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Can you teach a hands-on skill online? A scoping review of e-learning for point-of-care ultrasound in medical education

Peut-on enseigner une compétence pratique en ligne ? Une revue exploratoire de l'apprentissage en ligne pour l'échographie ciblée dans la formation médicale

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Abstract

Background: There is an increasing need and interest in teaching point-of-care ultrasound (POCUS) online. The objective of this study was to systematically review the literature regarding e-learning as a method for teaching POCUS in medical education, to assess the benefits and limitations of various styles of e-learning for POCUS, and to identify gaps in the literature that could help guide future research in this field.

Methods: A literature search was conducted on three databases including MEDLINE (Ovid), EMBASE and Cochrane Central Register of Controlled Clinical Trials on October 12, 2021, retrieving a total of 1630 studies. 31 studies met the inclusion and exclusion criteria. These studies were separated into different styles of e-learning and learner outcomes were analyzed based on Kirkpatrick's hierarchy.

Results: The studies were categorized into three styles of e-learning: a) blended learning b) online-only (asynchronous or synchronous) and c) use of handheld machines or telesonography. POCUS knowledge and image interpretation were successfully taught online, however online-only learning for image acquisition was not as consistently effective. Blended learning and telesonography were beneficial for learning image acquisition skills. Generally, novice learners benefited most from e-learning.

Conclusion: E-learning for POCUS is gaining in popularity in recent years. POCUS is a complex technical skill, and depending on the individual task being taught, different styles of e-learning may be more successful. These findings can inform future POCUS educational programs.

Résumé

Contexte : L'enseignement en ligne de l'échographie ciblée (ÉC) est l'objet d'un intérêt et de besoins croissants. L'objectif de cette étude était de passer systématiquement en revue la littérature sur l'apprentissage en ligne comme méthode d'enseignement de l'ÉC dans la formation médicale, d'évaluer les avantages et les limites des différents styles d'apprentissage en ligne pour l'ÉC et d'identifier les lacunes dans la littérature qui pourraient aider à orienter la recherche future dans ce domaine.

Méthodes : Une recherche a été effectuée dans trois bases de données, soit MEDLINE (Ovid), EMBASE et le Cochrane Central Register of Controlled Clinical Trials, le 12 octobre 2021, ce qui a permis d'extraire un total de 1 630 études. 31 études répondaient aux critères d'inclusion et d'exclusion. Ces études ont été classées selon différents styles d'apprentissage en ligne et les progrès des apprenants ont été analysés en ayant recours au modèle de la hiérarchie de Kirkpatrick.

Résultats : Les études ont été classées en trois styles d'apprentissage en ligne : a) apprentissage mixte b) uniquement en ligne (asynchrone ou synchrone) et c) utilisation d'appareils portatifs ou de la télésonographie. Les connaissances en matière d'ÉC et l'interprétation des images ont été enseignées avec succès en ligne, mais l'apprentissage uniquement en ligne pour l'acquisition des images n'a pas été aussi efficace. L'apprentissage mixte et la télésonographie ont été bénéfiques pour l'acquisition des compétences en matière d'acquisition d'images. En général, ce sont les novices qui ont le plus bénéficié de l'apprentissage en ligne.

Conclusion : L'apprentissage en ligne pour l'ÉC gagne en popularité ces dernières années. L'ÉC est une compétence technique complexe et, en fonction de la tâche précise enseignée, différents styles d'apprentissage en ligne peuvent s'avérer plus efficaces. Ces résultats peuvent éclairer les futurs programmes de formation en ÉC.

Introduction

Point-of-care ultrasound (POCUS) is commonly used at the bedside and has been shown to expedite patient care,[1-4] assist with diagnosis and procedures,[5-8] and improve outcomes.[9-11] Since its introduction in the 1990's, POCUS education has shifted from an initial focus on emergency medicine and trauma, and now spans multiple other specialties such as pediatric emergency medicine, internal medicine, anesthesia, and undergraduate medical education.[12,13] Traditionally, POCUS has been taught hands-on at the bedside through an apprenticeship model or via didactic lectures and workshops. However, in recent years, e-learning in medical education is rising in popularity, heightened by social distancing mandates during the COVID-19 pandemic.[14] There is an increasing need and interest in teaching POCUS online.[15-17] If successful, e-learning for POCUS could increase its reach globally by offering educational opportunities to learners who don't have local access to POCUS expertise.[18]

