Received: 10 December 2023 | Revised: 1 March 2024 | Accepted: 15 March 2024

DOI: 10.1002/emp2.13164

JACEP OPEN WILEY

ORIGINAL RESEARCH

Emergency Medical Services

Thoracic ultrasound may improve paramedic diagnostic and management accuracy in undifferentiated respiratory distress

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Prior presentations: This study was presented at the general session of the most recent NAEMSP national conference general session on 1/26/2023 in Tampa, FL. This study was also presented as a poster at the New York ACEP Scientific Assembly on07/11/ 2023 in Bolton Landing, NY.

Funding and support: By *JACEP Open* policy, all authors are required to disclose any and all commercial, financial, and other relationships in any way related to the subject of this article as per ICMJE conflict of interest guidelines (see www.icmje.org). The authors have stated that no such relationships exist.

Abstract

Objectives: Patients with chronic obstructive pulmonary disease (COPD) and congestive heart failure (CHF) exacerbations present with similar history and physical examination findings. This complicates both the diagnostic process and the creation of appropriate treatment plans for patients presenting in respiratory distress, particularly in the prehospital setting. Thoracic point-of-care-ultrasound (POCUS) may increase diagnostic accuracy; however, its potential to improve patient management by emergency medical services clinicians is unknown. We aimed to determine whether a brief thoracic POCUS educational intervention would improve prehospital diagnostic accuracy and treatment plans for patients with COPD and CHF exacerbations.

Methods: In this prospective pre-/post-study, paramedics completed a thoracic POCUS training program. The pre-test presented history and physical examination data for 10 patients and asked paramedics to diagnose each patient with COPD or CHF exacerbation and to select the appropriate treatment(s). The post-test asked paramedics to interpret ultrasound images in addition to selecting diagnosis and treatment(s). Pre-post differences in average cumulative diagnostic and management accuracy were analyzed using paired two-tailed *t*-tests.

Results: Thirty-three paramedics participated in the study. At baseline, paramedics selected the accurate patient diagnosis and treatment(s) 73% and 60% of the time, respectively. On the post-test, diagnostic accuracy improved by 17% (95% confidence interval [CI]: 11–24, $p < 0.001$) and appropriate treatment selection improved by 23% (95% CI: 16–28, $p < 0.001$). Paramedics correctly interpreted ultrasound images 90% of the time.

Conclusion: Effective training of paramedics to recognize the clinical scenario of undifferentiated respiratory distress and their associated thoracic ultrasound images may lead to improved treatment plans.

Supervising Editor: Nichole Bosson, MD, MPH

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KEYWORDS
diagnostic accuracy, POCUS, point-of-care-ultrasound, prehospital ultrasound, respiratory distress, thoracic ultrasound, ultrasound

1 | INTRODUCTION

1.1 | Background

Emergency medical services (EMS) clinicians often serve as the first point of medical contact for patients presenting with respiratory distress.[1,2] Congestive heart failure (CHF) and chronic obstructive pulmonary disease (COPD) exacerbation represent two common diagnoses for patients with respiratory distress admitted following EMS transport.[2,3] The EMS clinician's ability to differentiate between respiratory distress due to COPD versus CHF exacerbation is critical as the treatment pathways for these two conditions diverge early in the management course.[4,5] Differentiating CHF and COPD in the prehospital setting based solely on history and physical examination findings is often challenging as these conditions present with similar signs and symptoms, and lung auscultation by paramedics has limited diagnostic accuracy, especially in a moving ambulance.[6,7] Thoracic point-of-care-ultrasound (POCUS) represents a potentially useful prehospital adjunct to the history and physical examination for patients with respiratory distress. For example, the presence of diffuse, bilateral B-lines, an artifact created by interstitial fluid in the lungs, suggests that the patient is experiencing a CHF exacerbation.[8–11]

1.2 | Importance

Evidence supports the feasibility of introducing POCUS into EMS clinician practice for the diagnosis and treatment of patients with respiratory distress. EMS clinicians can obtain images of interpretable quality in the field that support the diagnosis of CHF.[12–15] A recently published work by Russell et al. found that thoracic ultrasound improved the frequency and time to administration of prehospital CHF therapy;[15] the authors did not comment on the treatment of patients presumptively diagnosed with COPD based on the absence of B-lines. Understanding the teachability, feasibility, and the effects on diagnostic accuracy and changes in patient management related to prehospital POCUS for patients with undifferentiated respiratory distress is critical as more EMS agencies consider implementation, which requires investment of time and monetary resources.

