SYSTEMATIC REVIEW

Progress in lung ultrasound education: An updated systematic review

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ABSTRACT

Background: Thoracic ultrasound (TUS) is integrated into clinical practice across various medical specialties to aid with diagnosis and procedural safety. Significant variability in training approaches and standards exists between nations and individual centres.

Aim and objectives: To review how differences in published TUS training methods impact upon learning.

Methods: A literature search following PRISMA guidelines was conducted in Medline, Embase, Cochrane Library and Scopus, from Jan 2017 until May 2025. Studies involving TUS education using pre- and post-assessments of learning were included.

Results: 12,460 studies were screened, 235 full texts assessed, and 68 were included in the review. Studies were mainly observational cohorts targeting different healthcare professionals. Ten randomized controlled trials, four non-randomized comparison and one switching replications evaluating different interventions were identified. Physicians were the primary audience in 65% while 29% focused on other healthcare professionals. Class-based teaching was the most common educational tool (66%) sometimes combined with web-based (16%). 84% of studies involved practical training, with training on humans alone (in 63% of cases). Most educational tools led to significant improvements in test scores, although assessment validity was rarely addressed.

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Conclusion: Our review confirms various TUS educational methods are used in heterogenous participants. While most interventions demonstrated positive learning effects, few studies addressed how this translates to safe clinical use.

Key words: Thoracic ultrasound, Pulmonary ultrasound, Point-of-care ultrasound, medical education, training, clinical skills

Background

Thoracic ultrasound (TUS) is an essential tool in the clinical evaluation of patients with different respiratory conditions. Additionally, TUS guidance is considered standard of care for a wide range of invasive procedures (1, 2).

Despite being extensively used in many areas of healthcare, formalized ultrasound training varies considerably by specialty and geography. As a user-dependent modality, ultrasound requires structured, targeted training, as learning curves vary between protocols (3, 4). Different studies have highlighted how the delivery of standardized training and certification is often limited, with two studies from the Netherlands identifying limited access to experts as a major barrier to achieving proficiency, resulting in more than half of the residents in pulmonary medicine reported having access to *no supervision* (5-7).

In 2009, the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) published training recommendations which incorporated an arbitrary minimum number of ultrasound examinations to be performed prior to achieving competency. The most recent EFSUMB recommendations were updated to address the difference between theoretical knowledge and clinical proficiency, recommending stepwise assessment (e.g. theoretical test and direct observations including objective scores) to integrate ultrasound knowledge, technical skills, and clinical decision making. However, a suggested number of supervised examinations remains and there remains a lack of clarity regarding theoretical and practical domains.

Several TUS training courses have been developed across specialties, but evidence on the most effective training approaches is lacking. In 2018, a systematic review by Pietersen et al. explored and found a wide variation in training modalities, ranging from entirely class-based courses to combinations of class-based lectures with hands-on training on patients, volunteers, or simulators. While most interventions improved knowledge and or skills, the small number of studies with few participants, heterogeneity in methods, and variability in training time and equipment made it impossible to establish evidence on a preferred teaching method (8).

Given the expanding role of TUS, increasing ultrasound accessibility, and the urgent need for structured training, this review aims to update and synthesize current evidence on TUS education and serves as an update to Pietersen et al.'s 2018 systematic review on lung ultrasound training.

Method

Protocol and registration

The systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (9). The protocol was prospectively registered in the PROSPERO database (ID CRD42024523081).

Inclusion and exclusion criteria

Studies were eligible for inclusion if all of the following criteria were met:

- Including healthcare professionals working with humans.
- Evaluating an educational intervention involving TUS or POCUS with specific data for thoracic or lung ultrasound.

- Reported at least one objective measure of knowledge and/or skill (pre- and post-intervention or with a randomized or non-randomized control group serving as a baseline) ensuring that the learning effect corresponds to at least Kirkpatrick Level 2 (10).

Studies were excluded if one of the criteria applied:

- Focusing on other organ systems or ultrasound protocols without presenting specific lung data.
- Solely reported cost-benefit analysis, certification procedures, or diagnostic accuracy without training outcomes.
- Case reports or descriptive reports of TUS education without assessments.

Search strategy

A literature search was conducted systematically in Medline (Ovid), Embase (Ovid), Cochrane Library and Scopus using a broad search strategy improved with a research librarian from the Medical Research Library at Odense University Hospital, Denmark.

To minimize the risk of omitting relevant studies, no language, species, or publication type limits were applied, and grey literature (including conference abstracts) was included. The search was restricted to publications from January 2017 to update and supplement the systematic review by Pietersen et al. (8). Search string consisted of three concept groups with associated keywords and MeSH terms:

1. Anatomy: Lung* OR pulmona* OR thora* OR mediastin* OR pleura
2. Ultrasound terminology: ultrasound OR ultrasonic OR ultrasonograp* OR sonograph*
3. Educational terms: medical education* OR learn* OR train* OR clinical competence OR curriculum OR clinical assessment OR skill.

Truncation (*) was used to capture variations of word endings. The search was conducted on 21th of March 2024 with an updated search the 5th of May 2025, and the full search string is presented in Table 1.

Study selection and data extraction

Search results were imported into Covidence® (Veritas Health Innovation, Melbourne, Australia) for duplicate removal and screening. All titles and abstracts were screened by two independent reviewers (PGB and CK), resolving disagreements by discussion. Full-text screening was then conducted independently by the same reviewers, with a third reviewer (PIP) consulted to resolve remaining conflicts.

