CHEST

Point-of-Care Lung Ultrasound in Emergency Medicine

A Scoping Review With an Interactive Database

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BACKGROUND: This scoping review was conducted to provide an overview of the evidence of point-of-care lung ultrasound (LUS) in emergency medicine. By emphasizing clinical topics, time trends, study designs, and the scope of the primary outcomes, a map is provided for physicians and researchers to guide their future initiatives.

RESEARCH QUESTION: Which study designs and primary outcomes are reported in published studies of LUS in emergency medicine?

STUDY DESIGN AND METHODS: We performed a systematic search in the PubMed/MEDLINE, Embase, Web of Science, Scopus, and Cochrane Library databases for LUS studies published prior to May 13, 2023. Study characteristics were synthesized quantitatively. The primary outcomes in all papers were categorized into the hierarchical Fryback and Thornbury levels.

RESULTS: A total of 4,076 papers were screened and, following selection and handsearching, 406 papers were included. The number of publications doubled from January 2020 to May 2023 (204 to 406 papers). The study designs were primarily observational (n = 375 [92%]), followed by randomized (n = 18 [4%]) and case series (n = 13 [3%]). The primary outcome measure concerned diagnostic accuracy in 319 papers (79%), diagnostic thinking in 32 (8%), therapeutic changes in 4 (1%), and patient outcomes in 14 (3%). No increase in the proportions of randomized controlled trials or the scope of primary outcome measures was observed with time. A freely available interactive database was created to enable readers to search for any given interest (https://public.tableau.com/app/profile/blinded/viz/LUSinEM_240216/INFO).

INTERPRETATION: Observational diagnostic studies have been produced in abundance, leaving a paucity of research exploring clinical utility. Notably, research exploring whether LUS causes changes to clinical decisions is imperative prior to any further research being made into patient benefits.

CHEST 2024; 166(3):544-560

KEY WORDS: emergency medicine; lung ultrasound; respiratory symptoms

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ABBREVIATIONS: EM = emergency medicine; F&T = Fryback and Thornbury; LUS = lung ultrasound; RCT = randomized controlled trial

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Take-home Points

Study Question: Which study designs and primary outcomes are reported in the published studies of lung ultrasound in emergency medicine?

Results: Primarily observational studies (375 of 406 [92%]) with a diagnostic accuracy outcome (320 of 406 [79%]) were identified.

Interpretation: Observational diagnostic studies have been published in abundance, with very few publications exploring clinical utility.

Point-of-care lung ultrasound (LUS) is considered a core competency in emergency medicine (EM), and it is integrated into the diagnostic pathway of various clinical presentations.[1-4] Various meta-analyses solidify the evidence of diagnostic accuracy within dyspnea in general, [5] pleural effusion,[6] cardiogenic pulmonary edema,[7] pulmonary embolism,[8] COVID-19,[9] pneumonia,[10] and pneumothorax.[11] However, evidence of patient benefit is needed for any initiative in clinical medicine, and for LUS in EM such evidence remains unclear.[12]

Evidence appraisal for a diagnostic test is complex, and it is rarely possible to assess its value purely based on diagnostic accuracy. Different schemes have been proposed to help describe the effectiveness of a test, but one suggested by Fryback and Thornbury (F&T) has become more widely adopted.[13-18] This hierarchical model consists of six progressive levels as a "chain of evidence" (Table 1).[19,20] The hierarchical model's key feature is that a test which performs poorly at one level is unlikely to perform well at a higher level.[15,21]

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DOI: https://doi.org/10.1016/j.chest.2024.02.053

The research field of LUS in EM has increased abundantly during the last decade, and to our knowledge, there is no complete overview of the evidence. We hypothesize that an evidence gap on clinical benefits remains, and an overview of existing research is paramount in guiding future studies and systematic reviews.[22]

The aim of this scoping review was to provide an overview of the evidence of LUS in EM with particular emphasis on randomized controlled trials (RCTs) and studies with a primary outcome conforming with F&T Levels 3 to 6. The review questions included the following: (1) Which study designs are used in original LUS studies in EM, and what are the time trends? (2) Which primary outcomes and F&T levels are used in original LUS studies in EM, and what are the time trends? and (3) Which methodologic features are used in terms of the sampling methods (convenience/consecutive), the diagnostic role of ultrasound (triage, add-on, or replacement), the number of sonographers, expertise of sonographers (training and experience), and roles of sonographers (treating physicians or investigators)?

Study Design and Methods

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews checklist.[23] To ensure public online registration, a protocol has been published.[24]

Eligibility Criteria

We included original quantitative studies on LUS in adult ED patients (aged ≥ 18 years). Studies with mixed settings (ie, ED and ICU), populations (ie, adult and pediatric), or methods (ie, mixed-methods studies) were eligible. Only peer-reviewed journal papers and papers written in English were included.

The exclusion criteria were as follows: comprehensive LUS (ie, mediastinal lymph nodes, diaphragmatic movement, contrast-enhanced or procedural LUS); simulation studies (ie, simulated settings, simulator manikins, or simulated patients); nonphysician sonographer studies (eg, medical students, nurses, technicians); and study designs that included review, protocol, meta-analysis, case study, letter, conference abstract, or exclusively qualitative analysis (rationale is given in the protocol).[24]

Search Strategy

The PubMed/MEDLINE, Embase, Web of Science, Scopus, and Cochrane Library databases were searched. The search strategy was created with the assistance of a research librarian. It included four primary conditions that were combined with "AND" statements: (1) ultrasound; (2) point-of-care; (3) lung; and (4) ED. Database-specific index terms were used when deemed appropriate (ie, MeSH or Emtree terms). Likewise, we incorporated a few limits when feasible (ie, English language, NOT review, and NOT conference abstract [full search strings are provided in e-Appendix 1]). The databases were searched from their inception until May 13, 2023 (updated September 1, 2022, and September 27, 2021).

TABLE 1] Fryback and Thornbury Levels and Interpretation Examples

Level 1: Technical efficacy	A study that assesses the technical quality of images
Level 2: Diagnostic accuracy efficacy	A study that correlates the presence or absence of, for example, pneumothorax on CT imaging with its presence on LUS (the ability of the test to detect a clinical phenomenon)
Level 3: Diagnostic thinking efficacy	A study in which LUS enables the health care provider to diagnose precisely when using ultrasound findings
Level 4: Therapeutic efficacy	A study that investigates if the usage of LUS and trusting the diagnosis will also enable a more precise treatment of a given patient presentation (that patients with a pathologic finding on LUS were consequently given a different treatment more often than those in whom there was no pathology)
Level 5: Patient outcome efficacy	A study that investigates whether patients who underwent LUS had a better clinical outcome (not just a more accurate diagnosis or more appropriate treatment)
Level 6: Societal efficacy	A study that aims to identify potential societal efficacy, for example, by using a cost-effectiveness analysis on the effect of LUS

LUS = lung ultrasound.

