory diaphragm obtained with the curved and the linear transducers |
| 14            | Final Written Examination and Laboratory Examination | | |
Images to be acquired in the first half of the course focused on structures in the abdominopelvic and thoracic regions. The hand-held instruments were equipped with a low frequency, phased-array transducer that is well suited to visualize structures that are deeply situated in the body.

For each laboratory exercise, students were given a list of image objectives for that topic. Each image objective specified a title, a window, and a view for that image, as well as specific anatomical structures that were to be labeled in the image. During each laboratory exercise, the instructor highlighted relevant surface anatomy and reviewed step-by-step instructions for acquiring each image. In the first half of the course, when the hand-held instruments were used, the instructor then demonstrated how to acquire each image in real-time, using self-scanning. The display on the hand-held ultrasound device was a touch screen that contained both the ultrasound image being acquired and the instrument controls. The display from the instructor’s instrument was shared with the class in real-time using the set-up shown in Figure 1. In this set-up, the camera of iPhone 6™ mobile phone (Apple Inc., Cupertino, CA) was focused on the display of the ultrasound instrument. This image was mirrored to the instructor’s desktop computer using a wireless connection, and made available to the class using the “share screen” feature of the videoconferencing tool. Students could see the image being acquired by the instructor in real time, as well as the results of adjustments in instrument settings, such as depth and gain, to optimize the image. Students could also see how different imaging modes (B-mode, M-mode, and color flow Doppler mode) were used by the instructor, as well as use of the “freeze” and “scroll” functions. Students could not see the movement of the transducer on the instructor’s body during live demonstrations, but together, the assigned textbook readings, videos, and detailed laboratory instructed provided sufficient detail to guide students in manipulating the transducer. Students were taught how to save and download images from the hand-held ultrasound device to a portable data storage device. Students could annotate their images either on the ultrasound instrument or after downloading to a personal computer. Students then used electronic mail to submit images to the instructor for formative evaluation and used the University’s password-protected learning management system to submit images for summative evaluation.

The images to be acquired in the second half of the course focused on the structures of the musculoskeletal system and of the neck. To image these more superficially situated structures, a high-frequency, linear transducer was required, and Acuson S2000 transducer (Siemens Medical Solutions USA Inc., Malvern, PA) was available on a cart-based, hospital-type instrument located in the ultrasound laboratory on campus. Therefore, in the second half of the course, as the students extended the range of structures to be imaged, they also began using a different type of ultrasound instrument and transducer, and transitioned from self-scanning in a private setting to self-scanning in the campus ultrasound laboratory.

When using the hand-held ultrasound instruments in the first half of the course, one camera could capture both the image being acquired and the operation of the controls because the image and the controls were on the same display screen of the instrument. When using the hospital-type instruments, two cameras were required for instruction—one camera (of the iPhone used above) focused on the screen, and a second camera of an iPad® tablet computer, model MD150LL/A (Apple Inc., Cupertino, CA) focused on the keyboard controls. It was cumbersome to use videoconferencing to simultaneously live-stream the video output of two cameras, so to demonstrate image acquisition using the hospital-type instrument, pre-recorded videos were prepared. These videos showed the image on the screen (captured by the iPhone camera) as the instructor self-scanned, and the image of the keyboard (captured by the iPad camera) as the instructor made adjustments to optimize image quality. Simultaneous video recordings were collected and then edited with iMovie® software, version 10.1.8 (Apple Inc., Cupertino, CA) to create a final “picture in picture” recording, with the video of keyboard operation overlaid onto the image of the instrument’s screen. A still frame of one such video is shown in Figure 2. Since the iPhone and the iPad were both the personal property of one of the authors, the only expenses were purchases of a small tripod to hold the iPhone (shown holding the iPhone in Figure 1) and the Padcaster™ frame (Padcaster, LLC., New York, NY) used to secure the iPad to a tripod. The time required to produce a 20-minute instructional video was about six hours.

These pre-recorded videos were shown during the live laboratory sessions using videoconferencing with the instructor providing narration and explanations to the students. The videos were then made available for asynchronous streaming on the course website, and it

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**FIGURE 1** Set-up used to share display of instructor’s hand-held ultrasound instrument with the class during live, remote videoconferencing laboratory exercises. The camera of a mobile phone (A) was focused on the display of the instructor’s hand-held ultrasound device (B) and the live image of the display was mirrored using a wireless connection to the instructor’s computer screen (C). The instructor’s computer screen was then shared with the class using the videoconferencing application. The transducer (D) of the hand-held ultrasound device is shown. The display of the ultrasound instrument contains both the image and the controls for optimizing the image.
would have been possible to assign these videos for asynchronous viewing by the students without showing them in laboratory sessions. However, one advantage of using these videos in the live laboratory sessions was that the instructor could pause at points during the live demonstration to make extended comments and answer questions. Also, viewing the videos together maintained a consistent format for live, instructor-student interaction during the laboratory sessions, even though students were not actively scanning. Thus, while image acquisition in the first half of the course was demonstrated in real-time, image acquisition in the second half of the course was demonstrated using pre-recorded videos that were shown and discussed in the live laboratory sessions. Also, in the first half of the course, students could practice image acquisition at any time using their handheld devices at home, but in the second half of the course, students practiced image acquisition on the hospital-type instruments by scheduling time in the ultrasound laboratory on campus.

**Summative assessments of lecture content**

Summative assessment of lecture content was performed using the online examination tool of the university’s learning management system. All students were required to take these examinations during the regularly scheduled class meeting time at their remote sites. Questions on these examinations used true-false, multiple-choice, and short answer formats. Examples of questions are available as a Supporting Information File: Examples of Examination Questions on Lecture Content. Scores on these two online examinations counted for one-half of a student’s mid-term and final examination score, the other half being provided by their score on the laboratory part of the examination.