To identify additional studies, reference lists of included articles were screened using EndNote20® (Alfasoft AB, Gothenburg, Sweden), with records transferred to Covidence for independent screening.

Data was extracted into a structured Excel (Microsoft Corporation, Redmond, USA) template developed for this review. Essential variables included study design, population, intervention details, training duration, assessment methods, demography and outcomes.

Quality assessment and level of evidence

The quality of included studies was appraised using the Medical Education Research Study Quality

Table 1. Search string designed as a block search. Each block consists of associated keywords. The keywords are included as MeSH and text. * refers to truncation.

Lung*		Ultrasound		Medical Education
Pulmona*		Ultrasonic		Learn*
Thora*		Ultrasonograp*		Train*
Mediastin*	AND	Sonograph	AND	Clinical competence
Pleura				Curriculum
				Clinical assessment
				Skill

Instrument (MERSQI), which assesses seven domains (study design, number of institutions, response rate, outcome level, validity of assessment, and data analysis), with a maximum possible score of 18.

The Oxford Centre for Evidence-Based Medicine (CEBM) levels of evidence (13) were applied to classify study designs. Although risk of bias was assessed, the limited number of randomized trials led to the primary quality evaluation being performed using the MERSQI instrument.

Results

Study selection

The search yielded 12,460 records. After removal of duplicates, 7,647 titles and abstracts were screened, with 235 studies undergoing full-text review. Screening from the reference lists identified additional 21 records to be screened. The most frequent reasons for exclusion of full-text were focus on general point-of-care ultrasound (POCUS), or another organ-specific protocol without TUS-specific data, and subjective or survey-based outcomes without objective assessments.

Two studies included in the Pietersen et al. review were re-identified due to overlapping search period and are included in this analysis (11, 12). In total 68 studies met inclusion criteria, see Figure 1.

Geography and course participants

Seventeen countries were represented in the 68 studies, predominantly in high-income settings, with 42 (62%) from the United States with geographical spread presented in Figure 2. Physicians (65%) were the most frequent study population, with studies involving medical students (12%), nurses (12%) and other healthcare professionals including physiotherapists, paramedics, and flight personnel (18%) depicted in Figure 3. Several specialties were represented; 22

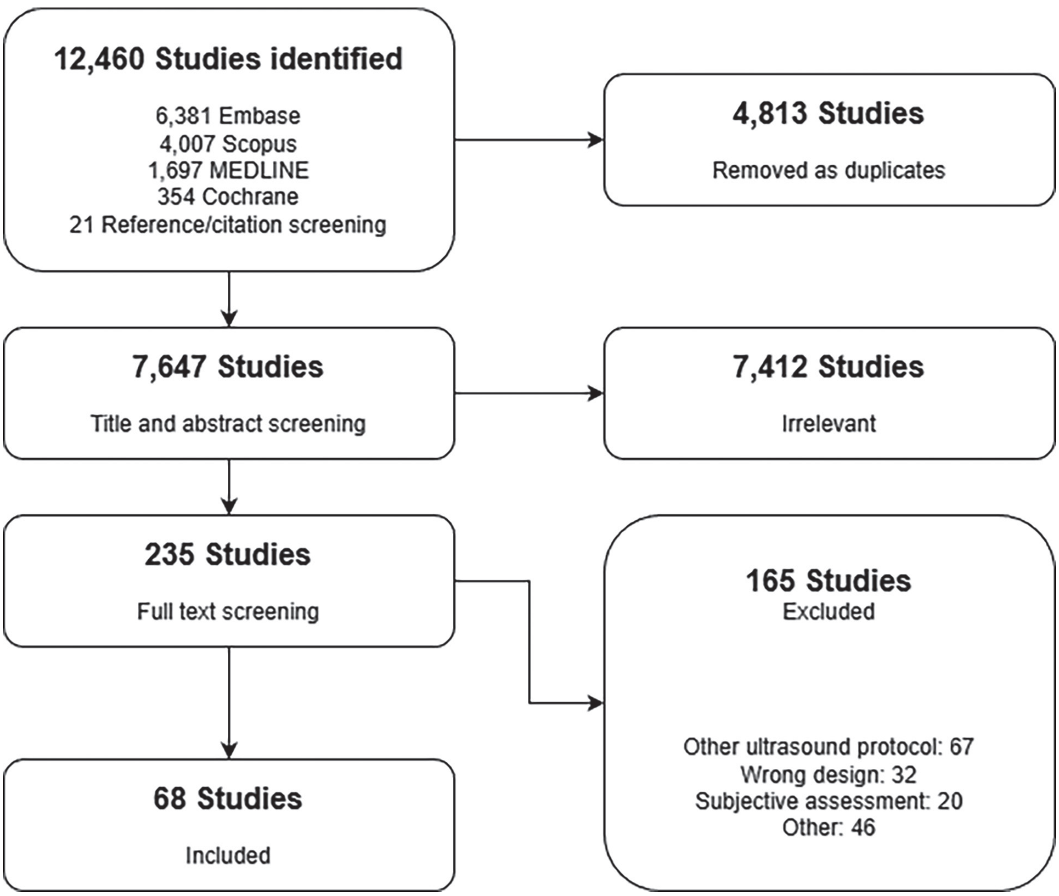

Figure 1. Flowchart of search strategy and screening process.