Additional studies were identified by handsearching the bibliographies and citations of the articles that proceeded to full-text screening.

Study Selection

Following duplicate removal, each title and abstract were independently screened by two authors (S. H. O., A. H. C., R. L., or A. R.). Then, each full-text paper was independently screened by two authors (S. H. O., A. H. C., R. L., or A. R.). Any disagreements were resolved via discussion between the reviewers and the last author (J. W.) if needed. Covidence (www.covidence.org) was used for digital duplicate identification, study selection, and data extraction.

Data Extraction and Synthesis

The initial charting form was calibrated through an independent extraction of 20 studies done in duplicate and discussed by four authors (S. H. O., S. H. S., R. A., and J. W.). Furthermore, duplicate data extraction was performed on a random sample of 20% of all included papers to explore the interrater variability on key variables. At random, one of each duplicate was discarded for the final database.

Data on both methodologic and ultrasound aspects were extracted, including clinical topic (eg, trauma, COVID-19, dyspnea), sonographer and ultrasound characteristics, study design, primary outcome measure, and F&T level. Whenever possible, the study design was extracted as written in the paper. One F&T level was applied to the study's primary outcome measure. Data extractors were introduced to the data extraction through a structured 1 h didactic meeting and guided by variable explanations in the data dictionary and online in Covidence (the full data dictionary is provided in e-Appendix 1).

A narrative synthesis of all the included studies was conducted within each of the designated clinical topics, emphasizing the study designs, the F&T levels, and time trends. All primary outcomes above F&T Level 2 were audited by the first author (S. H. O.), synthesized, categorized, tabulated, and exemplified explicitly.

To unfold the insights and potentials of all the data extracted, an interactive database was created in the Tableau Public platform that allows access, filtering, and sorting of all extracted data.

Results

Study Selection

We initially identified 4,076 papers, excluding 3,632 after title/abstract screening. Following review of 444 full-text papers, 282 were included. In addition, 124 studies were included based on handsearching references and citations. A total of 406 studies were ultimately included in this review (Fig 1).

Interrater Variability

Interrater agreement was 67% and 71% for the duplicate extractions of the F&T levels and study design, respectively. The corresponding Cohen's kappa coefficients indicated poor agreement (0.29 for F&T and 0.45 for study design) (e-Appendix 1). The "unclear" label chosen by one of the two raters was attributed to 16 of 27 and 10 of 24 disagreements in the F&T levels and study design. Apart from this, disagreement between Level 2 and Level 3 was most frequent in the F&T classification, whereas for study design, all disagreements occurred within the different categories of observational designs.

Overall Results

The largest clinical topics identified were dyspnea, COVID-19, and trauma (107, 105, and 85 papers included, respectively). In addition, infection and shock were identified as topics (33 and 26 papers). For studies with a combined, unspecific, or unselected patient population, the "Unselected" topic was computed (23 papers). The remaining papers were grouped into a "Miscellaneous" group covering topics such as pulmonary embolism suspicion, high-acuity (not trauma or shock), chest pain, pleuritic pain, or syncope (27 papers).

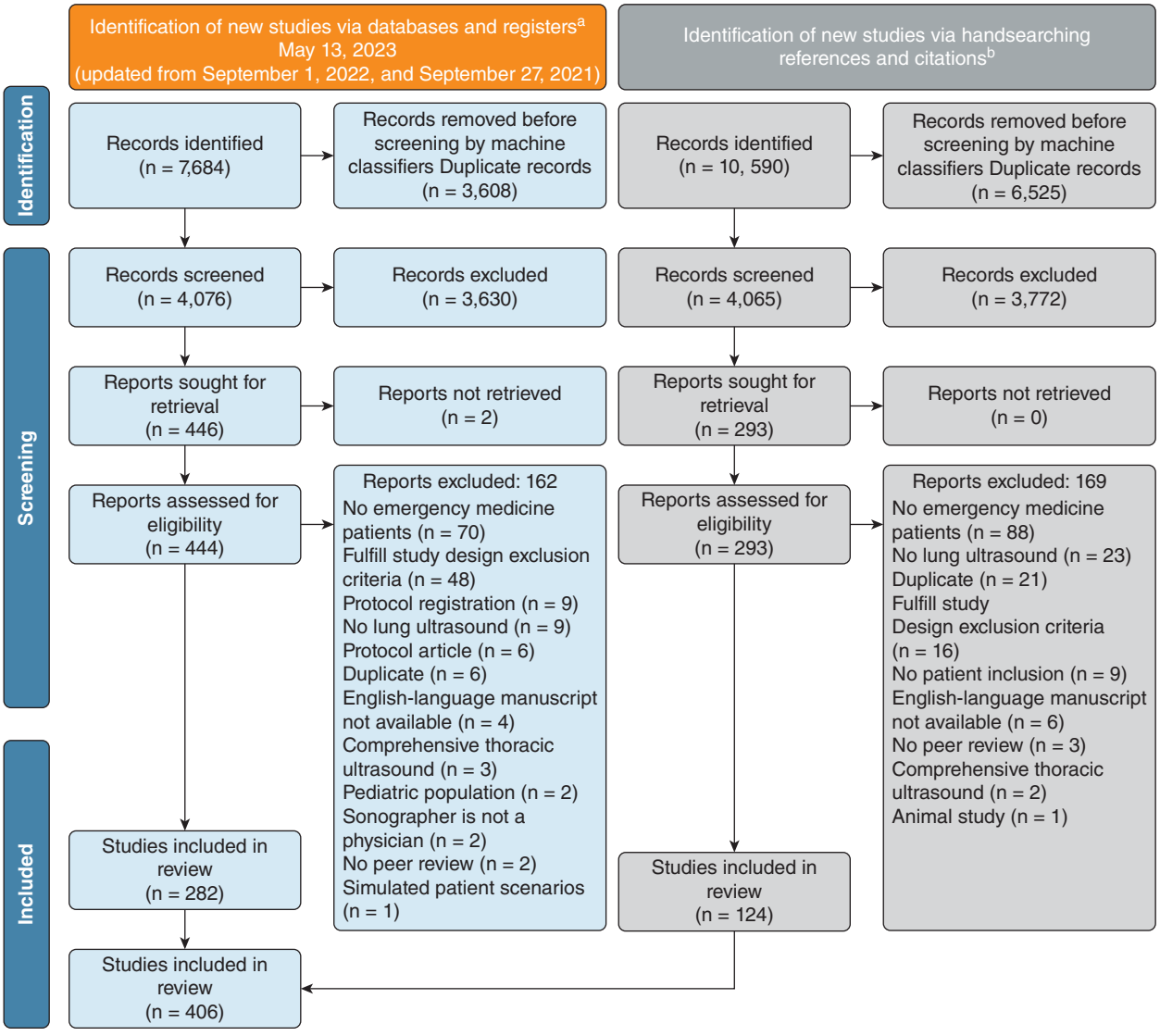

Figure 1 – *Preferred Reporting Items for Systematic Reviews and Meta-Analyses chart.* [a]*PubMed/MEDLINE, Scopus, Web of Science, Embase, and Cochrane Library.* [b]*Scopus and Web of Science.*