1.3 | Goals of this investigation

We designed a prospective pre-/post-study with the primary objective to assess whether a brief POCUS educational intervention would improve EMS clinician diagnostic and treatment plan accuracy using archived, real cases of patients who initially presented with respiratory distress.

2 | METHODS

2.1 | Study design and setting

This was a prospective pre-/post-educational intervention study from January to July 2022. The study included paramedics working within the Monroe-Livingston region in upstate New York. The region includes 12 advanced life support agencies that are a mix of commercial, third-service, and volunteer-based entities. These agencies serve the urban, suburban, and rural communities dispersed throughout two counties, which had a total of 145,645 calls for service in 2022. The paramedic regional protocols recommend the administration of bronchodilators and dexamethasone for COPD exacerbations and the administration of nitroglycerin for CHF exacerbations. Noninvasive positive pressure ventilation may be used in both conditions in patients with respiratory distress. The study protocol was reviewed and approved by the University of Rochester's Research Subjects Review Board.

2.2 | Selection of participants

Paramedics were recruited through the regional EMS email listserv and social media pages. To be eligible for the study, subjects had to be a New York State licensed paramedic and at least 18 years old practicing in the Monroe-Livingston region. Subjects completed an online consent form utilizing the REDCap software prior to completing any study materials.

2.3 | Educational intervention

Subjects completed a 63-minute educational program. This program was designed by an EMS-fellowship-trained emergency medicine (EM) attending with expertise in paramedic education, an EM attending with a focused practice designation (FPD) in advanced emergency medicine ultrasonography (AEMUS), and an EM resident. Subjects watched an online, pre-recorded 18-minute video detailing how to perform and interpret thoracic ultrasound. The video reviewed thoracic anatomy, probe selection, probe orientation, and probe positioning utilizing the zones of the thorax. The video described important ultrasound patterns including lung sliding, the lung-point sign, A-lines, and B-lines and detailed the ultrasound findings in common lung pathology including pneumothorax, pneumonia, and pulmonary edema. The video reviewed how to differentiate CHF and COPD exacerbations by the presence or absence of B-lines. Video materials were adapted from lectures created by two additional EM faculty with FPDs in AEMUS.

Subsequently, participants attended a 45-minute in-person training session. Participants learned to perform and interpret thoracic POCUS scans on volunteer patients utilizing a phased-array probe on both a Terason Smart 3200T and a Sonosite M-Turbo ultrasound machine. Additionally, subjects performed case-based simulated scans utilizing the SonoSim simulation program to exemplify the differences between A-lines and B-lines.

The Bottom Line

Differentiating chronic obstructive pulmonary disease (COPD) from congestive heart failure (CHF) is difficult in the prehospital setting. In this prospective pre/post study, paramedics demonstrated the ability to accurately differentiate COPD from CHF exacerbations using thoracic point-of-care-ultrasound (POCUS). This series highlights the utility of prehospital POCUS in the care of patients in respiratory distress.