**Formative and summative assessments of images acquired by the students**

At the beginning of the course, students were given the criteria that would be used to evaluate the images they submitted (Table 2). As described above, each laboratory exercise contained a list of image objectives. There were 28 image objectives for the first half of the course, and 44 image objectives for the second half of the course. Students received formative feedback on images they had acquired by submitting images using electronic mail to the instructor, and the instructor responded—within 24 hours—with comments and suggestions. Some students took advantage of this opportunity for feedback on a weekly basis, some after the completion of a series of laboratory sessions on a specific region of the body, but all students requested feedback as an examination approached. Formative feedback included technical suggestions for adjusting transducer position to obtain a better acoustic window or view, and for optimizing the gain, depth, and position of focal points. Feedback also included confirmation or revision of the identification of structures in an image.

Summative assessment of student performance in the laboratory portion of the course consisted of evaluation of images that the students submitted from a sub-list of the image objectives. One week before the mid-term examination, the instructor prepared a sub-list of 20 images for summative evaluation from the list of 28 objectives from the first half of the course. Similarly, one week before the final examination,
the instructor prepared a sub-list of 19 objectives for summative evaluation from the list of 44 from the second half of the course. These sub-lists were prepared to ensure that students covered a broad coverage of the content and not focus on images that they felt most comfortable acquiring. The students were required to select and submit ten images from each sub-list and had the option of submitting an eleventh image for extra credit. The final examination was not comprehensive.

Proficiency in acquiring images that are basic to a number of clinical examinations was demonstrated by students in the adapted course. In addition, proficiency in a number of ultrasound procedures that might be considered advanced techniques, such as the use of color flow Doppler and spectral Doppler to demonstrate normal and augmented flow in the popliteal vein (Figure 2), the use of M-mode to measure the changes in diameter of the inferior vena cava during respiration, and the use of spectral Doppler to distinguish low and high resistance arteries, was demonstrated, supporting the idea that both basic and advanced imaging ultrasound techniques can be taught using live, remote instruction.

Quantitative analysis

Cronbach’s alpha was run to determine the reliability of individual questions on lecture content on the midterm examination and final examination for the live, remote course. Cronbach’s alpha is a reliability coefficient that indicates internal consistency of the examination questions. An alpha coefficient was computed for all questions on each examination.

Statistical analysis was conducted on overall student examination scores for both the in-person and the live, remote courses for the midterm lecture examination, midterm practical examination, final lecture examination, and final practical examination using 2016 Excel® spreadsheet program (Microsoft Corp., Redmond, WA) and a P-value of <0.05 was considered statistically significant. Descriptive and inferential statistics were performed. A two-sample t-test assuming equal variances was used for comparisons.

Qualitative student feedback

At the end of the live, remote course, students had the opportunity to provide general comments on the course. Responses were voluntary and anonymous. Five of the 6 students enrolled in the live, remote course provided comments.

RESULTS

Comparison of summative assessments of the in-person and the live, remote courses

All questions on the live, remote midterm lecture examination had a Cronbach’s alpha coefficient of 0.72, while all questions on the live, remote final examination had an alpha coefficient of 0.54. A similar analysis on the questions from the in-person course was not performed because these examinations were administered using paper and pencil, and individual question scores had not been saved.

Unpaired t-tests assuming equal variances were run for comparison between each of the cohorts of the course to determine if there was a difference in scores due to the different format of teaching (Table 3). There was no significant difference between the midterm lecture examination scores for the in-person cohort and the live cohort in the course [t(8) = −0.09, P = 0.9]. There was no significant difference between the midterm practical scores for the in-person cohort and the live, remote cohort [t(8) = 0.51, P = 0.63]. There was no significant difference between the final lecture examination scores for the in-person cohort and the live, remote cohort [t(8) = 1.18, P = 0.27]. Finally, there was no significant difference between the final practical scores for the in-person cohort and the live, remote cohort [t(8) = −2.07, P = 0.07].

Examples of images submitted by the students for summative evaluation

Examples of images submitted by students in the live, remote course for summative evaluation are shown in Figure 3. For each image, the image objective is included in the figure legend. Images in Figure 3A–C are from the first half of the course, when the students were using the hand-held ultrasound instruments. Images in Figure 3D–F are from the second half of the course, when students were using the hospital-type instrument. All images in Figure 3A–C and Figure 3D–F were in grey scale, and the image objective is included in the figure legend.

### Table 2: Criteria used for ultrasound image assessment

| Category | Criteria |
|----------|----------|
| ANNOTATION (2 points) | - Image title (organ–window–view, e.g., liver–intercostal–long) - Student initials (first, middle, last) |
| TECHNICAL (3 points) | - Selection of examination (select appropriate examination type, e.g., cardiac, lung, musculoskeletal, etc.) - Body type/frequency (select appropriate "body type" on the hand-held instrument or frequency on the hospital-type machine.) - Depth (adjust depth so that structures, or region of interest are in the center of the screen.) - Gain (adjust gain so that anechoic structure are black.) - Selection of transducer<sup>a</sup> - Use of focal points<sup>a</sup> |
| ANATOMY (5 points) | - Required anatomy imaged - Required structures labeled correctly (from image objective) |

Note: A total of 10 points could be earned on each image. Points were distributed among three criteria, as indicated in the table.