Data charts categorized by clinical topic can be found in e-Appendix 1. The full interactive database can be accessed through the following URL: (https://public.tableau.com/app/profile/blinded/viz/LUSinEM_240209/INFO).

The overall number of papers published yearly within this field has increased dramatically, up to a running total of 15 papers in 2005; 37 in 2010; 105 in 2015; 204 in 2020; and 406 in 2023 (Fig 2).

Study Designs (Review Question 1)

Study designs were observational in 375 papers (92%); of these, 280 (69%) were observational prospective, 59 (15%) were observational retrospective, 25 (6%) were cross-sectional, 7 (2%) were observational with unclear design, and 4 (1%) were case-control studies. Case series comprised 13 of the included studies (3%).

Across all clinical topics, 18 RCTs were identified (Table 2). The highest proportion of RCTs was found in the shock (5 of 26 [19%]) and dyspnea (10 of 107 [9%]) clinical topics. In 2021, the overall number of RCTs peaked, with four published studies. However, no clear temporal trend was seen.

The F&T hierarchy distribution among RCTs was as follows: one Level 1, three Level 2, eight Level 3, one Level 4, five Level 5, and zero Level 6.

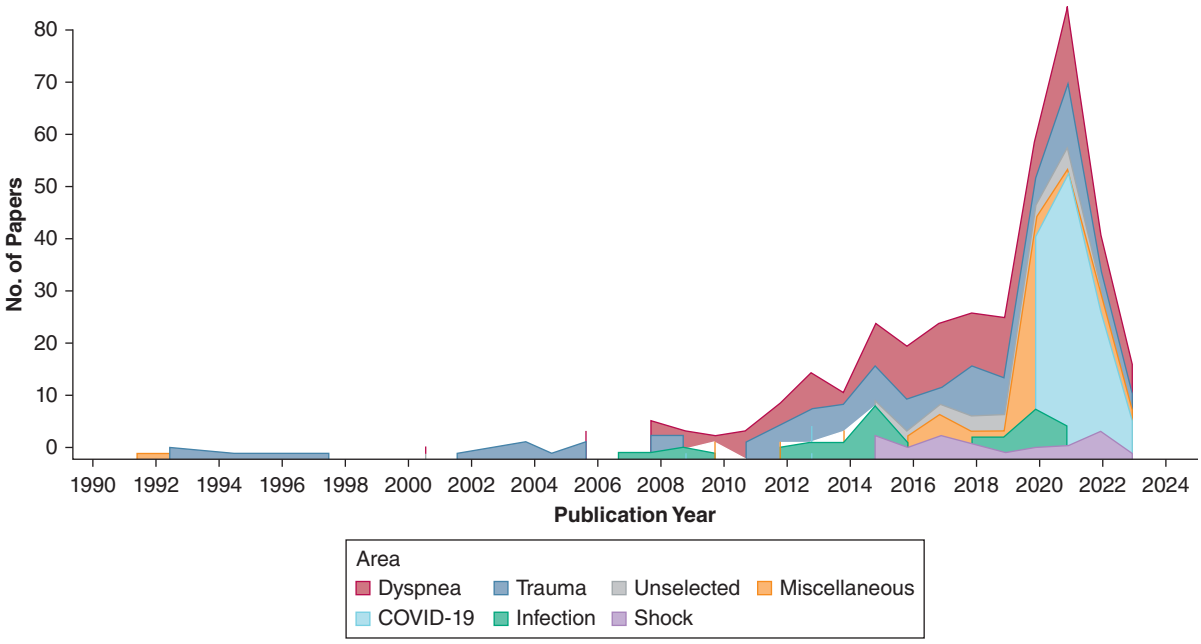

Figure 2 – *Papers over time.*

Primary Outcomes (Review Question 2)

A primary outcome on F&T Level 1 was found in 15 (4%) studies, Level 2 in 320 (79%), Level 3 in 32 (8%), Level 4 in 4 (1%), Level 5 in 14 (3%), and Level 6 in 0; in 21 studies, the categorization was deemed not applicable (ie, in case series) (Fig 3). A primary outcome on F&T Levels 3 to 6 was found in 50 papers (12%) (Table 3). Prior to 2014, only two studies applied a primary outcome in F&T Levels 3 to 6. Since then, the level has increased with 3 to 6 studies per year, except for 2017, which peaked with 10 studies.

Ultrasound Applications (Review Question 3)

The most used LUS protocol included the focused assessment of eight zones located anterior and lateral on the thorax (74 [18%]), followed by the use of 12 zones, including posterior zones (57 [14%]). The first was mainly used in studies of dyspnea (41 of 74 [55%]), whereas the latter was predominant in the COVID-19 studies (49 of 57 [86%]). Four zones, anterior and lateral, were often applied in trauma studies (29 of 48 [60%]) and substantially within dyspnea as well (14 of 48 [29%]).

Among 164 (40%) multiorgan ultrasound studies, cardiac ultrasound was used in 115 (28%) of the included studies; abdominal was applied in 92 (23%) (trauma protocols included), inferior vena cava in 66 (16%), and compression ultrasound for DVT in 41 (10%). Multiorgan ultrasound was used in 52 of 107 dyspnea studies, 45 of 85 trauma, 22 of 26 shock, 18 of 23 unselected, 8 of 104 COVID-19, 8 of 13 pulmonary embolism suspicion (from Miscellaneous), 3 of 33 infection, 3 of 4 high-acuity (from Miscellaneous), 5 of 9 remaining Miscellaneous areas (including acute kidney injury, cardiac arrest, chest pain, and syncope).

LUS was evaluated as an add-on test to the existing diagnostic pathway in 13 (72%) of 18 RCTs and as a replacement test (ie, replacing chest radiograph) in 3 (17%) of 18 papers.

