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Ultrasound in Emergency Medicine

LUNG ULTRASOUND FOR THE EMERGENCY DIAGNOSIS OF PNEUMONIA, ACUTE HEART FAILURE, AND EXACERBATIONS OF CHRONIC OBSTRUCTIVE PULMONARY DISEASE/ASTHMA IN ADULTS: A SYSTEMATIC REVIEW AND META-ANALYSIS

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☐ **Abstract—Background: Lung ultrasound can accelerate the diagnosis of life-threatening diseases in adults with respiratory symptoms. Objective: Systematically review the accuracy of lung ultrasonography (LUS) for emergency diagnosis of pneumonia, acute heart failure, and exacerbation of chronic obstructive pulmonary disease (COPD)/asthma in adults. Methods: PubMed, Embase, Scopus, Web of Science, and LILACS (Literatura Latino Americana e do Caribe em Ciências da Saúde; until 2016) were searched for prospective diagnostic accuracy studies. Rutter-Gatsonis hierarchical summary receiver operating characteristic method was used to measure the overall accuracy of LUS and Reitsma bivariate model to measure the accuracy of the different sonographic signs. This review was previously registered in PROSPERO (Centre for Reviews and Dissemination, University of York, York, UK; CRD42016048085). Results: Twenty-five studies were included: 14 assessing pneumonia, 14 assessing acute heart failure, and four assessing exacerbations of COPD/asthma. The area under the summary receiver operating characteristic curve of LUS was 0.948 for pneumonia, 0.914 for acute heart failure, and 0.906 for exacerbations of COPD/asthma. In patients suspected to have pneumonia, *consolidation* had sensitivity of 0.82 (95% confidence interval [CI] 0.74–0.88) and specificity of 0.94 (95% CI 0.85–0.98) for this disease. In acutely dyspneic patients, *modified diffuse interstitial syndrome* had sensitivity of 0.90 (95% CI 0.87–0.93) and specificity of 0.93 (95% CI 0.91–0.95) for acute heart failure, whereas *B-profile* had sensitivity of 0.93 (95% CI 0.72–0.98) and specificity of 0.92 (95% CI 0.79–0.97) for this disease in patients with respiratory failure. In patients with acute dyspnea or respiratory failure, the *A-profile without PLAPS* (posterior-lateral alveolar pleural syndrome) had sensitivity of 0.78 (95% CI 0.67–0.86) and specificity of 0.94 (95% CI 0.89–0.97) for exacerbations of COPD/asthma. Conclusion: Lung ultrasound is an accurate tool for the emergency diagnosis of pneumonia, acute heart failure, and exacerbations of COPD/asthma.** **© 2018 Elsevier Inc. All rights reserved.**

☐ **Keywords—lung ultrasound; diagnostic accuracy; pneumonia; acute heart failure; chronic pulmonary obstructive disease; asthma**

INTRODUCTION

Acute respiratory symptoms are frequent causes of emergency department (ED) visits, and respiratory impairment is a leading cause of hospital ward and intensive care unit (ICU) admissions. The differential diagnosis includes common pulmonary and cardiovascular diseases such as pneumonia, exacerbations of chronic pulmonary diseases, and acute heart failure syndromes, which may lead to rapid clinical deterioration. Thus, an immediate

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and accurate diagnosis is critical, because failure of, or delay in, diagnoses and treatment can have detrimental effects on patients. Delay in administering adequate antimicrobial therapy can increase the mortality in patients with pneumonia, and inadequate administration of beta-agonists can impair the cardiovascular function in patients with acute heart failure (1,2).

Chest radiography (CXR) is currently the first diagnostic imaging approach in patients with acute respiratory symptoms. However, several studies report CXR having poor sensitivity for detecting common respiratory diseases such as pneumonia and pulmonary edema from acute heart failure (3,4). Chest computed tomography (CCT) overcomes this limitation but increases costs and exposure to radiation, and patients need to be transported to the radiology department (5).

In the past decade, lung ultrasound (LUS) has attracted attention in emergency and intensive care medicine. It is radiation free, can be performed at the bedside in a few minutes, and can be interpreted in real time for multiple diagnoses. Along with other point-of-care ultrasound modalities, LUS accelerates the diagnostic process, increases the rate of correct diagnoses, and ensures appropriate treatment in the first hours after arrival at the ED (6,7). However, diagnostic accuracy studies have assessed different sonographic signs and subgroups of patients, with different values of sensitivity and specificity, even for the same target disease (8–10).

The aim of this systematic review and meta-analysis was to assess the accuracy of LUS for the emergency diagnosis of the most common diseases in adults with respiratory symptoms. We systematically reviewed the literature for prospective diagnostic accuracy studies of LUS for pneumonia, acute heart failure, and exacerbations of chronic obstructive pulmonary disease (COPD)/asthma. In addition to the overall diagnostic accuracy of LUS for these diseases, we measured the individual diagnostic accuracy of the different sonographic signs that were presented in the literature.

MATERIALS AND METHODS

The protocol of this review was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO; Centre for Reviews and Dissemination, University of York, York, UK; CRD42016048085). The review is reported according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (11).

Two independent authors (LJS and RRMB) selected the studies, extracted their data, and assessed their risk of bias and applicability concerns. Discrepancies were resolved by consensus. When a consensus could not be reached, a third author (RM) resolved the issue.

Data Sources and Search

With the aid of a biomedical librarian, PubMed, Embase, Scopus, Web of Science, and LILACS (Literatura Latino Americana e do Caribe em Ciências da Saúde) were searched for articles published up to December 2016. Key words covered concepts related to ultrasound, lung/pleura, and ED/ICU. (See Supplementary Table 1, available online, for the final search strategy.) The lists of bibliographical references of other systematic reviews and relevant studies were also reviewed for additional articles.

Study Selection

Titles and abstracts of all records were screened for any violation of the inclusion criteria. The full text of the remaining studies were reviewed for the presence of all inclusion criteria. In addition, we manually checked the citations of other systematic reviews and studies finally included in the review.

Studies were included if they met the following criteria: language of publication–English; design–prospective diagnostic accuracy study (not case-control design); population and settings–adults (≥16 years old) in EDs or ICUs; index test–LUS with the description of the sonographic sign(s) of positivity; reference standard–diagnostic strategies including a radiological imaging of the chest; target diseases–pneumonia (non-ventilator-associated), acute heart failure, and exacerbation of COPD or asthma. Our primary outcome was the number of true and false positives, and true and false negatives. We excluded studies in which the unit of analysis was not the patient, for example, those considering separately the two sides of the thorax or pulmonary areas.

As clinical judgment is essential when the diagnosis represents a clinical event and not only a morphological event, the final diagnosis by experts was considered as an appropriate reference standard. For pneumonia, we considered diagnostic strategies including CXR or CCT as an appropriate reference standard, but not CXR alone.

Data Extraction

Using a standardized form, the following data were extracted from the full text of the included articles:

- Study information: Year of publication, geographical location, and characteristics of the hospital settings
- Characteristics of the participants: Inclusion criteria, prevalence of the diseases, age, and sex
- Ultrasound examination: Sonographic signs of positivity, chest areas scanned, transducer formats, and frequencies and expertise of performers

- Reference standard: Diagnostic criteria for all reference methods
- Results: Numbers of true and false positive and true and false negative results

Methodological Quality Assessment

The included studies were assessed for their risk of bias and applicability concerns using version 2 of the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool (12).

Data Synthesis

Meta-analytical summaries were performed using random-effects hierarchical models (13). The overall diagnostic accuracy of the LUS (independently from the sonographic signs) was assessed using the Rutter–Gatsonis hierarchical summary receiver operating characteristic method (14). This method estimated the area under the curve (AUC) and 95% confidence interval (CI) of the overall sensitivity and specificity. The individual diagnostic accuracies of the different sonographic signs were assessed using the Reitsma bivariate model (15). This model estimates the summary values of sensitivity and specificity. In addition, we derived the summary values of positive likelihood ratio and negative likelihood ratio. Studies with zero cells received a 0.5 correction for all cells to avoid fitting errors.

Forest plots and summary receiver operating characteristics curves (Moses-Littenberg method) were visually explored for potential sources of heterogeneity (13). Characteristics of the patients and settings, reference standards, LUS operator, and the individual questions of QUADAS-2 were assessed. Interaction between a suspected variable and diagnostic accuracy (sensitivity and specificity) was tested by using a bivariate meta-regression (13). All statistical analyses were performed using the MADA package for R version 3.2.2 (R Foundation for Statistical Computing). A level of significance (α) of 0.05 was used for the statistical tests.

