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Ability of non-physicians to perform and interpret lung ultrasound: A systematic review

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Abstract

Background: Lung ultrasound is a useful tool in the assessment of pulmonary congestion in heart failure that is typically performed and interpreted by physicians at the point-of-care.

Aims: To investigate the ability of nurses, students, and paramedics to accurately identify B-lines and pleural effusions for the detection of pulmonary congestion in heart failure and to examine the training necessary.

Methods and results: We conducted a systematic review and searched online databases for studies that investigated the ability of nurses, students, and paramedics to perform lung ultrasound and detect B-lines and pleural effusions. Of 979 studies identified, 14 met our inclusion criteria: five in nurses, eight in students, and one in paramedics. After 0–12 h of didactic training and 58–62 practice lung ultrasound examinations, nurses were able to identify B-lines and pleural effusions with a sensitivity of 79–98% and a specificity of 70–99%. In image adequacy studies, medical students with 2–9 h of training were able to acquire adequate images for B-lines and pleural effusions in 50–100%. Only one eligible study investigated paramedic-performed lung ultrasound which did not support the ability of paramedics to adequately acquire and interpret lung ultrasound images after 2 h of training.

Conclusions: Our findings suggest that nurses and students can accurately acquire and interpret lung ultrasound images after a brief training period in a majority of cases. The examination of heart failure patients with lung ultrasound by non-clinicians appears feasible and warrants further investigation.

Keywords

Heart failure; lung ultrasound; nurse; ultrasound education

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The authors declare that there is no conflict of interest.

Supplemental Material
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Introduction

The careful assessment and management of congestion is an important yet difficult challenge in patients with heart failure.[1,2] Lung ultrasound (LUS) enables detection of pulmonary congestion in heart failure with higher sensitivity than auscultation or chest X-ray, and an increased number of LUS findings are associated with worse prognosis in heart failure patients.[3–5] In the current European Society of Cardiology heart failure guidelines LUS is mentioned as a class IIb, level C recommendation in the diagnostic evaluation of patients with acute heart failure.[6] The technique involves examining the chest wall to identify vertical artifacts originating at the pleural line (B-lines). Ultrasound can also be utilized to detect pleural effusions. Currently, LUS is used primarily by physicians at the point-of-care, and this rapid technique is relatively easy to learn.[7,8] Both in the US and Europe, nurses are managing heart failure patients in conjunction with physicians.[9–12] Furthermore, in resource-limited settings, nurses and community health workers may represent the primary providers for both acute and chronic heart failure patients. LUS performed by these providers may allow for lower-cost and more effective management of these patients.

The goal of this systematic review was to investigate the ability of nurses, students, and paramedics to accurately identify B-lines and pleural effusions, and to determine the extent of training necessary. By examining the ability of these providers to learn LUS, including medical students who have limited clinical experience, we aimed to investigate the feasibility of task-shifting towards LUS performed by non-physician providers in heart failure patients. Our hypothesis was that nurses, students, and paramedics can learn LUS within a relatively short training period.

Methods

Literature search strategy

A medical librarian searched PubMed, EMBASE, and Web of Science on 2 February 2018 and removed duplicates. The search strategy includes both MeSH and free-text terms in the title and abstract, such as “Ultrasound”, “Heart Failure”, “Medical Student”, “Nurse”, and “Emergency Medical Technician” (see Supplementary Material online). Two investigators (VS and PB) independently reviewed the search results, with discrepancies resolved by a third researcher with extensive LUS experience (EP).

We included full-text articles that involved nurses, medical students, and paramedics with none or only minimal ultrasound experience performing LUS to identify B-lines and pleural effusions. We excluded studies in which LUS was solely utilized for hemothorax or pneumothorax detection, and studies that did not assess image adequacy and/or diagnostic accuracy of LUS examinations. Search results were initially screened based on title and abstract (Figure 1). Abstracts, literature reviews, case reports, editorials, poster presentations, and letters to the editor were excluded. We employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Flow Diagram 2009 checklist to describe our methodology and findings (Supplementary Material Table 1).[13] The protocol for this systematic review was registered on PROSPERO (CRD42018087857).

