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ORIGINAL CONTRIBUTION

Diagnosing Acute Heart Failure in Patients With Undifferentiated Dyspnea: A Lung and Cardiac Ultrasound (LuCUS) Protocol

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Abstract

Objectives: The primary goal of this study was to determine accuracy for diagnosing acutely decompensated heart failure (ADHF) in the undifferentiated dyspneic emergency department (ED) patient using a lung and cardiac ultrasound (LuCUS) protocol. Secondary objectives were to determine if US findings acutely change management and if findings are more accurate than clinical gestalt.

Methods: This was a prospective, observational study of adult patients presenting to the ED with undifferentiated dyspnea. The intervention consisted of a 12-view LuCUS protocol performed by experienced emergency physician sonographers. The primary objective was measured by comparing US findings to the final diagnosis independently determined by two physicians blinded to the LuCUS result. Acute treatment changes based on US findings were tracked in real time through a standardized data collection form.

Results: Data on 99 patients were analyzed; ADHF was the final diagnosis in 36%. The LuCUS protocol had sensitivity of 83% (95% confidence interval [CI] = 67% to 93%), specificity of 83% (95% CI = 70% to 91%), positive likelihood ratio of 4.8 (95% CI = 2.7 to 8.3), and negative likelihood ratio of 0.20 (95% CI = 0.09 to 0.42). Forty-seven percent of patients had changes in acute management, and 42% had changes in acute treatment. Observed agreement for the LuCUS protocol was 93% between coinvestigators. Overall, accuracy improved by 20% (83% vs. 63%, 95% CI = 8% to 31% for the difference) over clinical gestalt alone.

Conclusions: The LuCUS protocol may accurately identify ADHF and may improve acute clinical management in dyspneic ED patients. This protocol has improved diagnostic accuracy over clinical gestalt alone.

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Dyspnea, one of the most common complaints evaluated in the emergency department (ED), has multiple and varied etiologies. In the United States, with five million people carrying a diagnosis of heart failure and an additional 650,000 diagnosed annually, patients with acute decompensated heart failure (ADHF) account for many of the presentations of acute dyspnea seen in EDs today.[1] Early diagnosis and goal-directed therapies are necessary for these patients to increase the efficacy and appropriateness of management, avoid unnecessary and potentially harmful interventions, and avoid delays in care. For example, the use of inhaled bronchodilators, in patients with undifferentiated dyspnea later found to have ADHF, is associated with worse outcomes.[2] A traditional work-up for ADHF, using chest radiography and serum brain natriuretic peptide, is not always diagnostic or helpful in elucidating the cause of dyspnea and has an overall diagnostic accuracy of only 65%.[3–7]

Bedside ultrasonography (US) may play a role in the management of patients with undifferentiated dyspnea by allowing early diagnosis of ADHF or by identifying alter-

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native etiologies. Multiple prior studies have attempted to differentiate ADHF by using lung US alone to detect pulmonary edema, which appears as diffuse B-lines, also termed alveolar interstitial syndrome (AIS).[3,5,6,8–11] This finding on bedside US is highly sensitive for ADHF,[3,9–13] but lacks specificity, as diffuse B-lines can be seen in a number of conditions including, but not limited to, ADHF, noncardiogenic pulmonary edema, bilateral pneumonia/pneumonitis, and lung cancer.[3,8,10,14]

Collapsibility and diameter variation with inspiration of the inferior vena cava (IVC) has been extensively studied independently of lung US.[1,15,16] Smaller variations in IVC diameter reflect elevated central venous pressure, a finding with a high sensitivity for detection of ADHF.[1] However, this finding also lacks specificity, as elevated central venous pressure can be seen in cardiac tamponade, pulmonary embolism, and valvular heart disease.[1]

