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Brief Report

Integrating point-of-care ultrasound in the ED evaluation of patients presenting with chest pain and shortness of breath

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ABSTRACT

Objective: The differential diagnoses of patients presenting with chest pain (CP) and shortness of breath (SOB) are broad and non-specific. We aimed to 1) determine how use of point-of-care ultrasound (POCUS) impacted emergency physicians' differential diagnosis, and 2) evaluate the accuracy of POCUS when compared to chest radiograph (CXR) and composite final diagnosis.

Methods: We conducted a prospective observational study in a convenience sample of patients presenting with CP and SOB to the Emergency Department (ED). Treating physicians selected possible diagnoses from a pre-indexed list of possible diagnoses of causes of CP and SOB. The final composite diagnosis from a chart review was determined as the reference standard for the diagnosis. The primary analysis involved calculations of sensitivity and specificity for POCUS identifiable diagnoses in detecting cause of CP and SOB. Additional comparative accuracy analysis with CXRs were conducted.

Results: 128 patients with a mean age of 64 ± 17 years were included in the study. Using a reference standard of composite final diagnoses, POCUS had equal or higher specificity to CXR for all indications for which it was used, except for pneumonia. POCUS correctly identified all patients with pneumothorax, pleural effusion and pericardial effusion. In patients with a normal thoracic ultrasound, CXR never provided any actionable clinical information. Adding POCUS to the initial evaluation causes a significant narrowing of the differential diagnoses in which the median differential diagnosis from 5 (IQR 3–6) to 3 (IQR 2–4) $p < 0.001$.

Conclusion: In evaluation of patients with CP and SOB, POCUS is a highly feasible diagnostic test which can assist in narrowing down the differential diagnoses. In patients with a normal thoracic ultrasound, the added value of a CXR may be minimal.

1. Introduction

Chest pain (CP) and shortness of breath (SOB) are among the most common chief complaints in the Emergency Department (ED) [1]. The initial management can be challenging due to the broad differential diagnoses, which often includes life-threatening conditions requiring rapid identification and management [2]. With many possible etiologies, understanding the cause of CP and SOB is essential for targeted interventions, and a timely management of patients. Typically, a chest radiograph (CXR) is part of the initial work up for these patients. However, previous studies have challenged the diagnostic utility of CXR for these indications, suggesting that in the evaluation of CP, CXRs yield clinically significant information in as few as 12% of studies [3-5]. Therefore, the limited sensitivity and specificity of CXR in the evaluation of CP and SOB raises questions about the diagnostic accuracy and initial diagnostic tests in patients with CP and SOB.

The use of point-of-care (POCUS) in the evaluation of CP and SOB is growing rapidly and in different clinical settings it shows promise as accurate point-of-care diagnosis is made possible [4-6]. Results of studies have shown that POCUS has excellent diagnostic accuracy for the

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pathologies most commonly encountered in patients presented with CP and SOB, and often higher than CXR [6-10]. POCUS most often diagnoses pneumothorax, pleural effusion, lung consolidation, pulmonary edema, and pulmonary embolism [11-16]. For example, with respect to pleural effusion, Ünlüer et al. have reported a sensitivity and specificity of bedside ultrasound as 93% and 93%, using CT as the gold standard [1]. With respect to pulmonary edema, Martindale et al. found 74% agreement with CT findings for lung ultrasound (versus 58% with CXR) [8]. In critical care cases, bedside lung ultrasound has been reported to yield a diagnosis for patients with acute respiratory failure in 90.5% percent of cases [1,6,7,17].

Despite being a rapidly evolving initial diagnostic modality, further studies are needed to determine whether POCUS actually increases the proportion of patients with undifferentiated CP and SOB who are correctly diagnosed and treated in the ED. Previous studies of the utility and efficacy of POCUS have largely focused on specific patient populations including ventilated patients, trauma patients and children, who likely have significant difference in incidence of disease, and concomitant pathology [8,18,19].

The objective of this study was to 1) determine how use of POCUS influenced emergency physicians' differential diagnosis, and 2) compare the US findings to chest radiograph and composite final diagnosis to assess relative sensitivities and specificities of each imaging modality in this patient population. Our hypothesis was that the use of POCUS would narrow the overall differential diagnosis of SOB and CP, and increase the proportion of patients who receive a correct presumptive diagnosis in the ED. We also investigated the hypothesis that POCUS would exhibit a comparable diagnostic accuracy compared with CXR in respect to pneumothorax, pleural effusion, pneumonia, and pulmonary edema.