Methodologic Features (Review Question 3)

The participant sampling was reported as consecutive in 3 (17%) of 18 RCTs and 94 (34%) of 280 prospective observational studies. It was coded as unclear or not reported in 2 (11%) of 18 RCTs and 79 (28%) of 279 prospective observational studies.

The number of physicians performing LUS was a single physician in 71 (17%) studies, 2 to 5 in 86 (21%), 6 to 10 in 16 (4%), 11 or more in 34 (8%), and not reported in 199 (49%).

The physicians' LUS experience in years was reported in 103 (25%) papers, and the number of studies including physicians with 1 year or less experience was 42 (10%). The experience in the number of scans was reported in 71 (18%) papers; it was < 30 scans in 22 (5%) papers, 31

TABLE 2] Randomized Controlled Trials

Study	Country	N	Primary outcome	Fryback and Thornbury Level	Intervention (i) Comparator (c) Reference test (r)	Test Strategy	Sampling Method	Sonographer Treating Physician/ Physician No.	Secondary Outcomes
Shock									
Peach et al 2022[25]	USA, South Africa	273	Sensitivity and specificity	Level 3, Diagnostic thinking efficacy	i: POCUS c: Standard diagnostic pathway r: Adjudication	Add-on	Convenience	Phys: Yes No.: —[a]	Sensitivity and specificity for subcategories of shock, change in the perceived category of shock and diagnosis
Li et al 2021[26]	China	97	28-d mortality	Level 5, Patient outcome efficacy	i: Cardiac and LUS c: No US	Add-on	Not reported	Phys: No No.: 2	Lactate reduction rate, cumulative fluid intake, and fluid balance within 24 and 72 h
Sabbadini et al 2021[27]	USA	29	Duration of US examination	Level 1, Technical efficacy	i: US hypotension protocol using handheld US c: US hypotension protocol using high-end US	NA	Convenience	Phys: No No.: 8	Time to complete each view, time for task switching, and image diagnostic quality
Atkinson et al 2020[28]	Canada, South Africa	273	Substudy (reduction in severity scores)	Level 5, Patient outcome efficacy	i: POCUS plus standard care c: Standard care without POCUS	Add-on	—	Phys: — No.: —	Shock index, modified early warning score, lactate, bicarbonate, and mean fluid bolus received
Atkinson et al 2018[29]	Canada, South Africa	273	30-d or discharge survival	Level 5, Patient outcome efficacy	i: POCUS c: No POCUS	Add-on	Convenience	Phys: Yes No.: —	Initial treatment (inotropes, IV fluids), investigations (CT use rate), admission rates (hospital, ICU), and LoS (hospital, ICU)
Dyspnea									
Zare et al 2022[30]	Iran	103	Randomization-to-diagnosis time	Level 5, Patient outcome efficacy	i: Early US c: Routine assessment r: Final diagnosis at discharge	Unclear	Convenience	Phys: — No.: —	Sensitivity and specificity within the early US group using final diagnosis as reference, sensitivity and specificity within the routine evaluation group using final diagnosis as reference, and the prevalence of final diagnoses

(Continued)

TABLE 2] *(Continued)*

Study	Country	N	Primary outcome	Fryback and Thornbury Level	Intervention (i) Comparator (c) Reference test (r)	Test Strategy	Sampling Method	Sonographer Treating Physician/ Physician No.	Secondary Outcomes
Pang et al 2021[31]	USA	130	Less than 15 B-lines at 6 h	Level 5, Patient outcome efficacy	i: 6 h LUS-guided treatment strategy c: Structured usual care	Add-on	Consecutive	Phys: No No.: —	Days alive and out of the hospital at 30 d
Riishede et al 2021[32]	Denmark	218	Presumptive diagnosis at 4 h agreeing with final diagnosis, percentage	Level 3, Diagnostic thinking efficacy	i: Cardiopulmonary US + physical examination c: Physical examination r: Adjudication	Add-on	Convenience	Phys: No No.: 21	Appropriate treatment, LoS, accuracy of diagnosis upon arrival, transfer to ICU/ward/home, 30-d readmission, in-hospital mortality, and 30-d mortality
Baker et al 2019[33]	Australia	442	Correct identification of significant pulmonary edema	Level 2, Diagnostic accuracy efficacy	i: LUS c: Standard of care r: Adjudication	Add-on	Convenience	Phys: Yes No.: 30	ED LoS, hospital LoS, costs, and discharge destinations
Gaber et al 2019[34]		59	Sensitivity and specificity	Level 3, Diagnostic thinking efficacy	i: Standardized US procedure c: US results anonymized to treating physician r: Adjudication for diagnosis	Add-on	Convenience	Phys: No No.: 4	Time to diagnosis
Pivetta et al 2019[35]	Italy	518	Diagnostic accuracy	Level 3, Diagnostic thinking efficacy	i: LUS c: Chest radiograph + NT-proBNP r: Adjudication	Replacement	Convenience	Phys: Yes No.: 44	Time to integrated diagnosis, net reclassification index, and net benefit
Seyedhosseini et al 2017[36]	Iran	50	Time to treatment	Level 4, Therapeutic efficacy	i: Lung US c: Normal diagnostic imaging	Add-on	Consecutive	Phys: No No.: 1	Hospital LoS
Stewart et al 2016[37]	USA	104	Changes to differential diagnoses	Level 3, Diagnostic thinking efficacy	i: Cardiopulmonary and DVT US + clinical assessment c: Clinical assessment + imaging and laboratory testing ordered per standard of care	Replacement	Convenience	Phys: No No.: —	Changes to physician orders or interventions, time to disposition assignment, time to perform the US protocol, and interrater reliability of the interpretation of US

(Continued)

