European Journal of Internal Medicine 106 (2022) 9–38

Contents lists available at ScienceDirect

European Journal of Internal Medicine

journal homepage: www.elsevier.com/locate/ejim

Review Article

POCUS in dyspnea, nontraumatic hypotension, and shock; a systematic review of existing evidence

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ARTICLE INFO

Keywords:
Point-of-care ultrasound
Dyspnea
Nontraumatic hypotension
Shock

ABSTRACT

Background: Point-of-care ultrasound (POCUS) has been adopted as a powerful tool in acute medicine. This systematic review aims to critically appraise the existing literature on point-of-care ultrasound in respiratory or circulatory deterioration.

Methods: Original studies on POCUS and dyspnea, nontraumatic hypotension, and shock from March 2002 until March 2022 were assessed in the PubMed and Embase Databases. Two reviewers independently screened articles for inclusion, extracted data, and assessed the quality of included studies using an established checklist.

Results: We included 89 articles in this review. Point-of-care ultrasound in the initial workup increases the diagnostic accuracy in patients with dyspnea, nontraumatic hypotension and shock in the ED, ICU and medical ward setting. No improvement is found in patients with severe sepsis in the ICU setting. POCUS is capable of narrowing the differential diagnoses and is faster, and more feasible in the acute setting than other diagnostics available. Results on outcome measures are heterogenous. The quality of the included studies is considered low most of the times, mainly because of performance and selection bias and absence of a gold standard as the reference test.

Conclusion: We conclude that POCUS contributes to a higher diagnostic accuracy in dyspnea, nontraumatic hypotension, and shock. It aides in narrowing the differential diagnoses and shortening the time to correct diagnosis and effective treatment.

Trial registry: INPLASY; Registration number: INPLASY202220020; URL: https://inplasy.com/.

1. Introduction

Point-of-care ultrasound (POCUS) is defined as the integration of ultrasound imaging into the physical examination by the treating physician. It has shown to speed up the diagnostic process, and to improve diagnostic accuracy and treatment. POCUS in acute medicine is practiced mostly for reasons of dyspnea, hypotension, and shock, which are also the most common reasons for sudden deterioration of medical patients.

Scanning protocols in dyspnea, hypotension, and shock vary in extent between single organ and multi-organ such as heart, lungs, and deep veins. At the discretion of the treating physician, a protocol is chosen that is the best tradeoff between speed and diagnostic accuracy.

Randomized controlled trials to investigate the value of POCUS in dyspnea, nontraumatic hypotension, and shock are scarce. Since focused ultrasound is nowadays considered a basic skill, we propose that it should not be withheld from patients.

In this systematic review we aim to critically appraise the existing literature on point-of-care ultrasound in dyspnea, nontraumatic hypotension, and shock in different hospital settings.

Abbreviations: AI, artificial intelligence; BLUE, bedside lung ultrasound in emergency; BNP, brain natriuretic peptide; COPD, chronic obstructive pulmonary disease; CT, computed tomography; CXR, chest X-ray; ED, emergency department; ICU, intensive care unit; IVC, inferior vena cava; MET, medical emergency team; POCUS, point-of-care ultrasound; PRISMA, preferred reporting items for systematic reviews and meta-analyses; NT-proBNP, N-terminal pro brain natriuretic peptide.

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https://doi.org/10.1016/j.ejim.2022.07.017
Received 2 May 2022; Received in revised form 20 July 2022; Accepted 26 July 2022
Available online 1 August 2022

2. Methods

As a framework to our literature search we created a list of conditions that are common in patients with dyspnea, nontraumatic hypotension, and shock: dyspnea, increased respiratory rate, hypoxia, and hypotension, shock, tachycardia, decreased urinary output, altered level of consciousness.

2.1. Search strategy and data collection

We searched the PubMed and Embase databases for all original studies published between March 2002 and March 2022 on adult patients with dyspnea, nontraumatic hypotension, and shock who were assessed using point-of-care ultrasound. In the PubMed database we used MeSH terms for our search: ("Ultrasonography"[Mesh] OR "Ultrasonography"[tiab] OR "Echocardiography"[Mesh] OR "Echocardiography"[tiab] OR "lung ultrasound"[tiab] OR "ultrasound"[tiab] OR "LuCUS"[tiab] OR "Point-of-Care Systems"[Mesh] OR "Point-of-Care Testing"[Mesh] OR "POCUS"[tiab] OR "point-of-care-ultrasound"[tiab]) AND ("Dyspnea"[Mesh] OR "Tachypnea"[Mesh] OR "Shock"[Mesh] OR "dyspnea"[tiab] OR "tachypnea"[tiab] OR "shock"[tiab] OR "hypotension"[tiab] OR "respiratory failure"[tiab] OR "pneumonia"[tiab] OR "sepsis"[tiab]) AND ("Emergency Service, Hospital"[Mesh] OR "Intensive Care Units"[Mesh] OR "Patients' Rooms"[Mesh] OR "Medical ward"[tiab] OR "general ward"[tiab] OR "Internal medicine"[tiab] OR "Internist"[tiab] OR "Emergency department"[tiab] OR "ED"[tiab] OR "Intensive Care Unit"[tiab] OR "ICU"[tiab] OR "MET"[tiab] OR "Medical Emergency Team"[tiab])

In Embase we used the terms point of care ultrasound/exp AND dyspnea/di OR point of care ultrasound/exp AND hypotension/di. Thirdly, we reviewed the reference lists of included papers.

We included English language prospective and retrospective clinical trials and observational studies. Diagnostic accuracy was the primary outcome measure. Secondary outcome measures were mortality, admission to ICU, length of stay, duration of treatment, and narrowing the differential diagnosis. Two reviewers (BK, DW) independently screened articles for inclusion, extracted data, and assessed the quality of included studies. Disagreements on study selection and gathering of data were discussed between the reviewers until consensus was reached.

2.2. Risk of bias

Both reviewers assessed the risk of bias of all selected studies using the Cochrane tool for randomized controlled trials (Risk of Bias 2) [1] and non-randomized studies (ROBINS-I) [2]. Risk assessment was discussed between reviewers until consensus was reached. Risk of bias assessment is tabulated in appendix I.

2.3. Analysis

We reported our literature search in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and this is displayed in appendix II. This systematic review was registered.

We will discuss the identified articles based on dyspnea in different settings and nontraumatic hypotension and shock in different settings.

3. Results

3.1. The impact of POCUS in patients with dyspnea in the emergency department

22 studies have investigated POCUS in undifferentiated dyspnea. Diagnostic accuracy was the primary outcome in 18 studies; in six studies secondary outcomes were assessed. The data are summarized in Table 1.

Zanobetti et al. [3] assessed the accuracy of POCUS compared with conventional workup in 2683 patients with acute dyspnea. In this prospective observational cohort study the scanning physicians had expertise in POCUS and were not involved in patient management. They were not blinded to findings in the primary assessment. The reference standard was the final diagnosis based on medical record review including POCUS findings as decided by two independent physicians. The POCUS diagnosis had a good concordance with final diagnosis and was superior in diagnosing acute heart failure. For pneumonia, acute myocardial infarction, and pleural fluid no superiority was found. Patients with asthma and COPD were less often correctly diagnosed by POCUS.

Bekgoz et al. [4] assessed if a modified BLUE protocol was capable of detecting the causes of acute dyspnea in this setting. They conducted a prospective observational cohort study with blinding of the POCUS trained physicians to clinical findings and patient management. The reference standard was the final diagnosis based on medical record review decided by one attending physician. The diagnostic accuracy for pneumonia, heart failure and pneumothorax was good. Correct identification of asthma/COPD was shown to be less successful. Comparable studies have been conducted by six study groups and a seventh in patients aged 75 years and above. All found similar results but had methodological shortcomings in blinding and patient involvement of the scanning physicians [5–11].

Laursen et al. [12,13] (two studies) demonstrated that POCUS increased the rate of correct presumptive diagnosis from 63.7 to 88% and could rule in and rule out life threatening conditions which they found in 14% of patients. All scans were performed by the same scanning physician who was blinded to clinical information.

Papanagnou et al. [14] found no improvement in diagnostic accuracy of POCUS when compared to final diagnosis. However, the scanning physicians in this study were the treating physicians and not blinded to clinical information.

Guttikonda et al. [15], House et al. [16], and Umuhire et al. [17] investigated the use of POCUS in a resource-limited setting. They found a diagnostic accuracy of 88%, a change in diagnosis and therapeutic management in 44.3 and 53.6% respectively, and an increase in diagnostic accuracy when POCUS was added to the conventional workup. In all three studies POCUS experienced physicians conducted or supervised the scanning. Only in the study by House et al. blinding to clinical information was undertaken whilst in the study by Guttikonda et al. the scanning physician was involved in patient treatment.

Buhumaid et al. [18], Lamsam et al. [19] and Zanobetti et al. [20] concluded that POCUS had a comparable accuracy to CXR. Its superior sensitivity in case of a normal lung ultrasound made the additional value of a CXR negligible. Only the research by Lamsam et al. [19] ensured blinding to clinical information.

Buhumaid et al and Stewart et al concluded that POCUS narrowed the differential diagnoses [18, 21]. In the former study scanning physicians were blinded to clinical information whilst in the latter they were not. Zanobetti et al. [20] found an important time benefit of POCUS. Its results were available instantaneously while the interpretation of a chest X-ray by a radiologist lasted 95 min on average. Comparable findings were made by Gaber et al. [22] and Zare et al. [23].

Riishede et al. [24] randomized 211 patients between blinding and unblinding of POCUS findings to the treating physicians and examined the impact of POCUS on concordance with final diagnosis. The primary outcome in both groups was comparable but the patients whose POCUS findings were unblinded to the treatment team received appropriate therapy more often with an absolute increase of 13,5%. Also the proportion of patients discharged within 1 day was larger (0.40 versus 0.24).

21 POCUS studies focused on dyspnea caused by acute heart failure. Diagnostic accuracy was the primary outcome in all. The data are summarized in Table 1.

Pivetta et al. [25,26] investigated twice if lung ultrasound could

Table 1
POCUS in patients with dyspnea in the emergency department.

Article	Ultrasound application	Objective	Result	Details	Study design
Anderson et al. 2013	Cardiac, lung, and IVC ultrasound	to assess the accuracy of POCUS in diagnosing acute heart failure among acutely dyspneic patients.	101 patients with dyspnea were included. POCUS had an excellent specificity but only moderate sensitivity in making the diagnosis of acute heart failure (AHF) in patients with acute dyspnea.	Specificity for AHF in the combination of cardiac, lung, and IVC ultrasound was 100% (95% CI, 95–100). This decreased to 93–97% when just 2 scanning sites were combined. The specificity of brain natriuretic peptide greater than 500 pg/mL was 83% (95% CI, 67–92). Interrater agreement between physician raters for the diagnosis of AHF was near-perfect: $\kappa = 0.97$	Prospective observational cohort study with a convenience sample of adult patients. Scanning physicians were trained in an emergency ultrasound fellowship and were blinded to clinical data. Reference standard was the discharge diagnosis based on medical record review by two physicians blinded to the POCUS results.
Baker et al. 2020	Lung ultrasound	To assess if lung ultrasound (LUS) in the hands of non-expert clinicians improves the recognition of pulmonary edema. Secondary objectives: to investigate the health care effect of introducing lung ultrasound for the patient, department and hospital?	442 patients with dyspnea in whom 218 underwent LUS and 224 did not. Diagnostic accuracy of LUS added to common diagnostic workup was significantly higher, but the effect size was small and fragile.	While experts show that LUS improves diagnosis of dyspnea, this study showed only a small albeit significant effect. Secondly, it showed that the first step toward expertise is neither dangerous, time consuming nor costly.	Prospective, single-blinded, parallel randomized controlled trial with a convenience sample of patients aged 60 years and above. Scanning physicians had completed a four hours training in lung ultrasound. All scans were reviewed by an expert in POCUS blinded to clinical information. Reference standard was the opinion of an experienced emergency physician, auditing the medical record after patient discharge, using a pre-formulated guideline.
Bekgoz et al. 2019	Lung, cardiac subcostal view, and deep veins ultrasound	to investigate the test performance characteristics of a POCUS protocol in detecting the causes of acute dyspnea.	383 patients with dyspnea. POCUS resulted in an accurate diagnosis of acute heart failure, pneumothorax, pneumonia, and pulmonary embolism (approx. 90%). However, in diagnosing asthma/COPD POCUS was less accurate in this setting.	This POCUS protocol in emergency department patients with dyspnea established the correct diagnosis at a mean rate of 77.5% across all disease categories.	Prospective, observational cohort study of consecutive adult patients with acute dyspnea. Scanning physicians were trained in basic and advanced POCUS with at least two years of experience. They were blinded to clinical information, and not involved in patient management. Reference standard was the final diagnosis which was decided by the attending physician who was aware of the complete medical record but blinded to POCUS findings.
Bourcier et al. 2014	Lung ultrasound	to assess the potential of lung ultrasound examination in the diagnosis of acute pneumonia.	144 patients with dyspnea and suspected pneumonia. LUS had a higher sensitivity for the diagnosis of acute pneumonia compared to chest X-ray (CXR) of 95% versus 60%, ($P < 0.01$). POCUS was particularly more effective when pneumonia was evolving for less than 24 h.	Lung ultrasound and CXR were compared against final diagnosis. 123 patients had a final diagnosis of pneumonia. Sensitivity and specificity of LUS were 95% and 57%; for CXR these were 60% and 76% respectively. Importantly, in case of symptoms <24 h 43/44 of patients had positive LUS while only 13/44 had a positive CXR. Secondary end point was the concordance of lung ultrasound and chest X-ray with chest CT when performed ($n = 23$). LUS concordance with chest CT was 100%; CXR concordance with chest CT was 52%.	Prospective observational cohort study of a convenience sample of adult patients with a suspected pneumonia. Scanning physicians were trained in POCUS in advance of the study and were also the treating physician. Reference standard was the final diagnosis decided by one senior physician who reviewed the medical record.
Buhumaid et al. 2019	Cardiac and lung ultrasound	To determine how use of POCUS influenced physicians' differential diagnosis, and to compare the ultrasound findings to chest radiograph and composite final diagnosis.	128 patients with chest pain or dyspnea. The diagnostic accuracy of POCUS and CXR was comparable in diagnosing pneumothorax, pleural effusion, and pulmonary edema. Benefits of POCUS were a reduction in costs, the speed of care delivery, and lacking radiation.	POCUS can assist in narrowing the differential diagnosis (due to its high sensitivity) and is a highly feasible diagnostic test. In patients with a normal thoracic ultrasound, the added value of a CXR may be minimal. The sensitivity and specificity of CXR and POCUS were: 38% (95% CI 13–70%) and 96% (95% CI 90–99%) versus 89% (95% CI 54–100) and 74% (95% CI 64–82%) respectively.	Prospective observational cohort study of a convenience sample of patients. Scanning physicians had completed a POCUS fellowship prior to the study and were blinded to other imaging studies but not to clinical information. Reference test was the final discharge diagnosis as decided by the treating physician.