<sup>a</sup>These criteria were required on the final examination only when the hospital-type instruments were used.
FIGURE 3  Examples of images acquired by the students and submitted for summative evaluation. (A) Ultrasound image of the hepatorenal recess submitted by a student for the mid-term examination. The image objective states: “Using an intercostal (or subcostal) window, acquire a long view of the hepatorenal recess. Label the hepatorenal recess, diaphragm, and liver. Use text Figure 8.10 for reference.” (B) Ultrasound image of heart submitted by a student for the mid-term examination. The image objective states: “Acquire a parasternal long axis view of the heart. Label the image parasternal long axis (PLAX) and identify the anterior leaflet of the mitral valve (MV), left ventricle (LV), left atrium (LA), and aortic valve. Use text Figure 7.3 for reference.” (C) Ultrasound image of the abdominal aorta submitted by a student for the mid-term examination. The image objective states: “Using an epigastric window, acquire a long view of the abdominal aorta showing the celiac artery and the superior mesenteric artery (SMA). Use text figure 8.18 for a reference.” (D) Ultrasound image of the anterior neck submitted by a student for the final examination. The image objective states: “Acquire a trans view of anterior neck at the level of the thyroid isthmus. Label the thyroid isthmus and the common carotid artery. Use text Figure 9.10 for reference.” (E) Ultrasound image of the tendon of the long head of the biceps brachii muscle in the intertubecular groove submitted by a student for the final examination. The image objective states: “Acquire a trans view of tendon of the long head of biceps brachii muscle in intertubecular groove. Label the tendon and lesser tubercle. Use text Figure 4.4 for reference.” (F) Ultrasound image of the pleural line submitted by a student for the final examination. The image objective states: “Acquire a long view of the pleural line using the linear transducer. Label the pleural line and the ribs. Use text Figure 6.1 for a reference.” Note that because tissue harmonics imaging (THI) was used to acquire this image, the “A” lines often seen in an ultrasound image of the pleural line are absent.
TABLE 3 Descriptive statistics for assessments of the in-person and the live, remote ultrasound imaging courses

| Assessment                        | Course type   | In-person (n = 6) | Live, remote (n = 6) | P-value |
|-----------------------------------|---------------|------------------|----------------------|---------|
|                                   | Mean % (± SD) | Median %         | Mean % (± SD)        | Median % | P-value |
| Midterm Lecture Examination       | 81.3 (±3.2)   | 83.0             | 82.3 (±4.5)          | 84.0     | 0.900   |
| Midterm Practical Examination     | 97.3 (±4.4)   | 99.5             | 96.0 (±2.4)          | 97.0     | 0.630   |
| Final Lecture Examination         | 85.6 (±2.6)   | 84.8             | 84.0 (±4.9)          | 84.0     | 0.270   |
| Final Practical Examination       | 91.7 (±4.8)   | 92.0             | 97.7 (±2.3)          | 98.5     | 0.070   |

Note: All values are reported in percentages. There was no significant difference between the in-person and the live, remote students' performance at $P < 0.05$.

earned 10 points out of a possible 10 points using the rubric shown in Table 2. The range of points earned on all images submitted for the midterm practical examination was 5–10. The range of points earned on all images submitted for the final practical examination was 7–10.

Qualitative student feedback

Table 4 shows extracted comments from students at the end of the live, remote course. The students appreciated the efforts to adapt the course to a live, remote format (Comments 2 and 4) and the convenience of using the hand-held instruments (Comment 1). One student was thoughtful about how ultrasound might be used in their career in the future (Comment 3). One student was candid about the difficulty of learning online and suggested that students have the ability to show the instructor their images in real time, and that the students be able to see the instructor using the transducer to acquire images (Comment 5).

DISCUSSION

The adaptation of a course in ultrasound imaging from an in-person to a live, remote learning format demonstrated that students without prior ultrasound experience could learn fundamentals of ultrasound physics and the acquisition of images that meet objective criteria for quality without in-person contact with an instructor. The success of this adaptation was measured by a comparison showing no statistically significant difference between assessment scores of students in the live, remote course with assessment scores of students enrolled in the in-person course held in the previous year. Assessment scores of both lecture content and image quality were included in this comparison. It may have been predicted that scores on the lecture content would be similar, since online teaching has been shown to effective in teaching theoretical aspects of imaging and related anatomy (Filippucci et al., 2007; Phillips et al., 2012; Bowra et al., 2015). However, it was uncertain whether students could learn a skill, such as ultrasound image acquisition using a live, remote form of instruction. There are four key factors that contributed to the successful performance of the students in developing the skill of ultrasound image acquisition in the live, remote course: (1) student preparedness and motivation; (2) anytime access to an ultrasound instrument for self-scanning practice; (3) defined criteria for assessment of image quality; and (4) formative feedback on image quality as the students were developing their imaging skills. The contribution of each of these factors to the students' success will be discussed.

Student preparedness and motivation

In terms of preparation, all students in the course were graduate students pursuing either a master's or a doctoral degree in anatomy and had successfully completed a graduate-level, dissection-based course in human gross anatomy that emphasized clinical applications. Thus, students were familiar with anatomical vocabulary and the relationship between organs in the human body. They were well prepared to learn how to view 3-dimensional anatomy in real-time on a 2-dimensional screen, one of the fundamental psychomotor skills used in acquiring ultrasound images (Nicholls et al., 2014). In terms of motivation, all students were enrolled in the ultrasound course to satisfy a degree requirement for elective courses, and were motivated to succeed because their grade in this course contributed to their overall grade point average in the graduate program. It has been observed that students who enroll in an ultrasound course that is voluntary or extracurricular may drop out because they underestimate the workload (Mackay et al., 2018), or may achieve lower than expected scores because the course is not part of their curriculum (Cawthorn et al., 2013). Students in both the in-person and the live, remote course were committed because their grade in the course became part of their academic record. Finally, it has been shown that increasing the weighting of practical examination assessments improved the average mark on that assessment, suggesting that student's effort on an assessment is related to the weight given to it (McDonald et al., 2016). In both the in-person and the live, remote courses, one-half of a student's final grade was the assessment of submitted images, giving students a great deal of motivation to acquire images that would receive a high score.