RESULTS

Characteristics of the Included Studies

From the 11,017 titles and abstracts screened, 25 studies involving 4241 patients were included. Fourteen studies assessed pneumonia (n = 1867 patients), 14 assessed acute heart failure (n = 2778 patients), and four studies assessed exacerbation of COPD or asthma (n = 527 patients) (16–40). Figure 1 shows the study selection process.

All included studies were published between 2008 and 2016. Most of them were European, and only three were multi-center (21,26,38). The main characteristics of the included studies appear in Table 1 (16–37).

Patients and prevalence. The prevalence of the target diseases varied across the studies, even in patients with the same inclusion criteria. Pneumonia had prevalence ranging from 30% to 85% in patients with respiratory symptoms indicative of this disease, from 21% to 39% in patients with acute dyspnea, and from 32% to 49% in patients with respiratory failure (16–29). Prevalence of acute heart failure varied from 35% to 88% in patients with acute dyspnea and from 24% to 40% in patients with respiratory failure (19–21,30–40). Exacerbation of COPD/asthma had prevalence ranging from 11% to 32% in patients with respiratory failure, and was 11% in the study that assessed patients with acute dyspnea (18–21).

Reference standard. Although CCT is considered the gold standard for diagnosing lung pneumonic infiltrates, only three studies used this method as the reference standard, and two other studies reported secondary results of the subgroup of patients who underwent CCT due to clinical indication (16,17,22,23,25). Thus, the most common reference standard was the final diagnosis (Table 1). In general, this method was applied by two independent experts at the end of hospitalization through the review of all clinical data, laboratory results, CXR, and CCT (when available), but excluding the LUS images. As there is no unquestionable gold standard method for diagnosing acute heart failure and exacerbation of COPD or asthma, all selected studies used the final diagnosis as the reference standard for these target diseases (Table 1).

Sonographic signs and LUS examination. Characteristics of LUS examination varied across the studies (Table 2) (16–40). In general, studies in patients suspected to have pneumonia performed a comprehensive LUS examination. Anterior, lateral, and posterior regions were scanned. We used the term *consolidation* to refer to lobar or sub-lobar sonographic consolidations, usually with air bronchograms, assessed in these patients. The unilateral or focal presence of scans with three or more B-lines, named *focal interstitial syndrome* was also assessed in these patients, alone or in parallel with the *consolidation*.

Four studies in patients with dyspnea or respiratory failure assessed pneumonia and exacerbation of COPD or asthma (18–21). From these, three studies also assessed acute heart failure (19–21). They used a sequential protocol for LUS examination, mainly according to the bedside lung ultrasound examination (BLUE) protocol (41). Excluding the deep vein ultrasound, not assessed in this review, this protocol involves primary scans of the

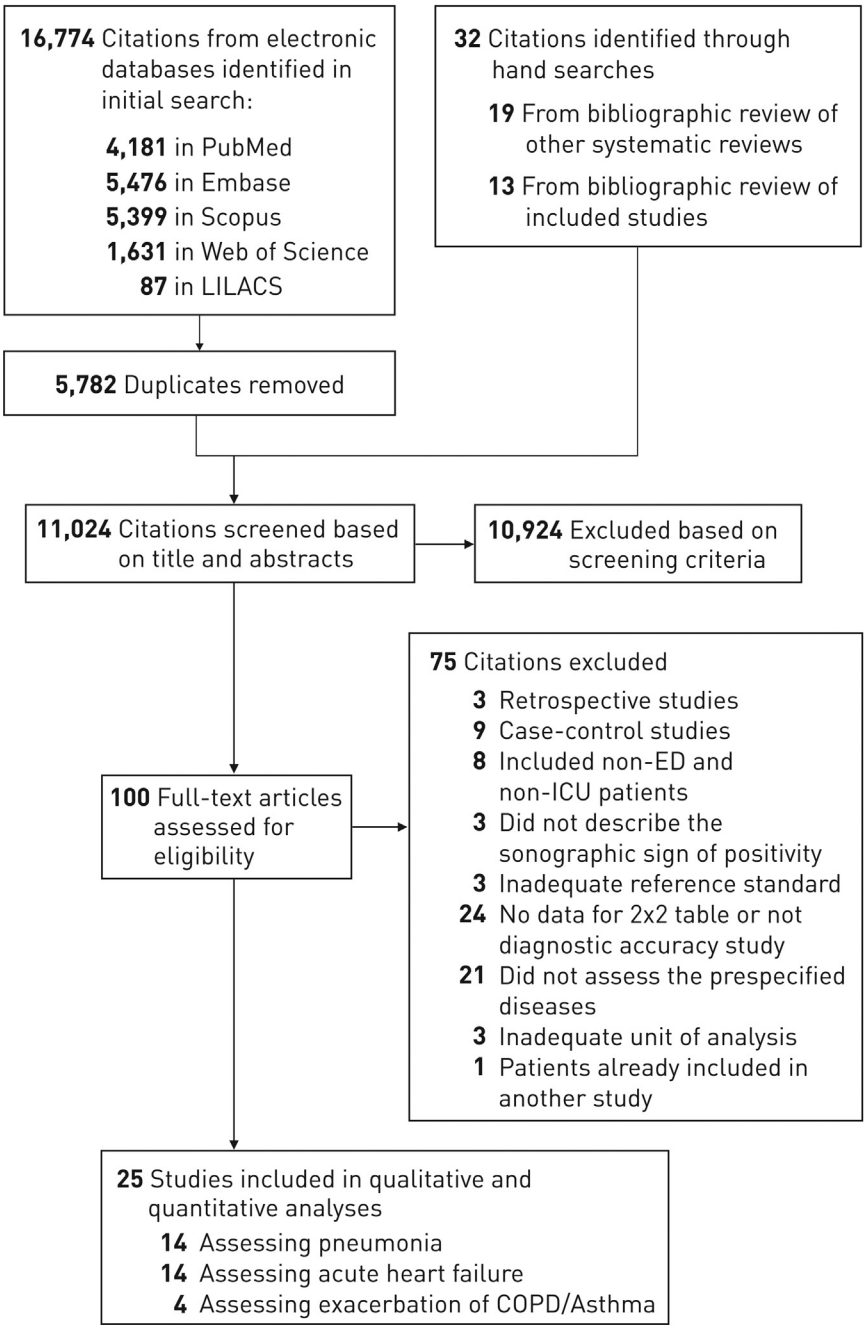

Figure 1. Flow diagram of study selection process. *Some studies assessed more than one target disease. LILACS = Literatura Latino Americana e do Caribe em Ciências da Saúde; ED = emergency department; ICU = intensive care unit; COPD = chronic obstructive pulmonary disease.

anterior thoracic regions. When no diagnostic profile is found in anterior regions, the examination progresses to search consolidations or pleural effusions in the posterior-lateral thoracic regions (posterior-lateral alveolar pleural syndrome [PLAPS]). According to the BLUE protocol, four sonographic patterns can be assessed to diagnose pneumonia: 1) *C-profile*: presence of alveolar consolidation, usually small and hypoechoic, in the anterior thoracic regions; 2) *Focal interstitial syndrome*: unilateral or focal presence of scans with three or more B-lines, also referred to as *A/B-profile*; 3) *B′-profile*: predominance of B lines associated with absence of lung sliding in anterior thoracic regions; and 4) *A-profile with PLAPS*: a normal examination of the anterior thoracic regions (lung sliding present and predominance of A-lines: *A-profile*) and the presence of consolidations or pleural effusions in the posterior lateral