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Table 1 (*continued*)

Article	Ultrasound application	Objective	Result	Details	Study design
Cibinel et al. 2012	Lung ultrasound	to evaluate the diagnostic accuracy of lung ultrasound in discriminating between cardiogenic and non-cardiogenic acute dyspnea.	56 patients with acute dyspnea. Lung ultrasound was an accurate and reproducible bedside tool in discriminating between cardiogenic and non-cardiogenic dyspnea. On the contrary, detection of pleural effusions does not allow reliable discrimination between different causes of acute dyspnea in unselected patients.	Presence of diffuse interstitial syndrome was highly predictive for cardiogenic dyspnea (sensitivity 93.6%, specificity 84%, PPV 87.9%, NPV 91.3%). On the contrary, US detection of pleural effusion was not helpful in the differential diagnosis (sensitivity 83.9%, specificity 52%, PPV 68.4%, NPV 72.2%). Finally, the coexistence of diffuse interstitial syndrome and pleural effusion is less accurate than diffuse interstitial syndrome alone for cardiogenic dyspnea (sensitivity 81.5%, specificity 82.8%, PPV 81.5%, NPV 82.8%).	Prospective observational cohort study of a convenience sample of patients. Scanning physicians were not blinded to clinical information but laboratory results and CXR. All scans were reviewed by two POCUS experts who decided on POCUS diagnosis. Reference standard was the final diagnosis of dyspnea decided by two independent physicians based on medical record review but blinded to the lung ultrasound results.
Cortellaro et al. 2012	Lung ultrasound	to compare the diagnostic accuracy of lung ultrasound and CXR in a clinical suspicion of pneumonia.	120 patients with dyspnea. Lung ultrasound was superior to CXR in identifying pneumonia and executed in less than 5 min. It was always feasible in the dyspneic patient at the emergency department.	The test characteristics sensitivity, specificity, positive likelihood ratio (PLR) and negative likelihood ratio (NLR) in patients with pneumonia were: Ultrasound 99% (95% CI 93.3% to 99.9%), 95% (95% CI 82.7% to 99.4%), PLR 19.3 (95% CI 4.99% to 74.2%), NLR 0.01 (95% CI 0.002 to 0.09). CXR 67% (95% CI 56.4% to 76.9%), 85% (95% CI 73.3% to 95.9%), PLR 4.3 (95% CI 2.04 to 37.7), NLR 0.39 (95% CI 0.20 to 0.76). In 30 patients chest CT was done which identified a pneumonia in 26 of them. Ultrasound was concordant for diagnosing pneumonia in 25. CXR was concordant for diagnosing pneumonia in 18. Both ultrasound and CXR were concordantly negative in 3 out of 4 patients.	Prospective observational cohort study of a convenience sample of adult patients. One scanning physician, described as an expert in POCUS, was blinded to CXR results but not clinical information. Reference standard was the discharge diagnosis which was determined by the treating physicians and based on clinical, radiological and laboratory results.
De Carvalho et al. 2021	Cardiac and lung ultrasound	the objective of our study was to assess POCUS add-on investigation to standard diagnosis approach in elderly patients with acute respiratory failure.	89 patients with dyspnea. POCUS showed a very good concordance ($\kappa = 0.82$) with final diagnosis. A routine diagnostic approach showed moderate concordance with final diagnosis ($\kappa = 0.52$).	POCUS had a higher sensitivity and specificity than routine diagnostics in diagnosing patients with dyspnea.	Prospective observational cohort study of a convenience sample of patients aged 75 years and above. One scanning physician trained in POCUS was aware of the initial diagnosis based on clinical, laboratory, and radiological results. Reference test was the final diagnosis as decided by the adjudication committee based on medical record review including ultrasound image recordings.
Dehbozorgi et al. 2019	Cardiac and lung ultrasound	to examine if POCUS is a useful tool in diagnosing acute heart failure in patients with undifferentiated acute dyspnea.	100 patients with acute dyspnea. POCUS had a higher accuracy than clinical diagnosis, and can be a useful tool in the emergency department to differentiate between cardiac and non-cardiac causes of acute dyspnea.	In 46 cases (46%) the preliminary diagnosis was acute heart failure and in 18 cases the preliminary diagnosis was COPD (18%). The final diagnosis of heart failure was made in 28 patients and COPD in 27 patients. The calculated sensitivity, specificity, PLR, NLR of the ultrasound protocol were: 64% (95%CI, 44%–82%), 97% (95% CI, 90%–100%), 23.14 (95%CI, 5.74–93.3), 0.37 (95%CI, 0.22–0.6).	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had completed an ultrasound course and were supervised by POCUS certified emergency physicians. They were not blinded to clinical information. Reference standard was the discharge diagnosis decided by two independent senior physicians based on medical record review but POCUS results.
Gaber et al. 2019	Cardiac, lung, and IVC ultrasound	To determine the diagnostic accuracy and time required to obtain an accurate diagnosis in patients with acute dyspnea comparing POCUS and standard therapy.	59 patients with dyspnea. POCUS resulted in more rapid (in this study more than 4.3 h), but equally accurate diagnoses, as compared to standard of care in patients presenting with acute dyspnea.	The median (IQR) time from randomization to diagnosis was 21 (10 to 15) minutes for unblinded ultrasound patients versus 244 (128 to 360) minutes for standard of care blinded ultrasound group ($P < 0.001$).	Prospective block randomized, standard therapy controlled, blinded evaluation of a POCUS strategy in a convenience sample of adult patients. Scanning physicians were trained in POCUS with at least two years

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Table 1 (*continued*)

Article	Ultrasound application	Objective	Result	Details	Study design
				Scanning physicians who were blinded to the patient's history and physical exam had higher diagnostic certainty than the treatment team before the ultrasound results were known (82% [95% CI, 77 to 87] vs. 74% [95% CI, 69% to 79%], $P = 0.018$)	of experience and blinded to the patient's medical history and not involved in patient management. Reference standard was the final diagnosis which was decided by two independent physicians based on medical record review. They were blinded to the ultrasound diagnosis and clinical diagnosis.
Gallard et al. 2015	Cardiac and lung ultrasound	To evaluate the performance of POCUS for the etiologic diagnosis of acute dyspnea, considering routine examinations as the standard of care.	130 patients with acute dyspnea. The diagnostic accuracy positively changed approximately 20% with addition of POCUS to conventional workup.	Higher accuracy than conventional evaluation 90% (CI 84–95) vs 67% (CI 57–75) for left-sided heart failure. Also, high accuracy for decompensated COPD (95%) and pneumonia or pleural effusion (86%).	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were trained in POCUS with an average experience of two years and did not have knowledge of any clinical information and were not involved in patient management. Reference standard was final diagnosis decided by two independent experts based on medical record review but POCUS results.
Gargani et al. 2008	Lung ultrasound	To evaluate the accuracy of lung ultrasound to predict the cardiac origin of dyspnea, compared to natriuretic peptides.	149 patients with dyspnea. B-lines detected with lung ultrasound are a simple and useful method for the differential diagnosis of cardiogenic versus non-cardiogenic acute dyspnea.	Cardiogenic dyspnea was confirmed in 122 patients and ruled-out in 27 patients. The number of B-lines was significantly correlated to NT-proBNP values ($r = 0.69$, $p<0.0001$). Receiver operating characteristic analysis, showed an area under the curve of 0.893 for B-lines and 0.978 ($p = 0.001$) for NT-proBNP, in predicting the cardiac origin of dyspnea.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were experienced in lung ultrasound however amount of training is not defined. They were not involved in clinical management but not explicitly blinded to clinical information. Reference standard was final diagnosis decided by two independent cardiologists based on medical record review including echocardiography in all patients but blinded to NT-proBNP and lung ultrasound.
Glöckner et al. 2016	Lung ultrasound	to determine the accuracy of lung ultrasound for evaluation of acute dyspnea in comparison to NT-proBNP levels	25 patients with dyspnea. LUS was highly specific but moderately sensitive to identify patients with acute heart failure.	Sensitivity of 40% is moderate as compared to previous reports (70 –92%). Median age was 72 years (IQR 60.5–80.5), 68% ($n = 17$) were male and 76% ($n = 19$) had a previous history of chronic heart failure. 60% ($n = 15$) of patients had a final adjudicated diagnosis of acute heart failure.	Prospective observational cohort study of a convenience sample of adult patients. Two scanning physicians who are experts in POCUS conducted and two experts who interpreted the lung ultrasounds. They were blinded to clinical information. Reference standard was the final diagnosis decided by two independent physicians based on medical record review including echocardiography but blinded to lung ultrasound.
Glöckner et al. 2020	Lung ultrasound	to determine the diagnostic accuracy of lung ultrasound in diagnosing acute heart failure as underlying etiology of acute dyspnea.	89 patients with acute dyspnea. Sensitivity to diagnose acute heart failure was 54.2% and specificity 97.6%.	The sensitivity of lung ultrasound to diagnose acute heart failure increased to 75% when patients who were treated with diuretics before arrival at the emergency department were excluded.	Prospective observational cohort study of a convenience sample of adult patients. Scanning was performed by two medical students who were extensively trained in lung ultrasound by two POCUS expert physicians. Image interpretation was done by two expert physicians who were blinded to clinical information. Reference standard was the final diagnosis decided by two independent physicians based on medical record review including echocardiography but blinded to lung ultrasound.
Goffi et al. 2013	Lung ultrasound	To evaluate the diagnostic impact of lung ultrasound by comparing the main diagnosis, the most likely pathophysiologic	50 patients with acute dyspnea. LUS resulted in a positive change in diagnostic accuracy: Cohen's kappa increased from	Cohen's kappa for clinical assessment was 0,25 and lung ultrasound 0,94.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were POCUS

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Table 1 (*continued*)

Article	Ultrasound application	Objective	Result	Details	Study design
		dysfunction, and the etiological diagnosis, as indicated by the treating physician.	0,25 to 0,94 before and after ultrasound use. Lung ultrasound resulted in a change in therapeutic management in 58% of patients.	In 58% therapeutic management was changed (19 cases new drug, 10 cases not giving a previously considered treatment, 6 cases new procedure, 5 cases different disposition plan).	experts not blinded to clinical information. Reference standard was the final diagnosis decided by two physicians based on medical record review but lung ultrasound.
Golshani et al. 2016	Cardiac, lung, and IVC ultrasound	to compare POCUS with brain natriuretic peptide (BNP) in differentiating cardiogenic causes of acute dyspnea.	48 patients with dyspnea. POCUS was an accurate tool to differentiate cardiogenic causes of acute dyspnea in emergency settings with the advantage of no false positive results when compared to BNP testing. The high rate of cardiac and renal dysfunction in critically ill patients limits the discriminative role of BNP.	Final diagnosis dichotomized between cardiac and non-cardiac origin was 100% compatible with echocardiographic results. The area under the receiver operating characteristic curve for POCUS and BNP for differentiating the cardiogenic cause of dyspnea were 86.4 (95% CI: 74.6–98.3) and 66.3 (95% CI: 49.8–89.2), respectively. POCUS revealed the cardiogenic cause of acute dyspnea in 18 cases (0 false positive) and BNP in 44 cases (24 false positives).	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were physicians who had completed a ten-day course in POCUS didactics and hands on training prior to the study. They were involved in clinical management and not blinded to clinical information. Reference standard was a comprehensive echocardiography performed by a cardiologist blinded to clinical information.
Guttikonda et al. 2018	Multi-organ POCUS	to assess a diagnostic strategy using POCUS to distinguish patients with different etiologies of acute dyspnea for timely management in a resource-limited setting.	100 patients with dyspnea. Concordance between initial diagnosis with POCUS and final hospital diagnosis at discharge showed agreement in diagnosis in 88% of patients.	Cohen's Kappa for diagnostic concordance was Kappa = 0.805 (p = .000). Sensitivity and specificity of the diagnostic strategy used in this study to identify acute heart failure was 97.3 and 93.3%, respectively.	Prospective observational cohort study of a convenience sample of patients aged 16 years and above. One physician who was trained in POCUS conducted all scans and was involved in patient management and not blinded to clinical information. Reference standard was final diagnosis at discharge as decided by two independent physicians based on medical record review.
House et al. 2020	Lung ultrasound	to evaluate the impact of lung ultrasound on clinical decision-making of physicians caring for patients presenting with dyspnea in Nepal.	280 patients with dyspnea. LUS led to a change in diagnosis in 44.3%. Management was changed in 53,6%, mostly medication related.	In more than half (53,6%) there was a change in diagnostic and therapeutic management. These changes were related to medication (83,3%), patient disposition (13.3%), and consultation of other specialties (2.7%).	Prospective observational cohort study of a convenience sample. Scanning physicians completed an eight h training on lung ultrasound and proctored scanning. All scans were reviewed by one of two expert sonographers who were blinded to clinical information and ultrasound image interpretation. Reference standard was a standardized data collection form with pre-test diagnosis, post-test diagnosis and categorical analysis how LUS findings may have impacted acute management in terms of disposition, treatment, consultation, and other.
Javaudin et al. 2021	Lung ultrasound	to investigate the diagnosis performance of lung ultrasound for suspected community acquired pneumonia and its impact on antibiotic treatment initiation.	148 patients with suspected community acquired pneumonia. LUS resulted in an improvement of diagnostic accuracy for community acquired pneumonia from 27% to 77%.	Congruence between initial pneumonia classification and final diagnosis was 27% (95% CI 20 to 35) in the routine procedure and 77% (95% CI 71 to 84) in the lung ultrasound assisted pneumonia classification.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had different levels of POCUS expertise ranging from beginners to experts and were blinded to clinical information. Reference standard was the final diagnosis decided by an expert panel of three physicians based on medical record review including lung ultrasound recordings but not image interpretation.
Koh et al. 2018	Cardiac, lung, and deep veins ultrasound	to determine the overall diagnostic accuracy of POCUS in patients with undifferentiated dyspnea.	231 patients with dyspnea. Lung ultrasound yielded the correct diagnoses in 68.3% (136/199) of patients. In patients with lung ultrasound B-profile (n = 60), the addition of cardiac POCUS was able to differentiate cardiogenic pulmonary edema	32 patients had an uncertain final diagnosis and were excluded from the final analysis. 60 patients manifested the B-profile indicative of pulmonary edema on lung ultrasonography. 49 patients with pneumonia, 29 had C profiles and 3 had A/B profiles.	Prospective observational cohort study of a convenience sample of patients aged 21 years and above. The scanning physicians were three, of whom two had completed a 20 h training in POCUS and one was a board certified physician. They were unaware of clinical information.

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Table 1 (*continued*)

Article	Ultrasound application	Objective	Result	Details	Study design
			from non-cardiogenic causes in 42 (70.0%) patients. POCUS is more useful in ruling-in than in ruling-out a differential diagnosis in evaluating patients with undifferentiated dyspnea.	62 patients with asthma/COPD of whom 40 had A-profiles. 4 patients with pneumothorax had A'-profiles. 41 out of 76 patients with the adjudicated diagnosis of heart failure had combined B-profile and poor cardiac contractility on ultrasonography. This study demonstrated lower sensitivities but similar specificities for dyspneic patients than other studies.	All scans were reviewed by two POCUS experts with more than five years of ultrasound experience who were blinded to clinical information and initial diagnosis. Reference standard was the final diagnosis decided by two independent physicians who were not aware of POCUS findings and based their decision on medical record review.
Lamsam et al. 2018	Cardiac, lung, and IVC ultrasound	to compare POCUS with chest radiography in patients with an undifferentiated respiratory or chest complaint.	59 patients with dyspnea or chest pain (five excluded due to three no CXR and one no respiratory complaint and one no diagnosis). POCUS was completed in all patients. Primary outcome of clinical diagnosis at discharge as well as secondary outcome of chest CT diagnosis was comparable between POCUS and CXR.	54 received CRX; 24 also received chest CT. Primary endpoint: clinical diagnosis at discharge. POCUS and CXR sensitivities and specificities were 79% v. 67%, $p = 0.37$ and 71% v. 83%, $p = 0.16$. Their PPV and NPV were 66% v. 73%, $p = 0.41$ and 83% v. 78%, $p = 0.55$. Secondary endpoint chest CT diagnosis. POCUS and CXR sensitivities and specificities were 76% v. 65%, $p = 0.41$ and 71% v. 100%, $p = 0.16$. Their PPV and NPV were 87% v. 100%, $p = 0.19$ and 56% v. 54%, $p = 0.90$.	Prospective observational cohort study of a convenience sample of adult patients. Scans were performed by one medical student who had completed a two h training session by a POCUS fellowship trained physician and who was blinded to any clinical information. All scans were reviewed by a POCUS expert blinded to the medical student's interpretation. Two reference standards were used: discharge diagnosis based on medical record review and in a subset of 24 patients chest CT diagnosis.
Laursen et al. 2013	Multi-organ POCUS	To evaluate POCUS in patients with acute respiratory symptoms.	134 patients with acute respiratory symptoms. POCUS can be used to rule in and rule out life-threatening conditions in patients presenting with acute dyspnea.	Life-threatening conditions that were missed on initial evaluation were found in 14% of patients who underwent POCUS. POCUS' diagnostic properties for the diagnosis of an acute life-threatening condition, when using audit as gold standard, was as follows: sensitivity 100% (95% CI, 85.2%–100%); specificity, 93.3% (95% CI, 86.7%–97.3%); PPV 76.7% (95% CI, 57.7%–90.1%); and NPV 100% (95% CI, 96.3%–100%).	Prospective observational cohort study of a convenience sample of adult patients. One scanning physician who was an expert in POCUS was blinded to clinical information. Reference standard was final diagnosis which was decided by two independent physicians based on medical record review.
Laursen et al. 2014	Multi-organ POCUS	To investigate the null hypothesis that POCUS in addition to usual initial diagnostic tests does not increase the percentage of patients admitted with respiratory symptoms who receive a correct presumptive diagnosis compared with the current diagnostic methods.	315 patients with respiratory symptoms 157 with POCUS and 158 without. POCUS resulted in an upward shift in diagnostic accuracy by 24.3% (95% CI 15.0–33.1).	Higher percentage of correct presumptive diagnosis (88,0% vs 63,7%) after 4 h.	Prospective, parallel-group, single-blind randomized controlled trial of a convenience sample of adult patients, with a superiority design. One scanning physician who was an expert in POCUS was blinded to clinical information. Reference standard was final diagnosis which was decided by an audit team and based on medical record review and blinded to patient allocation to treatment or control group.
Liteplo et al. 2009	Lung ultrasound	to determine the optimal POCUS protocol and test threshold to diagnose congestive heart failure and to compare the diagnostic efficiency of POCUS with NT-proBNP levels.	94 patients with acute dyspnea in whom heart failure was one of the possibilities in the differential diagnoses. LUS could be applied to assess for heart failure in dyspneic patients. Congruent LUS and NT-proBNP results alter the odds of heart failure.	POCUS could be used alone to assess for heart failure in dyspneic ED patients. It performs similarly (overlapping CIs) to NT-proBNP in that the likelihood of heart failure is increased when the test is positive and decreased when negative. Ultrasound has the advantage of being noninvasive and immediately available. The data suggest that congruent NT-proBNP and scanning results may alter the odds of heart failure, compared to the NT-proBNP test alone.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians with prior ultrasound experience and medical students with limited POCUS training which included a prove of proficiency by scanning and interpreting a minimum of five lung ultrasounds. They were involved in patient management and not blinded to clinical information but NT-proBNP values. Scans were all supervised by one POCUS expert who was blinded to clinical information and NT-proBNP results.