Eligible studies were divided into three groups: training and performance of LUS by nurses (*n*=5), students (*n*=8), and paramedics (*n*=1). We utilized an NIH Quality Assessment tool to assess study methodology in regard to the appropriateness of the study sample, clarity of objectives and methodology, and results reporting. Two investigators (VS and PB) independently rated each of the 12 questions for each study, in addition to an overall score, with discrepancies in the overall score resolved by a third reviewer (EP) (Supplementary Material Tables 3.1–3.4).[14]

Data extraction and statistical analyses

Data from each study were extracted by one investigator (VS), verified by a second investigator (PB), and reported in Tables 1–3 and in the Supplementary Material. We collected information regarding the study design, objectives, ultrasound and training methodologies, and diagnostic accuracy. Where necessary, we contacted corresponding authors to clarify information (*n*=3). Included studies were reviewed for potential sources of bias that may have impacted upon the main results.

Authors used mainly descriptive statistics to summarize their findings. Image adequacy and agreement with physician interpretation as the reference standard are reported as percentages, diagnostic accuracy is reported as sensitivity and specificity with 95% confidence intervals, and written examination results are reported as mean test scores and standard deviations as reported in the studies. Where possible, outcomes in each subcategory (nurses, students, paramedics) are aggregated as percentage ranges. p values <0.05 were considered statistically significant.

Results

Our search yielded 979 unduplicated publications, 14 of which were included in this review. These studies were conducted between 2011 and 2015, and took place across North America, Europe, Asia, and Africa. The number of participants ranged from *N*=2 to *N*=195 and the number of patients ranged from *N*=5 to *N*=226. The number of lung zones examined and definitions of a positive lung zone, positive exam, and degree of pleural effusion varied (Tables 1–4). A list of inclusion and exclusion criteria for each study is provided (see Supplementary Material).

Nurses

Five studies investigated the feasibility of nurse-performed LUS[15–19] (Table 1[20]). The number of nurses ranged from *n*=2 to *n*=5. The duration of didactic training ranged from 0 to 12 h, and hands-on training ranged from 58 to 62 practice LUS examinations.

Two studies involved specialized nurse-led outpatient heart failure clinics.[15,17] Nurses in one of these studies had prior experience performing ultrasound of the pleural space prior to study start.[15] When compared with LUS performed by an expert or with expert review of the nurses' images, the studies reported a sensitivity ranging from 88% to 92% and specificity from 93% to 99% for nurses to detect pleural effusions. Heart failure nurses detected B-lines with a sensitivity of 79% and specificity of 91% based on the expert review of nurses' images.[17] In another study, cardiology nurses were able to identify clinically significant pleural effusions in hospitalized patients following cardiac surgery with 98% sensitivity and 70% specificity when compared with expert-performed LUS.[16] Two studies, using physician medical record review as the reference standard, found that internal medicine and emergency medicine nurses could use LUS to identify a cardiac etiology in patients presenting with undifferentiated dyspnea by detecting B-lines with sensitivities ranging from 95% to 100% and specificities ranging from 88% to 100%.[18,19] One of these studies also examined the diagnostic accuracy of combining nurse-performed LUS with brain natriuretic peptide levels (suspected cardiogenic dyspnea cut-off levels ≥ 400 pg/mL), reporting a sensitivity of 99% and specificity of 92% for detecting B-lines as compared with physician medical record review.[18]

Several methodological aspects should be considered with respect to these studies. The time required to perform LUS was specified in two studies, and ranged from <2 to 4 min.[18,19] The number of lung zones examined ranged from six to eight. One study characterized an examination as positive for pulmonary congestion if three or more B-lines were found in two or more zones.[18] In another study, three or more B-lines total indicated pulmonary congestion.[17] One study utilized the LUS findings based on a comprehensive, pre-defined protocol.[19,20] Pleural effusions were categorized as "not present" or "insignificant" or "significant".[15,16] In one study, pleural effusions were considered present if found bilaterally.[17]

Students

Eight studies explored whether ultrasound-inexperienced students in the medical field could identify and interpret B-lines and pleural effusions.[21–28] We categorized these studies to differentiate whether LUS was performed on (1) standardized patients (i.e. actors), healthy volunteers, and training simulators, or (2) actual patients. The number of participating students ranged from n=3 to n=195, and their years in medical school ranged from first to fifth (of six) year of education. Assessment was based on either expert imaging or expert evaluation of students' skills and/or images. In two studies, the experts were unblinded to the diagnoses.[21,26] Where reported, the number of lung zones examined ranged from two to six.[21–26]