E-learning has been defined as an approach that is "based on digital media and devices as tools to improve access to training, communication, and interactions"[19] between learners and teachers, and includes styles such as asynchronous, synchronous and blended learning.[19,20] E-learning has several advantages such as improved access in remote locations, increased convenience for the learner, lower overall cost and instructor time savings, and some potential pitfalls, such as technical difficulties and challenges in teaching clinical skills.[14,16,21] E-learning for point-of-care ultrasound can include a wide variety of POCUS applications and instructional designs, such as interactive online modules, online image libraries, and blended learning (with a "flipped classroom" followed by hands-on scanning), among others. Specific to POCUS, the increasing availability of handheld ultrasound devices and telesonography may offer additional learning opportunities for POCUS that can complement traditional e-learning.[18,22-24]

A previous scoping review about POCUS in medical education, published in 2020, provided an overview of the ways that POCUS is taught, including didactic, hands-on instruction and simulation.[13] This review compared web-based didactic vs. in-person teaching in nine studies, and found that Web-based teaching was non-inferior in most of the included studies. However, the studies included were from prior to 2017, and a large body of new evidence about e-learning has been published since. Additionally, given the broad scope of the review, they did not assess the full breadth of e-learning for POCUS, and its advantages or disadvantages. This current scoping review was undertaken to better understand the benefits and limitations of different styles of e-learning for POCUS in medical education. A scoping review style was selected due to the heterogenous data, including a variety of learners at different levels of training, variety of POCUS applications and study types.

Objectives

The primary objective of this study was to explore the breadth of literature regarding e-learning as a method for teaching point-of-care ultrasound in medical education, and to (a) describe the benefits and limitations of various online teaching methods for this hands-on skills and (b) discover gaps in the literature as it relates to e-learning for POCUS, and explore directions for future educational research and educational innovations in this field.

Methods

Data sources

We conducted a literature search on three databases on October 12, 2021: MEDLINE (Ovid) (1946-), EMBASE (Ovid) (1947-), and Cochrane Central Register of Controlled Clinical Trials (Ovid) with the help of a medical librarian. No date limits were placed on the search. A concept map was created, which included keywords and medical subject headings related to "ultrasonography" or "POCUS" AND "medical education" or "curriculum" AND "virtual" or "e-learning" (Figure 1). References of these papers were also reviewed. A total of 1630 studies were initially retrieved.

#	Searches	Results
1	exp Ultrasonography/	461344
2	POCUS.tw,kf.	1282
3	((point of care or bedside?) adj3 (ultrasound? or ultrasonograph* or sonograph* or echocardiograph* or FAST or eFAST)).tw,kf.	5593
4	or/1-3	463610
5	exp Education, Medical/	174948
6	teaching/ or models, educational/ or exp simulation training/	68975
7	exp Curriculum/	91097
8	(educat* or train* or teach* or instruct* or curriculum?).tw,kf.	1383372
9	or/5-8	1469318
10	Computer-Assisted Instruction/	12224
11	Education, Distance/	5471
12	(virtual* or online or webbased or web based or elearning or e-learning or remote*).tw,kf.	409444
13	or/10-12	418901
14	4 and 9 and 13	826

Figure 1. Ovid Medline Search Strategy MEDLINE(R) and Epub Ahead of Print, In-Process, In-Data-Review & Other Non-Indexed Citations and Daily 1946 to October 11, 2021. Search Strategy.

Study selection

After removal of duplicates, 1119 studies underwent initial review by title and abstract. Inclusion criteria included studies related to point-of-care ultrasound and e-learning in medical education. Studies were excluded if they related to non-point of care ultrasound (radiology ultrasound, echocardiograms, fetal ultrasound), if the educational intervention did not involve e-learning (primarily simulation, phantoms used in-person, without the direct study of an online learning component; or tele-medicine and tele-sonography for clinical rather than educational purposes), if the participants were not physicians, if the article was not written in English, or if it was an opinion piece or commentary. After applying these inclusion and exclusion criteria, 214 studies remained that subsequently underwent full-text review. After review of the full-text studies, 31 studies were ultimately included in the scoping review (Figure 2).