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Article	Ultrasound application	Objective	Result	Details	Study design
					Reference standard was the final diagnosis decided by two independent physicians based on medical record review but blinded to lung ultrasound.
Mantuani et al. 2016	Cardiac lung and IVC ultrasound	To compare the accuracy of the treating physician's diagnostic impression before and after results of POCUS were available, as compared to final diagnosis.	57 patients with dyspnea. POCUS improved the treating physician's immediate overall diagnostic accuracy for acute heart failure, COPD/asthma and pneumonia. It was capable of excluding pneumonia and acute heart failure at the bedside.	Diagnostic accuracies were compared between initial diagnosis after anamnesis and physical exam and EKG (accuracy 53%), again after addition of POCUS (accuracy 77%), with final diagnosis as the reference test. When POCUS was applied sensitivity and specificity were 100% and 95% in patients with a final diagnosis of acute heart failure and 100% and 83% in patients with pneumonia.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had completed an ultrasound fellowship and were involved in patient management and not blinded to clinical information. Reference standard was the final diagnosis decided by two independent physicians based on medical record review but not POCUS results.
Miller et al. 2012	IVC and abdominal aorta ultrasound	to determine the test characteristics of inferior vena cava scanning for diagnosing acute heart failure in the evaluation of patients with acute dyspnea.	89 patients with acute dyspnea. Inferior vena cava index with a cut off value of 33% had sensitivity and specificity values of 80% and 81% to identify acute heart failure.	Inferior vena cava index (IVCexpiration -IVCinspiration / IVCexpiration) and ratio IVC and abdominal aorta were calculated. Cardiac tamponade or right ventricular failure may also cause a IVC index. An IVC index less than 33% had a sensitivity of 80% (95% CI, 63%- 91%), a specificity of 81% (95% CI, 68%−90%), and a positive likelihood ratio of 4.3 for diagnosing acute heart failure.	Prospective observational cohort study of a convenience sample of patients aged 50 years and above. Scanning physicians had followed a four h POCUS training and were not blinded to clinical information. Reference standard was final diagnosis decided by three independent physicians based on medical record review but not POCUS analysis.
Msolli et al. 2021	Lung ultrasound	to evaluate the accuracy and reproducibility of lung ultrasound in the diagnosis of congestive heart failure after two hours of POCUS training.	700 dyspneic patients. LUS using a B-lines score at a cut-off 15 had a sensitivity of 88% and specificity of 75%. The area under receiver operating characteristic curve was 0.86 for B-lines score.	There was excellent agreement for the diagnosis of heart failure using B-lines score (kappa = 0.81).	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had completed a two h training and conducted ten supervised lung ultrasounds prior to participating in this study. They were involved in patient management and not blinded to clinical information. Reference standard was final diagnosis decided by two independent physicians and based on medical record review including POCUS images.
Nazerian et al. 2010	Cardiac ultrasound	to investigate the accuracy of POCUS in patients with acute dyspnea for the diagnosis of acute heart failure.	145 patients with dyspnea. Diagnostic accuracies to identify acute heart failure of NT-proBNP and Boston criteria were both 49% and cardiac POCUS 75%. A combination of all three tests resulted in a diagnostic accuracy of 82%.	Time needed to complete focused cardiac ultrasound was four minutes (interquartile range 2–6 min). Mitral inflow analysis using pulsed Doppler (E/a ratio) with a restrictive pattern showed better sensitivity and specificity for the diagnosis of acute left sided heart failure compared with reduced left ventricular ejection fraction (82% versus 61% and 90% versus 76%). Diagnostic accuracy of the restrictive pattern was greater than that of NT-proBNP and of the Boston criteria (75% versus 49%). Diagnostic performance of a model that integrated Boston criteria, NT-proBNP, and the restrictive pattern had a diagnostic accuracy of 82% in this population.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had POCUS competence and completed an additional four h training with special emphasis on focused Doppler cardiac POCUS. They were not involved in patient management and blinded to clinical information but obvious signs and symptoms. Reference standard was the final diagnosis decided by three independent physicians and based on medical record review but not POCUS and NT-proBNP values.
Nazerian et al. 2016	Lung ultrasound	to assess the diagnostic accuracy of the combination of lung ultrasound with procalcitonin (PCT) when the final diagnosis was supported by a chest CT imaging.	128 patients with acute dyspnea. A combination of LUS and PCT showed a high sensitivity for the diagnosis of pneumonia in patients presenting with respiratory complaints of	Sensitivity of a negative LUS/ procalcitonin (<0.25 ng/ml) was higher than negative CXR/ procalcitonin (96.7 vs 80.3%, $p <$ 0.05). Specificity of positive dual test results was not different. Thirty-seven out of 45 patients	Prospective observational cohort study of a consecutive sample of adult patients with dyspnea in whom a chest CT was ordered. Scanning physicians were POCUS experts with more than five years of experience. They were blinded

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			uncertain origin that underwent chest CT. The sensitivity of this combination was significantly higher when compared with the sensitivity of LUS alone and PCT alone.	(82.2%) with positive CXR had a final diagnosis of pneumonia. CXR showed false negative results in 24 (18.7%) patients. A false negative combination of LUS/PCT test was observed in 2 cases (1.6%).	to clinical information but obvious signs and symptoms and not involved in patient management. Reference standard was the final diagnosis decided by two physicians based on medical record review and included chest CT results but not procalcitonin, lung ultrasound, or chest X-ray.
Nakao et al. 2021	Multi-organ POCUS	to determine the classification performance of POCUS compared with chest x-ray in its ability to recognize acute heart failure.	81 dyspneic patients. POCUS had a sensitivity of 92.5% and specificity of 85.7% to identify acute heart failure. Chest x-ray had a sensitivity of 63.6% and specificity of 92.9%. Overall POCUS was more accurate than CXR ($p = 0.0003$).	Only patients of 50 year and older were included. Diagnostic accuracy measures to identify acute heart failure: POCUS sensitivity of 92.5% (95% CI 83.4–97.5%) and specificity of 85.7% (95% CI 57.2–98.2%). Chest X-ray sensitivity of 63.6% (95% CI 50.9–75.1%) and specificity of 92.9% (95% CI 66.1–99.8%).	Prospective observational cohort study of a consecutive sample of patients with dyspnea aged 50 years and above. Scanning physicians were expert sonographers and involved in patient management and not blinded to clinical information. All scans were evaluated by the ultrasonography team who were blinded to clinical diagnosis. Reference standard was the final diagnosis at discharge as decided by the study team based on medical record review.
Öhman et al. 2019	Cardiac, lung, and IVC ultrasound	To evaluate a cardiac and lung POCUS protocol for diagnosing acute heart failure.	100 patients with acute dyspnea. The diagnostic accuracy of the combination of cardiac and lung ultrasound in patients with dyspnea was higher than of either cardiac ultrasound (measuring E/e' as proxy for left atrial pressure) or lung ultrasound alone. Adding the inferior vena cava index did not improve diagnostic accuracy.	The diagnostic accuracy of point of care cardiac and lung ultrasound for acute heart failure was assessed using BNP of more than 400 ng/l or a BNP of less than 100 ng/l in combination with congestion on chest radiography and structural heart disease on conventional echocardiography as a reference standard. The POCUS protocol had a sensitivity of 100% (95% confidence interval: 91.4–100%), a specificity of 95.8% (95% confidence interval: 84.6–99.3%), and an area under the curve of 0.979 for diagnosing acute heart failure.	Prospective observational cohort study of a convenience sample of adult patients. One scanning physician who was an expert in POCUS was not blinded to vital signs and obvious clinical signs but not involved in patient management. Reference standard for acute heart failure was the combination of comprehensive echocardiography and presence of a high NT-proBNP or combination of moderately elevated NT-proBNP and signs of heart failure on chest X-ray.
Özkan et al. 2015	Lung ultrasound	to determine the accuracies of lung ultrasound and the stethoscope as parts of physical examinations of patients with mild or moderate dyspnea.	60 patients with dyspnea allocated to either lung ultrasound ($n = 30$) or stethoscope ($n = 30$) examination. The diagnostic performance of a stethoscope and LUS in patients with dyspnea was comparable to rule out heart failure and to diagnose pneumonia.	In this study stethoscope examination appeared to be as valuable as lung ultrasound for the exclusion of heart failure and the affirmative diagnosis of pneumonia without lengthening the time required for the exam.	Prospective randomized trial of a consecutive sample of adult patients. Three scanning physicians had completed two days of POCUS training and three others had completed two days of stethoscope training. They were involved in patient management and not blinded to clinical information. Reference standard was the final diagnosis decided by the treating physician.
Patel et al. 2018	Lung ultrasound	to determine the accuracy of the BLUE protocol in giving a correct diagnosis in patients presenting with acute respiratory distress.	50 patients with acute respiratory distress. The BLUE protocol provided the accuracy of 90.31% in diagnosis of acute respiratory distress.	Sensitivity and specificity for different etiologies: Pneumonia ($n = 17$) 94% and 94% Pneumothorax ($n = 5$) 80% and 100% Pulmonary edema ($n = 13$) 92% and 100% COPD ($n = 14$) 85% and 89% Pulmonary embolism ($n = 1$) 100% and 100%	Prospective observational cohort study of a convenience sample of patients aged 12 years and above. POCUS expertise of the scanning physicians is not specified. They were not blinded to clinical findings but not involved in patient management. Reference standard was the final diagnosis decided by the treating physician based on all clinical information but the lung ultrasound results.
Papanagnou et al. 2017	Multi-organ ultrasound	to examine the impact of POCUS on the clinical impression of physicians evaluating dyspneic patients.	115 patients with dyspnea. Addition of POCUS to the clinical assessment resulted in no change in concordance	Post-ultrasound clinical diagnosis matched the final diagnosis 63% of the time (95%CI, 53–70%), compared to 69% pre-ultrasound (95%CI, 60–76%).	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were trained in POCUS and supervised at the

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			between clinical in final diagnosis.		bedside by experts. They were involved in patient management and aware of all clinical information prior to conducting the scanning. Reference standard was the final diagnosis based on medical record review.
Parlamento et al. 2009	Lung ultrasound	to assess the ability of lung ultrasound to confirm clinical suspicion of pneumonia and the feasibility of its integration in common clinical practice.	49 patients with suspected community acquired pneumonia. Lung ultrasound was more capable of correctly diagnosing community acquired pneumonia when compared to chest X-ray.	Pneumonia was confirmed in 32 cases (65.3%). In this group we had 31 (96.9%) positive lung US and 24 (75%) positive CXR. In 8 (25%) cases, lung ultrasound was positive with a negative CXR. In this group, chest CT always confirmed the LUS results. In one case, LUS was negative and CXR positive. A complete lung ultrasound examination (scanning anterior, lateral and posterior chest wall) was feasible in all the patients, whereas obtaining both posterior-anterior and lateral CXR views was feasible in 28 (66%) cases only.	Prospective observational cohort study of a convenience sample of patients aged 16 years and above. One scanning physician with more than a decade of POCUS experience who was not involved in patient management but not blinded to clinical signs. Reference standard was either chest X-ray assessed by a radiologist blinded to POCUS results or chest CT which was assessed by another radiologist also blinded to POCUS.
Pirozzi et al. 2014	Multi-organ POCUS	to evaluate if combined approach of standard diagnostics and POCUS would improve the accuracy of acute undifferentiated dyspnea.	168 patients with acute dyspnea. Application of POCUS in the frontline resulted in a much higher concordance rate between initial and final diagnosis when compared to traditional workup without POCUS.	In 88 patients POCUS was performed immediately and in 80 patients POCUS was delayed for 1 h and conducted after an initial diagnosis was made. POCUS integration into the clinical examination at the bedside resulted in a concordance rate between initial and final diagnosis of 0,94 versus 0,22 without POCUS. Also a wrong diagnosis was made in 50% of cases without the application of POCUS versus 5% in the patients who were exposed to ultrasound at the bedside.	Prospective randomized trial of a consecutive sample of adult patients. Scanning physicians were well trained in POCUS, duration not specified, and blinded to clinical information but not to obvious signs and symptoms of the patients. They were not involved in patient management. Reference standard was the final diagnosis as decided by two independent physicians based on medical record review. They were blinded to POCUS results and diagnosis of the treating physician.
Pivetta et al. 2015	Lung ultrasound	To evaluate the performance of a diagnostic approach implementing lung ultrasound with the clinical assessment in differentiating acute heart failure from noncardiac causes of acute dyspnea.	1005 patients with acute dyspnea. The combination of LUS and clinical workup had the highest accuracy in differentiating acute heart failure from non-cardiac causes of dyspnea. LUS-integrated accuracy measures were as follows: sensitivity 97% [95% CI, 95%−98.3%]; specificity 97.4% [95% CI, 95.7%−98.6%]) in differentiating acute heart failure from noncardiac causes of acute dyspnea.	Clinical workup and LUS alone had relatively high accuracy in the identification of acute heart failure, whereas CXR showed only moderate accuracy. (Sensitivity and specificity for LUS compared with CXR ($P < 0.01$)). Clinical workup with integration of LUS had the highest accuracy. Initial clinical workup without LUS (sensitivity, 85.3% [95% CI, 81.8%−88.4%]; specificity, 90% [95% CI, 87.2%−92.4%]) CXR alone (sensitivity, 69.5% [95% CI, 65.1%−73.7%]; specificity, 82.1% [95% CI, 78.6%−85.2%]), Natriuretic peptides alone (sensitivity, 85% [95% CI, 80.3%−89%]; specificity, 61.7% [95% CI, 54.6%−68.3%]; $n = 486$).	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had a heterogenous level of POCUS experience ranging from less than ten lung ultrasounds performed to long time expert. Their inter and intra rater variabilities were assessed in a sample of 200 scans with Kappa values between 0.92 and 0.97. They were involved in patient management and not blinded to clinical information. Reference standard was the diagnosis at discharge as decided by two independent physicians who were blinded to lung ultrasound results.
Pivetta et al. 2019	Lung ultrasound	To evaluate the accuracy of a diagnostic approach combining lung ultrasound and clinical assessment as compared to the traditional acute heart failure diagnostic work-up (clinical evaluation with CXR and natriuretic peptide	518 patients with acute dyspnea. LUS resulted in a an increase in diagnostic accuracy of 7%.	Addition of LUS had higher area under curve (AUC) of 0.95 versus clinical evaluation alone (AUC 0.88) in identifying acute heart failure. Combining LUS with clinical evaluation reduced diagnostic errors by 7.98 cases/100 patients, as compared to 2.42	Prospective randomized trial of a convenience sample of adult patients. Scanning physicians had different levels of POCUS experience but were all described as competent. They were involved in patient management and aware of clinical