2. Methods

2.1. Inclusion and exclusion criteria

This was a single-center prospective observational study conducted in an ED at Massachusetts General Hospital (MGH), a tertiary, academic hospital. The ED has about 110,000 visits per year, and 35,000 of these result in admission to the hospital. Admitted patients with CP and SOB are generally admitted to the medical or cardiac wards. Exceptions are unstable patients with acute ST elevation MI and those with a complete heart block who are referred directly to the cardiology catheterization labs.

In the ED, initial assessment and imaging testing are typically ordered based on symptoms and signs. Thus, symptoms of CP and SOB were chosen as inclusion criteria rather than a set of specific presumptive diagnoses. Patients were included if they were over the age of 18, had a chief complaint of CP and/or SOB, and had a CXR ordered by the treating emergency physician (EP) for clinical reasons. Patients were excluded if they were referred from an outside hospital with a known diagnosis, if the EP was aware of the results of any diagnostic imaging prior to data collection, if the patient was known or found to be pregnant during the course of care, if the patient was unavailable to complete any portion of the ultrasound exam, or if the patient was unable to provide informed consent for any reason, including clinical instability.

This study was conducted in accordance with the Helsinki Declaration and approved by the hospital ethics committee and Internal Review Board. Informed consent was obtained from each patient prior to the study enrollments.

2.2. Data collection

Study investigators were physicians-sonographers (PS) with specified ultrasound fellowship training. If a patient was found to meet eligibility criteria, the PS asked the EP to select possible diagnoses from a list of common cardiopulmonary conditions. The primary diagnosis was defined as the most likely diagnosis as determined by the treating physician. After the primary clinical assessment, treatment and further diagnostic tests were ordered by the EP based on clinical needs.

The complete list of differential diagnoses included: 1) asthma/chronic obstructive pulmonary disease, 2) acute coronary syndrome, 3) pulmonary embolism, 4) pericarditis, 5) aortic dissection, 6) malignancy, 7) musculoskeletal-related chest pain, 8) upper respiratory illness, and 9) other category which includes diagnoses such as nonspecific chest pain, gastro-intestinal etiologies, and anxiety. Of the differential diagnoses, 5 are validated sonographic diagnoses: pneumothorax, pneumonia, pleural effusion, pulmonary edema, and pericardial effusion.

A focused ultrasound examination of the heart and lungs was then performed by the PS who was blinded to any additional imaging obtained at that encounter (CXR, CT, MRI), and unblinded to other relevant clinical information. The PS disclosed their final imaging findings to the EP. The EP was then re-surveyed on the differential diagnoses after receiving the US data. This design was implemented to simulate the real clinical scenario at our institution, in which EPs frequently perform their own POCUS, in order to stratify their differential diagnoses and further imaging studies.

Additional clinical data was obtained retrospectively including patient demographics and final composite diagnosis, and recorded by the PS. As in regular clinical encounters, the EP had access to all available patient data including all available imaging, in order to inform their clinical decisions.

A sample size of 128 was targeted in order to achieve 80% power to detect a difference of 0.5 in mean number of differentials, assuming a standard deviation of 2 differential diagnoses, and using a paired *t*-test (with a 0.05 two-sided significance).

2.3. Ultrasound protocol

Emergency ultrasound fellows or attendings with ultrasound fellowship training performed and interpreted scans. At all times, participating patients received the standard care.

Studies included focused cardiac and thoracic examinations. The focused cardiac examination was conducted using a phased array probe and included a protocol to obtain at least 2 of the 4 basic cardiac views (subxiphoid view, parasternal long view, parasternal short view and apical four chamber view). This scanning protocol is consistent with previously published assessments of SOB or undifferentiated respiratory failure, including the Rapid Assessment of Dyspnea with Ultrasound: RADiUS, which incorporates 2 cardiac views and 6 lung views [20]. Other similar protocols include SEARCH 8E's which assesses: empty thorax, edematous lung, extended focused assessment with sonography for trauma (E-FAST), effusion, equality (the ratio between left and right ventricle), ejection fraction, exit (aorta) and entrance (inferior vena cava [IVC]) and endocardial movement [21,22]. Cardiac images were interpreted for presence or absence of: 1) pericardial effusion, 2) decreased LV systolic function, and 3) RV strain.