TABLE 2] *(Continued)*

Study	Country	N	Primary outcome	Fryback and Thornbury Level	Intervention (i) Comparator (c) Reference test (r)	Test Strategy	Sampling Method	Sonographer Treating Physician/ Physician No.	Secondary Outcomes
Laursen et al 2014[38]	Denmark	315	Presumptive diagnosis at 4 h agreeing with final diagnosis	Level 3, Diagnostic thinking efficacy	i: Multiorgan US + standard diagnostic testing c: Standard diagnostic testing r: Adjudication	Add-on	Convenience	Phys: No No.: 1	Correct presumptive diagnosis following primary clinical assessment, appropriate treatment within 4 h, number of advanced diagnostic tests ordered, confirmation suspected diagnosis on advanced diagnostic tests, ICU admission, hospital-free days within 1 mo, readmissions within 1 mo, time to diagnostic or therapeutic thoracocentesis, hospital LoS, in-hospital mortality rate, and mortality within 30 d following admission
Pirozzi et al 2014[39]	Italy	168	Incorrect initial diagnosis	Level 3, Diagnostic thinking efficacy	i: POCUS c: Standard diagnostic pathway r: Adjudication	Add-on	Convenience	Phys: Yes No.: 3	Sensitivity and specificity, hospital LoS, deaths in the ED, and patients discharged or transferred to ICU and general medicine wards
Trauma									
Avila et al 2018[40]	USA	173	Sensitivity and specificity	Level 2, Diagnostic accuracy efficacy	i: B-mode LUS c: B-mode + M-mode LUS r: CT scan and expert US review	Add-on	Consecutive	Phys: — No.: 1	
Helland et al 2016[41]	USA	260	Sensitivity and specificity	Level 2, Diagnostic accuracy efficacy	i: Single view per hemithorax LUS c: Four views per hemithorax LUS r: Chest CT scam	Replacement	Convenience	Phys: — No.: 44	

(Continued)

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TABLE 2] (Continued)

Study	Country	N	Primary outcome	Fryback and Thornbury Level	Intervention (i) Comparator (c) Reference test (r)	Test Strategy	Sampling Method	Sonographer Treating Physician/ Physician No.	Secondary Outcomes
Chest pain									
Guner et al 2020[42]	Turkey	208	ED LoS	Level 5, Patient outcome efficacy	i: POCUS c: No POCUS	Add-on	Consecutive, when investigator or sonographers were present	Phys: No No.: 1	Cost, changes to preliminary diagnosis, hospitalization, and discharge rates

LoS = length of stay; LUS = lung ultrasound; NA = not applicable; NT-proBNP = N-terminal pro–B-type natriuretic peptide; POCUS = point-of-care ultrasound; US = ultrasound; USA = United States of America.
[a]— = not reported.

100 scans in 18 (4%) papers, and > 101 scans in 31 (8%) papers.

LUS was performed by the treating physician in 67 (17%) studies, not reported or unclear in 208 (51%) studies, and performed by another physician, not responsible for patient care, in 131 (32%) studies.

Discussion

This scoping review mapped 406 studies of LUS in EM. We have produced a complete overview of the current state of the research, presented within clinical topics, time trends, study designs, and the F&T levels of the primary outcomes. A freely available online interactive database was created to enable readers to sort, filter, and count on any given interest.

Most studies were observational, and 18 RCTs were identified, with no clear rising trend over time. We found 50 studies that applied a primary outcome above F&T Level 2 (ie, diagnostic thinking, therapeutic, clinical, or societal impact).

The abundance of observational designs and paucity of RCTs is in alignment with previous findings that suggested few RCTs among studies published in 2015 and top 100-cited studies in the overall point-of-care ultrasound research field.[59,60] The limited number of randomized studies is surprising even within well-established clinical topics such as COVID-19, trauma, and infection. Despite a substantial belief in the importance of LUS during the COVID-19 pandemic, to our knowledge, no RCT on LUS and COVID-19 in the ED context was ever performed. In contrast, studies on shock displayed a different balance between study designs, with a much higher proportion of RCTs.

Indeed, randomization is not a self-standing goal; it is highly intertwined with the scope of the research question. However, to verify clinical benefit hypotheses, randomization is inescapable in evidence-based medicine. The importance of observational diagnostic accuracy studies is most certainly not to be neglected. However, the high number of comparable observational studies is hardly rational. Although study reproducibility is obviously desirable, the research implications might be saturated within a certain threshold of study repetition.

Overall trends in the F&T hierarchy revealed high activity on Level 2 and moderate movement into Level 3. However, notably, Level 4 (therapeutic efficacy) was rarely aimed for and seemed to have been surpassed

TABLE 3] Primary Outcome Measures Assessed With Fryback and Thornbury Level 3 and Higher

Level	Measurement Construct	Measure/Indicator	Example From Included Studies
Level 3: Diagnostic thinking efficacy *Does the test affect the prognostic/ diagnostic assessment?* N = 32	Timing	Time to diagnosis N = 2	*"The average time needed to formulate the ultrasound diagnosis was 24 ± 10 min, whereas the formulation of the ED diagnosis required a significantly longer time (186 ± 72 min;* P = *.025)."* (Zanobetti et al 2017[43])
	Agreement	Diagnostic agreement/ concordance N = 15	*"4 h after admission to the emergency department, the percentage of patients with a correct presumptive diagnosis was significantly larger in the point-of-care ultrasonography group than in the control group (*P < *.0001; Table 2). The absolute and relative effects were 24.3% (95% CI, 15.0-33.1) and 1.38 (1.01-1.31), respectively."* (Laursen et al 2014[38])
		Changes to primary diagnosis N = 6	*"The attending physician changed their primary diagnosis in 32% (95% CI, 22.2-41.4%) of cases when POCUS was performed by the US team, and in 40% (95% CI, 28.1–51.9%) of cases when a member of the primary team performed POCUS (Tables 3 and 4). Primary team-performed POCUS was noninferior to US team-performed studies when assessed with a noninferiority margin of 20% (*P < *.0001)."* (Beyer et al 2021[44])
		Changes to differential diagnoses N = 3	"The inclusion of heart and lung ultrasound to the conventional diagnostic evaluation of patients with CP and SOB significantly narrowed down the list of differential diagnoses in their initial ED evaluations. . . . *After the performance of ultrasound, the median number of differential diagnoses entertained decreased from 5 (IQR, 3–6) to 3 (IQR, 2–4),* P < *.001."* (Buhumaid et al 2018[45])
	Perception	Presumable imaging and cost reduction N = 1	*"Based upon the ultrasound examination results alone, the investigators' opinion was that 56 of the 100 [participants] (58%) did not need a CTPA (ie, the ultrasound examination revealed an abnormality of sufficient consequence that it established a convincing alternative diagnosis to PE or a DVT was identified). In none of these 56 cases did the CTPA identify a PE."* (Koenig et al 2014[46])
		Diagnostic certainty prior to and following the ultrasound N = 1	*". . . there was a significant 27.7% decrease in the mean aggregate complexity of diagnostic uncertainty before and after the hypotension protocol (1.85–1.34; −0.51 [95% CI, −0.41 to −0.62]). There was a significant increase in the absolute proportion of patients with a definitive diagnosis from 0.8% to 12.7% (+11.9%; 95% CI, 5.6–18.1)."* (Shokoohi et al 2015[47])
		Changes to patient management N = 2	*"Overall, POCUS was found to provide clinically useful information in 95% of patients (95% CI, 90–98). In 45% of patients (95% CI, 36–54), the ultrasound scan changed initial pre-ultrasound patient management plans by changing the working diagnosis (27%; 95% CI, 20-36), resulting in a new treatment intervention (24%; 95% CI, 17-32), resulting in a procedure/surgical intervention (14%; 95% CI, 9-22), leading to consultation with a specialist (14%; 95% CI, 8-21), and/or changing a disposition decision (8%; 95% CI, 4-14)."* (Stachura et al 2017[48])