Anytime access to an ultrasound instrument for self-scanning practice

In the first half of the course, each student had a hand-held, ultrasound instrument for personal use at home. During each laboratory session
The live, remote course

Table 4

| Comments of the students (n = 5) at the conclusion of the live, remote course |
|---|
| 1. "Having the handheld ultrasound machines to practice with was super helpful and convenient. I wish I could’ve kept it for longer!" |
| 2. "...[the instructor] worked hard to ensure the highest quality of education and hands-on learning through times with COVID. I am very satisfied with the handling of social-distanced learning with the ultrasound (US) machines" |
| 3. "I really enjoyed this class. I learned a lot and it has made me wonder if I can use ultrasound in my career in the future" |
| 4. "I think [the instructor] did an excellent job of adapting the class to be in an online format. Obviously, it is more ideal to do this class in-person and there were challenges but I believe [the instructor] handled the challenges very well and worked very hard to make sure we were able to understand and appreciate ultrasound" |
| 5. "My only 'comment' for this class was that it was difficult for learning online. While I think [the instructor] did an amazing job working to adapt the class, I feel I struggled a bit more with the class due to it being online. The videos for each lesson helped a lot. I think the class would be almost the same in-person as online if 2 things could be figured out: (1) being able to show the instructor what we are doing to get feedback and (2) that besides seeing the screen of the ultrasound during lab demonstrations, it would be helpful to see how the instructor is using the transducer to acquire images" |

In the first half of the course, students could attempt to duplicate the imaging protocol in real time as it was being demonstrated by the instructor. As mentioned earlier, the laboratory part of in-person courses in ultrasound imaging should have a low instructor-to-student ratio to ensure that all students get ample time handling the transducer under the guidance of the instructor. In practice, only one student, at any time, can actually be scanning in an in-person course, while other students in the group are less engaged, or engaged in tasks supporting the student who is actually scanning (Weiskittel et al., 2021). In the first half of the adapted course, all students had their own instrument and were actively engaged in self-scanning during the in-person laboratories and focused on the task of image acquisition. Outside of the scheduled laboratory session, each student had anytime access to the hand-held instruments for practice in the privacy of their homes and at any time it was convenient and fit their schedules. Repetition and gradual refinement of technique is thought to be one of the requirements for significant improvement in performance (Ericsson, 2008). While the students were not asked whether, or how often they took advantage of this opportunity for repeated practice, they did have the opportunity to use the hand-held instruments for practice at any time.

In the second half of the course, students had access to a cart-based, hospital-type instrument on campus and were required to schedule time in the laboratory on campus for self-scanning practice and image acquisition. Though not as convenient as having the hand-held instruments at home for their personal use, students could schedule practice time whenever the laboratory was available and fit their schedules. In the second half of the course, the students were familiar with the fundamentals of imaging, and could focus on obtaining the specific images that were required. A comparison between the hours per week that the students spent on imaging when using the hand-held instruments and the hours per week when using the instruments on campus was not made. It is reasonable to think that students spent more time self-scanning using the hand-held instruments, because of the convenience and because fundamental skills were being learned. In the second half of the course, students may have spent less time self-scanning because they had to make the extra effort to reserve time in the laboratory and to travel to campus. Anytime access to the hand-held instruments at home in the first half of the course may have made the process of learning image acquisition on hospital-type instruments more efficient.

Whether using the hand-held or the hospital-type instruments, students were able to acquire all the required images by self-scanning while either standing upright or sitting. In the clinical setting, most scanning of the chest, the abdomen, and the neck is done with the patient in a supine, or left lateral decubitus position. Therefore, modifications were made to the instructions for body positioning for imaging that were described in the required text. There can be differences in organ appearance or position when the body is upright, compared to when it is supine. For example, the internal jugular vein is easily identified in a supine patient because it is filled with blood. In the standing or seated position, venous pressure in the internal jugular vein is lower than the central venous pressure, and the vein may be partially collapsed and difficult to identify (Johnson et al., 2020). Visualization of the internal jugular vein while standing is facilitated by performing a Valsalva maneuver. As another example, the heart is ideally examined when the patient is in the left lateral decubitus position, which brings the heart closer to the anterior chest wall. When the student is self-scanning while seated, the heart can be brought closer to the chest wall by leaning forward. These differences in organ appearance due to different body positions provided opportunities to emphasize the dynamic anatomy and physiology of the living body and the importance of body positioning when scanning.

Self-scanning eliminates the need for a model for scanning practice, whether that model is a patient, a fellow student, or a paid volunteer. References to using self-scanning in ultrasound education are rare, most likely because teaching protocols try to replicate the supine or decubitus positions of the clinical patient. However, self-scanning is very convenient and has been used to maintain ultrasound training for radiology residents who were required to minimize patient contact during the Covid-19 (Tang et al., 2020). An additional benefit of self-scanning is that it allowed these residents to experience what is requested of the patient during an ultrasound exam, such as holding a breath to obtain images free of motion artifact, or maintaining a full urinary bladder during imaging of pelvic structures. Self-scanning also allows the student to experience the pressure of the transducer on the body surface that is required to obtain an optimal image.

Image objectives that specified the view and the window to be used and the structures to be identified in that image, and an assessment tool that clearly defined how images would be evaluated

Each laboratory session included a list of image objectives that specified the view (long, transverse, or oblique), the window (intercostal,
Two transitions were made by the students during the course, and a third is anticipated

There were two transitions in knowledge and skills that the students made during the course and a third transition is anticipated. First, the students made a transition from the three-dimensional anatomy seen during dissection, to the two-dimensional anatomy—and physiology—that can be visualized using ultrasound. The very first image that the students were asked to acquire was of the hepato renal recess. In the dissection laboratory, the hepatorenal recess can be demonstrated by elevating the liver in the opened abdominopelvic cavity and pointing to the now greatly exaggerated space between the visceral surface of the liver and the right kidney. Using ultrasound, the students could confirm that this recess appears as a linear reflection representing a potential space at the area of actual contact between liver and kidney that becomes a real space when filled with a perfusion. Dissection anatomy provided the students with essential vocabulary and a sense of how structures are related to each other in the body. Ultrasound imaging relies on this vocabulary and corrects, revises, and informs anatomical relationships by showing their actual appearance in the living body (Royer, 2019; Lufler et al., 2022).