Kajimoto et al.[17] were the first to assess lung, cardiac, and IVC US to differentiate ADHF from other causes of dyspnea. They found their scanning protocol to be highly sensitive and specific for diagnosing ADHF when performed by cardiologists and more accurate than lung US alone. Anderson et al.[18] later used a protocol similar to that of the study by Kajimoto et al. and found a specificity of 100% for diagnosing ADHF. Our study is similar to these two prior studies in that we also used a scanning protocol, composed of lung, cardiac, and IVC US to diagnose ADHF. However, to the best of our knowledge, our study is the first to evaluate the direct effect of US findings on acute management of dyspneic patients. Also, we chose to evaluate for the presence of pleural effusions and diastolic cardiac dysfunction, and to include patients previously treated (within 30 minutes) for ADHF. We chose to include these additional elements in an effort to improve sensitivity for detecting ADHF and allow greater real-world application.

The primary aim of this study was to determine the sensitivity, specificity, and likelihood ratios for diagnosing ADHF in the undifferentiated dyspneic ED patient using a 12-view lung and cardiac ultrasound (LuCUS) protocol. Our secondary aims were to determine if US findings acutely change management and if these findings were more accurate than clinical gestalt alone. We hypothesized that the use of this diagnostic protocol would increase accuracy for diagnosing ADHF and acutely improve clinical management.

METHODS

Study Design

This was a prospective, observational study of the diagnostic performance of the LuCUS protocol to diagnose ADHF in ED patients with undifferentiated dyspnea. The study was approved by the institutional review board, and all participating patients gave verbal informed consent.

Study Setting and Population

This study was conducted at an urban tertiary-care teaching hospital with over 120,000 annual ED visits. We enrolled a convenience sample of patients meeting the inclusion criteria: adult patients over 18 years old and a having primary complaint of undifferentiated dyspnea according to their treating clinicians. We defined undifferentiated dyspnea as at least two possible etiologies in the differential diagnosis, and this did not have to include ADHF as a potential diagnosis. An example of differentiated dyspnea would include a patient with known heart failure not compliant with medications or diet restrictions. We excluded patients in whom the treating clinicians were confident in their diagnoses after initial assessment; patients with electrocardiograms (ECGs) showing ST-segment elevation myocardial infarction; patients treated for ADHF with nitroglycerin, diuresis, or positive pressure ventilation greater than 30 minutes prior to US; patients refusing consent; and patients having been enrolled in the study at a prior ED visit. Both research assistants (RAs) and physicians identified study candidates through a standardized screening process. RAs enrolled patients when a study sonographer was available, typically Monday through Friday, 8 a.m. to 5 p.m.

Study Protocol

After initial history, physical examination, and 12-lead ECG, but prior to US, the treating clinician was ask by an RA to rank 10 possible etiologies of dyspnea in order of their likelihood (Table 1). The clinician only had to rank two possible etiologies, but could rank up to 10 diagnoses, including "other" where he or she could write in an alternative diagnosis not included on the list. Treating clinicians included board-certified emergency medicine (EM) physicians, EM residents (years 1 through 4), and third-year internal medicine residents.

The LuCUS protocol was performed and interpreted by three investigators: an EM US director and two EM US fellows. Each sonographer had greater than 1,000 previously performed US exams, including lung and cardiac exams. Each investigator was required to scan five patients at the bedside under the direct supervision of the principal investigator to ensure a standardized method of acquiring and interpreting images. Sonographers also spent 4 hours reviewing left ventricular function in the echocardiography reading room under the direction of a board-certified cardiologist. Sonographers were blinded to the treating clinician's initial assessment, patients' comorbidities, and the results of laboratory tests or imaging studies performed during the patients' ED encounters.

The LuCUS Protocol. Each sonographer conducted a two-part scanning protocol using a Mindray M7 (Mindray Medical International Limited, Shenzhen, China) US machine. Patients were in a position of comfort, semirecumbent and as close to 30 degrees of head elevation as possible.