Table 1. Characteristics of the Studies Included in the Systematic Review

Study	Geographical Location	Setting	Main Inclusion Criteria of Patients	Age (Years)*	n	Disease Assessed and Prevalence	Reference Standard
Bourcier et al., 2014 (16)	France	ED	Symptoms or signs of pneumonia†	77 (15)	144	Pneumonia, 85%	Final diagnosis‡
Cortellaro et al., 2012 (17)	Italy	ED	Symptoms or signs of pneumonia†	69 (±18)	120	Pneumonia, 67%	Final diagnosis‡
Liu et al., 2015 (22)	China	ED	Symptoms or signs of pneumonia†	71 (36–88)	179	Pneumonia, 62%	Chest tomography
Nafae et al., 2013 (23)	Egypt	ICU	Symptoms or signs of pneumonia†	Not reported	100	Pneumonia, 80%	Chest tomography
Nazemi et al., 2014 (24)	Iran	ED	Symptoms or signs of pneumonia†	61 (±17)	146	Pneumonia, 50%	Final diagnosis‡
Nazerian et al., 2015 (25)	Italy	ED	Symptoms or signs of pneumonia†	71 (±14)	285	Pneumonia, 30%	Chest tomography
Pagano et al., 2015 (26)	Italy§	ED	Symptoms or signs of pneumonia†	58 (±21)	105	Pneumonia, 65%	Final diagnosis‡
Parlamento et al., 2009 (27)	Italy	ED	Symptoms or signs of pneumonia†	61 (±22)	49	Pneumonia, 65%	Chest tomography or chest radiography
Ticinesi et al., 2016 (28)	Italy	ED	Symptoms or signs of pneumonia† in elderly with two or more chronic diseases	83 (±9)	169	Pneumonia, 57%	Final diagnosis‡
Unluer et al., 2013 (29)	Turkey	ED	Acute dyspnea	68 (±11)	72	Pneumonia, 39%	Chest tomography or chest radiography
Daabis et al., 2014 (18)	Egypt	ICU	Acute respiratory failure	49 (±16)	100	Pneumonia, 49% Exacerbation of COPD/asthma, 21%	Final diagnosis‡
Dexheimer et al., 2015 (19)	Brazil	ICU	Acute respiratory failure	73 (±15)	37	Pneumonia, 46% Exacerbation of COPD/asthma, 11% Acute heart failure, 40%	Final diagnosis‡
Gallard et al., 2015 (20)	France	ED	Acute dyspnea	80	130	Pneumonia: 21% Exacerbation of COPD/asthma, 11% Acute heart failure, 62%	Final diagnosis‡
Lichtenstein et al., 2008 (21)	France§	ICU	Acute respiratory failure	68 (±16)	260	Pneumonia, 32% Exacerbation of COPD/asthma, 32% Acute heart failure, 24%	Final diagnosis‡
Aggarwal et al., 2016 (30)	India	ED	Acute dyspnea or cardiopathy	64	42	Acute heart failure, 88%	Final diagnosis‡
Anderson et al., 2013 (31)	United States	ED	Acute dyspnea	62 (53–91)	101	Acute heart failure, 44%	Final diagnosis‡
Chiem et al., 2015 (32)	United States	ED	Acute dyspnea	55 (±12)	380	Acute heart failure, 35%	Final diagnosis‡
Cibinel et al., 2012 (33)	Italy	ED	Acute dyspnea	82 (29–94)	56	Acute heart failure, 48%	Final diagnosis‡
Glöckner et al., 2016 (34)	Germany	ED	Acute dyspnea	72 (60–80)	25	Acute heart failure, 60%	Final diagnosis‡
Kajimoto et al., 2012 (35)	Japan	ED	Acute dyspnea	78 (±10)	90	Acute heart failure, 59%	Final diagnosis‡
Liteplo et al., 2009 (36)	United States	ED	Acute dyspnea	74 (±14)	94	Acute heart failure, 42%	Final diagnosis‡
Mumoli et al., 2016 (37)	Italy	ED	Acute dyspnea	78 (±13)	226	Acute heart failure, 47%	Final diagnosis‡

(*Continued*)

Table 1. Continued

Study	Geographical Location	Setting	Main Inclusion Criteria of Patients	Age (Years)*	n	Disease Assessed and Prevalence	Reference Standard
Pivetta et al., 2015 (38)	Italy§	ED	Acute dyspnea	77	1005	Acute heart failure, 46%	Final diagnosis‡
Sartini et al., 2016 (39)	Italy	ED	Acute dyspnea	80 (±12)	236	Acute heart failure, 48%	Final diagnosis‡
Unluer et al., 2014 (40)	Turkey	ED	Acute dyspnea	70	90	Acute heart failure, 49%	Final diagnosis‡

ED = emergency department; ICU = intensive care unit; COPD = chronic obstructive pulmonary disease.
* Dispersion measures as reported by the studies.
† Symptoms or signs of pneumonia included: fever, cough, sputum production, pleuritic pain, dyspnea, and rales.
‡ The final diagnosis was made by experts through the review of all clinical, laboratory, and radiological data of the patient at the end of hospitalization.
§ Studies in two or more centers.

regions (PLAPS). The sonographic pattern assessed for exacerbations of COPD or asthma was the *A-profile without PLAPS*. This pattern consisted of a normal LUS examination of the anterior thoracic regions (predominance of A-lines with the presence of lung sliding: *A-profile*) and the absence of alveolar consolidations or pleural effusions in the posterior-lateral areas (*without PLAPS*). For acute heart failure, the *B-profile* was the only sonographic pattern assessed in the sequential LUS examination. This pattern consists of predominance of B-lines with the presence of lung sliding in anterior thoracic regions (Table 2).

In studies assessing only acute heart failure, patients with acute dyspnea were included. In general, anterior and lateral thoracic regions were scanned. Most of the studies scanned eight thoracic areas: anterior and lateral regions were separated by the anterior axillary lines and divided into upper and lower areas. The sonographic pattern primarily assessed was the *diffuse interstitial syndrome*, defined by the bilateral presence of two or more thoracic areas, which had positive scans for three or more B-lines. One study assessed a *modified diffuse interstitial syndrome* through a different lung ultrasound protocol (38). Three points in each hemithorax were scanned (second intercostal spaces at hemi-clavicular lines, forth intercostal spaces at anterior axillar lines, and fifth intercostal space at mid-axillar lines), and the result was deemed positive when two or more bilateral scans had three or more B-lines (Table 2). In addition, one study on patients with acute dyspnea assessed primarily the *B*-profile and two studies secondarily reported this pattern (32,36,40).

The reported experience and training of the LUS operators also varied widely among the studies. Studies assessing pneumonia included emergency medicine residents, trained emergency physicians, LUS expert emergency physicians, LUS expert intensivists, and radiologists. In addition to these operators, trained nurses, trained emergency ultrasound fellows, and cardiologists performed the LUS in studies assessing acute heart failure. Studies assessing exacerbation of COPD or asthma included trained emergency physicians, ultrasound expert intensivists, and trained physicians as LUS operators (Table 2).

Risk of Bias and Applicability Concerns

In general, the studies had low concerns about applicability in the three domains assessed. However, all studies had a high or unclear risk of bias in at least one domain of QUADAS-2 (Figure 2). The most compromised domain was patient selection. *Convenience sampling* and *inappropriate exclusion of patients* were the main causes of the high risk of selection bias. Flow and timing was the second most frequently compromised domain. *Nonapplication of the same reference standard for all patients* and *noninclusion of all patients in the analysis* were the main causes of the high risk of flow and timing bias. The main reason for the high risk of index test bias was not specifying the sonographic sign or pattern of positivity (threshold) in advance. The reference standard had a high risk of bias in two studies that were not blinded to the LUS (16,27).

Meta-analysis

Pneumonia. As shown in Figure 3, the overall diagnostic accuracy of LUS for pneumonia had an AUC of 0.948. The 95% CI of the overall effects estimates a sensitivity of approximately 0.85–0.95 and specificity of 0.75–0.90. Overall accuracy was similar (AUC of 0.942) when only studies that reported the results using CCT as the reference standard were considered (16,17,22,23,25). The summary of diagnostic accuracy of the main sonographic patterns of positivity for pneumonia appears in Table 3 (16–29). The accuracy of all reported sonographic patterns and the results of the individual studies on pneumonia can be seen in Supplementary Table 2 and in Supplementary Figure 1 (available online).