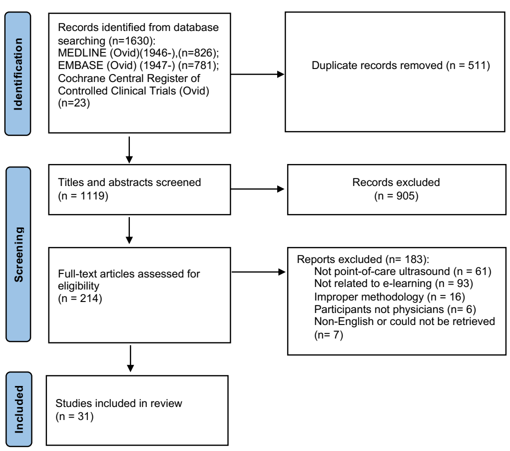

Figure 2. PRISMA chart of included and excluded articles for POCUS e-learning in medical education

Synthesis

The included studies were separated into three categories based on the primary type of e-learning: blended learning, online-only (asynchronous or synchronous), and studies involving the use of handheld machines or telesonography. Using a data abstraction form, content was synthesized for each study, including details about the participants and their level of training, the type of POCUS application studied, the study design, the instructional design of the educational intervention and comparison group (if applicable). Learner outcomes were identified and categorized into the Kirkpatrick hierarchy,[25] using a framework described in a previous scoping review about POCUS education:[13] K1, reactions (learner enjoyment or satisfaction); K2, learning (assessments of confidence, knowledge, image acquisition, image interpretation, procedural skills, knowledge retention); K3, behavior (assessment of ongoing POCUS use through monitoring of number of scans performed or self-report); K4, results (change in end-outcomes including clinical accuracy or procedural success rates, changes in patient management and patient satisfaction).

Results

We included thirty-one studies examining e-learning for point-of-care ultrasound in medical education in this review. The most common study types were prospective cohort studies (51.6%) and randomized controlled trials (22.6%) (Figure 3). The number of relevant publications increased over time, with 12/31 studies (38.7%) published in the last two years (2020-2021) (Figure 4).

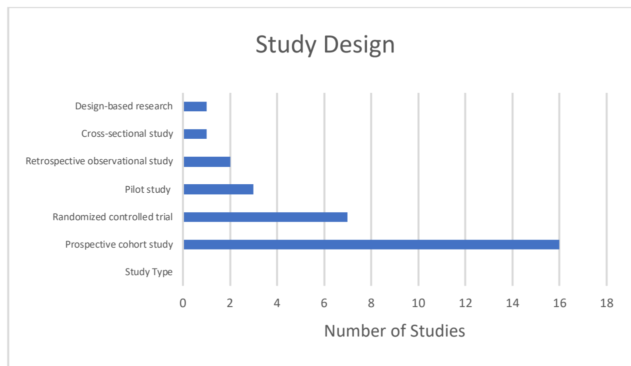

Figure 3. Types of study design for POCUS e-learning in medical education

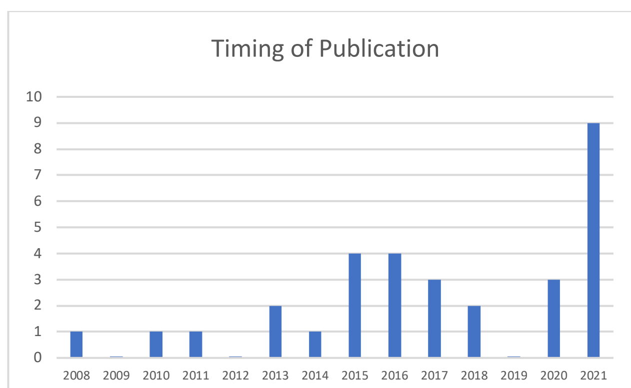

Figure 4. New relevant publications over time

Participants came from a range of medical and surgical specialties, most commonly Emergency Medicine (eight studies), Pediatric Emergency Medicine (four studies), and Anesthesia (four studies). The level of training of the participants was also very broad. Nine studies were related to undergraduate medical education, five studies related to postgraduate medical education (residents and fellows), three studies related to attendings, and 14 studies had participants from a mix of practice levels.