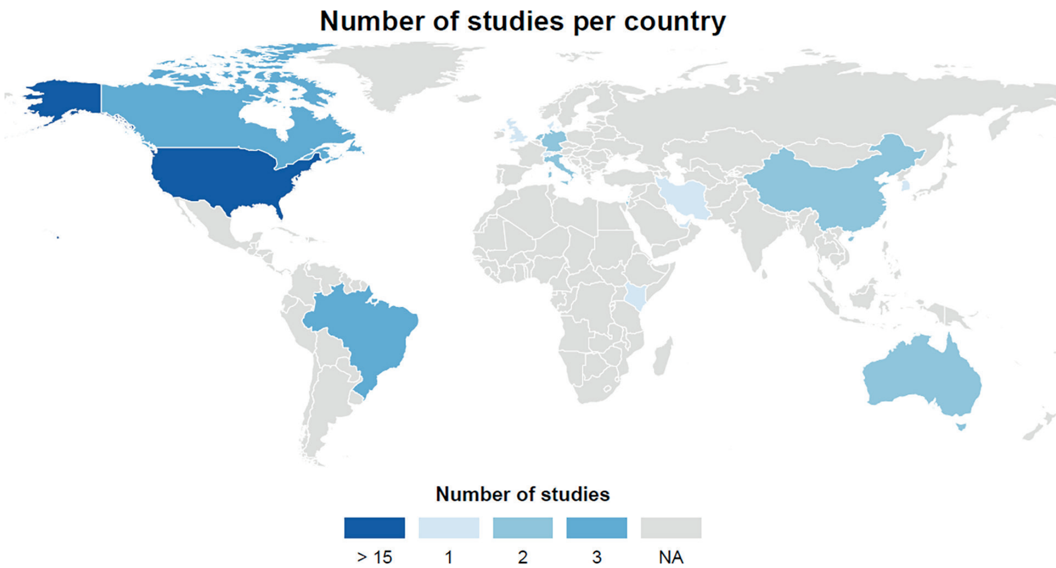

Figure 2. Geographical spread of studies.

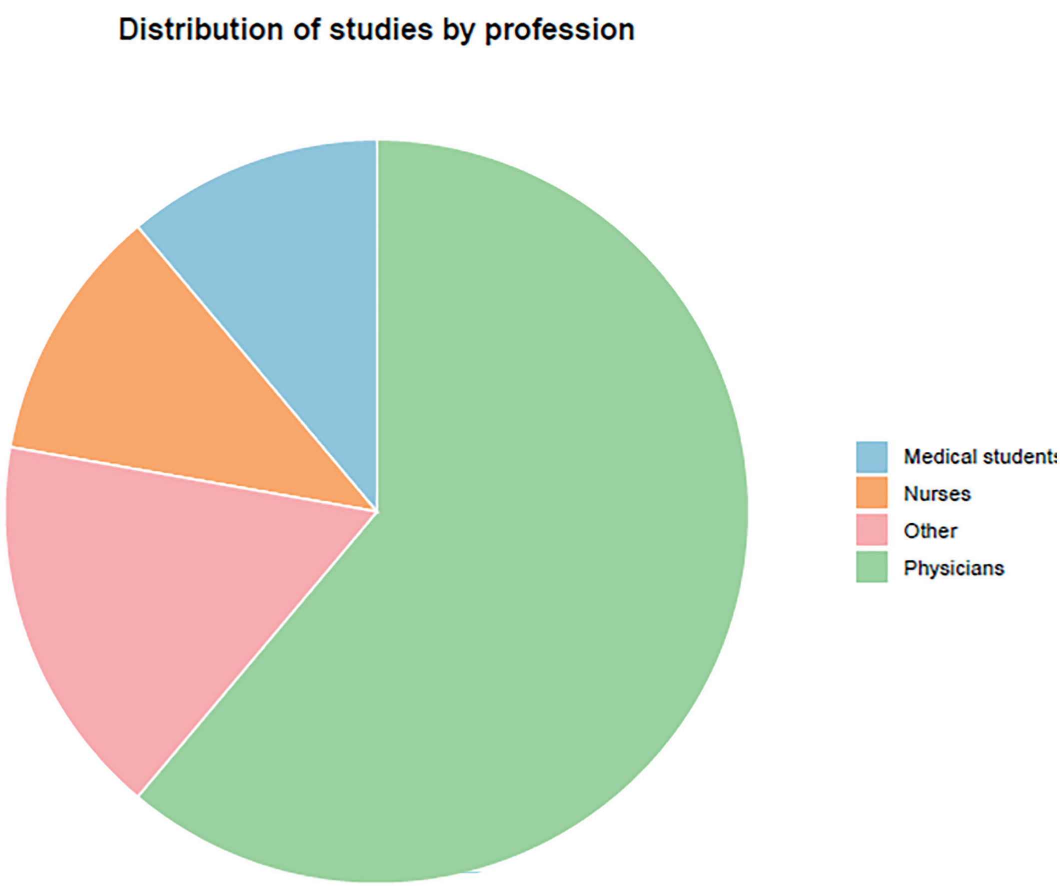

Figure 3. Distribution of professions in included studies.

(34%) internal medicine, 11 (17%) intensive/critical care, 10 (15%) from emergency medicine, 6 (9%) from pediatrics, with the remaining 19 studies representing a broad range of other specialties such as anesthesiology, surgery, and others.