Table 2. Characteristics of Lung Ultrasound Examination in the Included Studies

Study	Ultrasound Transducer	Patient Position	Chest Areas Examined	Sonographic Sign of Positivity	Ultrasound Executor
Bourcier et al., 2014 (16)	Convex: 3–5 MHz	Supine and sitting	Eight areas (not specified)	PNM: Consolidation with air bronchograms or focal interstitial syndrome*	Trained emergency physicians
Cortellaro et al., 2012 (17)	Convex: 3.5 MHz	Supine and sitting or supine and lateral	Two areas (upper and lower) in each anterior and lateral region plus the posterior regions	PNM: Consolidation or focal interstitial syndrome*	LUS expert physician
Liu et al., 2015 (22)	Convex: 3.5–5.0 MHz	Not reported	All intercostal spaces from apex to diaphragm in hemi-clavicular, anterior axillar line, mid axillar line and para-vertebral line.	PNM: Consolidation with air bronchograms, focal interstitial syndrome*; C-profile† and pleural line abnormalities	Trained emergency physicians
Nafae et al., 2013 (23)	Convex: 3.5 MHz	Not reported	Two areas (upper and lower) in each anterior and lateral region plus the posterior regions	PNM: Consolidation with or without air bronchograms and focal interstitial syndrome*	Not reported
Nazemi et al., 2014 (24)	5 MHz	Not reported	Not reported	PNM: Consolidation with air bronchograms	Radiologists
Nazerian et al., 2015 (25)	Linear: 4–8 MHz, or Convex: 3.5–5 MHz	Supine, semi-recumbent or sitting	Two areas (upper and lower) in each antero-lateral and posterior region	PNM: Consolidation with or without air bronchograms	Experienced emergency or IM physicians and trained EM or IM residents
Pagano et al., 2015 (26)	Convex: 2–5 MHz	Supine or sitting	Two areas (upper and lower) in each anterior and lateral region plus the posterior regions if can sit	PNM: Consolidation with air bronchograms or focal interstitial syndrome*	LUS experienced physician
Parlamento et al., 2009 (27)	Convex: 3.5–5 MHz	Supine, sitting and lateral	Two areas (upper and lower) in each anterior and lateral region plus the posterior regions	PNM: Consolidations with air bronchograms	LUS expert emergency physician
Ticinesi et al., 2016 (28)	Convex: 2–5 MHz	Supine and sitting	Two areas (upper and lower) in each antero-lateral and posterior region	PNM: Consolidations with dynamic air bronchograms	Experienced emergency physician
Unluer et al., 2013 (29)	Micro-convex: 3.6 MHz	Not reported	Two areas (upper and lower) in each anterior region plus lateral and posterior region	PNM: Consolidation or focal interstitial syndrome*	Trained emergency physicians
Daabis et al., 2014 (18)	2.5 or 5.0 MHz	Supine or semi-recumbent	Sequential: Two areas (upper and lower) in each anterior, lateral and posterior region	PNM: C-profile†, or focal interstitial syndrome* or A-profile with PLAPS‡ COPD/Asthma: A-profile without PLAPS§	Not reported

(*Continued*)

Table 2. Continued

Study	Ultrasound Transducer	Patient Position	Chest Areas Examined	Sonographic Sign of Positivity	Ultrasound Executor
Dexheimer et al., 2015 (19)	Convex: 3–5 MHz	Semi-recumbent	Sequential: Two areas (upper and lower) in each anterior, lateral and posterior region	PNM: C profile†, or focal interstitial syndrome*, or A-profile with PLAPS‡ COPD/Asthma: A-profile without PLAPS§ AHF: B-profile‖	Trained physicians
Gallard et al., 2015 (20)	Convex: 3–5 MHz	Not reported	Sequential: Anterior, lateral and posterior regions	PNM: C-profile†, or focal interstitial syndrome*, or A-profile with unilateral PLAPS‡ COPD/Asthma: A-profile without PLAPS§ AHF: B-profile‖	Trained emergency physicians
Lichtenstein et al., 2008 (21)	Micro-convex: 5 MHz	Supine or semi-recumbent	Sequential: Anterior regions, and posterior-lateral regions if necessary	PNM: C-profile†, focal interstitial syndrome*, B′-profile¶, A-profile with PLAPS‡ and any of these signs COPD/Asthma: A-profile without PLAPS§ AHF: B-profile†	LUS expert intensivist
Aggarwal et al., 2016 (30)	Not reported	Not reported	Second and fifth intercostal spaces in para-sternal, hemi-clavicular, anterior axillar and mid axillar lines	AHF: More than five B-lines in total	Not reported
Anderson et al., 2013 (31)	Convex: 3–5 MHz	Not reported	Two areas (upper and lower) in each anterior and lateral region	AHF: Diffuse interstitial syndrome# and more than ten B-lines in total	Trained EUS fellows and fellowship
Chiem et al., 2015 (32)	Convex: 2–5 MHz	Not reported	Two areas (upper and lower) in each anterior and lateral region	AHF: Diffuse interstitial syndrome#	Trained emergency residents
Cibinel et al., 2012 (33)	Convex: 3.5 MHz	Supine or semi-recumbent	Two areas (upper and lower) in each anterior and lateral region	AHF: Diffuse interstitial syndrome# and pleural effusion	Emergency physicians
Glöckner et al., 2016 (34)	Phased array: 2–5 MHz	Not reported	Two areas (upper and lower) in each anterior and lateral region	AHF: Diffuse interstitial syndrome#	Experienced sonographers
Kajimoto et al., 2012 (35)	Phased array: 1.7–3.5 MHz	Supine or sitting	Two areas (upper and lower) in each anterior and lateral region	AHF: Diffuse interstitial syndrome#	Cardiologists
Liteplo et al., 2009 (36)	Convex: 2–5 MHz	Not reported	Two areas (upper and lower) in each anterior and lateral region	AHF: Diffuse interstitial syndrome#	Trained emergency physicians or medicine academics

(*Continued*)

Table 2. Continued

Study	Ultrasound Transducer	Patient Position	Chest Areas Examined	Sonographic Sign of Positivity	Ultrasound Executor
Mumoli et al., 2016 (37)	Convex: 2.2–5.5 MHz	Not reported	Two areas (upper and lower) in each anterior and lateral region	AHF: Diffuse interstitial syndrome#	Trained nurses
Pivetta et al., 2015 (38)	Convex: 3–5 MHz	Not reported	Second intercostal spaces at hemi-clavicular lines, forth intercostal spaces at anterior axillar lines and fifth intercostal space at mid axillar lines	AHF: Modified diffuse interstitial syndrome**	Experienced emergency physicians
Sartini et al., 2016 (39)	Convex: 3–5 MHz	Not reported	Second and fifth intercostal spaces at the hemi-clavicular, anterior axillar and mid axillar lines	AHF: Diffuse interstitial syndrome#	Experienced emergency physicians
Unluer et al., 2014 (40)	Micro-convex: 3.5 MHz	Not reported	Two areas (upper and lower) in each anterior and lateral region	AHF: B-profile‖	Trained nurses

PNM = pneumonia; COPD/asthma = exacerbation of chronic obstructive pulmonary disease or asthma; AHF = acute heart failure; PLAPS = posterior-lateral alveolar-pleural syndrome; EM = emergency medicine; LUS = lung ultrasound; IM = internal medicine; EUS = emergency ultrasound.
* Unilateral or focal presence of one or more scans with at least three B lines.
† Any alveolar consolidation in anterior thoracic areas. Most frequently small hypoechoic peripheral consolidations, without air bronchograms.
‡ Predominance of A-lines and presence of lung sliding in anterior thoracic areas and consolidation or pleural effusion in posterior-lateral areas.
§ Predominance of A-lines and presence of lung sliding in anterior thoracic areas without consolidation or pleural effusion in posterior-lateral areas.
‖ Predominance of B-lines in anterior thoracic regions and lung sliding present.
¶ Predominance of B-lines in anterior chest regions and lung sliding absent.
# Presence of scans with three or more B lines, in at least two chest areas bilaterally.
** Presence of three or more B-lines in at least two chest points bilaterally.

Six studies assessed the accuracy of *consolidation* in patients clinically suspected to have pneumonia (22–25,27,28). Summary sensitivity was 0.82 (95% CI 0.74–0.88) and specificity was 0.94 (95% CI 0.85–0.98). When only the three studies using the CCT as the reference standard were considered, the results were very similar, with sensitivity of 0.78 (95% CI 0.70–0.84) and specificity of 0.95 (95% CI 0.68–0.99) (22,23,25).

Five studies assessed the parallel presence of *consolidation* or *focal interstitial syndrome* in patients clinically suspected of having pneumonia or with acute dyspnea (16,17,23,26,29). Summary sensitivity was 0.96 (95% CI 0.90–0.98) and specificity was 0.74 (95% CI 0.55–0.87). Again, when only studies that reported results using CCT as the reference standard were considered, the results were similar, with sensitivity of 0.93 (95% CI 0.80–0.98) and specificity of 0.74 (95% CI 0.46–0.91) (16,17,23).

Three studies reported on the accuracy of the *C-profile* in patients with respiratory failure or suspected of having pneumonia, with summary sensitivity of 0.24 (95% CI 0.18–0.32) and specificity of 0.97 (95% CI 0.89–0.99) (18,21,22). Four studies assessed the presence of any pattern of the BLUE protocol in patients with dyspnea or respiratory failure, with summary sensitivity of 0.87 (95% CI 0.76–0.93) and specificity of 0.85 (95% CI 0.74–0.91) (18,21).

As can be noted in Supplementary Table 2 and in the forest plot in Supplementary Figure 1, the results of sensitivity and specificity were highly heterogeneous among the included studies on pneumonia, even for the same sonographic pattern of positivity. Two variables were suspected as sources of heterogeneity and were included in the bivariate meta-regression for pneumonia. The presence of a high or unclear risk of selection bias was correlated with a worse specificity ($p = 0.009$), and inappropriate exclusion of patients was not associated with heterogeneity ($p = 0.48$).