A broad range of POCUS applications were assessed (Figure 5). The most common applications included were lung ultrasound and focused assessment of sonography in trauma (FAST). Only three of the studies specifically looked at procedural applications,[26-28] including US-guided IV's and US-guided central lines. Only one study directly compared different POCUS applications in terms of their relative difficulty to learn online, and concluded that among four applications, image interpretation learning curves were variable depending on the learner and POCUS application; for example, soft tissue US being easier to learn than cardiac.[29]

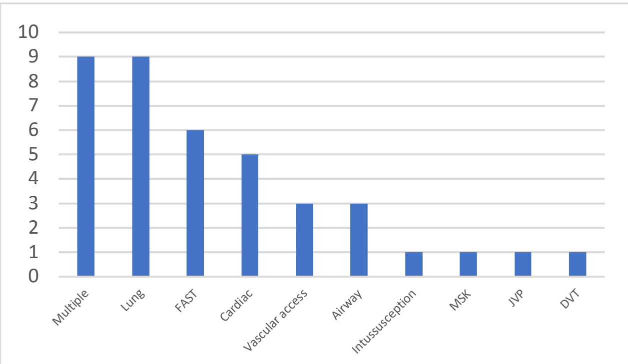

Figure 5. POCUS applications included in the selected studies.
Legend: Some studies included more than one application. If four or more applications were included, this was categorized as "multiple". (FAST- focused assessment of sonography in trauma, MSK- musculoskeletal, JVP – jugular venous pressure, DVT – deep vein thrombosis)

Three styles of e-learning relevant to POCUS education were identified: blended learning, online-only (asynchronous or synchronous), and studies involving the use of handheld machines or telesonography. Appendix A, Table 1 outlines the study details and results, divided by the type of e-learning (also see Tables S1, S2 and S3 in the supplement for more detailed study results).

Blended learning (Appendix A; Table 1A)

There were 12 studies included in the blended learning category. The instructional designs featured various forms of e-learning (interactive online modules, listening to a podcast,[30] listening to pre-recorded lectures, or short web-based teaching (5-10 minutes)[31]), followed by hands-on scanning. Most of the e-learning occurred before the hands-on component, while in one study, "sandwich e-learning" was described, with pre-course and post-course e-learning components.[32] The hands-on training mostly consisted of the traditional POCUS workshop format with practice in small groups with an instructor and live models. In other studies, the hands-on training occurred on a high-fidelity simulator or phantom.[26,33] 9/12 of the studies had a comparison group, which typically involved classroom teaching (instead of the e-learning component), followed by hands-on training. Learner satisfaction was assessed in 9/12 studies, with mixed results. In some studies, learners found the e-learning enjoyable or similar to the in-person teaching.[26,30,34] while one study found that the majority of learners preferred traditional classroom-based teaching.[31] Another study found that novices tended to prefer e-learning, while experienced POCUS users preferred classroom-based teaching.[35] Blended learning appeared to be an effective format for knowledge transfer, including image interpretation skills. Some of the blended learning studies were promising in terms of the ability to teach image acquisition skills, though for the most part this appeared to rely on the hands-on component of the training. In one study where, after e-learning, medical students practiced on a high-fidelity simulator without instructors, they found that image acquisition skills were significantly lower in this group compared to those taught hands-on by an instructor.[33] However, in another study without in-person instructors, participants were able to effectively learn procedural skills with e-learning followed by practice on a simulator.[26] Only one study in this category assessed a Kirkpatrick level 3 outcome, and the authors did not find that learners had sustained lung POCUS use after their blended learning workshop.[31] There were no level 4 studies. Overall, studies promoted the blended learning or the "flipped classroom" approach, stating that it could be used to enhance traditional POCUS workshops by promoting active learning and allowing learners to take maximal advantage of hands-on scanning time by coming prepared to the workshop.[20,36]

Online-only, including asynchronous and synchronous learning (Appendix A; Tables 1B and 1C)

Online-only learning methods included asynchronous (nine studies) and synchronous (four studies) teaching methods. Examples of instructional designs included online image libraries to practice image interpretation, interactive modules, online quizzes and virtual POCUS rotations or conferences. Some courses were as short as 5-10 minutes,[37,38] and some spanned up to 10 days.[15] In two of the studies, programs adapted their curriculum in response to the COVID-19 pandemic.[15,16] Results regarding learner satisfaction were overall positive, exposing participants to a broad range of POCUS cases and pathology. However, participants reported that the online learning had some obstacles, including internet access, availability of a computer or mobile device, eye fatigue from long hours of computer use, and the lack of practice with real patients.[16] The possible areas for improvement included integration of portable ultrasound, inclusion of hands-on scanning and limiting technical difficulties.[15] Many of the studies included assessments of knowledge and image interpretation, with mostly positive results. Only three of the studies examined image acquisition after online-only learning, with mixed results. One study found that EM residents who underwent a virtual course compared to an in-person POCUS rotation did significantly worse on a practical test.[16] Another study examining a 30-min asynchronous curriculum for learning cardiac ultrasound found overall poor performance in obtaining adequate cardiac views (ranging from 27.3-68.2% success rate).[39] In contrast, after a nine-hour online curriculum, medical students were overall successful on a hands-on test, and there was a positive correlation between online quiz performance and hands-on skills performance.[40] Another theme that arose in several of the studies was the relative benefit of online-only learning for novices vs. experienced US users. Studies consistently reported that online-only learning was more beneficial and well-received by novices.[39,41]