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		measurement) in patients with acute dyspnea.		cases/100 patients in the CXR/ NT-proBNP group.	information but blinded to chest X-ray and NT-proBNP values. Reference standard was the final diagnosis as decided by two independent physicians based on medical record review but blinded to lung ultrasound results.
Prosen et al. 2011	Lung ultrasound	to determine the diagnostic accuracy of lung ultrasound, NT-proBNP, and clinical assessment in differentiating heart failure related acute dyspnea from pulmonary related acute dyspnea.	218 acutely dyspneic patients. Of note, pneumonia, pulmonary embolism, pneumothorax were all excluded. B-lines, alone or in combination with NT-proBNP, had high diagnostic accuracy in differentiating acute heart failure related from COPD/ asthma-related causes of acute dyspnea.	Lung ultrasound could rule out heart failure in patients with elevated NT-proBNP levels (> 1000 pg/mL) and a history of HF but lacking B-lines. Moreover, ultrasound examination was the best single method for ruling in the diagnosis of acute heart failure. Compared with clinical assessment using modified Boston criteria and NT-proBNP testing, lung ultrasound had a significantly better receiver operating characteristics area under the curve with regard to diagnostic accuracy. The combination of LUS and point-of-care testing of NT-proBNP proved to be an even more reliable method for the identification of acute heart failure and its differentiation from COPD/ asthma-related causes of acute dyspnea.	Prospective observational cohort study of a consecutive sample of adult patients. Scanning physicians were all experienced in POCUS and were involved in patient management and not blinded to clinical information but NT-proBNP values. Reference standard was the final diagnosis as decided by two independent physicians based on medical record review but blinded to lung ultrasound.
Riishede et al. 2021	Cardiac and lung ultrasound	To investigate the hypothesis that adding POCUS to standard clinical examination of patients with signs of respiratory failure could increase the proportion of correct diagnosis.	211 dyspneic patients randomized in a 1:1 ratio to have POCUS results unblinded to the treating physician (intervention group) versus not (control group). The concordance between initial and final diagnosis was 79.25% (95% CI 70.3–86.0) in the POCUS group versus 77.1% (95% CI 68.0–84.3) in the control group in whom POCUS results were not unblinded to the treating physician.	The patients whose scanning results were unblinded received appropriate treatment in 77.1% (95% CI 70.3–86.0) of cases versus 65.7% (95% CI 56.0–74.3) in the control group which was an absolute increase of 13·5%. Overall in the intervention group of patients a large proportion spent less than 1 day in hospital, n = 42 (39·6%; 25·8–38·4) compared to the control group n = 25 (23·8%; 16·5–33·0) (p = 0·01) which was an absolute increase of 15·8%.	Prospective randomized trial of a consecutive sample of adult patients. Scanning physicians had different levels of POCUS competence and had all received a study specific POCUS training prior to the study. They were not involved in patient management but not blinded to vital signs. Reference standard was the final diagnosis as decided by two independent physicians based on medical record review but blinded to POCUS results.
Russell et al. 2015	Cardiac and lung ultrasound	To investigate if the use of POCUS would increase accuracy for diagnosing acute heart failure and improve clinical management in patients with undifferentiated dyspnea.	99 patients with undifferentiated dyspnea. POCUS resulted in an accuracy improvement of 20%; Specificity improved by 39%; Change in sensitivity was not significant.	accuracy improved by 20% (83% vs. 63%, 95% CI = 8% to 31% for the difference) using the LuCUS protocol over clinical gestalt alone. Specificity improved by 39% (83% vs. 44%, 95% CI = 22 to 51 for the difference), but the change in sensitivity (11% decrease, 94% vs. 83%, 95% CI = –4.4 to 26 for the difference) was not significant. Clinicians felt more confident in their diagnoses after the LuCUS protocol in 92% of cases. Overall, accuracy improved by 20% (83% vs. 63%, 95% CI = 8% to 31% for the difference) using the LuCUS protocol over clinical gestalt alone. Specificity improved by 39% (83% vs. 44%, 95% CI = 22 to 51 for the difference), but the change in sensitivity (11% decrease, 94% vs. 83%, 95% CI = –4.4 to 26 for the difference) was not significant. Clinicians felt	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had completed fellowships in POCUS and were all very experienced. They were not involved in patient management and blinded to clinical findings. Reference standard was the final diagnosis as decided by two independent physicians based on medical record review but blinded to POCUS results.

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				more confident in their diagnoses after the LuCUS protocol in 92% of cases. Overall, accuracy improved by 20% (83% vs. 63%, 95% CI = 8% to 31% for the difference) using the LuCUS protocol over clinical gestalt alone. Specificity improved by 39% (83% vs. 44%, 95% CI = 22 to 51 for the difference), but the change in sensitivity (11% decrease, 94% vs. 83%, 95% CI = –4.4 to 26 for the difference) was not significant. Clinicians felt more confident in their diagnoses after the LuCUS protocol in 92% of cases. Overall, accuracy improved by 20% (83% vs. 63%, 95% CI = 8% to 31% for the difference) using the LuCUS protocol over clinical gestalt alone. Specificity improved by 39% (83% vs. 44%, 95% CI = 22 to 51 for the difference), but the change in sensitivity (11% decrease, 94% vs. 83%, 95% CI = –4.4 to 26 for the difference) was not significant. Clinicians felt more confident in their diagnoses after the LuCUS protocol in 92% of cases. Overall, accuracy improved by 20% (83% vs. 63%, 95% CI = 8% to 31% for the difference) using ultrasound over clinical gestalt alone. Specificity improved by 39% (83% vs. 44%, 95% CI = 22 to 51 for the difference), but the change in sensitivity (11% decrease, 94% vs. 83%, 95% CI = –4.4 to 26 for the difference) was not significant. Clinicians felt more confident in their diagnoses after ultrasound scanning in 92% of cases.	
Sartini et al. 2017	Lung ultrasound	to compare and evaluate the performances of chest radiography, NT-proBNP and lung ultrasound to identify acute heart failure in patients with shortness of breath.	236 patients with dyspnea. LUS, NT-proBNP, and CXR each on their own show an imbalance between sensitivity and specificity to identify acute heart failure. When results are combined the majority of patients with acute heart failure will be identified.	On CXR signs of heart failure were reported in 106 patients (47%), of these 81 (76%) had a final diagnosis of acute heart failure. 33 patients were missed having acute heart failure on CXR. NTpro-BNP levels were positive (>300 pg/ml) in 172 patients (75%), of these 97 (56%) were diagnosed with acute heart failure. 17 patients were missed having acute heart failure using NTpro-BNP levels. LUS was indicative of heart failure in 80 patients (34%), of these 66 (82%) were diagnosed having acute heart failure. LUS missed 48 patients with a final diagnosis of acute heart failure.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were all trained in POCUS and conducted 50 supervised scans prior to participating in this study. They were not involved in patient management and blinded to clinical findings. Reference standard was the final diagnosis as decided by three independent physicians based on medical record review including NT-proBNP values, echocardiography, CXR, and ultrasound results.
Sezgin et al. 2020	Lung ultrasound	to investigate the effectiveness of lung ultrasound for the early diagnosis of pneumonia.	127 patients with suspected pneumonia. LUS had good diagnostic accuracy to identify patients with pneumonia.	A pattern of consolidation had a sensitivity of 98% and specificity of 95.8% to identify pneumonia. In absence of a consolidation pattern on lung ultrasound but presence of an interstitial lung	Prospective observational cohort study of a convenience sample of adult patients. One scanning physician had a POCUS expertise of more than 100 scans and was not involved in

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				pattern sensitivity and specificity were 93.3% and 88.2%.	patient management and blinded to clinical information. POCUS results were also reviewed by a radiologist who was blinded to clinical information and other radiologic imaging. Reference standard was the final diagnosis as decided by one treating physician and based on medical record review not including lung ultrasound results.
Sforza et al. 2017	Cardiac, lung, and IVC ultrasound	to test the utility and accuracy of LUS alone or combined with ultrasound of the heart and IVC in the identification of cardiogenic dyspnea with pocket ultrasound device.	68 patients with dyspnea. The integration of POCUS resulted in a high diagnostic accuracy in patients with dyspnea. Remarkably, chest X-ray and Boston clinical criteria risk score $\geq$ 8 performed suboptimal in detecting patients with acute heart failure.	Ultrasound examination time was always less than 3 min. The maximum accuracy (90%) for the diagnosis of cardiac disease was obtained in the combination of LUS positivity for bilateral interstitial syndrome and/or effusion AND reduced ejection fraction OR dilated and hypo-reactive IVC.	Prospective observational cohort study of a convenience sample of adult patients. One scanning physician with POCUS expertise level III (American Society Echocardiography) was not involved in patient management but not blinded to obvious clinical signs. All scans were reviewed by an independent physician experienced in POCUS blinded to clinical information. Reference standard was the final diagnosis as decided by one physician based on medical record review but blinded to POCUS results.
Stewart et al. 2016	Multi-organ ultrasound	to evaluate the effect of POCUS on the physicians' lists of differential diagnoses for patients presenting with shortness of breath	104 patients with dyspnea in whom 52 underwent ultrasound and 52 did not. By using POCUS the treating physician was able to rapidly narrow the differential diagnoses.	Average (SD) time to perform the scan was 5.7 (1.3) minutes (95% confidence interval, 5.4–6 min) Scanning influenced physician differential diagnoses to the same degree as laboratory and radiographic testing. Scanning did not alter the final diagnosis in this patient population.	Prospective randomized controlled trial in a convenience sample of adult patients. Scanning physicians had completed a basic POCUS training of 16 h and an additional training of two h focused on the scanning protocol used in this study. They were not involved in patient management and blinded to clinical findings. Reference standard was a prespecified ranking list of differential diagnoses which was completed twice by the treating physician before and after the intervention (i.e. either POCUS only or additional laboratory testing and imaging but no POCUS).
Umuhire et al. 2019	Multi-organ ultrasound	to determine the proportion of cases presenting with acute dyspnea in which ultrasound changes the clinician's diagnosis for the patient.	99 patients with dyspnea. Prior to POCUS, the physician leading diagnosis matched the final discharge diagnosis in only 34.3% of cases; after scanning, the physician leading diagnosis matched the final discharge diagnosis in 89% of cases.	Change the clinician leading diagnosis in 64.7% of cases. Increase in confidence Likert scale (mean) 3.5 to 4.7 (0–5). Most found diagnoses: Acute heart failure in 14 patients (53.8%) pre-ultrasound compared to 26 patients (100%) post-ultrasound. Pneumonia in 8 patients (38.0%) pre-ultrasound and in 18 patients (85.7%) post-ultrasound. Pleural effusion in 1 patient (10%) pre-ultrasound and 10 patients (100%) after POCUS. Massive pulmonary embolism 1 patient (25%) pre ultrasound and 4 patients (100%) post ultrasound Extra pulmonary TB 1 patient (14%) and 6 patients post ultrasound (85%).	Prospective observational cohort study of a convenience sample of adult patients. One scanning physician who had completed an ultrasound fellowship and more than three years of POCUS experience was not involved in patient management but not blinded to clinical signs. Reference standards were a ranking list of the three most likely differential diagnoses before and after POCUS and the diagnosis at discharge as stated in the medical record.
Wang et al. 2010	Cardiac ultrasound	to examine whether cardiac POCUS can provide additional information in differentially diagnosing patients with acute	84 patients with dyspnea. POCUS can provide additional information for differentiating the causes of acute dyspnea	Left ventricle end-diastolic dimension and BNP levels were independent predictors for acute heart failure. Left ventricular end-diastolic dimension was more	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had completed basic POCUS training

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Table 1 (*continued*)

Article	Ultrasound application	Objective	Result	Details	Study design
		dyspnea with the available plasma BNP levels.	with already available plasma BNP levels.	informative than ejection fraction in diagnosing the existence of heart failure or not. Left ventricle end-diastolic dimension was significantly larger in the acute heart failure group especially when plasma BNP levels were in the gray zone.	including 20 h cardiac scanning and had completed 120 non-cardiac POCUS and 30 cardiac POCUS under supervision. All scans in this study were recorded and supervised by a cardiologist who was blinded to clinical information and scan interpretation. Scanning physicians were involved in patient management and had access to clinical information. Reference standard was final diagnosis as decided by two independent physicians based on medical record review but blinded to cardiac POCUS results and BNP values.
Yamanoglu et al. 2015	IVC ultrasound	to test whether IVC diameter was suitable for differentiation of dyspnea caused by acute heart failure or pulmonary origin.	74 patients with acute dyspnea admitted to the ICU. IVC diameter at inspiration differentiated between a cardiac and pulmonary cause of dyspnea.	IVC diameter discriminated between cardiac and pulmonary cause of dyspnea ($P < 0.001$). IVC assessment using B-mode at inspiration had the greatest area under curve (0.87; 95% CI, 0.78–0.96).	Prospective observational cohort study of a convenience sample of adult patients. One scanning physician with a POCUS training focused at IVC assessment (six h theory 20 h practice) was not involved in patient management but not blinded to obvious clinical signs. Reference standard was the final diagnosis as decided by an audit team of 6 based on echocardiography and medical record review but blinded to POCUS findings.
Zanobetti et al. 2011	Lung ultrasound	to verify the concordance between lung ultrasound and CXR in different pathophysiologic conditions causing dyspnea, using CT scanning as the gold standard in case of mismatch between the two modalities.	404 patients with acute dyspnea. LUS and CXR showed a high overall concordance. A normal lung ultrasound had a 96% concordance rate with normal CXR. In 108 patients with discordant results a chest CT was conducted with similar accuracies for POCUS and CXR and a higher accuracy for POCUS in distinguishing free pleural effusion.	Ultrasound interpretation was completed during the scan, whereas the average time between chest X-ray request and its final interpretation was 1 h and 35 min.	Prospective observational cohort study of a convenience sample of adult patients. One scanning physician with POCUS expertise of more than two years who was involved in patient management and not blinded to clinical signs. Reference standard was radiologic diagnosis (CXR in 296 cases and chest CT in 108 cases) decided by a blinded radiologist.
Zanobetti et al. 2017	Cardiac, lung, and IVC ultrasound	to evaluate the feasibility and diagnostic accuracy of POCUS for the management of patients with acute dyspnea.	2683 patients with acute dyspnea. POCUS increased accuracy in diagnosing heart failure (sensitivity for the diagnosis of heart failure 88% vs 77%).	Good overall concordance (Cohen's $k = 0{,}71$). No statistically significant differences in the accuracy of POCUS and standard evaluation for acute coronary syndrome, pneumonia, pleural effusion, pericardial effusion, pneumothorax, and dyspnea from other causes. Ultrasound was more sensitive for diagnosing heart failure (sensitivity 88% versus 77%). Routine workup was better in the diagnosis of COPD/asthma (sensitivity 40% versus 91%) and pulmonary embolism (sensitivity 87% versus 92%).	Prospective observational cohort study of a consecutive sample of adult patients. Scanning physicians had POCUS expertise of more than two years including recordings of 150 cardiac and 150 lung ultrasound scans. They were not involved in patient management but not blinded to primary assessment. Reference standard was the final diagnosis as decided by two independent physicians based on medical record review of all information including ultrasound findings.
Zare et al. 2021	Cardiac and lung ultrasound	to evaluate the role of POCUS in early differentiation of the etiologies of acute undifferentiated dyspnea and its impact on faster patient disposition.	103 acute dyspneic patients. POCUS resulted in a decrease in time to diagnosis in all differential diagnoses to diagnosis. Overall time reduction was from 79 min to 43 min ($p < 0.01$).	The decrease in time to diagnosis came along with an equal level of diagnostic accuracy in all triage categories.	Prospective randomized study of a consecutive sample of adult patients. Scanning physicians with unspecified POCUS expertise were involved in patient management and not blinded to clinical signs. Reference standard was duration of time from randomization to clinical diagnosis as decided by the treating physician.

differentiate cardiogenic from other causes of dyspnea. The first study examined a convenience sample of 1005 patients and scanning physicians were trained in POCUS and involved in patient management and thus not blinded to clinical information. The second randomized 518 patients between POCUS versus no POCUS and blinded the scanning physicians to NT-proBNP and CXR. Lung ultrasound alone showed good diagnostic accuracy but the optimal result was obtained when lung ultrasound and conventional workup were combined.