Study design, quality and evidence level

Most studies had a small sample size, with 76% including fewer than 50 participants. Sample size ranged from 4 to 792. Observational cohorts evaluating training effect using pre- and post-assessments were the most frequent design, representing 53 out of 68 studies (mean MERSQI score 10.4). The 53 studies are detailed fully in appendix 1. The observational cohort pre- and post assessment studies are classified as CEBM level 4, except for one study (67) published only as an abstract, with insufficient methodological detail, and consequently included only in the appendix. Observational cohort studies are listed in appendix 1 but educational methods and characteristics for all included studies are listed in Table 2.

Ten randomized controlled trials were identified (12-21), four observational non-randomized controlled or comparison studies (22-25) and a randomized switching replications study (26). The randomized or comparison studies were classified as CEBM level 2b, indicating higher evidence strength than pre- and post-test designs. The studies demonstrated a median MERSQI of 12.2; a validated instrument for assessing methodological quality in medical education research, suggesting a higher methodological quality. Randomized controlled trials are presented in Table 3, observational controlled or comparison, randomized switching replication studies is presented in Table 4 and observational pre- and post-assessment studies are presented in Appendix 1.

Protocols and teaching method

Most studies taught TUS as a part of a specialty specific protocol such as Critical Care Ultrasound (CCUS) or a general POCUS-course; only a minority had TUS-specific curricula. Course duration ranged from a single 30-minute didactic session to multi-day courses with follow-up training. The preferred teaching method was class-based lectures, which were used in 66%. Web-based was used in 34% of the studies and a combination of both in 16%. The content in web-based solutions was rarely specified and included recorded presentations, commercial e-learning materials or self-made solutions.

Table 2. Characteristics of included studies.

Study participants	N 68 (100 %)
Physicians	44 (64.7 %)
Nurses	8 (11.8 %)
Medical students	8 (11.8 %)
Other healthcare professionals	12 (17.6 %)
Teaching method	
Class-based	45 (66.2 %)
Web-based	23 (33.8 %)
Combined class- and web-based	11 (16.2 %)
Supplementing hands-on	60 (88.2 %)
Hands-on training alone (e.g. simulation or supervision in clinic)	6 (8.8 %)
Hands-on training	
Simulator/phantom	14 (20.6 %)
Humans (hospitalized patients, volunteers, colleagues)	43 (63.2 %)
Unknown facilities or none	20 (29.4 %)
Assessment tool	
Theoretical skill assessment	58 (85.3 %)
Practical skill assessment (OSCE)	39 (57.4 %)
Theoretical and practical assessment	31 (45.6 %)

Hands-on training

Nearly all studies included a practical element (92%), typically hands-on scanning of patients or healthy volunteers. Simulators were used in 21% of studies, sometimes in combination with live scanning on humans. Scanning of colleagues or healthy volunteers occurred frequently, although patients with pathology were also used in different ways, such as during rounds or hand-picked for the hands-on session.

Assessment tool

Theoretical skill assessment was the most frequently used assessment tool (85%) and was

Table 3. Characteristics and results from randomized controlled trials.

Randomized controlled trials						
Author	**Design and aim/hypothesis**	**Participants**	**Teaching method**	**Assessment and statistics**	**MESRQI**	**Summarized conclusions**
Edrich et al. (12)	Block randomization 3:3:1 and control group. **Hypothesis:** Web-based teaching is non-inferior to class-based when teaching pneumothorax exclusion and leads to same performance as trained emergency physicians.	138 Physicians without TUS training (Anesthesia) 42 Physicians with TUS training (Emergency medicine)	Web-based: 25 min narrated video with same content + 5 min online demonstration video to perform LUS on him/ herself. **Classroom:** 45 min Traditional lecture + 20 min hands-on training on volunteer. **Control:** No intervention. **Emergency medicine group:** No intervention but formalized TUS course and daily use.	Theoretical: 10 MCQ with image or video **Practical:** OSCE-checklist + blinded image quality **Statistics:** Two sample t-test	14.5	LUS for the purpose of pneumothorax exclusion can be taught to anesthesiologists effectively with the use of web-based training
Haskins et al. (13)	Double randomization stratified by level of experience. **Hypothesis:** Web-based teaching is non-inferior to traditional teaching (pilot study).	18 Physicians (Anesthesia)	**Web-based:** 14 interactive modules about LUS and FAST using the USabcd.org platform + hands-on training. **Traditional:** Class-based lecture (1 h LUS and 1 h FAST) based on same material + hands-on training	**Theoretical:** 18 FAST questions and 57 LUS **Practical:** OSCE checklist + blinded image quality. Statistics: Medians with 95% CI	9.5	Both class- and web-based learning were associated with improvements in knowledge and practical performance and justify the an adequately powered, randomized controlled trial
Höhne et al. (18)	Manually randomization alternating on order of enrollment. **Aim:** To examine effect of app-based learning compared to traditional class-based hands-on training.	50 medical students	**Both groups:** Access to digital ultrasound learning modules and 4 hours scheduled hands-on on co-students. **Intervention:** AI-supported. App based step-by-step guidance with reference images and automatic marking of structures **Control:** Conventional: Instructor-led. Direct guidance from the tutor.	**Practical:** OSCE checklist and image quality score **Statistics:** Mann-Whitney U test	12.5	AI- and app-based learning methods in ultrasound education can be equally effective as traditional hands-on instruction for medical students.