2.4 | Data collection tools

Prior to viewing the video, subjects took a pre-test to determine their baseline ability to diagnose and treat patients with undifferentiated respiratory distress based solely on history and physical exam findings. The pre-test consisted of 10 cases crafted from actual patient encounters seen in a regional academic hospital emergency department (ED). The cases were selected from a list of all thoracic ultrasound images obtained and quality-reviewed in our ED in 2019. The list was sorted by image capture date and the first 10 patients whose ultrasounds were protocoled to assess for A- versus B-lines and were of good quality (received a 4 or 5 out of 5 on the American College of Emergency Physicians' ultrasound quality Likert-scale) were selected.[16] Each test question provided patient age, past medical history, history of present illness, and pertinent physical examination findings including initial vitals (Figure S1). For each case, the EMS clinician was asked two questions. The first question asked paramedics to select whether their leading diagnosis was CHF or COPD exacerbation, and the second question asked subjects to select their management plan(s) from a list of options including positive pressure ventilation, nitroglycerin, bronchodilators, dexamethasone, or none of the above.

Paramedics could obtain 1 point for selecting the correct diagnosis and 1 point for selecting the correct management plan on each of the 10 cases, for a total of 20 possible points. Correct answers were determined by the diagnosis and management given to patients in the ED. For patients with CHF exacerbations, correct management plans included nitroglycerin and excluded bronchodilators and dexamethasone. For patients with COPD exacerbations, correct management plans included bronchodilators and dexamethasone and excluded nitroglycerin.

After the in-person session, participants completed the study post-test. The post-test contained the same 10 cases as the pre-test with the addition of two 6-second ultrasound videos, one from each of the patient's lungs. These videos were the real-time images captured during the cases and secondarily reviewed as previously described. All ultrasound images used in the cases were captured using MindRay TE7 ultrasound systems. The case patients' videos were only used in the testing phase of this study; separate videos and images were used during the training session. The paramedics were again asked select a diagnosis and management plan. Paramedics were asked two additional questions to assess their accuracy at interpreting the ultrasound findings. Participants were not provided with answers to the case questions after the completion of the pre-test, during the training, or after the completion of the post-test.

The post-test diagnosis and management questions were graded using the pre-test rubric and point system. The ultrasound interpretation questions were graded as correct or incorrect based on the ultrasound-trained physicians' image interpretations, which were performed and recorded prior to this study's creation.

We collected descriptive data from each subject including demographics, paramedic experience, and previous ultrasound training and experience. All study materials were collected on the REDCap software.

2.5 | Measurements/outcomes

The primary outcome metrics were the change in diagnostic accuracy and management plan accuracy as measured by the difference in percentage points between the pre- and post-tests. This was obtained by comparing the percent of questions answered correctly on the pre-test versus the post-test.

Our secondary outcome measure was the EMS clinician's accuracy at interpreting ultrasound images, as determined by their score on the additional two post-test questions.

2.6 | Data analyses

Pre- and post-test results were exported from REDCap into Microsoft Excel spreadsheets. Descriptive statistics were calculated. Pre-post differences in diagnostic accuracy, appropriateness of treatment, and combined score of both were analyzed using paired two-tailed *t*-tests and 95% confidence intervals (95% CIs) were calculated. We performed a subgroup analysis comparing the pre-post differences in diagnostic accuracy, appropriateness of treatment, and combined score of both for the participants with versus without previous ultrasound training using paired two-tailed *t*-tests. All analyses were conducted in Microsoft Excel.

TABLE 1 Subject demographics and characteristics.

Characteristic	N (%)
Age in years, median (IQR)	35 (26–47)
Sex	
Female	12 (36.4%)
Male	21 (63.6%)
Paramedic experience	
0–2 years	10 (30.3%)
3–5 years	5 (15.1%)
6–10 years	5 (15.1%)
>10 years	13 (39.4%)
Previous ultrasound experience	
Previously used in the field	0 (0%)
Previous didactic training	11 (33.3%)
Competency after previous training (N = 11)	
No confidence in image interpretation	10 (90.9%)
Confident in interpretation >50% of time	1 (9.1%)

3 | RESULTS

Fifty-one paramedics consented to participate in the study. Thirty-three completed all study materials and were included in the analysis. The median participant age was 37 years (interquartile range (IQR): 26–47 years) and 21 (63.6%) were men. Eleven (33.3%) participants reported some previous training in thoracic ultrasound. Of those with previous experiences, 10 (90.9%) reported having no confidence in their image interpretation skills. None of the subjects had previously used ultrasound in the field (Table 1).