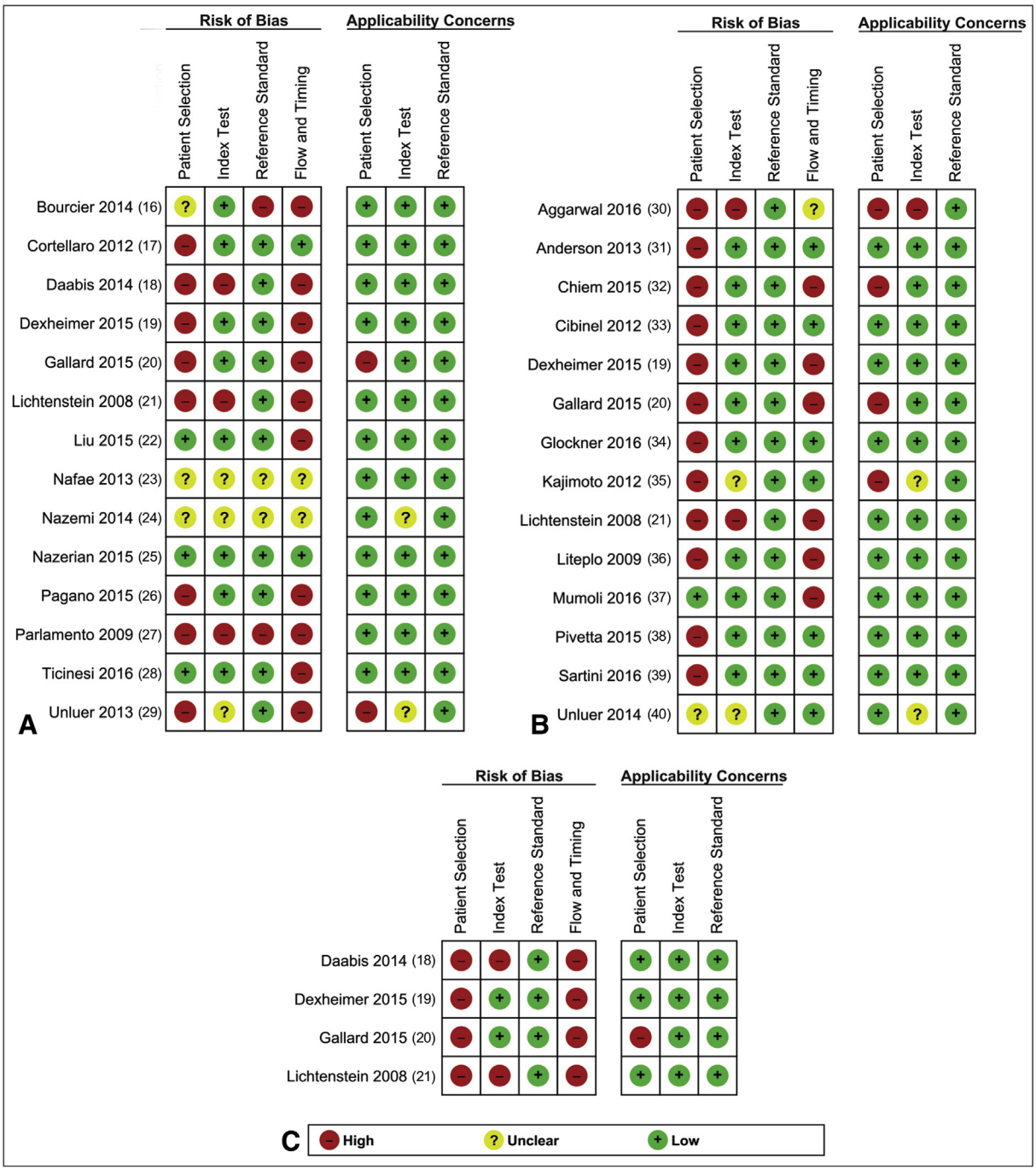

Figure 2. QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies, version 2) risk of bias and applicability concerns summary: review authors' judgments about each domain for each included study. (A) Studies assessing pneumonia (16–29); (B) Studies assessing acute heart failure (19–21,30–40); (C) Studies assessing exacerbations of COPD or asthma (18–21).

See Supplementary Tables 3 and 4 (available online) for further details.

Acute heart failure. Overall diagnostic accuracy of LUS for acute heart failure had an AUC of 0.914 (Figure 3). The 95% CI of the overall effects estimates a sensitivity of approximately 0.75–0.90 and specificity of 0.80–0.90. Diagnostic accuracy of main sonographic patterns appears in Table 4. For diagnostic accuracy of all sonographic patterns reported and results of individual studies, see Supplementary Table 5 and Supplementary Figure 2 (available online).

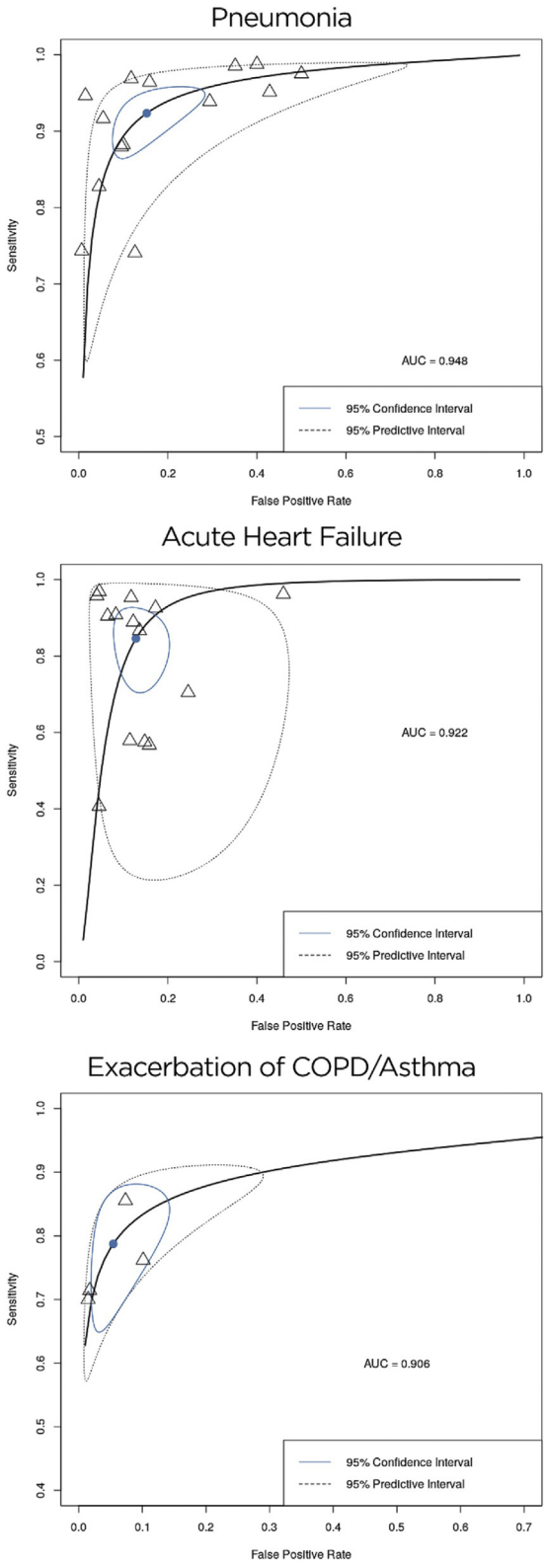

Figure 3. Hierarchical summary receiver operating characteristic (HSROC) curves for overall diagnostic accuracy of lung ultrasound for pneumonia, acute heart failure, and for exacerbations of chronic obstructive pulmonary disease (COPD)/asthma. AUC = area under the curve.

Eight studies reported the accuracy of the *diffuse interstitial syndrome* for acute heart failure in patients with acute dyspnea (31–37,39). Sensitivity was 0.73 (95% CI 0.48–0.89) and specificity was 0.84 (95% CI 0.76–0.90). In addition, one large study (n = 1005 patients) assessed the *modified diffuse interstitial syndrome*, with sensitivity of 0.90 (95% CI 0.87–0.93) and specificity of 0.93 (95% CI 0.91–0.95) (38).

Six studies assessed the *B-profile* in patients with acute dyspnea or respiratory failure (19–21,32,36,40). Sensitivity was 0.82 (95% CI 0.55–0.94) and specificity was 0.90 (95% CI 0.87–0.92). When only the two studies of patients with respiratory failure were analyzed, the *B-profile* had sensitivity of 0.93 (95% CI 0.72–0.98) and specificity of 0.92 (95% CI 0.79–0.97) (19,21).