Table 3 (*Continued*)

Randomized controlled trials						
Author	**Design and aim/hypothesis**	**Participants**	**Teaching method**	**Assessment and statistics**	**MESRQI**	**Summarized conclusions**
Kelm et al. (19)	Randomly assigned by staff office. **Aim:** Impact of a longitudinal ultrasound curriculum on long-term knowledge retention.	48 physicians (internal medicine)	**Both groups:** Half-day simulations-based ultrasound workshop: 1h class-based and 3 h hands-on. **Intervention:** Monthly morning reports (case-based class) and 'open-house' afternoon ultrasound rounds with hands-on. **Control:** No further education.	**Theoretical:** Image interpretation (pleural effusion) Blinded. **Statistics:** Cochran-Mantel-Haenszel and fishers exact test	12	Adding longitudinal ultrasound training improves knowledge retention.
Kumar et al. (14)	Randomization 1:1 Non-randomized control **Hypothesis:** HUD (Personal handheld ultrasound devices) will improve trainees POCUS-related knowledge and interpretation ability	149 physicians (internal medicine)	**All groups:** Standard 1 h POCUS lectures (30 min class-based + 30 min hands-on) weekly during rotation in the groups: **Intervention:** HUD to use during rotation **Conventional:** No-HUD **Control:** No-HUD Historical control: No POCUS teaching.	**Theoretical:** 74 questions (MCQ and interactive images). **Statistics:** Wilcoxon signed rank test	12.5	The POCUS curriculum improved knowledge test scores. Personal HUDs did not improve image interpretation.
Leidi et al. (20)	Randomized 1:1 computer-generated No stratification. **Aim:** Does Structured longitudinal POCUS tutoring (scheduled timeslots) enhance skills retention.	21 physicians (internal medicine)	**All groups:** Pre-course e-learning and one-day hands-on. **Intervention:** Specific tutor and timeslots scheduled for direct bedside supervision. When deemed competent self-scan with e-portfolio for asynchronous validation. **Control:** List of potential tutors to contact and access to same e-portfolio.	**Practical:** Blinded expert assessment of images **Statistics:** Fischer exact test	12	Structured tutoring can enhance training and may increase clinical proficiency.

Pietersen et al. (21)	Randomized 1:1:1 with block allocation 6 and 9. **Aim:** Compare immediate effect of simulation-based training, conventional training on healthy volunteers and no hands-on training.	66 physicians (respiratory medicine, emergency medicine and other)	All groups: Online theoretical baseline and theoretical test before inclusion and randomization. **VR-group:** Unsupervised training on virtual reality ultrasound simulator **Human:** Unsupervised training on healthy volunteer **Control:** No training	**Practical:** Two cases with LUS-OSAUS (blinded) **Statistics:** Two way ANOVA with Bonferroni	14	There was no difference in practical skill assessment score between physicians training on virtual reality simulator and on healthy volunteers.
Matthews et al. (15)	Randomized comparison study. Randomization stratified by program year. **Aim:** Comparing thoracic ultrasound skill retention with standard curriculum to standard curriculum supplemented with supervised examinations.	28 physicians (internal medicine)	**Both groups:** ½ day POCUS curriculum (vascular, cardiac and thoracic) with hands-on. + hands-on training 1 h each topic. Five additional 1 h lectures throughout the year. **Intervention:** Additional 20 supervised thoracic ultrasound examination at the bedside.	**Theoretical:** 13 MCQ **Practical:** OSCE-checklist (23 points) **Statistics:** Mann Whitney U-test	13.5	An ultrasound curriculum improved internal medicine residents knowledge. An additional 20 supervised examinations improved practical skills at 6 months retention test and an observed effect at 12 months.

Table 3 (*Continued*)

Randomized controlled trials						
Author	**Design and aim/hypothesis**	**Participants**	**Teaching method**	**Assessment and statistics**	**MESRQI**	**Summarized conclusions**
Soon et al. (16)	Randomization after baseline **Aim:** Assess if web-based learning is as least as effective as class-based learning to teach lung ultrasound assessment of pneumothorax and pleural effusion.	148 physicians (pediatric intensive care and emergency medicine)	Content in both groups were the same and made by the same instructor randomized to learning method. **Web-based:** 10 min interactive tutorial **Classroom:** 10 min class-based lecture	**Theoretical:** Knowledge on image acquisition and interpretation **Practical:** OSCE Image acquisition	12.5	Web-based teaching is at least as effective as traditional classroom teaching in improving the proficiency of novice learners.
Wang et al. (17) (abstract)	Unknown randomization **Aim:** Evaluate how peer-taught teleguidance teaching compares to traditional in-person teaching.	47 medical students	**Intervention:** Peer-instructed ultrasound teleguidance with butterfly iQ+. **Control:** Traditional in-person teaching	**Theoretical:** Unknown **Practical:** OSCE checklist **Statistics:** Two sided t-test	11.5	Peer-instructed teleguidance is an effective method of teaching ultrasound to undergraduate medical students.

Table 4. Characteristics and results from controlled or comparison studies.