Baker et al. [27] investigated if lung ultrasound practiced by novices contributed to the diagnostic accuracy for diffuse interstitial syndrome. 442 patients were randomized between the control group receiving conventional workup or the intervention group receiving an additional lung ultrasound. All scans were reviewed by a POCUS expert unaware of clinical information. Lung ultrasound had a small effect on diagnostic accuracy. This study demonstrated that lung ultrasound by novices was safe, not time consuming, nor costly.

Anderson et al. [28] conducted a combination of cardiac and lung ultrasound by POCUS proficient physicians who were blinded to clinical information and concluded that the specificity of POCUS for acute heart failure was excellent. Similar conclusions were drawn by Glöckner et al. (two studies), Russell et al., and Sforza et al. whose studies ensured blinding to clinical information [29–32]. Other studies by Cibinel et al., Dehbozorgi et al., Gargani et al., and Öhman et al. had equal findings but lacked blinding [33–36]. Golshani et al. [37] hypothesized that the high rate of cardiac and renal disfunction in this patient category impaired the discriminative role of brain natriuretic peptides whilst not affecting POCUS findings. They were not blinded to clinical information. Liteplo et al. [38] favored the use of POCUS because of its faster results. They together with Wang et al. [39] also stated that congruent ultrasound and NT-proBNP results have the best diagnostic ability. In both studies blinding was ensured by review of all scans by a POCUS expert blinded to scan interpretation and clinical information. Nazerian et al., Prosen et al, and Sartini et al. concluded that a combination of clinical criteria, NT-proBNP, and lung ultrasound yielded the best diagnostic results [40–42]. The research group of Prosen et al. [41] were involved in patient management. Nakao et al. [43] compared POCUS and CXR and found better accuracies in the former in identifying heart failure. In this study the scans were reviewed by the ultrasound team blinded to clinical information.

Miller et al. [44] and Yamanoglu et al. [45] investigated if scanning the inferior vena cava could differentiate cardiac dyspnea from other causes. The scanning physicians were not blinded to clinical information and patient with pulmonary hypertension or tricuspid regurgitation were excluded.

Six studies have assessed POCUS for dyspnea caused by pneumonia. All had diagnostic accuracy as their primary outcome. The data are summarized in Table 1.

Bourcier et al. [46] compared the diagnostic accuracies of CXR and POCUS in 144 patients with a suspected pneumonia. POCUS had a superior sensitivity. In a subgroup of 44 patients with pneumonia who had symptoms for less than 24 h CXR found positive findings in 13 versus 43 using POCUS. In this study the scanning physician was involved in patient management. Cortellaro et al. [47] and Parlamento et al. [48] found comparable results between lung ultrasound and CXR. They concluded that lung ultrasound was feasible in all patients and completed faster. The latter group also found that CXR taken from two orthogonal sites was only feasible in about two thirds of dyspneic patients. In both studies the scanning physicians were blinded to CXR but not to clinical findings.

Javaudin et al. [49] concluded that lung ultrasound improved diagnostic accuracy from 27% to 77%. The scanning physicians had varying POCUS and were blinded to clinical information. Sezgin et al. [50] found similar results.

Nazerian et al. [51] showed that the combination of procalcitonin and lung ultrasound further improved the sensitivity to identify pneumonia when using chest CT as the reference test. The scanning physicians were not involved in patient management and had expertise in lung ultrasound.

3.2. The impact of POCUS in patients with dyspnea in the ICU

Eleven studies investigated POCUS in patients with acute respiratory failure. Diagnostic accuracy was the primary outcome in eight. Other outcomes studied were physician's diagnostic confidence, change in patient management, time to diagnosis, and cumulative fluid administration. The data are summarized in Table 2.

Lichtenstein et al. [52] introduced the bedside lung ultrasound in emergency (BLUE) protocol to determine the etiology of respiratory failure in 260 ICU patients. The correct diagnosis was made in 90.5% of patients including acute heart failure, pneumonia, pneumothorax, asthma/COPD, and presence of venous thrombo-embolism as a proxy for pulmonary embolism. The scanning physicians were not involved in patient management and the reference standard was the final diagnosis as decided by the treating physicians unaware of the ultrasound results. Dexheimer Neto et al. [53] who classified themselves as non-experts in POCUS, repeated the BLUE protocol in a final study population of only 37 patients with acute respiratory failure. The scanning physicians were blinded to clinical information and obtained a high diagnostic accuracy of 84% with POCUS, which was better than CXR, but not significantly better than clinical gestalt alone which was 65%.

Other researchers have modified the BLUE protocol by adding a focused cardiac ultrasound or leaving out VTE assessment. Barman et al. [54] showed that POCUS changed the initial diagnosis, added a diagnosis, and had higher concordance with final diagnosis. Bataille et al. [55] compared lung ultrasound and the combination of cardiac and lung ultrasound and concluded that latter resulted in higher diagnostic accuracies for heart failure and pneumonia. Although they were not involved in patient management they were not blinded to obvious clinical clues. Sekiguchi et al. [56] applied a likewise approach and demonstrated this was able to better differentiate between etiologies of acute respiratory failure. However, the POCUS physicians were involved in patient management. Silva et al. conducted a multiorgan scanning protocol and was able to demonstrate comparable diagnostic accuracies to Lichtenstein et al. [57]. In this study no strict blinding to obvious clinical clues was applied but as a reference standard final diagnosis was based on medical record review including chest CT findings in 75% and echocardiography in 68% of cases. Smit et al. [58] compared lung ultrasound with chest CT in 79 patients. The scanning physicians had a heterogenous level of POCUS experience and were involved in patient management. They found 147 respiratory conditions (most commonly consolidation, interstitial syndrome, and pleural fluid) and emphasized that multiple respiratory conditions can be present in one patient.

Tierney et al. [59] assessed the ability of lung ultrasound by experienced physicians and CXR to identify lung pathology and the affected lobe. Agreement of POCUS and chest CT was 87% versus 62% of CXR. Scanning physicians were not involved in patient management but not blinded to obvious clinical signs. In this study it is concluded that POCUS in the ICU is a better alternative than CXR.

The studies by Wallbridge et al., Wang et al, and Xirouchaki et al. focused on other outcomes of POCUS. Wallbridge et al. [60] found an increase in the physician's diagnostic confidence by 44%. In this study no strict blinding to obvious clinical clues was applied. Wang et al. [61] showed that acute pulmonary edema was diagnosed faster and patient were given less intravenous fluids. They were not involved in patient management but not blinded to obvious clinical signs. In a study by Xirouchaki et al. [62] on mechanically ventilated patients lung ultrasound resulted in a direct change in management half of the times (number of lung ultrasounds was 253). 53 lung ultrasounds revealed findings not suspected by the primary physician such as pneumothorax, atelectasis, significant pleural effusion, consolidation, and diffuse interstitial syndrome. One scanning physician who was not blinded to obvious clinical signs conducted all the scans.

Table 2
POCUS in patients with dyspnea in the intensive care unit.

Article	Ultrasound application	Objective	Result	Details	Study design
Barman et al. 2020	Cardiac, lung, and deep veins ultrasound	to evaluate the impact of POCUS on etiological diagnosis and treatment plan of patients with acute respiratory failure.	108 patients with acute respiratory failure. The rate of correct initial diagnosis increased from 67.5% to 88% when POCUS was added. Ultrasound altered the diagnosis in 37% of cases.	The diagnosis was changed in 17% and an additional diagnosis made in 20%. The treatment plan was changed in 36% of the patients.	Prospective, observational cohort study of consecutive adult patients with acute respiratory failure. One scanning physicians with one year of POCUS experience was blinded to clinical data and not involved in clinical management of the patients. Reference standard was the final diagnosis on day seven after scanning made by a team of three senior intensivists on the basis of medical record review including ultrasound results.
Bataille et al. 2014	Cardiac and lung ultrasound	To assess the diagnostic accuracy of POCUS in patients with acute respiratory failure.	136 patients with acute respiratory failure. POCUS resulted in a change in diagnostic accuracy of 20–29% for different etiologies of acute respiratory failure. The largest effect was seen for acute heart failure and pneumonia.	The diagnostic accuracy for a combination of cardiac and lung ultrasound was higher when compared to lung ultrasound only: In case of pneumonia 0.83 versus 0.63 and in case of acute heart failure 0.94 versus 0.65.	Prospective, observational cohort study of consecutive adult patients with acute respiratory failure. Scanning physicians were well trained in using POCUS, not blinded to obvious clinical clues, but not involved in patient management. Reference standard was the final diagnosis of acute respiratory failure by two independent senior experts based on medical record review including ultrasound results.
Dexheimer Neto et al. 2015	Lung and deep veins ultrasound	to investigate the diagnostic accuracy of the BLUE protocol in acute respiratory failure performed by non-experts in POCUS.	42 Patients with acute respiratory failure. The BLUE protocol in patients with acute respiratory failure had a good agreement between with final diagnosis (kappa coefficient 0.81) and a superior accuracy when compared to CXR (84% vs 43% $p = 0.01$).	37 patients in final analysis (5 excluded because of rare etiology or no acute respiratory failure). No significant difference was found between LUS and the standard initial clinical evaluation (84% vs. 65%; $p = 0.12$). In this study LUS obtained by physicians who are not ultrasound experts resulted in sensitivity and specificity of 86% and 87%, respectively, for lung edema, and 88% and 90%, respectively, for pneumonia.	Prospective observational cohort study of a consecutive sample of adult patients. Scanning physicians were non-experts with five hours of theoretical training and ten supervised lung ultrasounds. They were blinded to patients' medical history and not involved in clinical management. Reference test was the final diagnosis made by the ICU team before patients were discharged from the ICU and did not include POCUS results.
Lichtenstein et al. 2008	Lung and deep veins ultrasound	To assess the potential of POCUS to diagnose acute respiratory failure.	260 patients with acute respiratory failure. For all patients with acute respiratory failure in the ICU, lung ultrasound (and deep vein analysis) yielded correct diagnoses in 90.5% of cases when compared with the final diagnosis	The diagnostic characteristics for different etiologies of acute respiratory failure were as follows: pulmonary edema 95% specificity and 97% sensitivity; COPD and asthma 97% specificity and a 89% sensitivity; pulmonary embolism 99% specificity and 81% sensitivity; pneumothorax 100% specificity and 88% sensitivity; Pneumonia 94% specificity and 89% sensitivity.	Prospective observational cohort study of a consecutive sample of adult patients. Two scanning physicians who are experts in POCUS not involved in patient management. Reference standard was final diagnosis as decided by treating ICU physicians but not aware of ultrasound findings.
Sekiguchi et al. 2015	Cardiac and lung ultrasound	to evaluate the diagnostic utility of POCUS in identifying causes of acute hypoxemic respiratory failure.	134 patients with acute respiratory failure. POCUS assisted in early bedside differential diagnosis of acute respiratory failure.	As primary test in acute respiratory failure low B-line ratio (proportion of chest zones with positive B-lines relative to all zones examined) was predictive of miscellaneous cause versus cardiogenic pulmonary edema or ARDS (receiver operating characteristic area under the curve [AUC], 0.82; 95% CI, 0.75–0.88). As a second test to further differentiate cardiogenic pulmonary edema from ARDS, left-sided pleural effusion (> 20 mm), the combination of a	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were all trained in POCUS however level of experience is not specified. They were involved in patient management and not blinded to clinical information. Scans were reviewed by a radiologist and cardiologist who were blinded to clinical information. Reference standard was the final diagnosis as decided by two investigators based on medical

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Table 2 (*continued*)

Article	Ultrasound application	Objective	Result	Details	Study design
				moderately or severely decreased left ventricular function and a large inferior vena cava minimal diameter (> 23 mm) were predictive cardiogenic pulmonary effusion (AUC, 0.79; 95% CI, 0.70–0.87).	record review but blinded to POCUS results.
Silva et al. 2013	Multi-organ POCUS	to prospectively investigate the clinical relevance of POCUS in patients with acute respiratory failure.	75 patients with respiratory failure. POCUS led to a positive change in diagnostic accuracy by 20%.	More accurate diagnoses with ultrasound (83% vs 63%). Greater diagnostic performance of ultrasound for pneumonia (0,74 vs 0,87), acute pulmonary edema (0,78 vs 0,93), decompensated COPD (0,8 vs 0,92) and pulmonary embolism (0,65 vs 0,81).	Prospective observational cohort study of a consecutive sample of adult patients. Two scanning physicians with expertise in POCUS and more than 3 years of experience were not involved in patient management but not blinded to obvious clinical signs. Reference standard was the final diagnosis as decided by two independent physicians based on medical record review including chest CT in 75% and echocardiography in 68% but blinded to POCUS results.
Smit et al. 2021	Lung ultrasound	to evaluate the diagnostic accuracy of a 6-zone lung ultrasound protocol, with chest CT as reference standard, using adequate blinding and including patients with multiple respiratory conditions.	79 patients with acute respiratory failure. LUS' sensitivity and specificity to detect consolidation were 0.76 and 0.92, respectively. For interstitial syndrome these were 0.60 and 0.69. For pleural effusion these were 0.85 and 0.77.	It is stressed that multiple respiratory conditions can be present in one patient since 147 respiratory conditions were found in the 79 patients. The respiratory conditions most commonly diagnosed were consolidation, interstitial syndrome, and pleural effusion. Sensitivities and specificities for lung ultrasound were 0.76 (95% CI: 0.68 to 0.82) and 0.92 (0.87 to 0.96) for consolidation; 0.60 (95%CI: 0.48 to 0.71) and 0.69 (95%CI: 0.58 to 0.79) for interstitial syndrome; 0.85 (95% CI: 0.77 to 0.91) and 0.77 (95% CI: 0.62 to 0.88) for pleural effusion.	Prospective observational cohort study of a consecutive sample of adult patients. Scanning physicians had all completed a basic training in POCUS but with different levels of experience. They were involved in patient management and not blinded to clinical information. They were blinded to chest CT results. Reference standard was chest CT diagnosis which was assessed by an independent radiologist blinded to POCUS findings.
Tierney et al. 2020	Lung ultrasound	To concurrently evaluate the accuracy of both lung ultrasound and CXR with chest CT not only for agreement of findings within the ipsilateral lung or a correlating CT zone, but within the specific anatomic lobe among a diverse patient population with acute respiratory failure diagnoses.	67 patients with acute respiratory failure who required intubation Overall agreement of lung ultrasound and chest CT with the correlating lobe was 87% and only 62% for chest X-ray ($p < 0.001$).	The agreement with chest CT was better for lung ultrasound than CXR for all reported categories (normal, atelectasis/ consolidation, interstitial process, pleural effusion, ground glass opacities).	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had more than three years of POCUS experience and completed a training session focused on the scanning protocol prior to participating in this study. They were not involved in patient management but not blinded to obvious clinical signs. Reference standard was chest CT result which was classified by a radiologist blinded to lung ultrasound findings.
Wallbridge et al. 2017	Jugular vein and lung ultrasound	To test the hypothesis that POCUS in acute respiratory failure would assist in diagnosing the cause of respiratory failure and impact patient management.	50 patients with acute respiratory failure. POCUS findings were compatible with alternative clinical diagnoses in 34%, enhanced diagnostic confidence in 44%, and modified management in 30% of cases.	Overall POCUS increased clinicians' diagnostic confidence in 22/50 cases (44%), altered the final clinical diagnosis in 5/50 cases (10%) and provided an additional diagnosis (in conjunction with primary clinical diagnosis) in a further 12/50 cases (24%). As a result of the ultrasound findings, patient management was modified in 15/50 cases, giving a 'number needed to scan' of four.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians all attended the same POCUS training meeting level one training requirements of the Royal College of Radiologist. They were not involved in patient management but not blinded to obvious clinical signs. Reference standards were clinical diagnosis as decided by the treating physicians based on complete workup but blinded to ultrasound results; and diagnostic confidence on a three-points scale as decided by the treating physician before