As shown in Supplementary Table 5 and in the forest plot in Supplementary Figure 2, the selected studies had heterogenous results of sensitivity and specificity. Two variables were suspected as the sources of heterogeneity and were included in the bivariate meta-regression. The lack of reporting or not specifying the sonographic pattern of positivity in advance was correlated with a higher sensitivity (p = 0.01), and the inclusion of a consecutive sample of patients was correlated with a higher sensitivity (p = 0.008) in the analysis of diffuse interstitial syndrome. See Supplementary Tables 6 and 7 (available online) for more details.

Exacerbation of COPD/asthma. The *A-profile without PLAPS* was the only sonographic pattern assessed for exacerbation of COPD or asthma, and had sensitivity of 0.78 (95% CI 0.67–0.86) and specificity of 0.94 (95% CI 0.89–0.97) in patients with acute dyspnea or respiratory failure (Table 5). The AUC was 0.906 (Figure 3).

As shown in Table 5 and in the forest plot of Supplementary Figure 3, there was heterogeneity in the results of diagnostic accuracy of LUS for exacerbations of COPD or asthma, mainly for sensitivity. However, no variable was suspected as the source of heterogeneity in visual assessment, and we did not perform a meta-regression for this disease.

DISCUSSION

This study systematically reviewed the available literature for prospective studies on the accuracy of the LUS for the emergency diagnosis of pneumonia, acute heart failure, and exacerbations of COPD/asthma. Twenty-five studies were included, most of which had assessed pneumonia and acute heart failure. The studies were heterogeneous in their characteristics and results, and the overall methodological quality was low, demanding cautious interpretation of the findings. The meta-

Table 3. Diagnostic Accuracy of the Sonographic Patterns for Pneumonia

Sonographic Sign	Included Patients	Reference Standard	Number of Studies (References)	Confirmed and Total Patients	Sensitivity (95% CI)	Specificity (95% CI)	Positive LR (95% CI)	Negative LR (95% CI)
Consolidation	Clinically suspected for pneumonia	Final diagnosis, chest tomography, or chest tomography/ radiography	6 (22–25,27,28)	473/933	0.82 (0.74–0.88)	0.94 (0.85–0.98)	15.8 (5–51.7)	0.18 (0.11–0.30)
Consolidation	Clinically suspected for pneumonia	Chest tomography	3 (22,23,25)	279/564	0.78 (0.70–0.84)	0.95 (0.68–0.99)	15.9 (2.2–141)	0.22 (0.15–0.43)
Consolidation or focal interstitial syndrome*	Clinically suspect for pneumonia or with acute dyspnea	Final diagnosis, chest tomography, or chest tomography/ radiography	5 (16,17,23,26,29)	380/541	0.96 (0.90–0.98)	0.74 (0.55–0.87)	3.76 (2.0–7.8)	0.05 (0.01–0.18)
Consolidation or focal interstitial syndrome*	Clinically suspect for pneumonia or with acute dyspnea	Chest tomography	3 (16,17,23)	129/159	0.93 (0.80–0.98)	0.74 (0.46–0.91)	3.7 (1.5–11)	0.08 (0.02–0.41)
Focal interstitial syndrome*	Clinically suspected for pneumonia or with respiratory failure	Final diagnosis or chest tomography	4 (18,21–23)	324/639	0.12 (0.03–0.32)	0.97 (0.85–0.99)	4.0 (0.20–32)	0.90 (0.68–1.14)
C-profile†	Clinically suspected for pneumonia or with respiratory failure	Final diagnosis or chest tomography	3 (18,21,22)	244/539	0.24 (0.18–0.32)	0.97 (0.89–0.99)	10.65 (1.7–64)	0.77 (0.68–0.91)
A-profile with PLAPS‡	Respiratory failure or acute dyspnea	Final diagnosis	2 (18,21)	132/360	0.50 (0.30–0.70)	0.86 (0.67–0.95)	3.72 (0.9–14.2)	0.57 (0.30–1.02)
Any profile of the BLUE protocol§	Respiratory failure or acute dyspnea	Final diagnosis	4 (18–21)	176/527	0.87 (0.76–0.93)	0.85 (0.74–0.91)	5.93 (3–11.5)	0.14 (0.07–0.31)

CI = confidence interval; LR = likelihood ratio; PLAPS = posterior-lateral alveolar pleural syndrome posterior-lateral alveolar pleural syndrome; BLUE = bedside lung ultrasound examination.

* Unilateral or focal presence of one or more scans with at least three B-lines.

† Any alveolar consolidation in anterior chest areas. Most frequently small hypoechoic peripheral consolidations, without air bronchograms.

‡ Absence of B-lines and presence of lung sliding in anterior thoracic areas associated with consolidation or pleural effusion in posterior-lateral thoracic areas.

§ BLUE protocol consists of a sequential examination of the anterior thoracic regions and, if necessary, in posterior-lateral ones. Sonographic patterns of pneumonia in the anterior thoracic regions are: C-profile, unilateral (focal) interstitial syndrome, and B′-profile; and including the posterior-lateral areas is the A-profile plus PLAPS.

Table 4. Diagnostic Accuracy of Sonographic Patterns for Acute Heart Failure

Sonographic Sign	Included Patients	Number of Studies (References)	Confirmed and Total Patients	Sensitivity (95% CI)	Specificity (95% CI)	Positive LR (95% CI)	Negative LR (95% CI)
Diffuse interstitial syndrome*	Acute dyspnea	8 (31–37,39)	534/1208	0.73 (0.48–0.89)	0.84 (0.76–0.90)	4.8 (2.0–9.3)	0.31 (0.12–0.67)
Modified diffuse interstitial syndrome†	Acute dyspnea	1 (38)	463/1005	0.90 (0.87–0.93)	0.93 (0.91–0.95)	14 (10.1–19.3)	0.1 (0.08–0.13)
B-profile‡	Acute dyspnea or respiratory failure	6 (19–21,32,36,40)	381/997	0.82 (0.55–0.94)	0.90 (0.87–0.92)	8.40 (4.4–12.4)	0.19 (0.05–0.51)
B-profile‡	Respiratory failure	2 (19,21)	79/297	0.93 (0.72–0.98)	0.92 (0.79–0.97)	12.30 (3.3–41.1)	0.07 (0.01–0.35)
Symmetric B-pattern in lateral thoracic regions	Acute dyspnea	2 (32,36)	174/474	0.50 (0.43–0.57)	0.90 (0.84–0.94)	5.31 (2.7–10.5)	0.54 (0.44–0.67)

CI = confidence interval; LR = likelihood ratio.
* Bilateral presence of scans with three or more B lines, in at least two chest areas, considering two anterior and two lateral areas in each side.
† Bilateral presence of three or more B lines in two or more chest points, considering three points by hemithorax: at the second, fourth and fifth intercostal spaces, respectively in the hemi-clavicular, anterior axillar and middle axillar lines.
‡ Predominance of B-lines in anterior thoracic regions associated with lung sliding.

analysis suggests that LUS is highly accurate. However, the results of the diagnostic accuracy for pneumonia and acute heart failure had important differences, depending on the sonographic sign considered.

Our results of the overall diagnostic accuracy of LUS are consistent with recent systematic reviews. Llamas-Álvares et al. included 16 studies in their meta-analysis and reported overall sensitivity of 0.80–0.90, specificity of 0.70–0.90, and an AUC of 0.93 when LUS was used to diagnose pneumonia (8). However, these authors included studies on ventilator-associated pneumonia and with patients at settings other than the ED or ICU. Martindale et al. assessed the accuracy of LUS for diagnosing acute heart failure and reported an overall sensitivity of 0.82–0.87 and specificity of 0.91–0.94 (10). These authors included eight studies in their meta-analysis. However, diffuse interstitial syndrome was the only sonographic pattern assessed. Our database searches found no previous systematic reviews that had assessed the diagnostic accuracy of LUS for exacerbations of COPD/asthma for comparison.