Following the online and in-person training, paramedic diagnostic accuracy and appropriate management plan selection improved significantly (Figure 1). Average cumulative paramedic diagnostic accuracy improved from 73% on the pre-test to 90% on the post-test, for a total improvement of 17% (95% CI: 11–24, $p < 0.001$). Average cumulative paramedic management accuracy improved from 60% on the pre-test to 83% on the post-test, for a total improvement of 23% (95% CI: 16–28, $p < 0.001$). Paramedics interpreted ultrasound images correctly, on average, 90% of the time. When comparing the pre-post differences of the 11 participants with previous ultrasound education to the 22 participants without previous experience, there was no significant difference in the diagnostic, management, or ultrasound interpretation accuracy between groups (Table S1).

A large portion of the improvement in average cumulative paramedic diagnostic and management accuracy stemmed from cases 5, 7, and 9. The pre- and post-test results for these questions are displayed in Figure 2. The average improvement in diagnostic accuracy on these three questions was 52.7%, while the average improvement on the remaining seven questions was 2.6%. The average cumulative change in these three cases accounted for 89.8% of the total change in diagnostic accuracy between the pre- and post-test. As for management plan accuracy, the average improvement on these three questions was 41.7%, while the average improvement on the remaining seven questions was 14.7%. The average cumulative change in these three cases accounted for 54.8% of the total change in management accuracy between the pre- and post-test (Table 2).

4 | LIMITATIONS

This was a small convenience sample of paramedics. Paramedics who volunteered to participate are likely highly motivated to learn and incorporate a new technology into their practice, which may not generalize to all EMS clinicians. Additionally, although 51 paramedics consented for our study, only 33 completed the educational intervention. The drop out was mainly due to difficulty coordinating in-person sessions that worked for both EM physicians and paramedics, as both parties have shift-work based schedules. Eleven (33%) subjects had some previous didactic ultrasound training. Of those, one had attended multiple ultrasound training sessions and felt comfortable interpreting images. Of the remaining 10, one had training to look for lung sliding as part of a critical care course and the remaining nine had a brief hands-on session during their paramedic class. These 10 paramedics reported no confidence in their ability to interpret ultrasound images on a Likert scale prior to this educational intervention. These clinicians attended a single thoracic ultrasound training session during their year-long paramedic class and, in the average of 3 years since

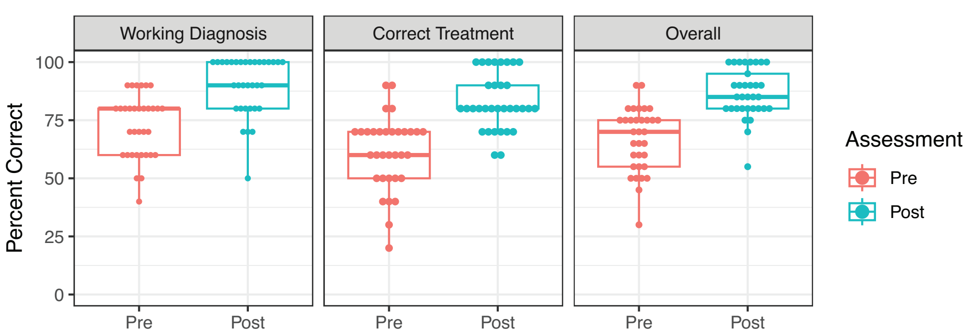

FIGURE 1 Percent correct on the pre-test and post-test for each subject on the working diagnosis questions, the treatment questions, and the total score. The median, interquartile range, and range for each breakdown are demonstrated with boxplots.