(Continued)

TABLE 3] *(Continued)*

Level	Measurement Construct	Measure/Indicator	Example From Included Studies
		Perceived benefit from ultrasound on clinical decision-making N = 2	*". . . clinician-reported diagnostic impressions changed in 27% and disposition plans changed in 13% of patients after ultrasound. A change in either diagnostic impression or disposition plan was reported for 28.8% patients overall (95% CI, 25.6-32.2%)."* (Reynolds et al 2018[49])
Level 4: Therapeutic efficacy *Does the test change or cancel planned treatment?* N = 4	Timing	Time to treatment N = 1	*"The median admission-treatment time interval for the BLUE group was 17 min, while it was 38 min for the control group. The difference between the two groups was statistically significant (P < .0001)"* (Seyedhosseini et al 2017[36])
	Management/ decisions	Number of therapeutic or management alternations decisions based on POCUS N = 2	*"Among the 756 patients, 76 (10%) required at least 1 immediate treatment. The global therapeutic impact of the initial imaging workup was 10%, and was considered to be appropriate in 75 (99%) patients."* (Zieleskiewicz et al 2018[50])
		Appropriateness of the observed course of action N = 1	*"The primary outcome criterion was the level of appropriateness of the observed course of action as assessed by the expert panel by a simple binary outcome (appropriate or inappropriate)."* *". . . the expert panel considered the course of action appropriate in 493 of 510 cases (96.7%; 95% CI, 94.7%-98.0%)."* (Planquart et al 2022[51])
Level 5: Patient outcome efficacy *Do patients who take the test fare better than similar patient who do not?* N = 14	Surrogates (BNP, b-lines, severity scores)	B-lines reduction N = 2	*"After the 6-h treatment period, the number of patients with B-lines ≤ 15 was 14 (27.5%) in the usual care arm and 14 (25.0%) in the LUS-guided arm (P = 0.83). The total number of B-lines per patient at 6 h was also similar (35.4 ± 26.8 vs 34.3 ± 26.2; P = 0.82)."* (Pang et al 2021[31])
		Decrease in congestive parameters (NT-proBNP, symptoms, pulmonary congestion, cardiac filling pressures, cumulative fluid loss) N = 1	*". . . patients in the treatment arm had a significantly greater improvement in all decongestive parameters during treatment, including echocardiographic parameters, pulmonary congestion on LUS, natriuretic peptides, fluid loss, and symptoms compared with those in the standard care arm."* (Öhman et al 2017[52])

(Continued)

TABLE 3] *(Continued)*

Level	Measurement Construct	Measure/Indicator	Example From Included Studies
		Reduction in severity scores (ie, Shock Index or EWS) N = 1	*"The Shock Index (SI) improved by a similar degree during initial treatment in the control and POCUS groups (mean reduction in control 0.39, 95% CI 0.34 to 0.44 vs. POCUS 0.33, 0.29 to 0.38). The MEWS improved during resuscitation in each group, but with no meaningful difference between groups (mean reduction in control 2.56, 2.22 to 2.89 vs. POCUS 2.91, 2.49 to 3.32)." (Atkinson et al 2020[28])*
	Length of stay	ED length of stay N = 3	*"Unadjusted and adjusted HRs from the Cox regression analyses are presented in Table 2. Lung POCUS was not significantly associated with ED length of stay (adjusted HR, 1.11 [95% CI, 0.85-1.46]; P = 0.44) and time to disposition decision (adjusted HR, 1.05 [95% CI, 0.79-1.40]; P = 0.73)."* (Nakao et al 2020[53])
		Association between POCUS and time to admission request/ disposition N = 2	*"The primary outcome in this study was time to ED disposition, calculated from EHR timestamps of ED arrival and time of admission request."* *"Average treatment effects on the treated (ie, patients receiving ultrasonography) showed a statistically significant improvement in TTD when POC ultrasonography was performed within the time frame of 15 min to 1 h, with a reduction in TTD of 26.7 min (95% CI, 2.8-58.3)"* (Hall et al 2016[54])
	Composite	Composite of readmissions, ED visits, and days of outpatient follow-up 30 d postdischarge N = 1	*". . . the primary objective is to compare complications (hospital admissions, emergency department [ED] revisits, and length of outpatient follow-up) in the first 30 d after ED discharge in patients with confirmed COVID-19 who were managed with versus without lung ultrasound."* *"Use of the lung ultrasound was associated with a greater probability of hospital admission (odds ratio 5.63, 95% confidence interval 3.31 to 9.57; P < .001). However, it was not significantly associated with mortality or short-term complications."* (Gil-Rodrigo et al 2021[55])
	Mortality	30-d or discharge survival N = 1	*"We found no important difference between groups for the primary outcome of survival to 30 days or hospital discharge for the 270 patients (98.9%) for whom follow-up was complete. One hundred four of 136 patients (76.5%; 95% CI, 68.4% to 83.3%) in the point-of-care ultrasonography group survived compared with 102 of 134 patients (76.1%; 95% CI, 68.0% to 83.1%) in the control group (difference 0.35%; 95% CI, −10.2% to 11.0%)."* (Atkinson et al 2018[29])
		28-d mortality N = 1	*"The 28-day mortality rate was not significantly different between the two groups (50.6% vs. 60.0%)."* (Li et al 2021[26])
	Patient-reported	Patient-rated level of discomfort N = 1	*"The median patient-rated level of discomfort for all three types of POCUS was 1 (IQR 1-1, range 1-8). The proportion of patients rating the level of discomfort two or lower was: FATE 96.7% (95% CI, 94.5-98.8%), FLUS 98.2% (95% CI, 96.5-99.8%) and LCU 98.2%*

(Continued)