Telesonography (Appendix A; Table 1D)

There were six studies that described the use of handheld portable US machines or telesonography for education purposes. This appears to be an emerging area in the literature, with all six studies having been published in the last five years (since 2016), and 3/6 in 2021. The instructional design sometimes included "live" telesonography, where a handheld US device is used by a learner on themselves, a family member or a model, and the instructor is connected remotely in real-time, allowing them to see the position of the transducer and the US images.[28,42] In other studies, learners used a handheld device to practice scanning and submitted videos to an online portfolio for asynchronous quality assurance and feedback for their learning.[17,43] Two of the studies were descriptions of implementing an online POCUS curriculum due to restrictions related to the COVID-19 pandemic.[17,42] The "ADAPT" curriculum was a multi-institutional program that pooled resources and expertise from various POCUS programs in the United States, making the program more feasible.[17] Potential advantages of courses that utilize telesonography were highlighted, including reducing travel time, reducing total training costs, and allowing learners to troubleshoot their own images without faculty physically intervening and taking control of the transducer.[42] Telesonography (often combined with online learning modules) appeared to be an effective teaching format for improving learners' confidence, transfer of knowledge, image interpretation, and importantly image acquisition (assessed in three studies), with all six studies reporting positive or non-inferior results in Kirkpatrick level 2 outcomes.

Discussion

Our review found that the number of relevant publications increased over time, reflecting a shift to e-learning that has occurred in medical education since the COVID-19 pandemic. Consistent with a previous scoping review,[13] we found a significant number of studies focusing on undergraduate medical education. With the shift to teaching POCUS to large number of medical students early in their training, there is a relative disparity in the number of educators equipped to teach sonographic techniques, especially in resource-poor areas. E-learning could extend the reach of educators further than traditional in-person training. Promisingly for teaching POCUS at the undergraduate level, our review found that novice learners had greater satisfaction scores and benefited most from e-learning.[35,39,41] This finding may be due to the fact that novice learners are more accepting of novel e-learning approaches, whereas more experienced POCUS users have developed a preference and familiarity with traditional methods of teaching.[35,44]

POCUS is a complex technical skill, involving image acquisition, image interpretation, clinical understanding, and integration into clinical care. Our review suggests that different styles of e-learning may be more appropriate to target these individual tasks. POCUS knowledge and image interpretation can likely be taught purely online, however e-learning for image acquisition was not as consistently successful. Blended learning or the "flipped classroom" can address this gap and maximize efficiency for POCUS workshops by promoting active learning, allowing participants to come to the hands-on teaching more prepared, and focusing on image acquisition skills for the in-person component of a session. Previous studies have similarly found that part-task training in image interpretation could be a valuable complement to bedside teaching for POCUS.[29,45] Telesonography, while more resource-intensive, may be able to provide the best of both worlds by allowing participants to learn POCUS completely remotely but also facilitate hands-on practice.

This review revealed several gaps in the literature. While multiple POCUS applications were featured in the included studies, due to the heterogenous nature of the studies, it is unclear whether certain POCUS applications are more amenable to being taught online than others. Due to limited included studies about US-guided procedures, it is difficult to draw general conclusions about the ability to learn these procedures online, although the included studies had positive findings.[26-28] Importantly, there were very few Kirkpatrick level 3 outcomes and no level 4 outcomes in the included studies, thus it remains unclear how e-learning affects sustained POCUS scanning, and whether it improves accuracy, procedural success rates or leads to changes in patient management in the clinical setting. Given the paucity of literature regarding these important patient-level outcomes, future POCUS educational curricula and studies should attempt to capture and report on these higher levels of learning outcomes and transfer of skills to the bedside. This could include longitudinal tracking of learners' achievement of POCUS credentialing, tracking number of scans performed in the clinical setting following an educational intervention, and the clinical accuracy of their scanning through quality assurance.

There are some limitations to this review. Conference abstracts and poster presentations were excluded, and studies were limited to the English language. Given the nature of performing a scoping review, formal critical appraisal of study quality was not performed. There are also limitations of the included studies themselves, including often single-center studies with small sample sizes, and some with no comparison group.