Observational controlled or comparison studies						
Author	**Design and aim/hypothesis**	**Participants**	**Teaching method**	**Assessment and statistics**	**MESRQI**	**Summarized conclusions**
Beaulieu et al. (23)	Controlled prospective observational cohort study **Hypothesis:** Additional e-learning and hands-on training improves residents' proficiency.	Intervention: 37 Physicians (junior residents) **Control:** 15 Physicians (senior residents)	**Control and intervention:** Basic education with traditional apprenticeship teaching. **Intervention:** 2.5 h self-directed e-learning followed by 60-90 min bedside hands-on training.	**Theoretical:** Online **Practical:** OSCE-Checklist **Statistics:** Students t-test	12	Combining web-based education, hands-on training, and simulation can lead to better proficiency compared to traditional apprenticeship teaching methods.
Jedwab et al. (22)	Controlled prospective observational cohort study **Hypothesis:** Online self-learning with optional hands-on training is non-inferior to traditional bedside teaching.	51 medical students	**Control:** In-person lung ultrasound training during rotation. Hands-on practice on each-other and in the ward. **Intervention:** Web-based self-learning online course total duration 4-5 h. Optional self-practice hands-on.	**Theoretical:** Interpretation (max 10 points) **Practical:** Probe handling Identification of pathology (max 8 points)	11.5	Medical students can do self-learning from a web-based platform and perform at a equivalent level to students trained using a traditional hands-on approach.
Shi et al. (25)	Observational comparison study **Aim:** Evaluate the impact of a goal-directed curriculum on performance and self-confidence.	64 physicians (emergency medicine)	**Both groups:** 2.5 day training courses **Traditional training:** Lectures on basic knowledge and standard views followed by hands-on training. Not pathology. **Goal-directed training:** Pre-reading. Lectures with 3D anatomi videos combined with hands-on. Simulated pathology videoes. Case-based group sessions.	**Practical**: Obtaining views and interpreting **Statistics:** Two sample t-test and Wilcoxon rank-sum	12.5	A goal-directed intensive but brief ED POCUS course is associated with increase in performance.

Table 4 (*Continued*)

Observational controlled or comparison studies						
Author	**Design and aim/hypothesis**	**Participants**	**Teaching method**	**Assessment and statistics**	**MESRQI**	**Summarized conclusions**
Vafaei et al. (26)	Randomized switching replications study Aim: Evaluate the effect on feedback during evaluation in increasing clinical skills.	30 physicians (emergency medicine)	Participants were evaluated after performing chest ultrasonography in three rounds with two months in-between. Switched between feedback and no feedback	**Practical**: 15 min OSCE. (20-items) **Statistics:** Paired sample t-test	12.5	Giving feedback led to a significant improvement in score in future evaluations.
Weimer et al. (24)	Observational comparison study Aim: Evaluate subjective and objective gain og practical and theoretical skills.	302 medical students	Intervention 1: 10 week course Intervention 2: 2 day ultrasound course during clinical part Control: No formalized ultrasound courses.	**Theoretical:** Image interpretation **Practical**: OSCE checklist Statistics: Fishers exact and Mann-Whitney	10.5	Integration of ultrasound courses in the early medical school can result in objective gain in competency.

implemented almost exclusively as a Multiple Choice Test (MCQ). A practical assessment, as an observed practical checklist or Objective Structured Clinical Examination (OSCE) setup, was performed in 39 studies (57%) and a combination of both OSCE and MCQ in 31 studies (46%).

Ten studies (15%) did not directly examine the learning effect of their theoretical course material but focused on effect of artificial intelligence (AI), in-person scheduled feedback, hand motion analytics or practical application skills e.g. image acquisition, optimization or interpretation. In three of these studies, a theoretical course was completed prior to the pre-assessment; in one study, theoretical course material was introduced after the pre-assessment, but the assessment included image acquisition alone (27-30). Four studies tested innovative teaching methods for hands-on training. Three studies tested the effect of real-time tele-guidance/feedback, with all finding a learning effect. One study examined app-based feedback (17, 18, 31, 32). Five of the studies which did not provide hands-on training tested image interpretation based on video presentations separate to a practical assessment. Retention testing was conducted in eleven studies, varying from 1 to 18 months post-training.

Study characteristics are shown in Table 2.

Effectiveness of educational interventions

Most studies demonstrated improvements in knowledge and/or practical skills (corresponding to Kirkpatrick level 2), however five studies did not show any learning effect. Lum et al. did not improve medical students' written test scores after a simulation session. Participants' pre-score assessment was after a lecture, combined hands-on training, but before simulation (33). Tivendale et al. did a pilot study training nurses and physiotherapists using 10-hours of e-learning material followed by hands-on and mentored wards. After completing the e-learning, the level of theoretical knowledge did not change significantly during practical training. After hands-on training participants proficiency in image interpretation was deemed sufficient (34). Vallangca et al. tested the effect of an online POCUS course to advanced practice providers, supplemented by monthly hands-on training. While theoretical knowledge assessed by multiple-choice testing declined, practical lung ultrasound skills evaluated by an in-person checklist demonstrated a significant improvement in clinical practice (35). Parker et al. offered a two-week POCUS elective with class-based, hands-on and self-learning demonstrating a not significant improvement across all domains (36). Patel et al. arranged group-iterative training among four sonographers after a three hours TUS education. Group-iterative training demonstrated an non-significant improvement in image interpretation (30). Few studies applied explicit pass/fail thresholds for clinical proficiency.

Randomized or comparison studies

Web-based learning

Beaulieu (23), Edrich (12), Haskins (13), Jedwab (22) and Soon et al. (16) compared web-based learning to established methods such as apprenticeship learning or didactic sessions. None of the studies used the same material or assessment method, they trained physicians or medical students and included a total of 374 participants. All of the studies found web-based learning as least as effective or non-inferior to the compared method but, due to the heterogeneous designs, focus varied from short training to exclude pneumothorax to more extensive TUS training.