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Table 2 (*continued*)

Article	Ultrasound application	Objective	Result	Details	Study design
					and after POCUS results were known.
Wang et al. 2014	Cardiac and lung ultrasound	To evaluate the usefulness of POCUS in patients with acute pulmonary edema.	128 patients with acute pulmonary edema randomized between POCUS (66) and standard care (62). POCUS resulted in a faster time to diagnosis of the etiology of pulmonary edema and a lower cumulative fluid infusion volume.	The patients in whom ultrasound was done had a shorter time to diagnosis of the pulmonary edema etiology; lower cumulative fluid infusion volume at 6, 12, 24, 72 h. Length of stay in ICU, hospital and mortality rate were equal between groups. Subgroup analysis showed shorter ICU stays for patients with cardiogenic and fluid overload pulmonary edema.	Prospective randomized trial on an convenience sample of adult patients. Scanning physicians had all completed a basic POCUS training by WINFOCUS and were certified as basic-level provider. They were not involved in patient management but not blinded to obvious signs. Reference standard was time to final diagnosis of pulmonary edema as decided by the treating physician and cumulative fluid volume at prespecified time points.
Xirouchaki et al. 2014	Lung ultrasound	to examine the impact of performing lung ultrasound on clinical decision making in mechanically ventilated critically ill patients.	189 mechanically ventilated patients with acute respiratory deterioration in whom 253 lung ultrasounds were performed. The use of lung ultrasound significantly influenced the decision-making process with a change in management directly as a result of scanning in 119 out of 253 cases (47%).	108 studies (42.7%) were performed for unexplained deterioration of arterial blood gasses, and 145 (57.3%) for a suspected pathologic entity (pneumothorax, significant pleural effusion, diffuse interstitial syndrome, unilateral lobar or total lung atelectasis, and pneumonia). In 53 out of 253 cases (21%), lung ultrasound revealed findings which supported diagnoses not suspected by the primary physician (seven cases of pneumothorax, nine of significant pleural effusion, nine of pneumonia, 16 of unilateral atelectasis, and 12 of diffuse interstitial syndrome)	Prospective observational cohort study of a convenience sample of adult patients. One scanning physician with extensive POCUS experience who was not involved in patient management but not blinded to clinical information. Reference standard was the clinical diagnosis as decided by the treating physician blinded to ultrasound results.

3.3. The impact of POCUS in patients with dyspnea in the medical ward

Seven studies investigated POCUS in ward patients with undifferentiated dyspnea. The data are summarized in Table 3. Diagnostic accuracy was the primary outcome in six, change in primary diagnosis and time to initiation of appropriate therapy in one. The largest study was conducted in a short stay unit by Volpicelli et al. [63] who assessed the potential of lung ultrasound in diagnosing alveolar interstitial syndrome in 295 patients. Scanning physicians were trained in POCUS and blinded to clinical findings. Interstitial syndrome was detected with a sensitivity of over 85% and specificity of 97%. Others concluded that lung ultrasound identified patients with heart failure better than chest X-ray and was a more useful instrument to monitor treatment effect in this patient category than repeat measurements of NT-proBNP levels [64–66].

Sen et al. [67] examined the BLUE protocol in patients with respiratory failure and showed a good overall diagnostic accuracy of 84%, applied by experienced POCUS users, which was higher than for clinical diagnosis.

Mearelli et al. [68] showed in a study of 315 patients with a suspected community acquired pneumonia that application of lung ultrasound by experts resulted in an excellent accuracy. The scanning physicians were blinded to clinical information and demonstrated to outperform the diagnostic accuracy of chest X-ray assessed by a radiologist.

Ben-Baruch Golan et al. [69] found that the main effects of application of a cardiac and lung ultrasound in patients admitted for dyspnea, chest pain, or worsening peripheral edema were twofold. The first was a change in diagnosis in 28%. The second a faster initiation of appropriate therapy which was five hours with POCUS versus 24 h without. The patient population was randomized between an intervention and control group and the scanning physicians blinded to clinical findings.

3.4. The impact of POCUS in patients with nontraumatic hypotension and shock in the emergency department

Sixteen studies to investigate the role of POCUS in patients with nontraumatic hypotension and shock have been conducted, including five studies on POCUS and sepsis, and two studies assessing both circulatory and respiratory complaints. The data are summarized in Table 4. Diagnostic accuracy was the primary outcome in eleven, whilst the other studies focused on clinical decision making, disposition time, and 30-day mortality.

Javali et al. [70] showed that POCUS increased the percentage of correct presumptive diagnosis from 45% to 89%. The single scanning physician was blinded to clinical information. Comparable results were found by Shokoohi et al. [71], Jones et al. [72], Leroux et al. [73], and Volpicelli et al. [74] but only the first study group ensured blinding of the scanning physicians. Sasmaz et al. [75] also found similar results but the scanning physicians were involved in patient care.

In addition to an increase in diagnostic accuracy Ahn et al. [76] found that POCUS was an effective tool to help physicians narrow the differential diagnoses and to increase their confidence on diagnosis and treatment strategy. Moore et al. [77] concluded that they found a good correlation between physicians trained in POCUS and cardiologists in estimation of cardiac ejection fraction in patients with symptomatic hypotension. In both studies no blinding of the scanning physicians occurred but they were not involved in patient care.

A retrospective analysis by Jones et al. [78] found that a hyperdynamic left ventricular function on POCUS was highly specific for sepsis as the etiology of shock. An approximate 40 percent of the patient population was excluded due to insufficient image interpretability.

Becker et al. [79] concluded that the diagnostic accuracy of a POCUS incorporated clinical approach to identify the cause of shock or

Table 3
POCUS in patients with dyspnea in the medical ward.

Article	Ultrasound application	Objective	Result	Details	Study design
Ben-Baruch Golan et al. 2020	Cardiac and lung ultrasound	to evaluate the effect of POCUS exam integrated early into the evaluation of medical patients with chest pain, worsening peripheral edema, or dyspnea.	60 patients of whom 30 underwent POCUS and 30 did not. POCUS resulted in a change in diagnosis in 28%. Secondly, the patients in the POCUS group received appropriate therapy earlier (5 h vs 24 h).	Cardiac and lung ultrasound yielded clinically relevant findings among 79% of patients which led to alteration of the primary diagnosis among 28% of patients. Time to appropriate treatment was shorter among patients in the POCUS group (median time of five h [95% confidence interval: 0.5–9] versus 24 h [95% CI: 19–29].	A pilot, single-center, prospective, randomized controlled trial of adult patients. Two scanning physicians who were trained in POCUS with at least two years of experience were blinded to clinical information, and not involved in patient management. Reference standard was the time to correct primary diagnosis and time to appropriate treatment based on the decision by two independent internal medicine physicians who reviewed the complete medical records.
Filopei et al. 2014	Lung ultrasound	To assess the feasibility and diagnostic accuracy of residents trained in lung ultrasound with a pocket device for evaluating patients with dyspnea.	69 patients with dyspnea. LUS by extensively trained residents improved diagnostic accuracy in patients with dyspnea who were thoroughly assessed using conventional diagnostics (including complete history, physical exam, laboratory and imaging studies).	Clinical diagnosis of dyspnea was based on a standard diagnostic evaluation including complete history, physical exam, and all relevant laboratory and imaging studies, including chest x-ray (94%) and computed tomography (22%). Training residents to apply lung ultrasound in non-ICU settings appears to be feasible. However, limited training in lung ultrasound resulted in no change in diagnostic accuracy.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were residents who completed a basic POCUS training and two of them completed an additional advanced training. They were involved in patient management and not blinded to clinical information. Reference standard was the final diagnosis decided by an expert panel of three physicians who were blinded to clinical and ultrasound diagnosis.
Mearelli et al. 2021	Lung ultrasound	To assess the usefulness of lung ultrasound for identifying community acquired pneumonia among adult patients with suspected lower respiratory tract infection.	315 dyspneic patients. The receiver operating characteristics AUC for identifying community acquired pneumonia was 0.93 for LUS and 0.71 for CXR ($p<0.001$).	A POCUS pattern of consolidations with or without alveolar-interstitial syndrome predicted the diagnosis of pneumonia with bacterial and mixed bacterial and viral etiologies with positive predictive values of 99% (95% CI, 94–100%) and 97% (95% CI, 81–99%), respectively.	Prospective observational cohort study of a convenience sample of adult patients. Two scanning physicians with eight years of POCUS experience were blinded to clinical information and patient management but aware that suspected lower respiratory tract infection was the reason of admission. Reference standard for diagnosing community acquired pneumonia was chest X-ray assessed by a radiologist blinded to lung ultrasound findings. Reference standard for predicting outcome was discharge or death within 30 days based on medical record review.
Perrone et al. 2017	Lung ultrasound	to define the role of LUS in the differential diagnosis of dyspnea.	130 patients with dyspnea. LUS showed sensitivity and specificity higher than CXR and confirmed its correlation to the diagnosis of heart failure, to serum BNP levels, and to systolic function.	Interstitial syndrome at initial LUS discriminates "cardiac" from "pulmonary" dyspnea with high sensitivity (93.75%; confidence intervals [CI]: 86.01%–97.94%) and specificity (86.11%; CI: 70.50%–95.33%). Sensitivity and specificity for a diagnosis of heart failure were higher for LUS (91% and 75%) than for CXR (73% and 61%) and pulmonary auscultation (82% and 36%) Interstitial syndrome pattern on admission was directly correlated with BNP levels ($p < 0.001$), and inversely related to global systolic function (as assessed by ejection fraction; $p < 0.05$). Sensitivity and specificity for	Prospective observational cohort study of a consecutive sample of adult patients. One scanning physician who was an expert in point-of-care ultrasound, however not specified, was blinded to clinical information, echocardiography and radiology results. Reference standard was the final diagnosis as decided by the treating physician and confirmed by an independent physician. They were blinded to lung ultrasound results.

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Table 3 (*continued*)

Article	Ultrasound application	Objective	Result	Details	Study design
				pneumonia LUS 73% and 82% versus CXR 64% and 84% respectively.	
Sen et al. 2017	Lung ultrasound (BLUE protocol)	To examine the utility, feasibility, and diagnostic accuracy of the BLUE protocol for respiratory deterioration.	49 patients with medical emergency team activation for respiratory deterioration. BLUE protocol showed a diagnostic accuracy of 84% in an in- patient population with acute respiratory deterioration.	The diagnostic accuracy of lung ultrasound in patients with acute respiratory deterioration was 84% versus 75% for clinical diagnosis.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were experienced in POCUS for several years. They were not involved in patient management and blinded their findings to the treatment team. The POCUS recordings were reviewed by two independent experienced sonographers blinded to the clinical context. Reference standard was the final diagnosis as decided by two independent physicians based on medical record review but blinded to POCUS results.
Vitturi et al. 2011	Lung ultrasound	To evaluate the hypothesis that lung ultrasound can be a reliable diagnostic tool in internal medicine patients, whose clinical conditions are generally less severe and have already been stabilized and treated in emergency settings.	152 patients with dyspnea. Lung ultrasound had good sensitivity 97% and acceptable specificity 79% in diagnosing patients with cardiogenic dyspnea.	Lung ultrasound findings showed positive correlation with the clinical diagnosis and with the biochemical data. Reductions in the number of B lines during treatment were significantly greater in the group of patients treated for heart failure ($p < 0.005$), while this was not the case for the reduction in NT-proBNP values ($p = 0.37$). Therefore, ultrasound seems to be a more promising tool for short-term patient follow-up. The results of lung ultrasound were characterized by very good intra- and inter-operator concordance (expressed as the K coefficient of Cohen: 0.98 and 0.9, respectively)	Prospective observational cohort study of a consecutive sample of adult patients. Two scanning physicians with excellent intra and inter rater variability for lung ultrasounds in this study but no specification on their level of POCUS skills nor experience. They were involved in patient management and not blinded to clinical findings. Reference standard was the final diagnosis as decided by a panel of physicians based on medical record review but not the lung ultrasound results.
Volpicelli et al. 2006	Lung ultrasound	To assess the potential of lung ultrasound to diagnose alveolar interstitial syndrome.	295 patients of whom 160 were diagnosed with a cardiopulmonary disease. B-lines showed a sensitivity of 85.7% and a specificity of 97.7% in recognition of radiologic interstitial syndrome.	Of note, mostly chest X-ray as a reference test. When compared to diagnosis at discharge: False-negative cases include ten acute heart failure (seven with positive and three with negative chest x-ray) and one multiple and diffuse bilateral pneumonia. False positives include four right sided pneumonia (three basal, one apical), one lung cancer, one rheumatoid arthritis, and one fever in aplastic anemia.	Prospective observational cohort study of a consecutive sample of adult patients. Scanning physicians were specially trained to perform lung ultrasound, this is not further specified, and they were blinded to CXR and clinical findings. Multiple reference standards were used: chest X-ray assessed by a blinded radiologist; final diagnosis as decided by medical record review but not lung ultrasound.

respiratory distress was superior to conventional workup in a resource-limited setting. The scanning physicians were involved in patient management.

Cortellaro et al. [80] studied the diagnostic accuracy of POCUS in identifying the focus of infection in patients with sepsis. POCUS was conducted by the treating physician within ten minutes after the primary assessment and improved the diagnostic accuracy from 52.5% to 75%. Secondly, it was able to immediately identify the source of infection in 73% whilst standard workup took 6 h to do so.

Hall et al. [81] found a beneficial effect of POCUS on disposition time of almost an hour. Importantly, the scanning physicians were involved in patient care.

Coen et al. [82] found that POCUS to guide fluid administration reduced the necessity of invasive monitoring (i.e. central venous catheter) whilst Haydar et al. [83] concluded that POCUS resulted in a change in the treatment plan of intravenous fluid administration in more than 40% of the patients. In the former study the scanning physicians had involvement in patient care whilst in both studies the investigators were not blinded to clinical signs.

Atkinson et al. [84] assessed the effect of POCUS on survival until discharge or 30 days. A prospective convenience sample of 270 adult patients with undifferentiated nontraumatic hypotension was randomized between assessment with or without using POCUS by physicians proficient in its use. They were involved in patient management. They found no difference in survival nor in the secondary outcomes fluid administration, inotropes, rate of admission to ICU, and length of stay. Only patients with truly undifferentiated shock were included, patients with a high suspicion of acute abdominal aneurysm and a clear mechanism of shock were excluded. Musikatavorn et al. [85] found no positive effect on 30-day mortality of patients with sepsis who received an inferior vena cava assessment to guide intravenous fluid management. They were involved in patient management.

Table 4
POCUS in patients with nontraumatic hypotension and shock in the emergency department.