The focused thoracic examination was conducted using a curvilinear probe and included six thoracic zones: anterior (bilaterally between sternum and anterior axillary line), lateral (bilaterally between anterior and posterior axillary line), and posterior (bilaterally between the posterior axillary line and spine). Pulmonary images were interpreted by the study investigators for the presence of lung sliding, pleural effusion, consolidation, and B-lines.

We defined a POCUS diagnosis of pneumonia as the presence of a lobar consolidation or multiple patchy consolidation with hyperechoic artifacts consistent with air bronchograms. In a majority of the cases a disruption of pleural line extending inferiorly with air bronchogram, and irregular consolidations (shred sign), with or without pleural effusion were defined as pneumonia. Isolated interstitial consolidation without additional artifacts were not considered as a pneumonia. Pulmonary edema was defined as the presence of diffuse B-lines (≥3) in both lung fields, with or without pleural effusion. The lack of pleural sliding as compared with the opposite side was considered as pneumothorax.

We look for the presence of pleural effusion from right and left upper quadrant views and confirmed with the presence of spine sign.

2.4. Statistical analyses

The differential diagnoses before and after POCUS were compared using Wilcoxon signed-rank tests. Sonographic diagnosis and CXR diagnosis were compared using the McNemar test. Kappa scores were assessed to measure interrater reliability of sonographic diagnoses (bedside ultra-sonographer versus expert reviewer). A two-sided $p < 0.05$ was considered to indicate statistical significance. All statistical analyses were conducted using SAS version 9.4 (SAS Institute Inc., Cary, NC).

3. Results

128 patients presenting with chest pain and/or shortness of breath were included in the study. The mean age was 64 ± 17 years. 55% were male (71/128) and 45% were female (57/128). 34% (44/128) presented with chest pain, 37% (47/128) with shortness of breath, and 29% (37/128) with both CP and SOB. Baseline characteristics of the patients are summarized in the Table 1.

Of these patients, 27% (35/129) were ultimately diagnosed with conditions that can be accurately assessed via rapid POCUS (pneumothorax, pericardial effusion, pneumonia, pulmonary edema, and pericardial effusion).

3.1. Ultrasound findings

The proportions of patients with specific ultrasound findings are provided in Table 2. In these patients the most common positive POCUS findings were diffuse B-lines and pleural effusions in lung ultrasound and a decreased ejection fraction and RV dilation. (Table 2). POCUS took an average of 10.0 min to be completed.

Of the 128 lung ultrasound studies, 43% (55/128) were normal, and 57% (73/128) were abnormal for pathology. Of the 55 normal lung ultrasound studies, 87% (48/55) were associated with a normal chest radiograph. The abnormal CXRs associated with normal US were positive for: 5 with possible atelectasis, 1 with known speculated lesion, 1 with mild pulmonary edema that needed no treatment. (Fig. 1).

The inclusion of heart and lung ultrasound to the conventional diagnostic evaluation of patients with CP and SOB significantly narrowed down the list of differential diagnoses in their initial ED evaluations. EPs were presented with a list of 14 potential diagnoses from which 5 diagnoses were directly assessed using ultrasound. The diagnoses amenable to US diagnosis were included: 1) pneumothorax, 2) pleural effusion, 3) pneumonia, 4) pulmonary edema, and 5) pericardial effusion. On average, the EP initially considered 5 diagnoses in their initial differential based upon history and physical exam and of these, an average of 2 (IQR 1–4) of the 5 diagnoses were conducive to sonographic evaluation. After the performance of ultrasound, the median number of differential diagnoses entertained decreased from 5 (IQR 3–6) to 3 (IQR 2–4), $p < 0.001$ (Table 3). Following POCUS evaluation there was a statistically significant decrease in all sonographically identifiable diagnoses. These results are consistent with previous studies in which point-of-care ultrasound was found to be a feasible and accurate diagnostic tool in patients presenting with dyspnea [19-21].

Interestingly, the differential of non-sonographic diagnoses also decreased following ultrasound. This may be because when a compelling positive finding was considered the likely sole cause of symptoms, other diagnoses became much less likely (Occam's razor) (Table 3).