The lung portion of the LuCUS exam interrogated four anterior/lateral lung zones in each hemithorax with a curvilinear probe.[14] Sonographers recorded the number of B-lines seen between two ribs in each lung zone. Greater than three B-lines in a rib space was considered a "B-profile." An examination that had at least two zones in each hemithorax with B-profiles was considered positive for diffuse B-lines or AIS.[4,19]

The cardiac portion of the LuCUS exam consisted of the following views:

Table 1
Dyspnea Differential Diagnosis

Acute coronary syndrome	Pleural effusion
Acutely decompensated heart failure	Pneumonia
Chronic obstructive pulmonary disease /asthma	Pulmonary embolism
Lung cancer	Mixed
Noncardiogenic pulmonary edema	Other

1). Subxiphoid view—examined IVC diameter and collapsibility during inspiration in the long axis. The IVC diameter was measured 2 cm caudal to the hepatic vein inlet,[20] using M mode with the cursor placed perpendicular to the IVC. An IVC with a maximal diameter of ≥2 cm and <50% collapse was considered plethoric. An IVC with a maximal diameter of ≤2 cm and >50% collapse was considered collapsible. Intermediate was defined as an IVC that did not fit either criteria.
2). Parasternal long- and short-axis views—left ventricular ejection fraction was estimated visually in the parasternal long-axis view by wall contraction and thickening.[21,22] Ejection fraction was confirmed in the parasternal short-axis view at the level of the papillary muscles.

Unique Elements of the of the LuCUS Exam. The exam assessed for the presence of a pleural effusion in the midaxillary line in the Extended Focused Assessment with Sonography in Trauma[23] position bilaterally. The exam also assessed diastolic function in the apical four-chamber cardiac view by measuring the ratio of the peak transmitral inflow velocity (E) to the average of the septal and lateral mitral annular velocities (e'^{Avg})—E/e'^{Avg}—obtained using pulsed-wave and tissue Doppler imaging, respectively. Diastolic function was graded as normal, indeterminate, impaired (grade 1), pseudo-normal (grade 2), or restrictive (grade 3).[22,24–26] Criteria for detecting and grading diastolic dysfunction were predefined and developed using the recommendations of the American Society for Echocardiography[27] in conjunction with a cardiologist board-certified in echocardiography.

After the LuCUS protocol was completed, the sonographer reported to the treating clinician the leading diagnosis based on objective US findings. The treating clinician then reranked his or her differential diagnosis post-US on a standardized data collection form, eliminating any pathology no longer under consideration. The clinician was also asked how the US findings would affect patient management, including changes in treatment, obtaining a new consult, admission to a different level of care, disposition, and overall confidence in the diagnosis. Ten percent of images were randomly selected for blinded review by coinvestigators to assess the percentage of observed agreement. Approximately two-thirds of images were randomly selected for blinded review by a cardiologist board-certified in echocardiography to assess interobserver reliability for identifying and grading diastolic dysfunction.

nice

Outcome Measures

Demographic information was collected including each patient's age, sex, and comorbidities. We also collected vital signs at presentation, admission diagnosis, cardiac biomarkers obtained in the ED, and ED interventions. This information was abstracted by RAs, trained in data abstraction according to recommendations from a previously published study.[28] Abstractors were blinded to US results and final discharge diagnosis.

Acute decompensated heart failure was defined sonographically as a combination of the following findings: 1) a plethoric IVC *plus* 2) at least one B-profile bilaterally or any pleural effusion *plus* 3) moderately to severely depressed left ventricular ejection fraction (<45%) or grade 2 or 3 diastolic dysfunction (for US findings suggesting alternative diagnoses like chronic obstructive pulmonary disease [COPD] or asthma, pneumonia, noncardiogenic pulmonary edema, or normal, see Figure 1).