Article	Ultrasound application	Objective	Results	Details	Study design
Ahn et al. 2017	Multiorgan ultrasound	to evaluate if POCUS narrows the differential diagnoses, if it increases the physicians' level of confidence in the diagnosis, and to determine its accuracy and test characteristics.	308 patients with dyspnea, hypotension, or chest pain. The diagnostic accuracy of POCUS in the evaluation of patients with dyspnea, chest pain, or symptomatic hypotension was good. POCUS was an effective tool to help physicians narrow the differential diagnosis and to increase diagnostic confidence.	The number of differential diagnoses was significantly reduced from 2.5 to 1.4 (2.5 ± 1.5 vs. 1.4 ± 0.7; $p < 0.001$). The level of confidence in the diagnosis was also increased significantly. Diagnostic accuracy, the overall concordance rate with the criterion standard was 89.0% (274/308), with an overall kappa coefficient value of 0.870 ($p < 0.001$)	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were three: one with extensive experience in POCUS and two who were trained during one year. They were not involved in patient management but not blinded to obvious clinical signs. The number of differential diagnoses and the physician's level of confidence in diagnosis were assessed both before and after using a prespecified list of disease entities. Final diagnosis was decided by the treating inpatient physician based on selection of one diagnosis from the same prespecified list of disease entities.
Atkinson et al. 2018	Multi-organ ultrasound	To assess the effect of POCUS on clinical outcomes for patients with undifferentiated hypotension.	270 patients with undifferentiated hypotension (136 with and 134 without POCUS). POCUS assessment in patients with undifferentiated hypotension compared to conventional workup did not result a change in survival.	There was no significant difference in survival (difference 0.35%; 95% CI −10.2% to 11.0%); no difference in fluid administration, inotropes, rate of admission to ICU, and length of stay. Only patients with truly undifferentiated or occult shock were included. Exclusion of pregnant women; high suspicion of abdominal aneurysm, myocardial infarction with ST segment elevation, and patients with a clear mechanism of shock.	Prospective randomized study of a convenience sample of adult patients. Scanning physicians were all accredited in POCUS but no additional information is specified. They were involved in patient management and not blinded to clinical signs. Reference standard was rate of survival until discharge or 30 days as decided by two independent physicians based on medical record review and blinded to randomization between groups and ultrasound results.
Becker et al. 2017	Multi-organ ultrasound	To assess the effects of POCUS on diagnostic accuracy for critically ill patients in a resource-limited setting.	180 patients enrolled with signs of shock or respiratory distress. Patients were divided into two groups that were assessed clinically with or without POCUS depending on the POCUS skills of the treating physician. Diagnostic accuracy of a POCUS incorporated clinical approach to identify the cause of shock or respiratory distress using POCUS was superior to conventional workup.	The initial diagnosis was compared with final diagnosis. Diagnostic accuracy was higher for patients who received the POCUS examination (71.9%) than those who did not (57.1%). Significant change in diagnostic accuracy for cardiac diagnoses only.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were trained in POCUS and demonstrated their competency prior to participating in this study. No details on level of POCUS are stated. They were involved in patient management and not blinded to clinical information. Reference standard was diagnosis after 24 h or discharge diagnosis whichever came earlier as decided by two independent physicians and based on medical record review.
Coen et al. 2014	Lung ultrasound and IVC and cardiac ultrasound in case of interstitial syndrome	to demonstrate whether a less invasive approach (POCUS) is not inferior to the classic protocol in patients with septic shock.	51 patients with septic shock (defined as 2 or more SIRS criteria and hypotension despite 20 mL/kg intravenous fluids or serum lactate >4). POCUS application to guide fluid administration resulted in a reduction in the necessity of invasive monitoring (i.e. central venous catheter).	Sonographic evaluation of the inferior vena cava was feasible in 92% of patients. Lung ultrasound was performed in 100% of cases. In the first 6 h, only 61.7% of patients received a CVC, an average of 5.5 L of crystalloids were administered, and only 4 patients developed clinical overt pulmonary edema. Mortality was 34% at 28 days and 38.3% at 60 days.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were POCUS certified or had completed a two day POCUS training and proctored scanning thereafter. They were involved in patient management and not blinded to clinical findings. Reference standards were achievement of modified surviving sepsis campaign

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Table 4 (*continued*)

Article	Ultrasound application	Objective	Results	Details	Study design
					goals namely a prespecified mean arterial pressure of 65 mmHg; lactate clearance; and change in IVC diameter.
Cortellaro et al. 2017	Multi-organ ultrasound	To evaluate the diagnostic accuracy of a POCUS-implemented approach compared with the final diagnosis in patients with sepsis. Secondary outcome was to compare the time to septic source identification between POCUS and standard workup.	200 patients with sepsis criteria were clinically assessed. The treating physician formulated a provisional diagnosis and noted a therapeutic and diagnostic treatment plan. Immediately after this all patients underwent POCUS before standard additional workup was undertaken.	Diagnostic accuracy of the provisional diagnosis was 52.5%. POCUS improved the provisional diagnosis by 22.5%. A septic source was identified in 178/200 patients (89%). The most common identified sources were pneumonia (39.5%), urinary tract infection (23%), and abdominal infection (19.5%). The standard work-up identified a septic source within 1 h in 21.9% of the population (39/178), within 3 h in 52.8% (94/178), and within 6 h in 71.3%. POCUS-implemented diagnosis (all within 10 min) identified 130/178 septic sources with a sensitivity of 73%. Among the 48 sources not immediately identified by POCUS, 30 were urinary tract infections. POCUS was false positive in one patient resulting in a specificity of 95%.	Prospective observational cohort study of a consecutive sample of adult patients. Scanning physicians were trained in POCUS and board certified. Reference standard was discharge diagnosis as decided by two independent physicians based on medical record review but blinded to POCUS results.
Hall et al. 2016	Multi-organ POCUS	To determine the effect of POCUS on the disposition time in patients with nontraumatic hypotension.	3834 unique patients presented with shock during an 18-month period, and 703 (18.3%) patients received POCUS. Time spent in the emergency department was shorter for patients with signs of shock in whom POCUS was performed.	On average, time to ED disposition was 50.5 min less ($P < .001$) for patients who received POCUS (214.1 min; IQR, 146.4) versus those who did not (264.6 min; IQR, 168.2). The proposed mechanism is that POCUS helps narrowing the differential diagnosis, perhaps increasing clinician confidence in the underlying diagnosis, thus speeding up disposition to definitive management.	Retrospective observational cohort study of adult patients. Scanning physicians and medical students had a heterogenous level of POCUS proficiency which is not specified. They were involved in patient management and not blinded to clinical information. Reference standard is time to disposition from the emergency department as decided by registered time of arrival until registered time of disposition.
Haydar et al. 2012	Cardiac and IVC ultrasound	to evaluate the effect of POCUS on the clinical decision making process in adult patients with sepsis.	74 patients with sepsis. POCUS changed the initial diagnosis in 17% (mostly volume depletion versus cardiac contractility). POCUS altered the treatment plan in 53%.	Clinical plans were compared before POCUS and after POCUS. Alterations to the treatment plan were present in 39 patients (53%): 33 changes in intravenous fluid administration, 5 changes in vasoactive medication, and 1 alteration in plans for blood transfusion. Physicians' certainty increased across all sepsis severity categories after POCUS.	Prospective cohort study of a convenience sample of adult patients. Scanning physicians had completed a three h training on POCUS and 25 focused cardiac scans prior to participation in this study. They were not involved in patient management but not blinded to obvious clinical symptoms. Reference standards were the pre specified data sheets which were completed before and after POCUS results were provided to the treating physician. On both sheets information on clinical diagnosis, treatment plan and level of confidence for both diagnosis and treatment were noted.
Javali et al. 2020	Multi-organ POCUS	to test POCUS as an early approach to improve the accuracy of diagnosis and to narrow the differentials in cases of nontraumatic undifferentiated hypotension.	100 patients with shock. Addition of POCUS to clinical evaluation led to an increase of correct presumptive diagnosis from 45 to 89%.	There was an almost perfect agreement with the final diagnosis with a κ of 0,89.	Prospective cohort study of a convenience sample of adult patients. One scanning physician who was trained in POCUS without further details specified, was not involved in patient management and blinded to clinical information. Reference standards were

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Table 4 (*continued*)

Article	Ultrasound application	Objective	Results	Details	Study design
					firstly the combined clinical diagnosis as decided by the emergency physician based on all clinical information and POCUS findings and secondly the final diagnosis as decided by the treating physician.
Jones et al. 2004	Multi-organ POCUS	To test the hypothesis that POCUS would significantly narrow the differential diagnoses of patients with nontraumatic, symptomatic, undifferentiated hypotension and would significantly improve physician accuracy in identifying the correct diagnosis.	184 nontraumatic hypotensive patients randomized between immediate and delayed POCUS in their primary assessment. POCUS in patients with nontraumatic hypotension resulted in a positive change in diagnostic accuracy of 30%.	Higher percentage of correct preliminary diagnosis at 15 min in POCUS group (80% vs 50%).	Prospective randomized clinical trial of a convenience sample of adult patients. Scanning physicians were POCUS proficient with at least one month of ultrasound rotation, an additional training prior to this study. They were not involved in patient management but not blinded to obvious clinical signs. Reference standard were preliminary diagnosis based on a prespecified datasheet with possible diagnoses and final diagnosis based on medical record review by the primary investigator.
Jones et al. 2005	Cardiac ultrasound	To assess the hypothesis that POCUS findings of hyperdynamic left ventricular function in adult patients with undifferentiated symptomatic hypotension will be specific for the diagnosis of septic shock.	184 patients with nontraumatic undifferentiated symptomatic hypotension of whom 81 were excluded in the analysis due to uninterpretable ultrasound. Image interpretability was defined as a minimum of two standard views obtained during focused cardiac ultrasound by an independent physician. The presence of hyperdynamic left ventricular function on POCUS was highly specific for sepsis as the etiology of shock.	Categorizing cardiac function into hyperdynamic; normal-mildly reduced; severely reduced. A final diagnosis of septic shock was made in 38% (39/103) of patients. Seventeen of 103 (17%) patients had hyperdynamic left ventricular function with an interobserver agreement of $k = 0.8$. The sensitivity and specificity of hyperdynamic left ventricular function for predicting sepsis were 33% (95% CI 19%–50%) and 94% (85%–98%). Hyperdynamic left ventricular function had a positive likelihood ratio of 5.3 for the diagnosis of sepsis and was a strong independent predictor of sepsis as the final diagnosis with an odds ratio of 5.5 (95% CI 1.1–45).	Preplanned retrospective analysis of a convenience sample of adult patients. Scanning physicians were POCUS proficient with at least one month of ultrasound rotation, an additional training prior to this study. They were not involved in patient management but not blinded to obvious clinical signs. Reference standards were sufficient visual clarity defined as image interpretability of at least two standard views by an independent physician and final diagnosis as decided by medical record review by the primary investigator.
Leroux et al. 2021	Multi-organ POCUS	To explore the added value of POCUS to assess the cause in patients with nontraumatic undifferentiated shock.	85 hypotensive patients. Shock identification with conventional workup was inferior to a POCUS guided workup. The same conclusion was drawn on initiation of therapeutic management.	Conventional workup versus POCUS to identify the type of shock resulted in a Cohen's κ for routine strategy of 0.33 (95% CI, 0.26–0.4) versus 0.88 (95% CI, 0.83–0.93) for POCUS. In therapeutic management Cohen's κ were 0.21 (95% CI, 0.14–0.28) and 0.9 (95% CI, 0.85–0.94) respectively. The physician's confidence increased from 3.9 before POCUS to 9.3 after ($P < 0.001$).	Prospective cohort study of a consecutive sample of adult patients. Scanning physicians were experienced in POCUS with completion of multiple courses and at least 100 cardiac POCUS exams. They were not involved in patient management but not blinded to clinical signs nor test results. Reference standard was the final diagnosis as decided by an expert panel of three based on medical record review including POCUS images but not interpretation.
Moore et al. 2002	Cardiac ultrasound	To study if POCUS can accurately assess left ventricular function in symptomatic hypotensive patients.	a prospective observational study of the accuracy and utility of echocardiographic determination of LVF in patients presenting to the ED with symptomatic hypotension. a prospective observational study of the accuracy and utility of echo-	Left ventricular function was categorized into hyperdynamic/normal; moderately reduced; severely reduced. In 36 patients all five views were obtained; in one patient no cardiac views were obtained. Cardiac POCUS ejection fraction estimation had a correlation coefficient (R) of 0.86 between emergency physician and	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were trained in POCUS and followed a cardiac POCUS training prior to participating in this study. They were not involved in patient management but not blinded to clinical signs. Reference standard was image

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Table 4 (*continued*)

Article	Ultrasound application	Objective	Results	Details	Study design
			cardiographic determination of LVF in patients presenting to the ED with symptomatic hypoten- 51 patients with symptomatic hypotension. Cardiac ultrasound with assessment of left ventricular function was considered a valuable tool in the diagnostic evaluation of unexplained hypotension. The correlation coefficient (R) was 0.86.	cardiologist. This is comparable with an R between cardiologist estimation of ejection fraction on echocardiography.	interpretation by two independent cardiologists for image quality and prespecified classification of left ventricular function based on visual estimation.
Musikatavorn et al. 2021	Inferior vena cava ultrasound	to evaluate the 30-day mortality outcome of patients with sepsis who were treated with ultrasound-assisted fluid management during the first six hours compared with those who were treated with standard care strategy.	202 patients with sepsis allocated to ultrasound guided treatment ($n = 101$) or standard care ($n = 101$). IVC ultrasound to guide initial fluid resuscitation in sepsis did not improve the 30-day survival probability or other clinical parameters compared to usual-care strategy. IVC ultrasound-guided resuscitation was associated with less amount of fluid used.	Investigators decided to stop the trial before the target number of participants was recruited due to the possible ineffectiveness of the intervention. No significant difference between the treatment groups in six hours lactate clearance, SOFA score at 72 h or the length of hospital stay. However, the rate of vasopressor use and the cumulative fluid administration in 24 h was lower in patients with the ultrasound guided treatment protocol.	Prospective randomized study of a convenience sample of adult patients. Scanning physicians had POCUS experience consisting of regular training sessions including at least one formal examination on their scanning skills. They were involved in patient management and not blinded to clinical information. Reference standard was final outcome, biochemical results and SOFA score as decided by an independent physician based on medical record review.
Sasmaz et al. 2017	Multi-organ POCUS	To assess if POCUS changes the initial diagnosis or management of patients with shock and hypotension of unknown cause.	180 patients with hypotension. POCUS was an appropriate diagnostic tool that improved accuracy of preliminary diagnosis and hence start of appropriate therapy.	The preliminary diagnosis established by the physician prior to the use of POCUS was consistent with the definitive diagnosis in 60.6% of the patients (n = 109). The percentage of consistency between the preliminary diagnosis and definitive diagnosis after POCUS was 85.0% (n = 153). The preliminary diagnosis was modified in 32.2% (n = 58) of 180 patients by POCUS. After the use of POCUS, the treatment plan was modified for 90 (50%) patients while a new treatment plan was developed for 40 (22,3%) patients after the use of POCUS. Similarly, the treatment plan developed for 50 (27,7%) before the use of POCUS was abandoned.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had all completed a basic POCUS training but no information on level of experience is provided. They were involved in patient management and not blinded to clinical information. Reference standard was the final diagnosis as decided by an independent panel of 3 physicians based on medical record review.
Shokoohi et al. 2015	Multi-organ POCUS	To assess the impact of an ultrasound hypotension protocol on diagnostic certainty, diagnostic accuracy, treatment plans, and resource utilization in patients with undifferentiated hypotension.	118 hypotensive patients. POCUS led to a change in diagnostic accuracy in 27,7%, less diagnostic uncertainty, and 11,9% more definitive diagnoses. POCUS also resulted in a change in medical management of 24.6%.	Significant decrease of mean aggregate complexity of diagnostic uncertainty (27,7%) and significant increase of patients with a definitive diagnosis (0,8% vs 12,7%). Presumptive diagnosis showed excellent concordance with final diagnosis (Cohen $k = 0{,}80$). 24,6% had significant change in the use of intravenous fluids, vasoactive agents, or blood products. There were also significant changes in major diagnostic imaging (30.5%), consultation (13.6%), and emergency department disposition (11.9%).	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were experienced POCUS users but no further specifications are provided. They were not involved in patient management and not aware of clinical information. Reference standard were a prespecified questionnaire on shock etiology, and diagnostic certainty and final diagnosis as decided by 2 independent physicians based on medical record review and blinded to POCUS results.
Volpicelli et al. 2013	Multi-organ POCUS	to analyze the efficacy of POCUS for the diagnostic process of symptomatic, non-traumatic hypotensive patients.	108 patients with hypotension. The diagnostic accuracy of POCUS in patients with hypotension was good with Cohen's $k = 0.710$.	A good concordance was found between POCUS diagnosis and final diagnosis (Cohen $k = 0.710$ (95% CI, 0.614–0.806)) which increased to excellent after	Prospective observational cohort study of a convenience sample of adult patients. One scanning physician who is extensively trained in POCUS

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Table 4 (*continued*)

Article	Ultrasound application	Objective	Results	Details	Study design
				exclusion of cases where final diagnosis was not agreed upon (k = 0.971 (95% CI, 0.932–1.000)).	with over five years of experience was not involved in patient management but not blinded to the vital signs during primary assessment. Reference standard was final diagnosis as decided by three independent physicians based on medical record review but blinded to ultrasound findings.