A second transition that the students made during the course was from using the hand-held instrument to using the hospital-type instrument. It quite possible that the students could have learned how to operate the hospital-type instrument without prior use of the hand-held instrument, by instruction using videoconferencing demonstrations of scanning and operation of the keyboard controls, as was done in the second half of the adapted course. However, learning how to scan using the hand-held instruments may have given the students a great deal of confidence in acquiring ultrasound images before being introduced to the hospital-type instrument and shortened the learning curve for using the more complex instrument. The students learned and practiced the essential skills of imaging—manipulating the transducer, making adjustments to depth and gain, and labeling and retrieving images—using the hand-held instruments in the privacy of their homes and could submit images for formative feedback whenever they wished.

A third transition, and one that will be interesting to evaluate in the future, is how easily students in the live, remote course will be able to transition from self-scanning to scanning a human model or a patient. In a recent prospective study, ultrasound-naïve, first-year medical students studied four core ultrasound online modules (aorta-IVC, cardiac, renal, and superficial) that contained information on indications, normal sonoanatomy, and ultrasound technique, but had no opportunity for hands-on practice (Situ-LaCasse et al., 2021). After completing the online modules, students were asked to acquire certain ultrasound views on standardized patients while being evaluated by emergency medicine faculty and fellows trained in ultrasound. Evaluators used a rubric that gave points for successful demonstration of specific structures, e.g., “Show the abdominal aorta in long axis” and “Identify the spleen when scanning the liver”. All students earned a high score in this hands-on evaluation,

Formative feedback on image quality as the students developed their imaging skills

The formative feedback provided to students in the live, remote course was evaluation of still images and video clips that were acquired at home or in the ultrasound laboratory, and then submitted to the instructor by electronic mail. Such feedback would be considered “asynchronous”, as opposed to “synchronous” feedback where critique is provided in real-time as the students were scanning (Ferreira et al., 2015). It seems intuitive that corrective feedback to students while learning a skill should be immediate to prevent the formation of bad habits. However, one advantage of asynchronous feedback is that it allows the student time to wrestle with a problem before seeking assistance. Based on the quality of the images that the students submitted for formative review, it seemed apparent that a number of problems related to image acquisition had been worked on and solved by the students independently, reserving issues that could not be resolved for consultation with the instructor. A second advantage of asynchronous feedback is that it eliminated the temptation for the instructor to take the transducer from the hand of a student who is struggling to acquire an adequate image. While taking the transducer from the struggling student and quickly demonstrating a correct maneuver may be considered time-efficient, it may not provide the most benefit to the student because it affects the autonomy of the learner and the valuable aspect of hands-on exploration (Bahner et al., 2016; Knudsen et al., 2018). Whether feedback was provided in a live, remote laboratory exercise or via electronic mail, there was consistent use of conventional anatomical descriptions and of codified terms for transducer movement (Bahner et al., 2016). Thus, feedback during the live, remote course was consistent and understandable, whether provided live or asynchronously.

subcostal, epigastric, etc.) to be used, and the structures to be labeled. Technical standards were provided in an assessment tool (Table 2) and included documentation (title of the image and initials of the student), selection of the correct pre-set examination on the instrument, proper depth, appropriate gain, and placement of the region of interest in the center of the image. Importantly, a reference image was included in each objective. In the assessment of learner competency in ultrasound imaging, it has been noted that direct comparison against a reference standard provides the most robust data allowing sensitivity and specificity to be measured (Mullaney, 2019). The purpose of including a reference image in each objective was to provide students with a model to guide scanning practice, much as an anatomical atlas image guides dissection.

The assessment tool used here was similar to that described by others (Bahner et al., 2011) and divided the evaluation of ultrasound image quality into 3 subscales: (1) identification/orientation, (2) technical, and (3) image anatomy. The tool used here differs in that 50% of the score of each image, rather than 33%, is attributed to image anatomy, and that the identification of specific anatomical structures in each image was evaluated.

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suggesting that ultrasound-naïve medical students can transition to using basic hands-on skills in image acquisition after reviewing online modules. The success of these students in acquiring images without prior hands-on practice suggests that students in the live, remote course here will be able to transfer the psychomotor skills learned during self-scanning to scanning live models and patients.

The results presented here should be compared with other examples of adaptations of an in-person to a remote format for ultrasound instruction made during the Covid-19 pandemic. One such adaptation used pre-assigned short, online video lessons and a subsequent two-hour interactive virtual session to provide an understanding of POCUS concepts, an improvement in understanding of the corresponding anatomy, and a subjective improvement in students’ confidence with POCUS. A comparison before and after the instruction showed an increase in knowledge and confidence in using ultrasound. In this example, local circumstances did not permit any hands-on experience (Olivares-Perez et al., 2022). As a second example, a series of self-directed learning modules were developed for students who had requested ultrasound training in addition to that provided in their UME curriculum (Boulger et al., 2021). These modules with written so that students could work without the assistance of a faculty member by following detailed, step-by-step instructions using ultrasound instruments in the on-campus laboratory. Students created a digital portfolio stored on the ultrasound machine that was periodically reviewed during an in-person meeting with a faculty member (Boulger et al., 2021). A tele-ultrasound course was developed for undergraduate medical students in response to discontinued in-person teaching (Höhne et al., 2022). Students received electronic resources for study before attending a live, videoconferencing lecture and demonstration of imaging technique. During this session, students practiced imaging at home by scanning a volunteer friend or family member using a hand-held ultrasound instrument. Student performance was assessed online in a 30-min final examination using an Objective Structured Assessment of Ultrasound Skills (OSAUS) combined with an evaluation of images acquired during the OSAUS and throughout the course.

Meuwly et al. described and evaluated an online, commercially-designed application to train medical students in ultrasound imaging during the Covid-19 pandemic that focused specifically on the acquisition of the visuospatial and visuomotor skills required to manipulate the transducer to acquire an ultrasound image (Meuwly et al., 2021). This approach used an online simulator where students used the mouse of their computer to control a simulated transducer on the computer screen. Students were evaluated on their ability to relocate an image from a library of images stored on the online server.