Conclusion

E-learning for POCUS is gaining in popularity in recent years. As a result of the COVID-19 pandemic, there has been an impetus for medical education to adopt a virtual format. With this new educational focus, it is critical to understand if we can effectively teach a hands-on skill such as POCUS online. This scoping review suggests that different styles of e-learning may be more appropriate depending on the individual POCUS sub-task being taught. Online-only learning was effective for knowledge transfer and image interpretation but had mixed results for image acquisition. Blended learning and telesonography were beneficial for learning image acquisition skills. Generally, novice learners benefited most from e-learning. Future studies could compare various POCUS applications and the ease in learning them online, expand on the limited literature about learning POCUS-guided procedures online, and examine how e-learning affects sustained POCUS scanning and patient-level outcomes. The findings of this study can inform future POCUS educational programs and research.

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Appendix A. Table 1: Description of the included studies

Table 1A: Studies examining blended learning for POCUS in medical education							
Author, publication date, country, study design	Participants	Content	Intervention	Comparison	Outcome Measure	Results (Kirkpatrick levels)	Comments
Cawthorn et al., 2014,[33] Canada, Randomized interventional study	Medical students (n = 57)	Cardiac	Electronic modules with self-directed scan training on a high-fidelity ultrasound simulator	2 comparison groups: (1) Lectures with sonographer scan training (2) Electronic education modules with sonographer scan training	Image interpretation, image acquisition	K2	Worse image acquisition skills for e-learning group
Chenkin et al., 2008,[26] Canada, Randomized controlled noninferiority trial	Emergency Medicine residents and attendings (n = 21)	Ultrasound-guided vascular access	Asynchronous online learning followed by practice on simulators and live models	Didactic lectures followed by practice on simulators and live models	Procedural skills	K1 and K2	No difference between groups
Florescu et al., 2015,[30] Romania, Prospective educational study	Medical students (n = 76)	Basics, lung, cardiac, hepatobiliary, FAST	Podcast followed by a hands-on session, repeated every day for 5 days.	2 comparison groups: (1) Live lecture prior to hands-on session (2) No lecture (hands-on scanning only)	Image acquisition	K1 and K2	No difference between all 3 groups for image acquisition skills
Haskins et al., 2018,[34] USA, Pilot study (randomized)	Anesthesia residents and fellows (n = 18)	Lung and FAST	E-learning followed by hands-on training	Classroom lecture followed by hands-on training	Image acquisition	K1 and K2	No difference between groups
Heiberg et al., 2015,[27] Denmark, Prospective study	Medical students (n = 16)	Cardiac, FAST, lung, vascular access	E-learning followed by 4 hours of hands-on training	N/A	Image acquisition, procedural skills	K2	Improvement in scores after e-learning
Hempel et al., 2016,[32] Germany, Randomized, controlled, parallel group study	Medical students (n = 62)	FAST and lung	Pre- and post-course e-learning (sandwich e-learning) activities.	3 comparison groups: (1) post-course e-learning alone (2) precourse e-learning only (3) classroom-based learning	Knowledge retention	K1 and K2	No difference between groups. More satisfaction in post-course e-learning
Hempel et al., 2016,[46] Germany, Randomized, controlled, parallel group study	Medical students (n = 62)	FAST, lung and airway	Precourse e-learning, an on-site discussion (60 min), and a hands-on training session	Classroom-based presentations on the day of the course before hands-on training session	Knowledge, image acquisition	K2	Improved knowledge for case-based e-learning. No differences between groups for image acquisition skills.
Kang et al., 2015,[35] USA, Pilot study	Emergency Medicine Internal Medicine fellows and attendings (n = 47)	Multiple (not specified)	4.5 hours of online pre-recorded lectures, followed by 4.5 hours of small-group hands-on training	Large group course with live classroom lectures, followed by hands-on training	Knowledge	K1 and K2	Novices preferred e-learning. No differences in knowledge between groups.
Lin-Martore et al., 2021,[47] USA, Pilot study	Pediatric Emergency Medicine fellows and attendings (n = 17)	Intussusception	Web-based learning followed by a brief hands-on session (15 min)	N/A	Image interpretation, image acquisition	K2	Improvement in scores after e-learning
Platz et al., 2010,[48] Germany, Prospective educational study	Emergency Medicine residents and attendings (n = 55)	E-FAST	E-learning combined with a half-day hands-on session	2 comparison groups: (1) Traditional classroom didactic learning, with hands-on scanning (2) Control group with no training	Image interpretation	K1 and K2	No difference between e-learning and traditional classroom groups