Five of the eight studies involved students acquiring LUS clips on standardized patients, healthy volunteers, and simulators (Table 2).[22,23,25,27,28] Where reported, didactic training time ranged from 1 to 8 h.[22,23,27,28] The mean duration of hands-on training was 1.25 h (range 1–2 h). Three of these reported average image acquisition adequacy rates ranging from 87% to 100%.[22,25,28] Using clips of both normal and pathological lung findings, one study used a test to assess the students' ability to interpret LUS. Students demonstrated a significant improvement in the percentage of correct answers on the test (pre-training: 42.1%, post-training: 82.6%, p<0.001).[23] When the post-test scores of medical students were compared with those of Emergency Medicine residents, no significant difference was found (p=0.33).

Another study reported that, after training, there was a significant improvement in the number of students who attained interpretable images of the right pleural view (baseline: 51%, e-learning: 56%, e-learning and hands-on training: 100%), but not the left (p<0.01).[22]

A third study found that, for medical and physician assistant students utilizing an ultrasound simulator, clinical knowledge improved from a mean of 8.4 out of 21 possible points at baseline to a mean of 18.5 points (p<0.001) after training.[27] While there was a significant improvement in image adequacy, 48% of the images were still considered inadequate after training (p=0.003).

Methodologies across these studied varied. One study did not differentiate the training time dedicated to the identification of B-lines and pleural effusion from that of focused transthoracic echocardiography training.[27] The teacher–student ratio was reported in two studies as 1:4 and in one study as 1:5.[22,25,27] Time required to perform LUS was not reported in these studies.

Students performed LUS on patients in three studies (Table 3).[21,24,26] Two explored whether students could learn to identify B-lines and pleural effusions as part of a larger point-of-care ultrasound training program.[21,26] Since only the overall training time was reported, the time dedicated to LUS training is unclear. One of these studies noted that students were able to detect pleural effusion and B-lines in inpatients and outpatients with a sensitivity of 91% and a specificity of 95%, using expert sonographers as the gold standard.[21] The other study, including patients in the Emergency Department (ED), patients who required lung examinations, and healthy volunteers, reported a 96% physician agreement with students' image interpretation based on LUS findings.[26] These studies did not report the time required to perform LUS.

The third study assessed the ability of a medical student, pharmacy resident, and medical intern to perform a limited cardiac ultrasound on asymptomatic outpatient cardiology patients and healthy volunteers with remote, real-time guidance and without formal training. Using pocket-sized ultrasound devices, the trainees acquired lung images with a technical adequacy of 100%. Their images yielded interpretable results for the detection of B-lines with a sensitivity of 40% and specificity of 100% as compared with images acquired by sonographers with high-end ultrasound systems.[24] The total time required to acquire the series of cardiac views, in addition to lung views, was 5 min. The results reported for the medical student were reported in aggregate with those of the pharmacy resident and medical intern.

Teacher–student ratios were not reported for these studies. Only two studies reported specific LUS interpretation methods. A positive zone was defined as three or more B-lines, and one study further specified that LUS was positive for pulmonary congestion if at least one (of two total) zones was positive.[24,26] Pleural effusions were categorized as either present or absent on each side.[26]

Paramedics

One study investigated whether paramedics could perform LUS in patients with shortness of breath or objective signs of respiratory distress during transport in an urban setting[29] (Table 4). Participants (n=17) attended a 30-min lecture followed by 1.5 h of hands-on training. They were also offered a refresher course and supplementary material. Four lung zones of the anterior and lateral chest were examined. Time required to perform LUS was not reported. Among 25 patients, 59% of paramedic-performed examinations were deemed uninterpretable by expert sonographers, many due to over-gained images. Sixty-three percent of the interpretable examinations correlated with the final ED diagnosis of patients in the study. Paramedics were also asked to provide an overall impression of the lung ("dry" vs. "wet") based on a pre-specified ultrasound protocol.[30] Their interpretation was compared with the final ED diagnosis of a subset (n=15) of patients (Cohen's kappa = 0.74). This study did not meet its pre-defined endpoint of a >80% rate of interpretable paramedic-performed LUS images.