Previous meta-analyses have not reported results of diagnostic accuracy for the different sonographic signs of either pneumonia or acute heart failure (8–10,42). Although the overall diagnostic accuracy of LUS for pneumonia and acute heart failure is excellent, distinct

Table 5. Diagnostic Accuracy of Lung Ultrasonography* for Exacerbation of COPD/Asthma†

Source	Included Patients	Confirmed and Total Analyzed	Sensitivity (95% CI)	Specificity (95% CI)	Positive LR (95% CI)	Negative LR (95% CI)
Daabis et al., 2014 (18)	Respiratory failure	21/100	0.76 (0.54–0.89)	0.89 (0.81–0.94)	7.52 (3.74–15.14)	0.26 (0.12–0.57)
Dexheimer et al., 2015 (19)	Respiratory failure	4/37	0.70 (0.29–0.92)	0.98 (0.87–0.99)	47.6 (2.86–791.1)	0.30 (0.07–1.16)
Gallard et al., 2015 (20)	Acute dyspnea	14/130	0.71 (0.45–0.88)	0.98 (0.93–0.99)	41.43 (10.1–170.2)	0.29 (0.12–0.66)
Lichtenstein et al., 2008 (21)	Respiratory failure	83/260	0.85 (0.76–0.91)	0.92 (0.87–0.95)	11.65 (6.85–19.8)	0.15 (0.09–0.26)
Summary	Respiratory failure or acute dyspnea	122/527	0.78 (0.67–0.86)	0.94 (0.89–0.97)	14.57 (5.70–40.25)	0.22 (0.13–0.36)

COPD = chronic obstructive pulmonary disease; LR = likelihood ratio; CI = confidence interval.
* The A-profile without PLAPS was the only sonographic pattern assessed. It consists in the predominance of A lines and presence of lung sliding in anterior chest areas and absence of consolidation and pleural effusion in posterior lateral areas.
† All studies used the final diagnosis as the reference standard.

values of both sensitivity and specificity were found for the different sonographic signs as well as the different subgroups of patients. These findings highlight the importance of interpreting the LUS considering the diagnostic accuracy of the individual sonographic signs in conjunction with the clinical characteristics of the patients.

Sonographic *consolidation* was highly specific but moderately sensitive for pneumonia in patients suspected to have this disease. Additional search for *focal interstitial syndrome* increased the sensitivity but decreased the specificity. This may happen because, even while not detecting deep consolidations, LUS can detect the interstitial edema surrounding these lesions (43). Thus, *consolidation* seems useful mainly to confirm pneumonia, but is not sufficiently sensitive to rule it out. Parallel absence of *consolidation* and *focal interstitial syndrome* can better rule out this disease. Despite the very low sensitivity of *C-profile*, when this sign was present it seemed sufficiently specific to restrict the LUS examination to the anterior chest regions in critically ill patients with respiratory failure. In addition, the sequence of the BLUE protocol for LUS examination seems to improve the specificity of consolidations or pleural effusion in posterior or lateral regions (PLAPS), that are very common in critically ill patients (41). Although different reference standards were used in the studies on pneumonia, the diagnostic accuracy results were quite similar in the subgroup analyses of the studies that used computed tomography as the reference diagnosis. These findings give greater consistency to the other results that included studies with other reference standards.

Regarding acute heart failure, *diffuse interstitial syndrome* was only a moderately accurate indicator of this disease in patients with acute dyspnea. The presence of other diseases that follow this course, such as interstitial pneumonia, acute respiratory distress syndrome, and lung fibrosis, can compromise its accuracy for acute heart failure. The *modified diffuse interstitial syndrome* can be assessed more quickly and was the most accurate sonographic pattern for acute heart failure in stable patients with acute dyspnea. This finding was restricted to the study of Pivetta et al., but it was a large (n = 1005 patients), multiple-center study with experienced sonographers, with very consistent results (38). The *B-profile* had good diagnostic accuracy and seemed especially accurate in the subgroups of patients with respiratory failure. Although this finding is limited by the low number of studies, it is expected that nondependent lung areas are more characteristically affected in hydrostatic lung edema than by other causes of lung edema and in the most severe cases of acute heart failure.

Without overlapping parenchymal diseases, exacerbations of COPD or asthma do not coincide with a significant loss of lung parenchyma aeration or pleural effusions. Thus, the *A-profile without PLAPS* is the sonographic pattern for these diseases, with high specificity and moderate sensitivity in patients with acute dyspnea or respiratory failure. The sequential LUS examination, mainly using the BLUE protocol, seems to potentialize the accuracy for this diagnosis because the examination protocol is completed only in patients with no other diagnostic profiles in the anterior thoracic areas. Currently, the diagnostic assessment of these diseases is based on clinical examination. Routine CXR is recommended only when an alternative cause for the symptoms is suspected (44,45). Thus, despite the small number of included studies, LUS seems to be useful to confirm the diagnosis of COPD or asthma exacerbations and for ruling out alternative causes of the symptoms.

Our data suggest that LUS may be a valuable diagnostic method in the emergency diagnosis of adults with respiratory symptoms. Most of the sonographic signs have high specificity and can be quickly assessed immediately after the clinical examination, providing real-time results, with no exposure to radiation. In addition to accelerating the diagnostic process, LUS has the potential to minimize the number of radiological and laboratory tests, optimizing the use of financial resources (46). On the other hand, ultrasound is limited in extremely obese patients, and when subcutaneous emphysema, extensive dressings, or skin disorders are present. Another limitation of LUS is its observer-dependent nature, however, the learning curve is relatively fast and high interobserver agreement can be obtained (47,48).

Limitations

Limitations of this systematic review can be noted. The characteristics of LUS examinations were heterogeneous across the studies, with different machines, probes, and operator expertise levels. Even including only prospective studies, the overall methodological quality of the studies was low. Few studies on exacerbations of COPD or asthma were included; this may have increased the uncertainty in variance estimation of the random effects of the bivariate model (13). In addition, some analysis included studies with small samples, which can overestimate the results of meta-analysis. Finally, we did not contact the authors of primary studies and could not include studies with a mixed sample of patients in EDs (or ICUs) and hospital wards.

Although pneumonia, acute heart failure, and exacerbations of COPD or asthma are common and life-threatening diseases, no conclusions can be made about the effect of LUS on the prognosis of patients suspected

to have these diseases. More studies are needed to assess the overall clinical effects of LUS on the diagnosis of these diseases. Future randomized clinical trials comparing LUS with standard approach can better assess other relevant outcomes, such as mortality, length of hospital stays, and costs.

CONCLUSIONS

LUS has high accuracy for pneumonia, acute heart failure, and exacerbation of COPD/asthma, and seems to be a valuable complement to other diagnostic methods in the emergency diagnosis of these diseases in adults with respiratory symptoms. The interpretation of the LUS examination should take into account the accuracy of the individual sonographic signs to diagnose pneumonia and acute heart failure.

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SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jemermed.2018.09.009.