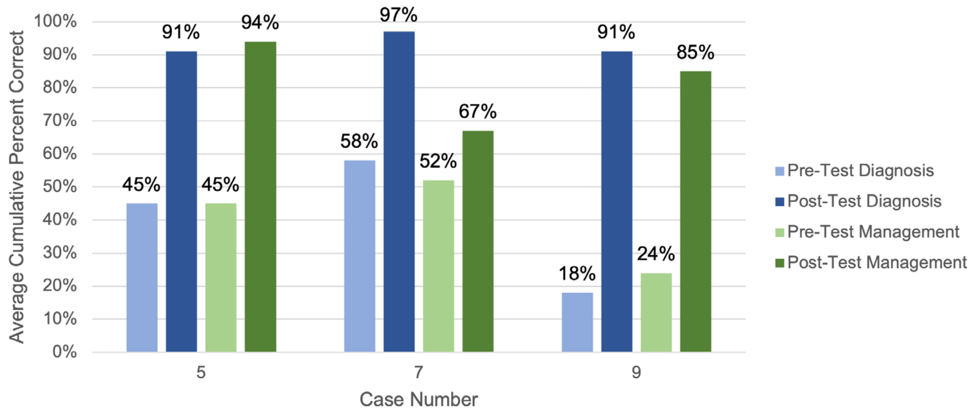

FIGURE 2 Average cumulative percent correct on the pre- and post-test diagnosis and management questions for patient cases 5, 7, and 9.

TABLE 2 Pre- and post-test diagnostic and management accuracy.

Case number	Pre-test diagnostic accuracy (N = 33)	Post-test diagnostic accuracy (N = 33)	Pre-test management accuracy (N = 33)	Post-test management accuracy (N = 33)
1	94%	97%	82%	97%
2	100%	94%	94%	94%
3	79%	91%	61%	91%
4	82%	79%	85%	76%
5	45%	91%	45%	94%
6	79%	79%	55%	79%
7	58%	97%	52%	67%
8	82%	85%	82%	82%
9	18%	91%	24%	85%
10	88%	97%	21%	64%

graduating, received no continued ultrasound education, which likely explains their lack of confidence with POCUS. The subgroup analysis comparing the pre-post differences of participants with versus without previous ultrasound training was limited by the small number of participants with previous training. On the post-test, paramedics interpreted images captured by EM physicians, which may be of higher quality than images that paramedics can obtain in the field. Finally, we did not follow subjects longitudinally and therefore cannot comment on the length of knowledge retention after our intervention.

5 | DISCUSSION

In this prospective study, a brief educational intervention was associated with increased paramedic diagnostic accuracy and appropriate treatment plan selection for patients with respiratory distress secondary to COPD or CHF. This study adds to the growing body of evidence suggesting that thoracic POCUS may positively impact the care of prehospital patients in respiratory distress.

Implementing POCUS into prehospital practice is not without costs, including not only the financial cost of the equipment, but also costs related to time and resources necessary to train EMS clinicians and maintain proficiency. In our study, a short, asynchronous, online video and in-person training session were associated with a high proportion of correct thoracic image interpretation by paramedics. Our subjects underwent a 63-minute educational program, which was similar to the 60-minute combined didactic and hands-on POCUS training regimen in Russell et al.[15] In the Russell trial, paramedics were similarly proficient in their image interpretation, supported by an inter-rater reliability between paramedic and expert interpretation of 80%.[15] The ability to effectively train paramedics in a partially asynchronous manner reduces the monetary and logistical burden of implementing POCUS in most EMS systems.

The key benefit of thoracic POCUS is to allow clinicians to obtain, interpret, and act on images rapidly to make real-time improvements in their patient management plans. Our study results provide further evidence that paramedics can be efficiently and effectively trained to correctly interpret ultrasound images in limited focused clinical scenarios. Our subjects were asked to interpret images captured by EM physicians in the ED, which could be of higher quality than those obtained by paramedics due to the quality or portability of equipment and the suboptimal environments in which they operate. However, previous field studies have shown that paramedics obtain images of interpretable quality up to 74.4% of the time.[13] We believe that, when integrated into a system with adequate education, appropriate equipment, and ongoing quality assurance and quality improvement activities providing feedback on image quality, interpretation and patient management, paramedics would be able to obtain images of interpretable quality similar to those utilized in our study.