Soon et al., 2020,[31] USA, Randomized controlled noninferiority study	Pediatric Emergency Medicine and Pediatric Critical Care fellows and attendings (*n* = 45)	Lung	Web-based teaching (10 min) and hands-on scanning	Live classroom lecture (10 min) and hands-on scanning	Image interpretation, image acquisition	K1, K2 and K3	No difference between groups. POCUS use was not sustained after the course
Tainter et al., 2017,[36] USA, Pilot study	ICU residents (rotators from surgery, anesthesia and emergency medicine) (*n* = 39)	Cardiac	Flipped classroom (four 5-min modules followed by hands-on scanning)	N/A	Knowledge	K1	Improvement in scores after e-learning
Table 1B: Studies examining online synchronous learning for POCUS in medical education							
Author, publication date, country, study design	Participants	Content	Intervention	Comparison	Outcome Measure	Results (Kirkpatrick levels)	Comments
Ienghong et al., 2021,[16] Thailand, Retrospective observational study	Emergency Medicine residents (*n* = 18)	Multiple (not specified)	Didactic lectures, journal club, image review were carried out as virtual conferences via various platforms.	Baseline (pre-covid) US rotation for EM residents, conducted over a 2 week period. Included didactic lectures, bedside US training with actual patients, journal club and image review process.	Knowledge, image acquisition	K1 and K2	Worse image acquisition skills for e-learning group
Platz et al., 2011,[41] USA, Prospective educational study	Emergency Medicine and surgery residents (*n* = 44)	E-FAST	Computer group listened to narrated lectures on desktop computers with headphones.	Classroom group with traditional lecture	Image interpretation	K2	Worse image interpretation skills for e-learning group (in those with previous US experience)
Riera et al., 2021,[49] USA, Cross-sectional study	Pediatric emergency medicine fellows (*n* = 3)	MSK (suprapatellar bursa effusions)	90-minute didactic training that was presented via a remote learning format	POCUS faculty (used as gold standard)	Image interpretation	K2	Good inter-rater reliability after e-learning
Zavitz et al., 2021,[15] USA, Description of educational innovation	Medical students (*n* = 141)	Multiple (not specified)	10 day virtual course including live scanning demonstrations and practicing ultrasound probe maneuvers using a cellphone	N/A	Image interpretation	K2	Improvement in scores after e-learning
Table 1C: Studies examining online asynchronous learning for POCUS in medical education							
Author, publication date, country, study design	Participants	Content	Intervention	Comparison	Outcome Measure	Results (Kirkpatrick levels)	Comments
Brown et al., 2020,[50] USA, Design-based research approach	Pediatrics and Pediatric Critical Care residents, fellows and attendings (*n* = 41)	Cardiac	Asynchronous (online image library of 90 questions)	N/A	Image interpretation	K1 and K2	Improvement in scores after e-learning
Chenkin et al., 2015,[37] Canada, Prospective educational study	Emergency medicine residents and attendings (*n* = 66)	Airway (confirm ETT placement)	Online asynchronous 10-min educational module and assessment tool	N/A	Image interpretation	K2	Improvement in scores after e-learning
Cuca et al., 2013,[51] Germany, Prospective educational study	Medical students and doctors (specialty not specified) (*n* = 36)	Lung and airway	Interactive asynchronous e-learning	Didactic group (1 day course with lectures and hands-on training)	Image interpretation and knowledge retention	K1 and K2	Improvement in scores after e-learning