Discussion

To our knowledge, this is the first systematic review investigating the ability of nurses, students, and paramedics to identify B-lines and pleural effusions on ultrasound. We found that nurses and – in a majority of cases – students can correctly identify B-lines and pleural effusions following 0–12 h of didactic training and 58–62 practice examinations and approximately 2–9 h of training, respectively. Only one study investigated paramedic-performed LUS, in which paramedics were struggling to identify B-lines and pleural effusions after 2 h of training.

We did not note any obvious differences in the abilities of participants to perform LUS across inpatient, outpatient, ED, and simulation settings. Apart from one study, all study participants had little to no background in ultrasound and varied in knowledge and experience related to heart failure.[13] These findings suggest that, after a relatively short training period, nurses, students, and paramedics can accurately learn to detect B-lines and pleural effusions by LUS.

Nurses

Nurse-performed LUS has the potential to improve outcomes in patients with heart failure by enhancing both the detection of subclinical pulmonary congestion and resultant management of congestion across a variety of settings.

Prior research has demonstrated that nurses can learn to perform and interpret inferior vena cava (IVC) ultrasound examinations with moderate to good agreement with expert sonographers.[31–33] One study in this current review found that nurse–expert correlation was greater for detecting B-lines and pleural effusions than for measuring the IVC diameter, suggesting that identifying B-lines and pleural effusions may be easier to learn than other ultrasound examinations.[17]

One study demonstrated that the diagnostic accuracy of nurse-performed LUS had higher sensitivity and negative predictive value when combined with brain natriuretic peptide levels in patients presenting to the ED with acute dyspnea.[18] Thus, the utility of nurse-performed LUS may prove to be even greater in the clinical context, wherein imaging results do not stand alone but rather serve as an additional data point in the patient assessment.

Prior research has demonstrated that nurse-led heart failure clinics can contribute to the reduction of unplanned heart failure hospitalizations.[10,15,17,34,35] Coupling this strategy with nurse-performed ultrasound of the pleural space and lungs to monitor pulmonary congestion has the potential to further improve outcomes and possibly decrease costs.

In resource-limited settings, nurses may screen for and manage common illnesses to allow patients to receive timely care.[36–38] Nurse-performed LUS could contribute to improved access to care in areas where, for instance, local health centers are significantly closer than the nearest hospital.

Students

The ability of students to perform and interpret LUS suggests that, after a short training period, LUS can be learned even with minimal clinical experience. In fact, two studies in this review involved first-year medical students, in the context of basic anatomy and physiology didactics. In studies that included other point-of-care ultrasound examinations, students performed better in LUS compared with cardiac and gallbladder ultrasound examinations, suggesting that LUS might be relatively easier to learn.[21,26] Given that medical students with little to no clinical experience are able to perform and interpret LUS, shifting this task to other healthcare professionals, including nurses, could prove to be a feasible intervention.

One study examined changes in patient management that occurred before and after physician review of students' ultrasound images.[26] However, the impact on diagnosis and management was reported for only combined student-performed point-of-care ultrasound examinations rather than LUS alone. Future research is needed to investigate how student-performed LUS may impact the assessment and management of patients with known or suspected heart failure.

Paramedics

As the first point-of-contact for 15% of patients who visit the ED in the US, paramedics seem to be ideally suited to learn LUS for improved pre-hospital management of acutely dyspneic patients.[39] In the study identified in this review, the low paramedic–patient ratio suggests that each paramedic performed few examinations. Perhaps with a greater number of patients and longer training, paramedic-performed LUS could be feasible as other paramedic-performed ultrasound examinations have been previously shown.[40–47] Heegaard et al. detail a one-year training period consisting of didactic and hands-on instruction in which paramedics were able to perform adequate Focused Assessment with Sonography in Trauma (FAST) and abdominal aortic (AAA) examinations.[42] LUS is a simple technique, and implementing a training method similar to that utilized in this study may yield more promising results.

Furthermore, paramedic-performed LUS might be even more useful in non-urban settings in which transportation times are longer and pre-hospital assessment has a greater impact on patient management. Further research is needed to investigate the feasibility of paramedic-performed LUS, ideally with more extensive training.

Implications

While the studies included in this review are small and should be supported by future larger investigations, they suggest that training non-physicians in ultrasound of the lungs and pleural space is feasible.