TABLE 3] *(Continued)*

Level	Measurement Construct	Measure/Indicator	Example From Included Studies
			(95 % CI, 96.5-99.8%). The proportion of patients rating the level of discomfort two or lower for both the heart, lung and deep vein examinations was 95.2% (95% CI, 92.6-97.8%).” (Laursen et al 2015[56])
	Patient safety audits	Prevalence of the perceived impact of POCUS on morbidity and mortality N = 1	*“POCUS was used in 27% (20/75, 95% CI, 17-38%) and not used in 73% (55/75, 95% CI, 62-83%) (Figure 1). In cases where POCUS was not used, retrospective review determined that if POCUS had been used it would have “likely prevented the M&M” in 45% (25/55, 95% CI, 32-59%).”* (Goldsmith et al 2020[57])

Credit is given to Parker et al[58] for conceptualizing this table format. BLUE = Bedside Lung Ultrasound in Emergency; BNP = B-type natriuretic peptide; CP = chest pain; CTPA = computed tomography pulmonary angiography; EHR = electronic health record; EWS = Early Warning Score; FATE = Focus Assessed Transthoracic Echocardiography; FLUS = focused lung ultrasound; HR = hazard ratio; LCU = limited compression ultrasonography; IQR = interquartile range; LUS = lung ultrasound; MEWS = Modified Early Warning Score; NT-proBNP = N-terminal pro–B-type natriuretic peptide; PE = pulmonary embolism; POC = point-of-care; POCUS = point-of-care ultrasound; SOB = shortness of breath; TTD = time to disposition request.

given the higher numbers in Level 5 compared with Level 4 (14 vs 4 studies). This illustrates the lack of evidence that diagnostic improvements caused by LUS lead to actual changes regarding clinical decisions on treatment or next-line diagnostic tests. Considering the hierarchical model by F&T, this approach could potentially mitigate researchers from taking leaps to design Level 5 or 6 studies with high risk of futility, while LUS has not yet performed well on Level 4.

Mortality is a clinical utility outcome that is often called for.[12,61] Correspondingly, mortality was the primary outcome in two studies on F&T Level 5.[29,62] They both investigated point-of-care ultrasound in shock where the patient mix is of high acuity and short-term mortality is not rare. However, length of stay in the ED or time to disposition was the dominating primary outcome on F&T Level 5, and this was prevalent in studies that included stable patients in the ED. Such a distinction between high-acuity and stable ED study populations will likely be beneficial when searching for future meaningful outcomes because although LUS might directly cause timely treatment alterations, improving mortality in the first, it possibly has other purposes in the latter (ie, time or cost benefits).

The ultrasound applications were notably heterogeneous. We identified a wide range of LUS protocols used. The two most frequent protocols were used in only 131 (32%) of 405 studies, or when excluding studies not reporting the LUS protocol (131 of 329 [40%]). This LUS protocol variation and potential equipoise have been the research scope of at least five comparative studies included in this review.[63-67]

The methodologic features were, not surprisingly, reported heterogeneously and incompletely. Diagnostic accuracy evidence, in general, and in point-of-care ultrasound research specifically, has historically suffered from poor reporting.[68,69] In point-of-care ultrasound research, a specific focus promoting reporting guidelines and investigator reporting responsibilities has been cultivated.[69-71] Sonographer number, experience, and patient relation should be considered key characteristics for describing LUS as a highly operator-dependent index test, but these were often not clearly reported. This absence may have caused the need for multiple study replicates, thereby contributing to a substantially high number of F&T Level 2 studies.

Future research in LUS in EM should strive to fill in the gaps illuminated in this mapping. We suggest that researchers aim for F&T levels that have not yet

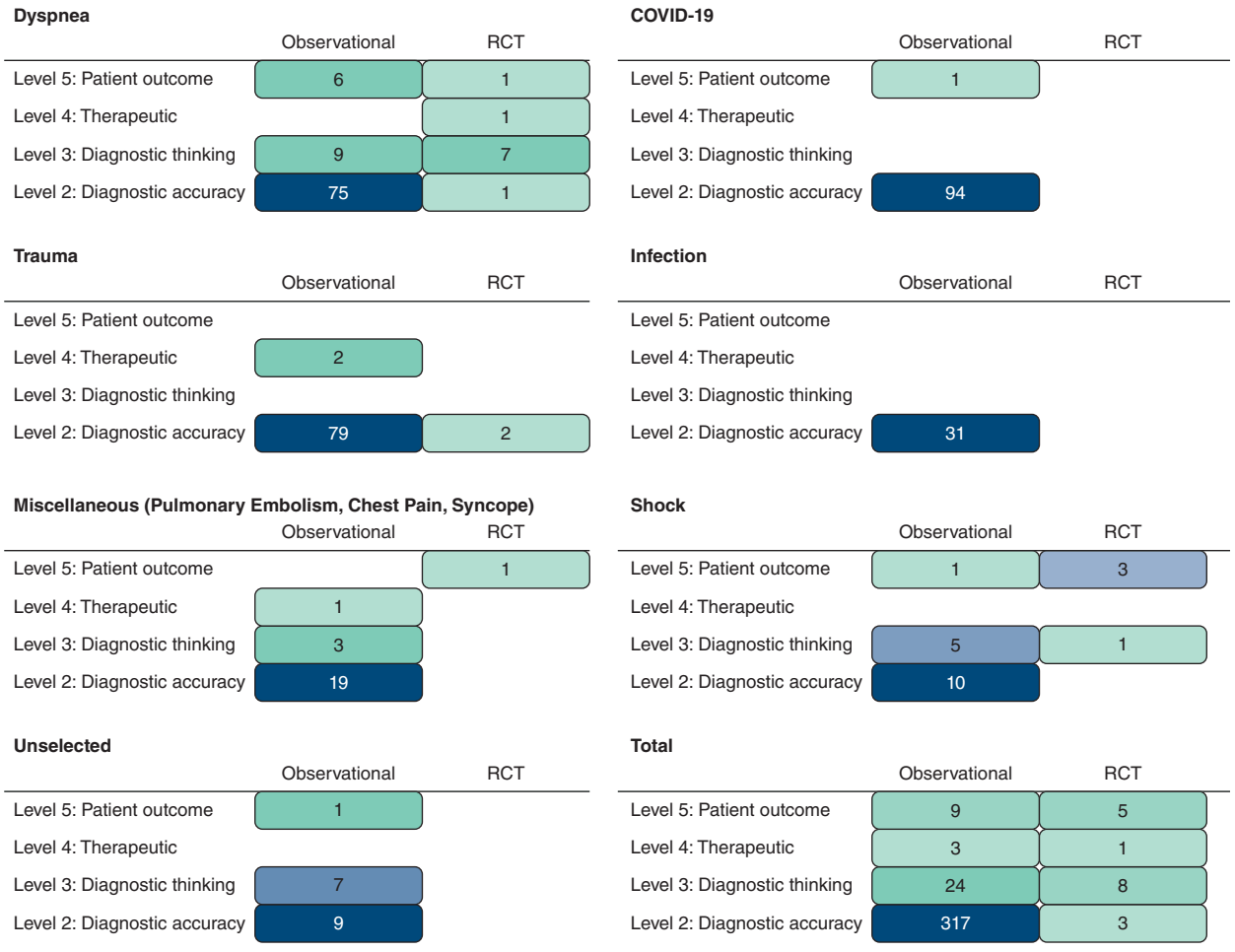

Figure 3 – *Study design and Fryback and Thornbury levels across topics. RCT = randomized controlled trial.*

been fully explored. Likewise, in doing so, randomized designs will expectantly become more represented. We advise researchers in LUS and EM to explore outcomes, such as patient-reported outcomes, costs, hospital-free days, and organ failure markers, together with other surrogate biomarkers. Some of these were found among the secondary outcomes in the included studies but rarely targeted as the primary outcome.