3.5. The impact of POCUS in patients with nontraumatic hypotension and shock in the ICU

Five studies to assess the role of POCUS in patients with shock have been conducted. Diagnostic accuracy was the primary outcome in two, 28-day mortality in two, and clinical outcome after 48 h in one. The data are summarized in Table 5.

Vaidya et al. [86] studied the ability of POCUS to classify the cause of shock and found excellent agreement for obstructive shock but less so for other causes due to overlap in ultrasound findings. POCUS expertise, involvement in patient management and blinding are not specified.

Sekiguchi et al. [87] conducted a pilot study to examine the consequence of POCUS on diagnosis, treatment plan, and physician's confidence in patients with severe sepsis or septic shock. The result was modest with no change on primary diagnosis, but a change in treatment in approximately 25% and an increase in confidence for a given treatment. Scanning physicians were not involved in patient management and all images were reviewed by a cardiologist blinded to clinical information.

The largest study to assess the role of POCUS on 28-day survival in patients with undifferentiated shock was conducted by Kanji et al. [88]. They assessed a prospective cohort of 220 consecutive patients who were assessed with or without POCUS to aid in recommendations on intravenous fluid and inotropes. They found a positive change in 28-day survival of ten percent, less stage three kidney injury and less need of renal replacement therapy. POCUS resulted in less fluid prescription and more inotropic agents. Scanning physicians were POCUS experts, not involved in patient management but not blinded to obvious clinical signs. Li et al. [89] conducted an outcome study in 94 patients of whom 49 received POCUS and found no difference in 28-day mortality. The clinical effect might have been subtle because of a small number of patients with abnormal ultrasound findings. Investigators were involved in patient care.

Lanspa et al. [90] compared POCUS and early goal directed therapy in a small pilot study and found no benefit. An explanation for this could have been that resuscitation with substantial amounts of intravenous fluids was started before randomization thereby reducing the size of any possible effect. The investigators were involved in patient care.

3.6. The impact of POCUS in patients with nontraumatic hypotension and shock in the medical ward

Two studies to assess the role of POCUS in patients with shock have been conducted which both focus on diagnostic accuracy as the primary outcome. The data are summarized in Table 6.

Blans et al. [91] demonstrated an increase in diagnostic accuracy by 27% and an increase in physician's certainty. In the study by Zieleskiewicz an increase in diagnostic accuracy of 14% and earlier start of first treatment were found [92]. In both studies the scanning physicians were involved in patient care.

3.7. Risk of bias assessment

Randomized controlled trials included in this systematic review were all evaluated with some concern or high risk of bias. The non-randomized trials were assessed as having a moderate to serious risk of bias. The reasons to assess the risk of bias as substantial are lack of blinding of the scanning physician to the intervention, selection of the scanning physicians, selection of study participants, and absence of an objective gold standard as the reference test in diagnostic accuracy studies. In addition, very few negative results have been published and therefore publication bias must be considered as well.

4. Discussion

This paper is the first systematic review on point-of-care ultrasound in dyspnea, nontraumatic hypotension, and shock and has included 89 original studies that fulfilled the pre-specified inclusion criteria.

Diagnostic accuracy of point-of-care ultrasound in patients with dyspnea (often a protocol that comprises cardiac, lung, and IVC ultrasound, and sometimes deep vein analysis) is higher when compared to not using POCUS in the initial workup. POCUS is able to identify heart failure and pneumonia and to rule out pneumothorax. It is less able to identify pulmonary embolism, COPD, and asthma which may present with normal POCUS findings or non-specific and sometimes subtle abnormalities on ultrasound.

Regarding our secondary outcome measures POCUS is capable of rapidly narrowing the differential diagnoses, and faster than CXR, where CXR needs reporting. No effect of POCUS in patients with dyspnea is seen on mortality rate, or admission rate to ICU. A reduction in length of stay and duration of treatment remains undetermined because this was found in one study only.

POCUS has better diagnostic properties to identify pneumonia than CXR, this effect is most pronounced when symptoms are present for less than 24 h, and more feasible in the acute setting when an X-ray from two orthogonal sides cannot be made. Systematic reviews and meta-analyses on this subject drew similar conclusions on the diagnostic properties of lung ultrasound to identify pneumonia [93,94].

Since the COVID-19 pandemic there has been a lot of interested in the use of lung ultrasound for screening purposes and prognostication of patients with COVID-19 pneumonia. Severe COVID-19 pneumonia consist of a progressive course of irregular pleural line thickening and an increase in number and distribution of B-lines and subpleural consolidations [95]. Lung ultrasound has shown to accurately assess disease severity and to be a reliable screening tool in conjunction with PCR testing [96–98].

In acute decompensated heart failure the discriminatory capabilities of POCUS and NT-proBNP are similar but POCUS is faster, can rule out patients with false positive NT-proBNP levels, and has more value in monitoring treatment effect. The sensitivity for POCUS is better than CXR. Two systematic reviews and meta-analyses found similar results [99,100].

An increase in diagnostic accuracy is found in patients with

Table 5
POCUS in patients with nontraumatic hypotension and shock in the intensive care unit.

Article	Ultrasound application	Objective	Results	Details	Study design
Kanji et al. 2014	Cardiac ultrasound	To assess the hypothesis that POCUS based recommendations for intravenous fluid and inotropes would improve survival compared to standard management in patients with undifferentiated vasopressor-dependent shock.	220 hypotensive patients 110 with ultrasound and 110 without. Cardiac POCUS resulted in a positive change in 28-day survival of 10%.	Less fluid prescription in ultrasound group (49 vs 66 ml/kg), more inotropic agents (22% vs 12%), improved 28-day survival (66% vs 56%), reduction of stage 3 acute kidney injury (20% vs 39%) and more days alive and free of renal support (28 vs 25 days).	Prospective cohort study of a consecutive sample of adult patients. Scanning physicians were well trained in advanced POCUS echocardiography (American College of Cardiology level II) and not involved in patient management but not blinded to obvious clinical information. Reference standard was 28-day survival based on medical record review.
Lanspa et al. 2018	Cardiac ultrasound	To compare a cardiac POCUS guided strategy for the management of septic shock with an early goal directed therapy strategy.	30 adult patients with early sepsis randomized equally between ultrasound and no ultrasound. Cardiac POCUS in this pilot study resulted in no difference in SOFA score at 48 h nor inpatient mortality, ICU-free days and ventilator-free days when compared to not using POCUS. However, resuscitation was started before randomization thereby reducing the size of any possible effect.	Randomization within a median of 3.5 h of meeting inclusion criteria into two groups of 15 patients. Patients had received a median of three liters of intravenous crystalloids prior to randomization. No experimental separation was observed in this randomized, controlled feasibility trial. Early lactate clearance, coupled with substantial fluid administration before randomization, suggests that patients were already resuscitated before arrival in the ICU.	Prospective randomized study of a convenience sample of adult patients. Scanning physicians were extensively trained in POCUS and were certified at level II of the American Society of Cardiology. They were not blinded to clinical signs and involved in patient management. Reference standard was the sequential organ failure assessment score (SOFA score) at 48 h based on medical record review by the study investigators.
Li et al. 2021	IVC, cardiac, and lung ultrasound	to investigate the effect of POCUS within the first hour of admission on the clinical outcomes of septic shock.	94 patients of whom 49 underwent ultrasound for hemodynamic decision making in septic shock. There was no difference in 28-day mortality between groups. Only 11 (22.4%) patients had abnormal ultrasound findings, and this percentage was less than expected, thus weakening the clinical effects.	POCUS showed no significant effect on 28-day mortality. Within the initial six hours, the ultrasound group tended to have a higher fluid balance and fluid intake than the conventionally treated group. The duration of vasopressor support was shorter in the ultrasound group.	Prospective randomized study of a consecutive sample of adult patients. Two scanning physicians with POCUS experience consisting of multiple courses and at least 150 POCUS exams were involved in patient management and not blinded to clinical findings and test results. Reference standard was 28-day mortality rate based on medical record review.
Sekiguchi et al. 2017	Cardiac ultrasound	To assess the hypothesis that the diagnostic impression, therapeutic plan, and confidence level of the treating physician would be influenced by POCUS information.	30 patients with severe sepsis and septic shock. Overall POCUS was considered beneficial by the treating physicians in 14 patients. It did not change the initial shock diagnosis. It resulted in a change in treatment plan in eight patients. Assessment of left and right ventricular function appeared to be difficult: over- and under estimation occurred in 40–50%.	POCUS changed the impression of secondary or tertiary subtypes of shock in six patients. In 12 patients LV function was incorrectly assessed (40%; 95% CI 25–58%), with overestimation and underestimation occurring in seven and five patients, respectively. RV function was estimated incorrectly in 15 patients (50%; 95% CI 33–67%), with overestimation and underestimation occurring in five and ten patients. confidence levels for the therapeutic plans improved post-POCUS for 11 patients (37%; 95% CI 22–55%).	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were trained sonographers and all images were supervised by a cardiologist. They were not involved in patient management but not blinded to clinical signs. Reference standard was a prespecified survey on type of shock, estimation of cardiac function, treatment, and confidence level of their treatment plans.
Vaidya et al. 2018	Multi-organ POCUS	To outline the role of POCUS in the evaluation of patients in shock.	100 patients with shock. A good correlation between POCUS and final diagnosis was found. POCUS classification of shock was excellent for obstructive causes but more difficult in other causes due to overlap in ultrasound findings.	Good concordance between POCUS shock classification and final diagnosis. Best accuracy for diagnosing obstructive shock, lowest for distributive shock. (Cohen's Kappa 1.0 and 0.6 respectively). Classifying shock was excellent in obstructive causes, lowest sensitivity in hypovolemic and lowest positive predictive value and specificity in distributive causes.	Prospective observational cohort study of a convenience sample of adult patients. No information is provided on level of POCUS expertise by the scanning physician. Because an extensive POCUS protocol is used we assume it likely they are POCUS proficient with at least some experience prior to this study. No information is given on involvement in patient management nor blinding to clinical results.

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Table 5 (*continued*)

Article	Ultrasound application	Objective	Results	Details	Study design
					Reference standard was the final diagnosis as decided by the treating physician based on clinical information but not POCUS results.

Table 6
POCUS in patients with nontraumatic hypotension and shock in the medical ward.

Article	Ultrasound application	Objective	Results	Details	Study design
Blans et al. 2021	Multiorgan ultrasound	To examine the hypothesis that POCUS would increase the diagnostic ability of the medical emergency team and increase the diagnostic certainty of the physician.	100 patients (52 with and 48 without POCUS) POCUS resulted in a positive change in diagnostic accuracy of 27%.	There were more correct diagnoses in the POCUS group (78% vs 51% ($P = 0.006$)). Physician's certainty improved significantly with POCUS ($P < 0.001$). No differences in 28-day mortality and first treatment were found.	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians had completed a basic POCUS training of four days. They were involved in patient management and not blinded to clinical signs. Reference standard was final diagnosis as decided by one independent physician based on medical record review.
Zieleskiewicz et al. 2021	Multi-organ POCUS	to assess the impact of implementing a POCUS-guided management on the proportion of adequate immediate diagnoses in relation to the definitive diagnosis.	165 patients with respiratory and/or circulatory failure. 83 with POCUS and 82 without. POCUS increased diagnostic accuracy by 14% and was faster in making a change in clinical decisions.	More accurate immediate diagnoses with POCUS (94% vs 80%), shorter time to first treatment (15 min vs 34 min). Lower in-hospital mortality rates (17% vs 35%), but not confirmed in the propensity score sample (29% vs 34%).	Prospective observational cohort study of a convenience sample of adult patients. Scanning physicians were all trained in basic POCUS skills prior to participating in this study. They were involved in patient management and not blinded to clinical information. Reference standard was the final diagnosis as decided by two independent physicians based on medical record review.

undifferentiated nontraumatic hypotension, shock, including sepsis, whilst no effect is found in patients with severe sepsis in ICU. The latter might be explained by the more severe illness in which the clinical picture will be more pronounced and the necessity for POCUS in making a correct diagnosis limited. A meta-analysis on undifferentiated shock also concluded that POCUS increased the diagnostic accuracy of undifferentiated shock in the emergency department [101].

Regarding our secondary outcomes POCUS narrowed the differential diagnoses. A positive effect of POCUS on mortality rate was found in one study only, limiting the interpretation of this finding. No effect was seen on admission rate to ICU, length of stay, and duration of treatment.

POCUS results in an increase in physician's confidence on diagnosis and treatment strategy of intravenous fluids and inotropic medication. Fluid guidance has shifted more and more towards assessing fluid tolerance using POCUS. A more advanced POCUS algorithm may provide guidance when to stop fluids and identify those who might benefit from fluid removal. Also, POCUS findings to assess volume status should always be interpreted in the clinical context because they are not without caveats [102].

Most of the studies in this systematic review have not blinded the POCUS physician to clinical findings or involvement in patient care. From a scientific perspective, blinding to clinical information might have been preferable to reduce bias. However, POCUS by definition is undertaken by the treating physician who integrates POCUS into the anamnesis and physical examination. Studying the value of POCUS with blinding to clinical findings reduces the generalizability of the results. Blinding to other imaging techniques or laboratory measurements when comparing their respective diagnostic accuracies is of course mandatory for the validity of a study. Future research should have a design that reflects POCUS use in real life and therefore focus on practicing POCUS by novice doctors with limited POCUS experience.

POCUS is a safe, and fast technique and it increases the diagnostic accuracy when added to the initial workup in patients with respiratory or circulatory deterioration. It narrows the differential diagnoses and speeds up in time to diagnosis. Its clinical utility is higher than a conventional CXR, and increasing availability of handheld devices means imaging at the bedside of the unwell patient is now a realistic prospect in most environments. POCUS in acute medicine can possibly reduce the number of additional investigations or consultations and costs [103–107]. However, large prospective studies testing this hypothesis have not been published thus far.

In other settings such as at the general practitioner's, the ambulance service, and in remote areas POCUS can also be applied. In conjunction with point-of-care laboratory testing and portable electrocardiogram an extensive workup outside the hospital is feasible. Teleconsultation to guide interpretation of scanning results already exist and it is expected that POCUS protocols will be supported by artificial intelligence (AI)in the nearby future.

Importantly, the skill of scanning is mandatory before POCUS can be safely practiced. This implies not only a basic POCUS course to acquire interpretable images but also training and bedside supervision to become proficient in scanning and interpreting. Almost all studies in this review were undertaken by POCUS experts or supervised by experienced physicians thereby reducing the generalizability of the presented data to the average Internal Medicine department across Europe.

A clinical guideline was published by the American College of Physicians for the use of POCUS [107]. In the accompanying editorial it is argued that stronger evidence is needed for wider applications, because most studies focus on POCUS by experienced sonographers [108]. Additional evidence on the advantages of POCUS may not be required,

because some truths are so self-evident, that we must hold them to be true [109]. To limit access to POCUS in acute medicine because of a lack of direct evidence of benefit could be considered controversial.

4.1. Limitations

This systematic review provides a large body of indirect evidence and outweighs the lack of direct evidence. As has been reported in the literature, executing well designed controlled trials on clinical outcome remains difficult if not unfeasible at all. Therefore we doubt whether high quality studies will be added to the evidence base.

As stated in the risk of bias assessment, all studies were prone to bias, often in the study design, the execution of the study, and generalizability of the results. In a minority of papers we considered the risk of bias as high making their findings less robust to be translated into clinical practice.

5. Conclusion

Point-of-care ultrasound substantially improves diagnostic accuracy in patients with dyspnea, nontraumatic hypotension, and shock. POCUS aides in narrowing the differential diagnoses, thereby shortening the time to correct diagnosis and effective treatment.

Declarations

Ethics approval and consent to participate is not applicable.

Consent for publication is not applicable.

Availability of data and materials is not applicable to this article as no datasets were generated or analyzed during the current study.

Funding is not applicable.

Acknowledgements are not applicable.

CRediT authorship contribution statement

Bram Kok: Conceptualization, Writing – review & editing, Writing – original draft. **David Wolthuis:** Conceptualization, Writing – review & editing, Writing – original draft. **Frank Bosch:** Conceptualization, Writing – review & editing. **Hans van der Hoeven:** Conceptualization, Writing – review & editing. **Michiel Blans:** Conceptualization, Writing – review & editing, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ejim.2022.07.017.

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