In a final example of novel approaches to meet the needs of students for remote clinical experiences during the Covid-19 pandemic, a virtual POCUS course was created for fourth year medical students to replace an existing POCUS elective (Zavitz et al., 2021). Each class meeting used videoconferencing and began with a review of recorded lectures, reading assignments, and case studies, followed by a live demonstration of scanning technique by the instructor using an ultrasound instrument. The students, in remote locations, used their cellular phones in place of an ultrasound transducer, and simulated transducer manipulation by aiming the camera of their phones on targets attached to the wall. The authors concluded that this course was an illustration that cognitive testing and general scanning technique for POCUS can be taught virtually in circumstances where in-person instruction is limited. The most significant difference between these five examples and the live, remote course described in this report is the timely and individual formative feedback provided to students before they submitted their images for summative evaluation. Formative feedback has been identified as a critical element in the acquisition of competence in ultrasound imaging (Arntfield, 2015).

It is important to note that solutions to the challenge of providing access to ultrasound instruction during the Covid-19 pandemic can be applied to the more general challenge of providing ultrasound instruction in circumstances where instructor and learners are separated, not by pandemic-mandated social distancing, but simply by physical distance. For individuals still in clinical training, ultrasound can be learned as part of their undergraduate or graduate curricula, but for practicing clinicians and instructors in anatomical sciences, an introduction to ultrasound with both didactics and hands-on instruction is often obtained in short courses or workshops that are associated with professional meetings. These learning experiences usually require travel to the instruction site and time away from professional responsibilities. The availability of live, remote courses in ultrasound imaging will help address both the access to ultrasound instruction and the shortage of competent instructors, that in turn will allow a broader use of ultrasound in clinical practice and in medical education. The adapted course described here can serve as a model for those who wish to teach a live, remote ultrasound course, and the lessons learned and described here can inform the design of such courses.

Limitations of the study

Because this study was conceived after completion of the live, remote course, there were questions not asked that would have provided useful information if the study had been planned in advance. For example, it would have been interesting to know how often students took advantage of using the hand-held instruments at home for self-scanning and the length of each self-scanning session. It would also be important to know if students used the hand-held instruments to scan members of their household, friends, or family members. Given the enthusiasm that students have for ultrasound imaging, it seems likely that students in the course may used the hand-held ultrasound instruments to scan other individuals. In the live, remote course, permission to scan friends and family members was neither explicitly given, or denied. Because the availability and use of hand-held ultrasound instruments will undoubtedly increase, students must know whether or not they are permitted to scan others. If permission to scan others is given, individuals to be scanned must be informed of the nature of the examination, the biosafety...
of the procedure, and the potential for incidental findings, and they should acknowledge that they have received this information and then provide their written permission for the scanning. For the live, remote course, a protocol for handling incidental findings was not in place, though advice on developing such protocols is available (Fox et al., 2011; Siegel-Richman & Kendall, 2017; Dietrich et al., 2022).

Related to the issue of handling incidental findings, there is the issue of ensuring personal privacy when ultrasound images are shared electronically. While students in the live, remote course submitted their images for summative assessment to the university’s password-protected learning management system, they submitted images for formative assessment to the instructor using electronic mail. In the future, students will be required to submit all images using the password-protected system to ensure the privacy of transmitted images. Finally, the students in the live, remote course suggested that they have the ability to show the instructor their attempts while acquiring images in real time to get immediate formative feedback. The students also suggested that they be able to see the instructor’s transducer as it was being manipulated. In the set-up used here, providing a view of the transducer on the body would require a camera in addition to those providing views of the instrument screen and instrument keyboard. All these suggestions are reasonable goals for future offerings of the course and raise questions about the most efficient and educationally productive methods to use video communication to teach ultrasound.

CONCLUSIONS

This study demonstrates that there were no statistically significant differences in assessment scores of students in an in-person course compared to a live, remote course in ultrasound imaging. Assessment scores of both lecture content and image acquisition were compared. The finding that assessment scores for image acquisition of the two groups of students were similar suggests that, contrary to the prevailing view, ultrasound image acquisition is not dependent on in-person contact between instructor and learner, but can be achieved through a live, remote interaction using video conferencing tools. While the incentive to adapt an in-person course in ultrasound imaging to a live, remote format was provided by the COVID-19 pandemic, this adapted format may find application in scenarios when instructor and learners are separated by constraints other than concern for disease transmission. Distance is one such constraint and can be any distance—local or global—between an instructor at one site and learners in multiple sites. This study supports a shift away from a dependence on in-person instruction in ultrasound and toward use of alternative methods of teaching that address limitations due to the shortage of instructors and physical accessibility to courses and workshops.