Technical options

Höhne (18), Kumar (14) and Wang J. et al.(17) compared innovative technical options to standard training. Kumar et al. randomized physicians to receive a personal handheld ultrasound device (HUD) after a POCUS lecture and structured combined class-based + hands-on sessions on a weekly basis. The curricula improved physicians knowledge, but a personal HUD did not improve knowledge further (14). Höhne et al. randomized medical students to receive instructor-led or app-based feedback during hands-on training. App-based feedback was equally effective as instructor-led feedback despite a higher pre-test score in the instructor group (18). Wang J. et al. randomized medical students to receive in-person feedback or teleguidance using a handheld device. Both methods were equally effective on knowledge gain (17).

Supervision and feedback

Matthews (15), Vafaei (26), Kelm (19) and Leidi et al. (20) explored the learning effect of structured supervision and feedback. Matthews and Vafaei et al. used a randomized controlled design and randomized switching replications design respectively. Adding twenty supervised examinations following a POCUS course led to significantly improved practical skills at six months and a trend toward superiority at 12 months (15). Structured feedback after an evaluation improved practical skills at future evaluations (26).

Leidi et al. randomized physicians to a personal tutor and fixed timeslots for supervision, or the option to contact and plan supervision from a list of available tutors, after a heart and lung ultrasound course. Participants in the intervention group were more likely to obtain autonomous proficiency and higher score in image optimization (20).

Kelm et al. randomized physicians to additional monthly morning reports (case-based didactics) and afternoon ultrasound rounds with hands-on working as an 'open house' session. The ability to identify pleural effusion declined in the control group (19). Shi et al. explored the effect on goal-directed and case based teaching compared with class-based lectures using standard views and no pathology, and found a significantly higher thoracic ultrasound performance score, as well as a significantly greater number of thoracic ultrasound examinations performed, among participants in the goal-directed curriculum (25). Weimer et al. compared knowledge and practical skills for medical school with and without formalized ultrasound courses and found formalized courses to improve objective skills (24). Finally, Pietersen et al. compared hand-on training in a virtual reality simulator to hands-on training on healthy volunteers and found no difference in practical assessment score based on facility (21).

Assessment methods

Assessment strategies were heterogeneous. 21 (31%) studies presented content or used a validated test. Knowledge assessment was the most frequently used method with 58 (86%) studies using MCQ. Practical skill testing was performed in 39 (57%) of the studies, often as an objective structured assessment (OSCE), but local practical protocol-specific checklists or image quality evaluations were used as well.

Discussion

This systematic review examined educational interventions for TUS training. The included studies, as in the prior systematic review, were highly heterogeneous in ultrasound protocols, teaching methods, participant groups, and assessment tools. Interventions involved a range of healthcare professionals and varied in scope—from identifying single pathological findings (e.g., pneumothorax or pleural effusion) to applying comprehensive TUS protocols for clinical or research purposes. Compared to previous reviews, the higher representation of non-physician professionals indicates a broader adoption of TUS throughout the healthcare system. Despite this variability, most studies demonstrated improvements in knowledge and/or skills (Kirkpatrick level 2). However, assessment approaches often focused on statistical improvement rather than determining whether the achieved competence was sufficient for independent clinical use.

Challenges in evaluation and implementation of TUS training

The diversity of training goals and formats likely reflects differences in local, specialty-specific, and resource-related requirements. Previous surveys, such as among U.S. Veterans Health Administration emergency physicians, have shown both high demand for TUS training and a perception that lack of training opportunities is a key barrier to broader point-of-care ultrasound (POCUS) implementation (37).

Some studies illustrate a critical gap between statistical significance and clinical readiness. For example, Mongodi et al. trained advanced practice nurses to recognize key lung ultrasound patterns; while performance improved significantly ($p < 0.0001$), the median correct identification rate for lung sliding was only 37.1% (38). Similarly, Mousa et al. reported significant post-training knowledge gains after a 2-hour course for ICU physicians, but fewer than half reached the study's 80% accuracy pass threshold (39). These examples highlight that meaningful clinical competence requires more than test-score improvement.

These findings align with Miller's pyramid of clinical competence, suggesting that while participants can demonstrate skills during theoretical and practical examinations, integrating these skills into patient care remains challenging. Future interventions may therefore benefit from longitudinal follow-up, extended supervision, or structured clinical mentorship (88).

Assessment methods also varied substantially. While many used objective structured clinical examinations (OSCEs) with checklists, others evaluated only image acquisition or interpretation skills, sometimes via simulators. Few studies integrated both domains. Lum et al. demonstrated that, despite correct theoretical image interpretation, participants often selected inappropriate probes or failed to use ultrasound in simulated clinical cases (33). These findings underscore the importance of choosing assessment methods that align with their intended purpose. While formative assessments may tolerate less validation, certification tests must demonstrate solid validity evidence and clearly defined, reliable pass/fail standards to ensure they measure the desired competencies.

The increased number of identified studies in this review compared to previous likely reflects the broader implementation of TUS. However, most studies still employ pre- and post-test designs without control groups. While such designs can demonstrate learning gains—which are expected after any training—they provide limited insight into *how* training should be structured, or which educational approaches are most effective. To advance the field, future research should include randomized trials comparing different teaching methods to optimize participants' skills, clinical application, and ultimately patient care and safety (40, 41).

Approximately one third of the studies presents the content of the test or use a validated test compared to one study in the last cohort. Fourteen new studies designed to compare educational interventions were identified, with Edrich et al. present in both reviews. Among those 15 studies 8 (53%) presented the content of the test. With more studies reaching a higher MERSQI and comparing different teaching methods more evidence on best possible training effect can be build. However, there is still a need for studies with bigger sample sizes and established pass/fail scores using validated tests comparing different domains e.g. practical and theoretical skills are needed to develop strong evidence on TUS education.