This study also has some limitations. First, the observational study design classification may not seem the most appropriate. Theoretically, they are often separated into cohort, case-control, cross-sectional, and diagnostic accuracy studies as distinct categories. However, because both diagnostic accuracy studies and observational studies tend to have their study designs poorly reported, we incorporated the broader nomenclature "observational study" to facilitate verbatim extraction.[72-74]

Second, the interrater agreement was poor when extracting study design and the F&T level. We suspect most of our disagreements are a result of studies' imprecision in the reporting of their primary outcomes, given the high disagreement rate attributable to "unclear" labels. Anecdotally, we believe that literature with primary outcomes from higher F&T levels or RCTs tend have a higher quality of reporting. Furthermore, for the creation of Table 3, the first author scrutinized all primary outcome measures assessed with F&T Levels 3 to 6 and reclassified, where appropriate, the level to synthesize a homogeneous overview. Under those assumptions, we deem the risk to be low for severe misclassifications in the database or conclusions presented.

Third, we considered only primary outcome measures for the F&T categorization. Primary outcome measures are, by definition, the estimate that researchers strive to add the most confidence into. However, we recognize

that secondary outcomes occasionally might be estimated with enough confidence and clinically meaningful differences to provide solid evidence and, therefore, should also be reflected in an impact on the F&T categorization. We regarded these incidents as rare. Aside from this potential for underestimating F&T distributions, misclassification clearly exists in this variable, given the poor reporting on outcome rationales and sample size determinations.

Fourth, despite independent title/abstract screening, studies may be missed. Index terms and key words are not well established for the point-of-care ultrasound field, leaving a high dependency on the title and abstract review. The search strategy included four primary conditions (ultrasound, point-of-care, lung, and ED), of which lung and point-of-care tend to be inadequately reported in abstracts. Therefore, we created another record library including all citations and references that the first author screened. Papers reporting either unspecified LUS or unspecified point-of-care ultrasound were screened in full text. We believe that handsearching has minimized the risk of excluding relevant amounts of data or systematically missing studies from any specific research niches, study designs, or study outcomes.

Finally, in line with the scoping aim of this review, we omitted any appraisal of the risk of bias and confidence in estimates (ie, Grading of Recommendations, Assessment, Development, and Evaluation tool). We conclude that studies on F&T Level 2 have been produced in abundance, but we cannot exclude the possibility that the reproduction of studies of this nature has been merited because of a high risk of bias in the existing literature.

Interpretation

Observational studies on F&T Level 2 have been produced in abundance, leaving a paucity of research exploring clinical utility. Few RCTs have been conducted within the overall field, which is likely associated with the low proportion of studies exploring the causal relationship between LUS in EM and clinical outcomes. Research exploring F&T Level 5 to 6 outcomes has high risks of futility because research on Level 4 (eg, changes to clinical decisions) does not seem to be well established at this time. While continuing along the diagnostic "chain of evidence," it is also important for researchers to define and report more homogeneous LUS protocols, the treating physicians' sonographic role and skills, and diagnostic roles for LUS.

Funding/Support

This study is funded by the the health region, Central Denmark Region, Denmark.

Financial/Nonfinancial Disclosures

The authors have reported to *CHEST* the following: S. H. O. reports a relationship with Danish Society for Ultrasound in General Practice that includes travel reimbursement, and a relationship with USabcd that includes speaking and lecture fees. M. D. A. reports relationships with the Danish Society for Ultrasound in General Practice and the Danish Emergency Medical Conference 10 (DEMC10) that include travel reimbursement. J. W. reports a relationship with DEMC10 that includes travel reimbursement. I. W. Y. M. reports a relationship with Research Chair, the John A. Buchanan Chair in General Internal Medicine, University of Calgary that includes funding grants, relationships with the 3rd Vice President of the American Institute of Ultrasound in Medicine and with the Governor, Alberta Chapter, American College of Physicians that include board membership, and relationships with American College of Physicians, the American Institute of Ultrasound in Medicine, Cornell University, University of Alberta, Sonography Canada, the Canadian Society of Internal Medicine, the Canadian Thoracic Society, American Society of Regional Anesthesia and Pain Medicine, the International Pediatric Nephrology Association, and the Canadian Rheumatology Ultrasound Society that include: speaking and lecture fees. None declared (A. H. C., H. K., B. L., R. A., M. H. L., A. H. K., M. B. C., C. F., L. T., A. R., R. L., J. D.).

Acknowledgments

Author contributions: The corresponding author accepts full responsibility for the conduct of the study, had access to the data, and controlled the decision to publish. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. Individual author contributions were as follows: S. H. O., drafting protocol, systematic literature search, title/abstract and full-text screening, data extraction, tables and figures, scoping synthesis, and drafting the manuscript; A. H. C., title/abstract and full-text screening, and review plus counseling of protocol and manuscript; H.K. and B. L., review plus counseling of protocol and manuscript; S. H. S., R. A., M. D. A., M. H. L., A. H. K., M. B. C., C. F., and L. T., J. D., and I. W. Y. M., data extraction, and review plus counseling of manuscript; R. L. and A. R., title/abstract and full-text screening, data extraction, and review plus counseling of manuscript; and J.W., review plus counseling of protocol, title/abstract and full-text screening upon disagreement,

data extraction, and review plus counseling of manuscript.

Role of the sponsors: The sponsor has no role in designing or executing the study or interpreting, writing, or submitting the manuscript.

Other contributions: The authors thank librarian Helene Sognstrup (AU Library, Health Sciences, Aarhus University, Denmark) for consultancy on the search strategy.

Additional information: The e-Appendix is available under "Supplementary Data."

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