REFERENCES

1. Mandell LA, Wunderink RG, Anzueto A, et al. Infectious Diseases Society of America/American Thoracic Society consensus guidelines on the management of community-acquired pneumonia in adults. Clin Infect Dis 2007;44:S27–72.
2. Salpeter SR, Ormiston TM, Salpeter EE. Cardiovascular effects of beta-agonists in patients with asthma and COPD: a meta-analysis. Chest 2004;125:2309–21.
3. Hagaman JT, Rouan GW, Shipley RT, Panos RJ. Admission chest radiograph lacks sensitivity in the diagnosis of community-acquired pneumonia. Am J Med Sci 2009;337:236–40.
4. Wang CS, FitzGerald JM, Schulzer M, Mak E, Ayas NT. Does this dyspneic patient in the emergency department have congestive heart failure? JAMA 2005;294:1944–56.
5. Hayden GE, Wrenn KW. Chest radiograph vs. computed tomography scan in the evaluation for pneumonia. J Emerg Med 2009;36:266–70.
6. Zanobetti M, Scorpiniti M, Gigli C, et al. Point-of-care ultrasonography for evaluation of acute dyspnea in the ED. Chest 2017;151:1295–301.
7. Laursen CB, Sloth E, Lassen AT, et al. Point-of-care ultrasonography in patients admitted with respiratory symptoms: a single-blind, randomised controlled trial. Lancet Respir Med 2014;2:638–46.
8. Llamas-Álvares AM, Tenza-Lozano EM, Latour-Perez J. Accuracy of lung ultrasonography in the diagnosis of pneumonia in adults: systematic review and meta-analysis. Chest 2017;151:374–82.
9. Chavez MA, Shams N, Ellington LE, et al. Lung ultrasound for the diagnosis of pneumonia in adults: systematic review and meta-analysis. Respir Res 2014;15:50.
10. Martindale JL, Wakai A, Collins SP, et al. Diagnosing acute heart failure in the emergency department: a systematic review and meta-analysis. Acad Emerg Med 2016;23:223–42.
11. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Intern Med 2009;151:264–9.
12. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med 2011;155:529–36.
13. Macaskill P, Gatsonis C, Deeks JJ, Harbord RM, Takwoingi Y. Chapter 10: Analysing and presenting results. In: Deeks JJ, Bossuyt PM, Gatsonis C, eds. Cochrane handbook for systematic reviews of diagnostic test accuracy, version 1.0. The Cochrane Collaboration. 2010. Available at: http://srdta.cochrane.org/. Accessed December 12, 2017.
14. Rutter CM, Gatsonis CA. A hierarchical regression approach to meta-analysis of diagnostic test accuracy evaluations. Stat Med 2001;20:2865–84.
15. Reitsma JB, Glas AS, Rutjes AW, Scholten RJ, Bossuyt PM, Zwinderman AH. Bivariate analysis of sensitivity and specificity produces informative summary measures in diagnostic reviews. J Clin Epidemiol 2005;58:982–90.
16. Bourcier JE, Paquet J, Seinger M, et al. Performance comparison of lung ultrasound and chest x-ray for the diagnosis of pneumonia in the ED. Am J Emerg Med 2014;32:115–8.
17. Cortellaro F, Colombo S, Coen D, Duca PG. Lung ultrasound is an accurate diagnostic tool for the diagnosis of pneumonia in the emergency department. Emerg Med J 2012;29:19–23.
18. Daabis R, Banawan L, Rabea A, Elnakedy A, Sadek A. Relevance of chest sonography in the diagnosis of acute respiratory failure: comparison with current diagnostic tools in intensive care units. Egypt J Chest Dis Tuberc 2014;63:979–85.
19. Dexheimer Neto FL, Andrade JM, Raupp AC, et al. Diagnostic accuracy of the bedside lung ultrasound in emergency protocol for the diagnosis of acute respiratory failure in spontaneously breathing patients. J Bras Pneumol 2015;41:58–64.
20. Gallard E, Redonnet JP, Bourcier JE, et al. Diagnostic performance of cardiopulmonary ultrasound performed by the emergency physician in the management of acute dyspnea. Am J Emerg Med 2015;33:352–8.
21. Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. Chest 2008;134:117–25.
22. Liu XL, Lian R, Tao YK, Gu CD, Zhang GQ. Lung ultrasonography: an effective way to diagnose community-acquired pneumonia. Emerg Med J 2015;32:433–8.
23. Nafae R, Eman SR, Mohamad NA, El-Ghamry R, Ragheb AS. Adjuvant role of lung ultrasound in the diagnosis of pneumonia in intensive care unit-patients. Egypt J Chest Dis Tuberc 2013;62:281–5.
24. Nazemi S, Farokhnia M, Pirouzi M, Najarion O, Ahmadipour H. Accuracy of ultrasound as a diagnostic tool of pneumonia for admitted patients in Infectious Disease Section of Afzalipour Hospital. Jamaican J Sci Technol 2014;25:48–54.
25. Nazerian P, Volpicelli G, Vanni S, et al. Accuracy of lung ultrasound for the diagnosis of consolidations when compared to chest computed tomography. Am J Emerg Med 2015;33:620–5.
26. Pagano A, Numis FG, Visone G, et al. Lung ultrasound for diagnosis of pneumonia in emergency department. Intern Emerg Med 2015;10:851–4.
27. Parlamento S, Copetti R, Di Bartolomeo S. Evaluation of lung ultrasound for the diagnosis of pneumonia in the ED. Am J Emerg Med 2009;27:379–84.
28. Ticinesi A, Lauretani F, Nouvenne A, et al. Lung ultrasound and chest x-ray for detecting pneumonia in an acute geriatric ward. Medicine (Baltimore) 2016;95:e4153.
29. Unluer EE, Karagoz A, Senturk GO, Karaman M, Olow KH, Bayata S. Bedside lung ultrasonography for diagnosis of pneumonia. Hong Kong J Emerg Med 2013;20:98–104.
30. Aggarwal M, Gupta M, Vijan V, et al. Use of lung ultrasound for diagnosing acute heart failure in emergency department of Southern India. J Clin Diagn Res 2016;10:TC05–8.
31. Anderson KL, Jenq KY, Fields JM, Panebianco NL, Dean AJ. Diagnosing heart failure among acutely dyspneic patients with cardiac,

inferior vena cava, and lung ultrasonography. Am J Emerg Med 2013;31:1208–14.
32. Chiem AT, Chan CH, Ander DS, Kobylivker AN, Manson WC. Comparison of expert and novice sonographers' performance in focused lung ultrasonography in dyspnea (FLUID) to diagnose patients with acute heart failure syndrome. Acad Emerg Med 2015;22:564–73.
33. Cibinel GA, Casoli G, Elia F, et al. Diagnostic accuracy and reproducibility of pleural and lung ultrasound in discriminating cardiogenic causes of acute dyspnea in the Emergency Department. Intern Emerg Med 2012;7:65–70.
34. Glöckner E, Christ M, Geier F, et al. Accuracy of point-of-care B-line lung ultrasound in comparison to NT-ProBNP for screening acute heart failure. Ultrasound Int Open 2016;2:E90–2.
35. Kajimoto K, Madeen K, Nakayama T, Tsudo H, Kuroda T, Abe T. Rapid evaluation by lung-cardiac-inferior vena cava (LCI) integrated ultrasound for differentiating heart failure from pulmonary disease as the cause of acute dyspnea in the emergency setting. Cardiovasc Ultrasound 2012;10:49.
36. Liteplo AS, Marill KA, Villen T, et al. Emergency thoracic ultrasound in the differentiation of the etiology of shortness of breath (ETUDES): sonographic B-lines and N-terminal Pro-brain-type natriuretic peptide in diagnosing congestive heart failure. Acad Emerg Med 2009;16:201–10.
37. Mumoli N, Vitale J, Giorgi-Pierfranceschi M, et al. Accuracy of nurse-performed lung ultrasound in patients with acute dyspnea: a prospective observational study. Medicine (Baltimore) 2016;95:e2925.
38. Pivetta E, Goffi A, Lupia E, et al. Lung ultrasound-implemented diagnosis of acute decompensated heart failure in the ED: a SIMEU multicenter study. Chest 2015;148:202–10.
39. Sartini S, Frizzi J, Borselli M, et al. Which method is best for an early accurate diagnosis of acute heart failure? Comparison between lung ultrasound, chest X-ray and NT pro-BNP performance: a prospective study. Intern Emerg Med 2016;12:861–9.
40. Unluer EE, Karagoz A, Oyar O, Vandenberk N, Kiyancicek S, Budak F. Lung ultrasound by emergency nursing as an aid for rapid triage of dyspneic patients: a pilot study. Int Emerg Nurs 2014;22:226–31.
41. Lichtenstein DA. BLUE-protocol and FALLS-protocol: two applications of lung ultrasound in the critically ill. Chest 2015;147:1659–70.
42. Al Deeb M, Barbic S, Featherstone R, Dankoff J, Barbic D. Point-of-care ultrasonography for the diagnosis of acute cardiogenic pulmonary edema in patients presenting with acute dyspnea: a systematic review and meta-analysis. Acad Emerg Med 2014;21:844–52.
43. Volpicelli G, Caramello V, Cardinale L, Mussa A, Bar F, Frascisco MF. Detection of sonographic B-lines in patients with normal lung or radiographic alveolar consolidation. Med Sci Monit 2008;14:CR122–8.
44. Global Initiative for Chronic Obstrutive Pulmonary Disease. Global strategy for the diagnosis, management, and prevention of COPD 2017. Available at: http://goldcopd.org/gold-2017-global-strategy-diagnosis-management-prevention-copd/. Accessed December 12, 2017.
45. Global Initiative for Asthma. Global strategy for asthma management and prevention 2017. Available at: http://ginasthma.org/2017-gina-report-global-strategy-for-asthma-management-and-prevention/. Accessed December 12, 2017.
46. Peris A, Tutino L, Zagli G, et al. The use of point-of care bedside lung ultrasound significantly reduces the number of radiographs and computed tomography scans in critically ill patients. Anesth Analg 2010;111:687–92.
47. Volpicelli G, Elbarbary M, Blaivas M, et al. International evidence-based recommendations for point-of-care lung ultrasound. Intensive Care Med 2012;38:577–91.
48. Gullett J, Donnelly JP, Sinert R, et al. Interobserver agreement in the evaluation of B-lines using bedside ultrasound. J Crit Care 2015;30:1395–9.

ARTICLE SUMMARY

1. Why is this topic important?

Pneumonia, acute heart failure, and exacerbation of chronic obstructive pulmonary disease (COPD)/asthma are common and life-threatening diseases in adults with respiratory symptoms, and lung ultrasound could accelerate their diagnoses.

2. What does this review attempt to show?

The clinical evidence from prospective studies on the accuracy of lung ultrasound in the emergency diagnosis of pneumonia, acute heart failure, and exacerbation of COPD/asthma.

3. What are the key findings?

Lung ultrasound is an accurate tool in the diagnosis of the three target diseases. For pneumonia and acute heart failure, the diagnostic accuracy had widely variation depending the sonographic sign used.

4. How is patient care impacted?

Lung ultrasound can accurately accelerate the diagnosis of pneumonia, acute heart failure, and exacerbation of COPD/asthma in adult patients.