It is not possible to establish a one-size-fits-all recommendation for TUS training. There might be methods which are 'more effective' but which cannot be delivered practically due to available equipment, expert knowledge and technical capabilities varying between hospitals, countries, specialties and professions. The use of TUS outside the hospital environment is also likely to require bespoke training, perhaps using less traditional teaching methods like app-based or AI-augmented hands-on training to support clinical learning. Supervision, teleguidance and feedback are teaching methods which could be incorporated into training if local environmental conditions make it beneficial or resources makes it the best possible solution. Future TUS training should emphasize a stepwise training model ensuring competences on each level of Millers pyramid with assessments corresponding to latest EFSUMB training recommendations, and ideally with assessment tools whose validity has been proven solid (42). Teaching methods can be adjusted to profession, setting and specialty as resources allow and published validated test should be used (43, 44). Figure 4 represents a suggestion for an educational pathway.

Strengths and limitations

This review is based on an extensive and systematic search strategy, including both peer-reviewed and grey literature, followed by a comprehensive screening process. This broad approach ensures a thorough mapping of the current evidence base. The inclusion of studies assessing both theoretical and practical skills, together with the growing focus on describing assessment methods, strengthens the overall evidence on TUS education.

Nevertheless, small sample sizes, heterogeneity in interventions, inconsistent use of validated assessment tools, and the lack of standardized pass/fail criteria limit the generalizability of findings. Studies comparing web-based and traditional classroom teaching suggest that online learning may be non-inferior for theoretical and practical knowledge acquisition; however, most were underpowered to confirm equivalence.

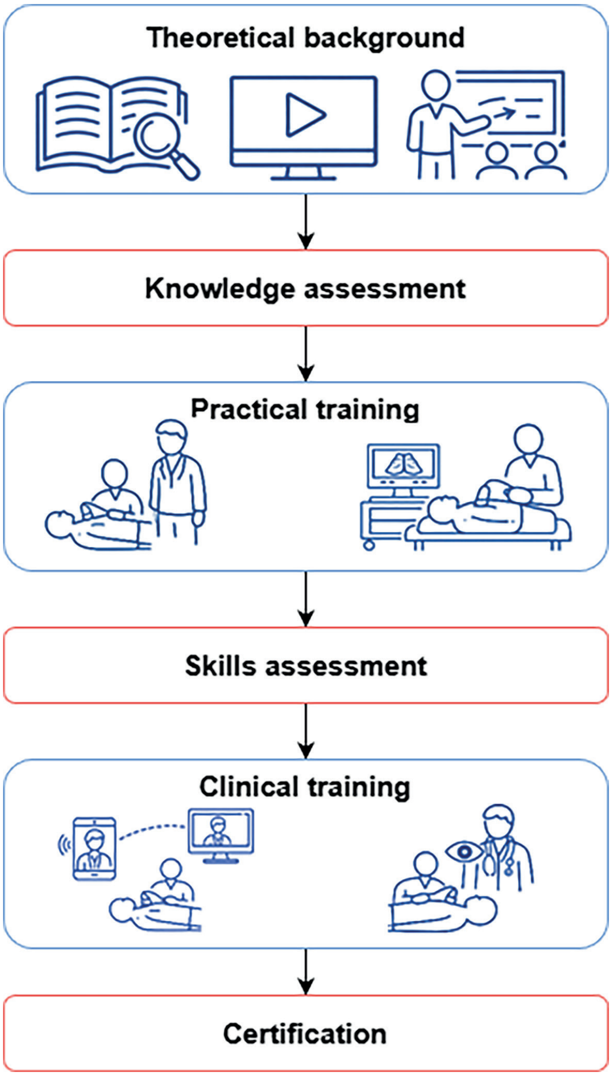

Figure 4. Illustrates an educational pathway and represents possible educational resources to incorporate into an educational program depending on setting and availabilities.

Furthermore, limited evidence on long-term retention and clinical translation, as highlighted above, underscores the need for locally and nationally defined minimum training requirements to ensure consistency and quality in TUS education.

Implications for practice and research in TUS training

Given the variability in resources, expertise, and technical infrastructure across settings, a single universal TUS training model is unlikely to be appropriate. Instead, curricula should be adaptable, integrating methods such as supervision, tele-guidance, and structured feedback based on local resources and settings and with an increased focus on clinical proficiency (40, 45). We also suggest the focus be moved from learners needing to achieve a fixed number of supervised examinations, to a stepwise evaluation with feedback and observations focusing on an individual's competencies (46).

Future research should use adequately powered randomized trials using standardized assessment tools and with proven solid validity evidence and explore, subsequently establish an adequate pass/fail score for clinical proficiency rather than test-score change alone. To establish the clinical impact of training, future studies should focus on patient related outcomes to examine if theoretical and practical skills are transferred and used in the clinic for the benefit of patients and/or healthcare systems (47). However, linking educational interventions to measurable patient outcomes remains inherently challenging due to the multitude of confounding variables and contextual factors involved. This complexity may explain why only few studies have successfully demonstrated a direct impact, emphasizing the need for robust, longitudinal designs that capture the full continuum from training to clinical practice.

Conclusion

TUS training interventions generally improve knowledge and skills, but evidence on achieving clinically sufficient proficiency is limited. There is no hard evidence on the most effective teaching method but our results suggest that different methods could be equally effective if theoretical and practical components are included. Standardized assessment frameworks and context-adapted curricula are essential to ensure safe and effective TUS practice across diverse healthcare settings.

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