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REFERENCES

Alhasan M, Al-Horani Q. 2021. Students’ perspective on the online delivery of radiography and medical imaging program during COVID-19 pandemic. J Med Imaging Radiat Sci 52:568–577.
Armfield RT. 2015. The utility of remote supervision with feedback as a method to deliver high-volume critical care ultrasound training. J Crit Care 30:441e1–441e6.
Bahner DP, Adkins EJ, Nagel R, Way D, Werman HA, Royall NA. 2011. Brightness mode quality ultrasound imaging examination technique (B-QUIET). J Ultrasound Med 30:1649–1655.
Bahner DP, Blickendorf JM, Bockbader M, Vira A, Boulger C, Panchal AR. 2016. Language of transducer manipulation: Codifying terms for effective teaching. J Ultrasound Med 34:183–188.
Bahner DP, Goldman E, Way D, Royall NA, Liu YT. 2014. The state of ultrasound education in U.S. medical schools: Results of a national survey. Acad Med 89:1681–1686.
Bahner DP, Royall NA. 2013. Advanced ultrasound training for fourth-year medical students: A novel training program at The Ohio State University College of Medicine. Acad Med 88:206–213.
Binks AP, LeClair RJ, Willey JM, Brenner JM, Pickering JD, Moore JS, Huggett KN, Everling KM, Arnott JA, Croniger CM, Zehle CH, Krane NK, Schwartzstein RM. 2021. Changing medical education, overnight: The curricular response to COVID-19 of nine medical schools. Teach Learn Med 33:334–342.
Bowra J, Dawson M, Goudie A, Mallin M. 2015. Sounding out the future of ultrasound education. Ultrasound 23:48–52.
Boulger C, Prats M, Niku A, Diaz M, Bahner DP. 2021. ITSUS: Integrated, tiered, self-directed ultrasound scanning for learning anatomy. Cureus 13:e16119.
Bullen TR, Brown K, Ogle K, Liu YT, Jurus RA. 2020. Using ultrasound to teach living anatomy to non-medical graduate students. Surg Radiol Anat 42:1383–1392.
Cawthorn TR, Nickel C, O’Reilly M, Kafka H, Tam JW, Jackson LC, Sanfilippo AJ, Johri AM. 2013. Development and evaluation of methodologies for teaching focused cardiac ultrasound skills to medical students. J Am Soc Echocardiogr 27:302–309.
Clevert A, Schwarze V, Nyhsen C, D’Onofrio M, Sidhu P, Brady AP. 2019. European Society of Radiology (ESR). ESR statement on portable ultrasound devices. Insights Imaging 10:89. https://doi.org/10.1186/s13244-019-0775-x
Dietrich CF, Goudie A, Chiorean L, Cui XW, Gilia OH, Dong Y, Abramowicz JS, Vinayak S, Westerway SC, Noilsæ CP, Chou Y-H, Blaivas M. 2017. Point of care ultrasound: A WFUMB position paper. Ultrasound Med Biol 43:49–58.
Dietrich CF, Hoffmann B, Abramowicz J, Badea R, Braden B, Cantisani V, Chammas MC, Cui XW, Dong Y, Gilja OH, Hari R, Nisenbaum H, Nicholls D, Nolsæ C P, Nürnberg D, Prosch H, Radzina M, Recker F, Sachs A, Saftoiu A, Serra A, Sweet L, Vinayak S, Westerway S, Chou YH, Blaivas M. 2019. Medical student ultrasound education: A WFUMB position paper. Part 1. Ultrasound Med Biol 45:271–281.

Dietrich CF, Fraser AG, Dong Y, Guth S, Hari R, Hoffmann B, Walter R, Abramowicz JS, Nolsæ CP, Blaivas M. 2022. Managing incidental findings reported by medical, sonography and other students performing educational ultrasound examinations. Ultrasound Med Biol 48:180–187.

Dinh VA, Fu JY, Lu S, Chiem A, Fox JC, Blaivas M. 2016. Integration of ultrasound in medical education at United States medical schools: A national survey of directors’ experiences. J Ultrasound Med 35:413–419.

Ericsson KA. 2008. Deliberate practice and acquisition of expert performance: A general overview. Acad Emerg Med 15:988–994.

Ferreira AC, O’Mahony E, Olani AH, Júnior EA, da Silva Costa F. 2015. Teleultrasound: Historical perspective and clinical application. Int J Telemed Appl 2015:306259.

Filippucci E, Meenagh G, Iagnocco A, Taggert A, Grassi W. 2015. Ultrasound clinical progress monitoring: Who, where and how? J Ultrasound Med 34:197–203.

Hoffmann B, Blaivas M, Abramowicz J, Bachmann M, Badea R, Braden B, Cantisani V, Chammas MC, Cui XW, Dong Y, Gilja OH, Hari R, Lamprecht H, Nisenbaum H, Nolsæ CP, Nürnberg D, Prosch H, Radzina M, Recker F, Sachs A, Saftoiu A, Serra A, Vinayak S, Westerway S, Chou YH, Dietrich CF. 2020. Medical student ultrasound education, a WFUMB position paper, part II. A consensus statement of ultrasound societies. Med Ultrasound 22:220–229.

Höhne E, Recker F, Schmok F, Brossart P, Raupach T, Schäfer VS. 2022. Conception and feasibility of a digital tele-guided abdomen, thorax, and thyroid gland ultrasound course for medical students (TELUS study). Ultraschall Med (in press; doi: https://doi.org/10.1055/a-1528-1418).

Hoppmann RA, Rao VV, Poston MB, Howe DB, Hunt PS, Fowler SD, Paulman LE, Wells JR, Richeson NA, Catalana PV, Thomas LK, Wilson LB, Cook T, Riffle S, Neuffer FH, McCallum JB, Keisler BD, Brown RS, Gregg AR, Sims KM, Powell CK, Garber MD, Morrison JE, Owens WB, Carnevale KA, Dietrich CF. 2011. An integrated ultrasound curriculum (iUSC) for medical students: 4-year-experience. Crit Ultrasound 3:1–12.

Johnson CD, Roe SM, Tansey EA. 2020. Using two-dimensional ultrasound imaging to examine venous pressure. Adv Physiol Educ 44:262–267.

Ivanusic J, Cowie B, Barrington M. 2010. Undergraduate student perceptions of the use of ultrasonography in the study of “living anatomy”. Anat Sci Educ 3:318–322.

Kendall JL, Hoffenberg SR, Smith RS. 2007. History of emergency and critical care ultrasound: The evolution of a new imaging paradigm. Crit Care Med 35:S126–S130.

Khoury M, Fotsing S, Jalali A, Chagnon N, Maheur S, Youssef N. 2020. Preclerkship point-of-care ultrasound: Acquisition and clinical transferability. J Med Ed Curric Dev 7:2382120520943615.

Knudsen L, Nawrotzki R, Schmiedl A, Muhfeld C, Kruschinski C, Ochs M. 2018. Hands-on or no hands-on training in ultrasound imaging: A randomized trial to evaluate learning outcomes and speed of recall of topographic anatomy. Anat Sci Educ 11:575–591.

Lambrecht JE, Zhang K, Tierney DM, Milliner P, Giovannini D, Barron K, Novak W, Patel SA, Doversal R, Cox EJ, LoPresti CM. 2022. Integration of point-of-care ultrasound education into the internal medicine core clerkship experience. J Ultrasound Med 41:33–40.