3.2. Does CXR add value if the thoracic ultrasound is negative?

We found variable agreement between the CXR and ultrasound findings, with kappa scores ranging from 1.0 (100% agreement) for pneumothorax, to 0.40 (40% agreement) for pneumonia. When thoracic ultrasound was negative, the CXR was also negative 87% of the time. In only 13% of cases (7/55) did CXR find something that ultrasound did not. 5/7 discrepant positive x-rays revealed possible atelectasis on chest radiographs. Of these, 2/7 were diagnosed with minor exacerbation of COPD and were discharged home, 2/7 required additional work-up of chest pain to rule out acute coronary syndrome, and 1/7 patients was felt to have a post-viral cough, observed overnight without evidence of desaturation and discharged the following day. For the remaining 2 discrepant CXRs, 1/7 revealed mild pulmonary edema in a patient with chest pain. He was admitted for blood pressure management. No diuretics were administered. 1/7 revealed a known speculated lung lesion, information that was already known to the provider team. This patient was ultimately admitted for acute exacerbation of chronic obstructive pulmonary disease (COPD), a condition that could not be ruled in or out by POCUS. In no patients with a normal lung ultrasound did the chest x-ray provide any new or actionable information. This suggests that a normal lung ultrasound is highly predictive of having a

Table 1
Patient demographics.

Patient characteristics (n = 128)	Number (%)
Mean age	64
Female	57 (45)
Presenting complaint	
Chest pain only	44 (34)
Shortness of breath only	47 (37)
Both chest pain and shortness of breath	37 (29)
Comorbidities	
Coronary artery disease	44 (34)
Chronic obstructive lung disease	33 (26)
Asthma	17 (13)
Congestive heart failure	30 (23)
Malignancy	22 (17)
Interstitial lung disease/pulmonary fibrosis	14 (11)
Most common final (composite) diagnosis	
Asthma/COPD	20
Pulmonary edema	19
Pneumonia	14
ACS	14
Pericarditis	5
URI	3
Malignancy	2
Pneumothorax	1
Pleural effusion	1
Atypical CP and Other Dx	68

Table 2
Cardiac and lung ultrasound findings (n = 128).

	Present	Absent	Indeterminate
Abnormal cardiac ultrasound	46 (36%)		
Decreased ejection fraction	36	92	0
Right ventricular dilation	10	107	11
Pericardial effusion	8	119	1
Pericardial effusion (significant)	2	125	1
Enlarged aortic root	6	99	23
Abnormal lung ultrasound	73 (57%)		
Absence of lung sliding	3	125	0
Right pleural effusion	27	96	5
Left pleural effusion	31	93	4
Diffuse B-lines	57	71	0
Irregular pleural line/sub pleural	60	68	0
Hepatization/air bronchogram	21	107	0