Based on the findings of the reviewed studies, nurses are able to record B-lines and pleural effusions with a minimum of ~4 h of training and students with a minimum of ~2 h of training.[17,28] The sensitivity of nurse-performed LUS was highest for instruction that involved longer hands-on training time as compared with didactic time. For student studies involving healthy volunteers, overall image adequacy was also highest in the study with longer hands-on than didactic training time.[23] In clinical practice, lung and pleural ultrasound training for non-physicians could employ brief training sessions with an emphasis on hands-on instruction.

Nurses already play an important role in the care of heart failure patients in a variety of settings and incorporating point-of-care ultrasound in the management of these patients could improve and expedite care and potentially reduce costs. For example, studies in heart failure clinics suggest that nurse-performed ultrasound examinations may provide prognostic information in patients with chronic heart failure and have the potential to improve patients' quality of life.[45–47] Other venues include resource-limited settings, especially in regions with long transport times where heart failure therapy could be initiated by pre-hospital providers.[48] Despite the findings of one study discussed in this systematic review, paramedic-performed lung and pleural ultrasound could be feasible, with adequate training, as prior studies have shown that paramedics are able to perform other, more complex, point-of-care ultrasound examinations.[29,42–46]

Limitations and future considerations

This systematic review is limited by the small number and sample sizes of relevant studies. Due to supplementary learning material or unreported training times, we could not always quantify the training that was required for participants to learn LUS. Ultrasound methodology and reference standards varied across the studies. In two studies, a subset of participants may have been performing a greater number of the total reported examinations than others.[15,24] Selection bias may have impacted findings in one study in which students selected examinations to log for review. In the same study, the assessment of diagnostic accuracy included only images deemed acceptable by the expert sonographer.[19] The findings of only one study in our review did not support the hypothesis that paramedics can successfully learn and interpret LUS, which may be attributable to publication bias. Nevertheless, we believe that this systematic review provides hypothesis-generating data that may inform future research.

Based on our findings there are several knowledge gaps that could be addressed by future investigations. It is unclear which training methods and duration would be most effective and sufficient to train nurses and paramedics in LUS for the assessment of patients with heart failure. Additionally, the determination of clinical settings in which these interventions would provide the greatest benefit to patients and clinical workflow warrants further research. Finally, cost-effectiveness should be evaluated in the context of longer term outcomes across various clinical settings.

Conclusion

Our findings suggest that nurses and students in the medical field can learn to perform and interpret B-lines and pleural effusions using LUS with limited training. The examination of heart failure patients with LUS by non-clinicians appears feasible and warrants further investigation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Implications for practice

- Lung ultrasound can be performed and interpreted by non-physicians, including nurses.
- Lung ultrasound may be learned despite minimal clinical experience.
- Non-physicians can learn lung ultrasound with short training periods.