Krishnan et al., 2013,[38] USA, Prospective educational study	Anesthesia residents and attendings (*n* = 79)	Lung (pneumothorax)	5-min online presentation followed by a quiz	N/A	Image interpretation and knowledge retention	K2	Improvement in scores after e-learning
Kwan et al.,[29] 2020, Canada, Multicenter prospective cohort study	Pediatric Emergency Medicine fellows and attendings (*n* = 172)	Soft tissue, cardiac, lung, FAST	Computer-based image repository and learning assessment system that allowed participants to deliberately practice image interpretation	N/A	Image interpretation	K2	Improvement in scores after e-learning, learning curves varied by type of application
Moro et al., 2021,[52] Italy, Prospective interventional, multicenter study	Obstetrics and gynecology attendings (*n* = 108)	Lung (detecting COVID pneumonia)	Online teaching program involving a pre-test, a 40 minutes theoretical course, a post-test	N/A	Image interpretation	K2	Improvement in scores after e-learning
Ray et al., 2017,[39] USA, Prospective observational study	Medicine, surgery and anesthesia medical students and residents (*n* = 180)	Cardiac	30-minute, goal-directed, web-based introductory course	N/A	Image interpretation, image acquisition	K1 and K2	Students' scores increased more than residents. Poor image acquisition skills
Situ-LaCasse et al.,[40] 2021, USA, Prospective cohort educational study	Medical students (*n* = 44)	Aorta/IVC, cardiac, renal, and superficial	Online training program comprised on various modules completed over 3 weeks.	N/A	Image acquisition	K1 and K2	Positive association between module quiz performance and the hands-on skills performance
Socransky et al., 2017,[53] Canada, prospective interventional study	Emergency medicine residents and attendings (*n* = 136)	JVP	Web-based teaching module with cognitive and motor components for teaching ultrasound-JVP	2 comparison groups: (1) Live teaching involving an in-person lecture and workshop (2) Control group provided with an article to read	Confidence, ongoing use (self-report)	K2 and K3	No difference between groups for confidence. The frequency of use remained higher in the live teaching group than online learning group
Table 1D: Studies examining telesonography for learning POCUS in medical education							
Author, publication date, country, study design	Participants	Content	Intervention	Comparison	Outcome Measure	Results (Kirkpatrick levels)	Comments
Drake et al., 2021,[28] USA, Randomized noninferiority trial	Medical students (*n* = 56)	FAST, lower extremity DVT, vascular access	Online modules for pre-learning, telesonography	Traditional (hands-on) scanning, this group also completed the same online modules as pre-learning	Image acquisition	K1 and K2	No difference between groups
Edrich et al., 2016,[54] Germany, Austria and USA, Randomized interventional study	Anesthesia residents, fellows and attendings (*n* = 180)	Lung (pneumothorax)	Web-based asynchronous lecture, followed by self-practice of lung US using a portable ultrasound machine, submitting clips for an online portfolio.	3 comparison groups: (1) Classroom training including hands-on practice on volunteer model (2) Control groups of no training (3) EM physicians (experienced in lung US)	Image acquisition, knowledge retention	K2	No difference between web-based and classroom-based groups
Fuchs et al., 2018,[55] Israel, Prospective cohort study	Medical students (*n* = 29)	Cardiac	Combination of e-learning software and self-practice using pocket ultrasound device	Formal, in-person cardiac ultrasound course which included in-person lectures and hands-on scanning. This group also had access to a pocket ultrasound device for ongoing practice	Image acquisition	K2	No difference between groups
Gargani et al., 2016,[43] multiple European	Nephrology and cardiology attendings	Lung US (B-lines)	Remote, web-based educational platform involving 2 parts - Part A:	N/A	Image interpretation	K2	Improvement in scores after e-learning

countries, Prospective educational study	(*n* = 44)		how to perform lung US, Part B: how to interpret B lines (sample videos and practice scans to submit to instructor until good inter-rater reliability)				
Nix et al., 2021,[17] USA, Prospective educational interventional study	Emergency medicine residents, fellows and medical students (*n* = 70)	Multiple (not specified)	Pre-learning with review of educational blogs, videos, and journal articles. Online lectures and weekly image review QA. Gamification (online quiz platforms), teleguidance (using handheld butterfly US) to practice image acquisition on themselves.	N/A	Confidence	K1 and K2	Improvement in scores after e-learning
Soni et al., 2021,[42] USA, Retrospective observational study	Attendings from multiple specialties (internal medicine, family medicine, critical care, emergency medicine) (*n* = 52)	Multiple (not specified)	Synchronous and telesonography (4-week course), including individual hands-on scanning sessions using telesonography	Established in-person 2 day POCUS course including lectures, image review and hands-on scanning	Image interpretation	K1 and K2	No difference between groups

Legend: K1: Kirkpatrick level 1 (reaction), K2: Kirkpatrick level 2 (learning), K3: Kirkpatrick level 3 (behavior), K4: Kirkpatrick level 4 (results), E-FAST: extended focused assessment of sonography in trauma, ICU: intensive care unit, US: ultrasound, MSK: musculoskeletal, ETT: endotracheal tube, IVC: inferior vena cava; JVP: jugular venous pressure, Deep vein thrombosis, QA: quality assurance