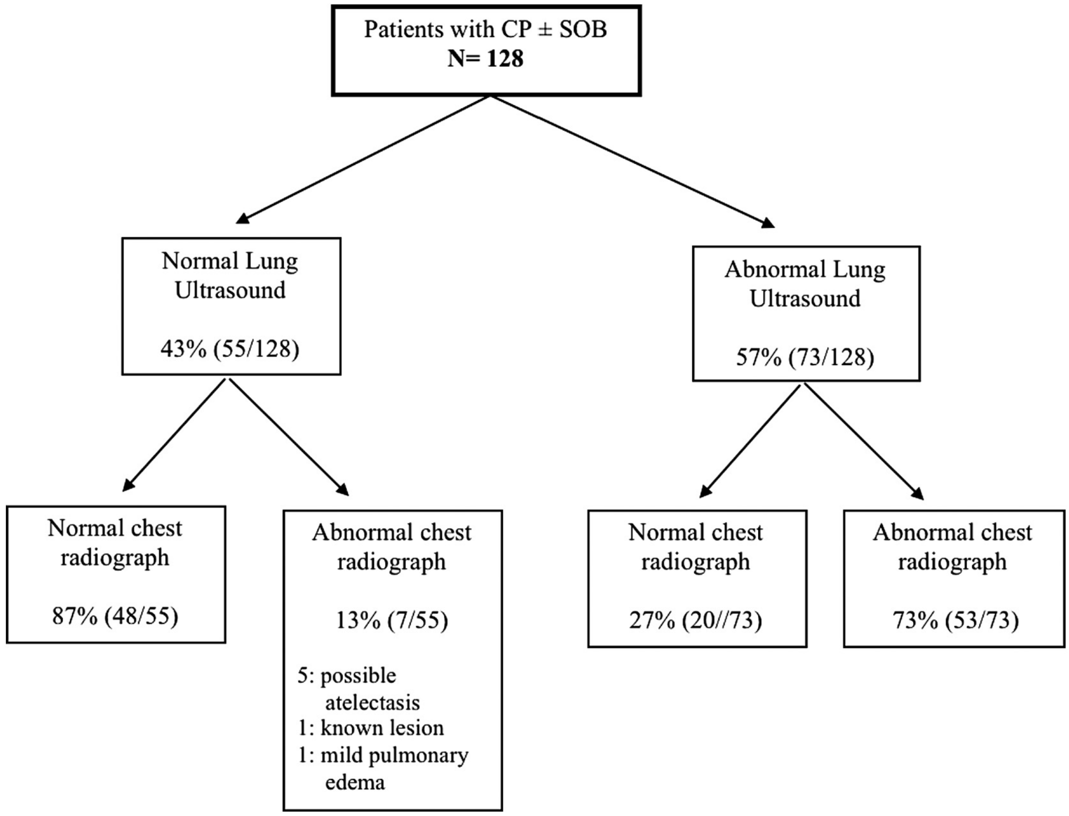

Fig. 1. Lung and chest radiograph results of 128 patients with chest pain and/or shortness of breath.

negative chest radiograph, or a positive CXR not requiring further intervention in the emergency context. POCUS may provide a higher proportion of actionable data, or in other words higher specificity without a clinically significant decrease in sensitivity. Given that ultrasound can be done faster than CXR at a lower cost and with no radiation, an ultrasound-first approach for evaluation of patients with chest pain or shortness of breath with a follow-up CXR only in patients with any positive findings on lung ultrasound may prove to be a reasonable approach.

Table 3
Effects of point-of-care ultrasound on the differential diagnoses for CP and SOB.

Presumptive Differential Diagnoses	Pre-POCUS Differential Diagnoses (%)	Post-POCUS Differential Diagnoses (%)	p-Value
Acute coronary syndrome	78	78	1.0
Pneumonia	77	49	<0.0001
Pulmonary edema	71	29	<0.0001
Musculoskeletal pain	51	52	0.85
Pericardial effusion	51	4	<0.0001
Pleural effusion	50	22	<0.0001
Pulmonary embolism	45	46	0.85
Pneumothorax	43	1	<0.0001
Asthma/COPD	39	28	0.03
Pericarditis	36	35	0.84
Upper respiratory tract infection	28	28	1.0
Aortic dissection	12	12	1.0
Malignancy	11	11	1.0
Other	9	9	1.0
Total number of ddx	5 (IQR 3–6)	3 (IQR 2–4)	p < 0.001

IQR = interquartile range.

3.3. Relative sensitivities of CXR and POCUS

Comparison of the relative sensitivities and specificities for the two tests revealed overlapping confidence intervals for all studies, except in the study of pneumonia. 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 (Table 4). Although the specificity of CXR in evaluation of pneumonia was higher than for POCUS (statistically significant) the sensitivity of POCUS was higher (clinically significant) (CXR 38% versus POCUS 89%). A driver of this discrepancy may be the high proportion of indeterminant studies for pneumonia (16 CXRs versus 30 POCUS). The inability to assess for pathology on indeterminate studies likely decreases the actual sensitivity of these exams in practice, though not the NPV. However, clearly defining indeterminate scans (with pathophysiologic rationale) may prove an essential component of ultrasound interpretation going forward, in order to maintain and improve the sensitivity of these studies. In practice, it is advantageous for POCUS, as a rapid bedside exam, to have a higher NPV, thus helping clinicians to safely avoid unnecessary further diagnostic work up. Therefore, as in this study, we argue that conservative definitions should be favored going forward, acknowledging the clinical use of ultrasound as a "rule-out" test, with the potential to eliminate the need for CXR.