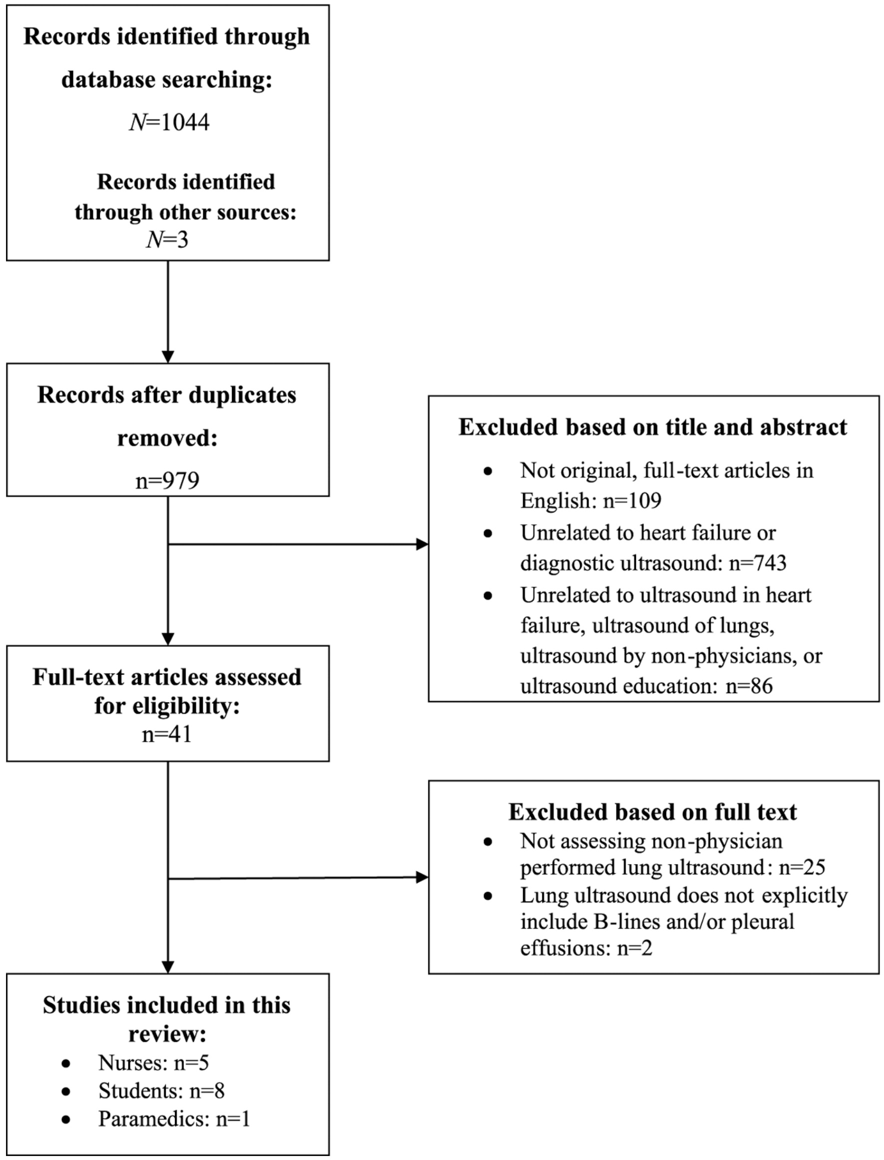

Figure 1.
PRISMA Flow Diagram.

Table 1.

Nurse-performed lung ultrasound.

First author Year Country	Patients *n*	Patient population	Nurses *n*	LUS goal	# Zones	Positive zone Positive overall	Didactic training; hands-on training	Reference standard	Diagnostic accuracy Sensitivity (95% CI) Specificity (95% CI)
Ünlüer 2014[19] Turkey	90	ED, dyspnea	2	B-lines	Six?	B-lines in four zones based on predefined protocol[20]	3 h; 60 scans	Expert medical record review (blinded to nurse LUS)	Nurse 1: Sens. 95% (84.2–99.4) Spec. 96% (85.5–99.5) Nurse 2: Sens. 100% (9I.8–100.0) Spec. 100% (92.5–100.0)
Dalen 2015[15] Norway	62	Outpatient HF clinic, routine follow-up care	2	Pleural effusion	Six	Three categories: '0' '5 mm'[b] '>5 mm'	0 h; 15–20 scans[d]	Expert LUS	Sens. 92% Spec. 99%
Graven 2015[16] Norway	59	Inpatient, median 5 days postcardiac surgery	2	Pleural effusion	Eight	Four categories: Not present Insignificant[b] Moderate Large[c]	0 h; three months' bedside education with 58 and 62 scans each	Expert LUS	Sens. 98% Spec. 70%
Gustafsson 2015[17] Sweden	104	Outpatient HF clinic, routine follow-up care	4	B-lines, pleural effusion	Seven	≥ 3 B-lines in one zone Evidence of pleural effusion	3 h (extra material given); 1 h	Expert image review (blinded to other clinical findings)	B-lines: Sens. 79% (59–91) Spec. 9I% (81–96) Pleural effusion: Sens. 88% (50–99) Spec. 93% (85–97)
Mumoli 2016[18] Italy	226	ED, acute dyspnea[a]	5	B-lines	Eight	≥ 3 B-lines in one zone B-lines in ≥ 2 zones bilaterally	12 h; 20 h	Expert medical record review (blinded to nurse LUS)	Sens. 95% (93–98) Spec. 88% (84–92)

[a] Shortness of breath with RR >24 breaths per minute, or O_2 saturation < 92%, or had been started on O2 therapy.

[b] If seen in costodiaphragmatic angle only.

[c] Moderate: if pleural effusion separated the diaphragm and the lung with a maximum distance of < 30 mm; large: if maximum distance <30 mm.