Landry A, Eicken K, Dwyer K, Hojayer J, Henwood T, Frasure S, Kimberly H, Stone M. 2017. Ten strategies for optimizing ultrasound instruction for group learning. Cureus 9:e1129.

Loukas M, Burns D. 2020. Essential Ultrasound Anatomy. 1st Ed. Philadelphia, PA: Wolters Kluwer. 275 p. ISBN 9781496383532.

Mackay FD, Zhou H, Lewis D, Fraser J, Atkinson PR. 2018. Can you teach your self-point-of-care ultrasound to a level of clinical competency? Evaluation of a self-directed simulation-based training program. Cureus 10:e3320.

Meyluwty JY, Mandralis K, Tenisch E, Guillo G, Fossard P, Morend L. 2021. Use of an online ultrasound simulator to teach basic psychomotor skills to medical students during the initial COVID-19 lockdown: Quality control study. JMIIF Med Edu 7:e31132.

Moore CL, Copel JA. 2011. Point-of-care ultrasonography. N Engl J Med 356:749–757.

Mullaney PJ. 2019. Qualitative ultrasound training: Defining the curve. Clin Radiol 74:327.e7–327.e19.

Nichols D, Maw J, Amundson SA, Khan J, Simon MN, Rangel J. 2019. Including insonation of topographic anatomy. Anat Sci Educ 12:472–474.

Nicholls D, Nolsøe CP, Nurnberg D, Prosch H, Radzina M, Recker F, Sachs A, Saftoiu A, Serra A, Vinayak S, Westerway S, Chou YH, Dietrich CF. 2020. Medical student ultrasound education, a WFUMB position paper, part II. A consensus statement of ultrasound societies. Med Ultrasound 22:220–229.

Höhne E, Recker F, Schmok F, Brossart P, Raupach T, Schäfer VS. 2022. Conception and feasibility of a digital tele-guided abdomen, thorax, and thyroid gland ultrasound course for medical students (TELUS study). Ultraschall Med (in press; doi: https://doi.org/10.1055/a-1528-1418).

Hoppmann RA, Rao VV, Poston MB, Howe DB, Hunt PS, Fowler SD, Paulman LE, Wells JR, Richeson NA, Catalana PV, Thomas LK, Wilson LB, Cook T, Riffle S, Neuffer FH, McCallum JB, Keisler BD, Brown RS, Gregg AR, Sims KM, Powell CK, Garber MD, Morrison JE, Owens WB, Carnevale KA, Dietrich CF. 2011. An integrated ultrasound curriculum (iUSC) for medical students: 4-year-experience. Crit Ultrasound 3:1–12.

Johnson CD, Roe SM, Tansey EA. 2020. Using two-dimensional ultrasound imaging to examine venous pressure. Adv Physiol Educ 44:262–267.

Ivanusic J, Cowie B, Barrington M. 2010. Undergraduate student perceptions of the use of ultrasonography in the study of “living anatomy”. Anat Sci Educ 3:318–322.

Kendall JL, Hoffenberg SR, Smith RS. 2007. History of emergency and critical care ultrasound: The evolution of a new imaging paradigm. Crit Care Med 35:S126–S130.

Khoury M, Fotsing S, Jalali A, Chagnon N, Maheur S, Youssef N. 2020. Preclerkship point-of-care ultrasound: Acquisition and clinical transferability. J Med Ed Curric Dev 7:2382120520943615.

Knudsen L, Nawrotzki R, Schmiedl A, Muhfeld C, Kruschinski C, Ochs M. 2018. Hands-on or no hands-on training in ultrasound imaging: A randomized trial to evaluate learning outcomes and speed of recall of topographic anatomy. Anat Sci Educ 11:575–591.
Schott CK, Kode KR, Mader MJ. 2020. Teaching vs learning: Impact of deliberate practice and formative feedback on developing point of care ultrasound skills. J Clin Ultrasound 48:437–442.

Siegel-Richman Y, Kendall JL. 2017. Incidental findings in student ultrasound models: Implications for instructors. J Ultrasound Med 36:1739–1743.

Situ-LaCasse E, Acuña J, Huynh D, Amini R, Irving S, Samsel K, Patanwala AE, Biffar DE, Adhikari S. 2021. Can ultrasound novices develop image acquisition skills after reviewing online ultrasound modules? BMC Med Educ 21:175.

Smith JB, Kendall JL, Royer DF. 2018. Improved medical student perception of ultrasound using a paired anatomy teaching assistant and clinician teaching model. Anat Sci Educ 11:175–184.

So S, Patel RM, Orebaugh SL. 2017. Ultrasound imaging in medical student education: Impact on learning anatomy and physical diagnosis. Anat Sci Educ 10:176–189.

Tang PH, Chen EM, Liang MM, Teo SY, Ong CL. 2020. Maintaining training with self-ultrasound during COVID-19. Acad Radiol 27:1491.

Vignon P, Mücke F, Bellec F, Marin B, Croce J, Brouqui T, Palobart C, Senges P, Truffy C, Wachmann A, Dugard A, Amiel J-B. 2011. Basic critical care echocardiography: Validation of a curriculum dedicated to noncardiologist residents. Crit Care Med 39:636–642.

Wagner M, Boughton J. 2018. PEARLS for an ultrasound physical and its routine use as part of the clinical examination. South Med J 111:389–394.

Weiskittel TM, Lachman N, Bhagia A, Andersen K, St. Jeor J, Pawlina W. 2021. Team-based ultrasound objective structured practice examination (OSPE) in the anatomy course. Anat Sci Educ 14:377–384.

Zavitz J, Sarwal A, Schoenbeck J, Glass C, Hays B, Shen E, Bryant C, Gupta K. 2021. Virtual multi-specialty point-of-care ultrasound rotation for 4th year medical students during COVID-19: Innovative teaching techniques improve ultrasound knowledge and image interpretation. AEM Educ Train 5:e10632.

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**SUPPORTING INFORMATION**

Additional supporting information may be found in the online version of the article at the publisher’s website.

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