4. Limitations

In our analysis, CXR and POCUS diagnoses were compared to the composite final discharge diagnosis, as selected by the treating physician. Use of the composite final diagnosis had certain advantages, such as incorporating other imaging findings and clinical information. However, in most cases physicians selected a single leading diagnosis at the end of the encounter as the primary etiology of their symptoms, without necessarily coding incidental findings. It is possible that in a

Table 4
Relative sensitivity and specificity of CXR and ultrasound with respect to final composite diagnoses.

	CXR			Ultrasound		
	Sensitivity	Specificity	Indeterminate	Sensitivity	Specificity	Indeterminate
Pneumothorax	1.0 (0.17–1.00)	1.0 (0.96–1.00)	0 (0)	1.0 (0.17–1.00)	1.0 (0.96–1.00)	0 (0)
Pneumonia	0.38 (0.13–0.70)	0.96 (0.90–0.99)	16 (13%)	0.89 (0.54–1.00)	0.74 (0.64–0.82)	30 (23%)
Pleural effusion	1.0 (0.17–1.00)	0.80 (0.73–0.86)	0 (0)	1.0 (0.17–1.00)	0.71 (0.63–0.78)	2 (2%)
Pulmonary edema	0.81 (0.56–0.94)	0.92 (0.86–0.97)	6 (5%)	0.78 (0.52–0.93)	0.93 (0.86–0.97)	14 (11%)

Note: There were zero instances in which pericardial effusion or atelectasis were the final composite discharge diagnosis.

proportion of the false positive studies, patients in fact had a component of either atelectasis, pneumonia, pleural effusion, CHF or pericardial effusion that was not captured in a parsimonious discharge diagnosis. In other words, we suspect that the specificities of both CXR and POCUS were underestimated using this method of analysis. As an example, although 8 POCUSs were positive for pericardial effusion, pericardial effusion was never coded as the principal diagnosis.

Another consideration is that a significant proportion of CXRs and POCUS were indeterminate (technically limited studies). CXRs were interpreted by radiologists within the context of regular clinical use. Therefore, this number is likely reflective of actual practice, in which a proportion of CXRs do not provide information which can be used to guide clinical decision making. A limitation of our study is that the POCUS exams were performed by sonographers who had special ultrasound training, rather than the treating emergency physician. Therefore, we cannot generalize the findings among emergency physicians without special ultrasound training. Therefore, it is possible that our rate of indeterminate scans underestimates the rate that would be ascertained in regular clinical practice by physicians with less training in POCUS.

Alternatively, another limitation to the study is that the sonographer was not directly involved in the patient's care, which could have limited the role of the POCUS in the physician's differential diagnosis. The main advantage of point of care ultrasound is that the clinician performs POCUS in the context of the clinical background and makes informed clinical decisions based on US interpretation. Therefore, had the ultrasonographer been the EP, it is possible that there may have been a lower rate of indeterminate scans. Finally, as sonographic interpretation continues to evolve, there remains variability in the way in which several pathologies are defined.

Changing the definition of pneumonia, for example to include scans that were positive for B-lines only, would significantly change our relative sensitivities and specificities.

Another consideration is that both CXR and POCUS findings were compared to the composite diagnosis as the gold standard. This had the advantage of incorporating all of the clinical information, including clinical impression, blood work, all imaging, and other studies. However, previous studies have largely used CT as a gold standard. Because not all patients presenting to the ED with CP or SOB required a CT, this information was used to guide the composite diagnosis in some but not all cases. In the absence of CT, either the CXR or POCUS may have introduced clinical bias on the composite diagnosis that is absent from the CT study which is conventionally interpreted by the radiologist, acting as a relatively independent third party.

5. Conclusion

In patients presenting to the ED with chest pain or SOB, use of ultrasound is a highly feasible diagnostic test which can narrow down the differential diagnosis. In initial evaluation of patients with CP and SOB, CXR and POCUS had comparable accuracy in diagnosing pneumothorax, pleural effusion, and pulmonary edema. In patients with a normal thoracic ultrasound, CXR never provided any actionable clinical information. Considering the benefits of POCUS in reducing cost of care, the speed of care delivery, and as a radiation free test, these data may suggest that the incorporation of ultrasound into the initial evaluation of ED patients with chest pain or shortness of breath may reduce the need for CXR in some cases and provide complementary information in others.

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Conflicts of interest

No conflicts of interest.

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