[d] Nurses had each completed ~200 ultrasound scans prior to the study period.

LUS: lung ultrasound; CI: confidence interval; ED: Emergency Department; HF: heart failure; Sens.: sensitivity; Spec.: specificity.

Table 2.

Student-performed LUS on healthy volunteers or simulators.

First author Year Country	Models	Students *n*	School year	LUS goal	# zones	Didactic training; hands-on training	Reference standard	Image adequacy and clinical knowledge test scores
Connolly 201 5[27] United States	Simulation	22	Not reported	B-lines, pleural effusion	?	4 h of online didactic material; 1 h	Expert image review	Image adequacy: pre-training 23%, post-training 51%; improved by 2.6 (1.1–4.2) points (p=0.003 *) Test scores: pre-training 8.4, post-training 18.5 of 21 points (p<0.001 *)
Eissa 2015[28] United States	Simulation	70	3	B-lines, pleural effusion	?	1 h; 1 h	Not reported	Image adequacy: pre-training 52.1% ± 18.5, post-training 87.3% ± 13.9 (p<0.001 *)
Heiberg 2015[22] South Africa	Healthy volunteers	16	3–5	Pleural effusion	Two	5–8 h of e-learning (including all POC modules);1 h	Expert image review	Image adequacy: right: pretraining 31%, post-training 100% (p<0.01 *). Left: pretraining 13%, post-training 50% (p<0.02, not significant)
Steinmetz 2016[25] Canada	Standardized patients	195	1	B-lines	Three	Text and video; 1 h	Expert image review	Image adequacy: 100%
Lim 2017[23] South Korea	Healthy volunteers	40	4	B-lines, pleural effusion	Six	1 h; 2 h	Expert image review	Image adequacy: 96% Test scores: pre-training 42.1 ± 13.7%, post-training 82.6 ± 10.7% (p<0.001 *)

* Statistically significant.

LUS: lung ultrasound; POC: point of care.

Table 3.

Student-performed LUS on patients.

First author Year Country	Patients *n* (# of LUS exams)	Patient population	Students *n* (school year)	LUS aim	# zones	Positive one Positive overall	Didactic training; hands-on training	Reference standard	Image adequacy and diagnostic accuracy
Mai 2013[24] United States	27 (5)	Outpatient cardiology and healthy volunteers who were asymptomatic	3 (not reported)	B-lines	Two	≥ 3 B-lines B-lines in ≥ 1 lung apices	0 h; < 1 h brief device orientation	Expert LUS and image review	Image adequacy: 100% Diagnostic accuracy: Sens. 40%, Spec. 100%
Andersen 2014[21] Norway	211 (59)	Inpatients and outpatients	30 (5)	B-lines, pleural effusion	Two	Not reported	< 1 h; ~8 h (including all POC techniques)	Expert image review	Image adequacy: 93% (95% CI: 84.3–98.2) Diagnostic accuracy: Sens. 90.5% (95% CI: 68.8–97.6), Spec. 94.7% (95% CI: 82.2–99.4)
Udrea 2017[26] United States	482 (47)	ED, patients requiring lung exam, and healthy volunteers	5 (1)	B-lines, pleural effusion	Six	≥ 3 B-lines Evidence of pleural effusion	18 h; ~13 h (including all POC techniques)	Expert image review	Agreement with expert diagnosis: 95.7%

LUS: lung ultrasound; CI: confidence interval; POC: point of care; ED: Emergency Department; Sens.: sensitivity; Spec.: specificity

Table 4.

Paramedic-performed LUS.

First author Year Country	Patients *n*	Patient population	Paramedics *n*	LUS aim	# zones	Positive zone Positive overall	Didactic training; hands-on training	Reference standard	Image adequacy and Diagnostic accuracy
Becker 2018[29] United States	25	Ambulance, undifferentiated respiratory distress[a]	17	B-lines	Four (continuous clips of anterior and lateral chest)	Predominance of B-lines based on predefined protocol[28]	0.5 hours plus extra material and refresher-training offered; 1.5 hours	Expert image review	Image adequacy: 41.2% Agreement with expert diagnosis: 62.5%

[a]Complaints of shortness of breath, or objective signs of respiratory distress, or non-invasively measured SpO2 < 92%. LUS: lung ultrasound; SpO2: oxygen saturation.