Before we allow paramedics to dedicate a portion of their transport time to performing thoracic ultrasound, we must prove that this technology has a meaningful impact on patient outcomes. Our study demonstrated that, in addition to correct image interpretation, thoracic POCUS training was associated with a higher proportion of patients in respiratory distress receiving appropriate management. This study complements the work of Russell et al, which showed that paramedic-performed thoracic ultrasound images improved the rate of CHF treatment administration by 39%.[15] In other pilot studies, paramedics stated that thoracic POCUS changed their clinical impression, treatment, and/or transportation decisions 12%–42% of the time.[13,14] Our study result, in combination with the current evidence, suggests that paramedics can effectively utilize thoracic ultrasound images to improve patient management in real time.

The pre-post differences in diagnostic and management accuracy in three of the 10 cases accounted for a large portion of our study result. Cases 5 and 9 represented patients with COPD who paramedics frequently misdiagnosed as a CHF exacerbation prior to the availability of thoracic ultrasound images. The patient in case 5's COPD exacerbation was secondary to a right lower lobe pneumonia; he presented with mixed lung sounds including bilateral expiratory wheezing and focal crackles at the right base. The patient in case 9 experienced profound air-flow restriction due to severe bronchoconstriction, leaving him with markedly decreased breath sounds bilaterally. Both patients were hypertensive and had normal end-tidal carbon dioxide values. Overall, paramedics had the most difficulty diagnosing patients with COPD exacerbations if they had mixed or decreased breath sounds and atypical vital signs such as severe hypertension or normocapnia. In these cases, thoracic POCUS images were utilized as a highly efficacious adjunct to the history and physical examination.

The patient in case 7 was presented with a CHF exacerbation who paramedics frequently misdiagnosed with decompensated COPD prior to viewing his ultrasound images. This patient was presented with pulmonary edema secondary to acute left ventricular dysfunction from a myocardial infarct. Compared to the other four CHF cases, who presented with some combination of severe hypertension, lower extremity edema, and bilateral rhonchi on auscultation, his presentation was more subtle, with no wheezing or rhonchi heard on auscultation. In this case, the patient's ultrasound videos showed greater than three B-lines in bilateral lung spaces, consistent with pulmonary edema. Given the limitations of auscultation at distinguishing between COPD and CHF,[6,7] POCUS is a useful adjunct to the physical exam, especially in cases with subtle presentations and mixed signs or symptoms.

In summary, a brief thoracic POCUS training intervention was associated with correct image interpretation, improved diagnostic accuracy, and appropriate treatment plan selection compared to history and physical examination alone for patients with undifferentiated respiratory distress. Thoracic POCUS images may be especially useful when diagnosing and managing COPD exacerbations in patients with mixed wheezing or decreased breath sounds and atypical vital signs. When considering our result in context with previous research, we propose that, when integrated into a system with adequate structured education and a longitudinal quality management program, thoracic POCUS has the potential to improve patient-oriented outcomes.

AUTHOR CONTRIBUTIONS

Emily Fitzgerald, John DeAngelis, Courtney Marie-Cora Jones, Julie Kittel, and Maia Dorsett designed the study. Emily Fitzgerald, Shelby Parker, Sarah Hancock, John DeAngelis, and Maia Dorsett executed the study and acquired the data. Emily Fitzgerald and Maia Dorsett analyzed and interpreted the data. Emily Fitzgerald drafted the manuscript. John DeAngelis and Maia Dorsett critically revised the manuscript. Courtney Marie-Cora Jones and Julie Kittel provided administrative support for the project. John DeAngelis and Maia Dorsett supervised the study.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Fitzgerald E, Parker S, Hancock S, et al. Thoracic ultrasound may improve paramedic diagnostic and management accuracy in undifferentiated respiratory distress. *JACEP Open*. 2024;5:e13164.
https://doi.org/10.1002/emp2.13164

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