Final diagnosis was determined independently by two emergency physicians (EPs; KC, ST) through a rigorous chart review; this diagnosis served as our criterion standard. Chart reviewers followed previously published methods,[28] which included training, standardized data forms and periodic monitoring. They were not blinded to the study hypothesis, but they were blinded to the LuCUS protocol results. Chart reviewers assessed all cases and arrived at their final diagnoses after reviewing all labs, imaging studies, medications administered, consults obtained, comprehensive echocardiography results, and discharge summaries from the index visits. Each review was performed independently and neither reviewer performed any of the US for this study. If the reviewers disagreed, a third blinded reviewer (FMR) made the decision on final diagnosis.

The effect of the LuCUS protocol was assessed in several ways: first, by determining whether there was a change in the top three etiologies in the differential diagnoses pre- and post-US; second, whether the top three etiologies in the differential diagnosis became more accurate in comparison to the patient's final diagnosis; and third, whether the protocol has immediate clinical effects, as evidenced by improvement in acute disease-specific ED management and changes in the treating clinician's confidence in the admission diagnosis.

Data Analysis

A pilot study using the LuCUS protocol was conducted, enrolling 20 ED patients with undifferentiated dyspnea. Analysis of the pilot data showed LuCUS to be 25% more sensitive and 24% more specific for diagnosing ADHF than for patients in whom US was not used.

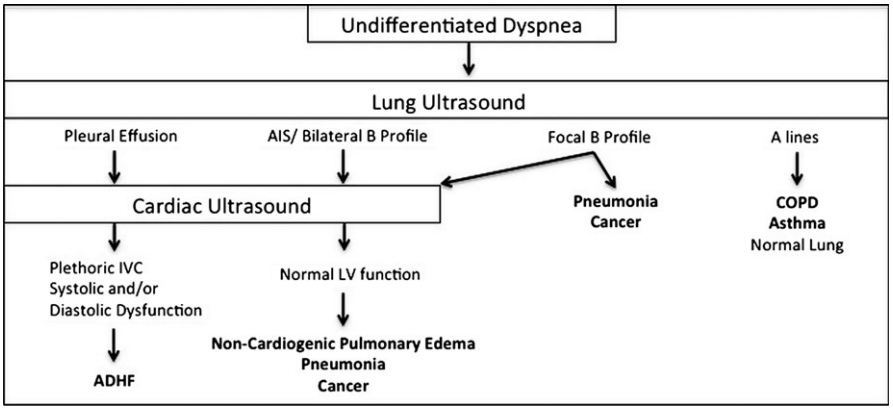

Figure 1. Algorithm for differentiating dyspnea using lung and cardiac US findings. ADHF = acutely decompensated heart failure; AIS = alveolar interstitial syndrome; COPD = chronic obstructive pulmonary disease; IVC = inferior vena cava; LV = left ventricular.

From these results, we calculated, based on a paired comparison, that a sample size of 96 patients would be needed to detect a 30% increase in accuracy with an α of 0.05 and a β of 0.20. Sensitivity, specificity, positive likelihood ratio (LR+), and negative likelihood ratios (LR–) were calculated, and 95% confidence intervals (CIs) were derived using SPSS (Version 21.0). A subanalysis (Table 2) was completed to see which variables, including B-lines, pleural effusions, IVC assessment, and left ventricular function, yielded the highest accuracy. Kappa and observed agreement were used to assess interrater reliability between coinvestigators' interpretations of images. Kappa was also used to assess agreement between EPs' and cardiologists' grading of diastolic dysfunction.

RESULTS

Between December 2012 and July 2013, the LuCUS protocol was performed on 104 patients presenting to the ED with undifferentiated dyspnea. Demographic and clinical information are listed in Table 3. The flow of the study is presented in Figure 2. Five patients were excluded: in four patients the US was not feasible due to poor scanning windows and body habitus, and one patient dropped out of the study prior to completion of the US.

Overall, 36 of 99 patients had a criterion standard diagnosis of ADHF, while 63 patients had an alternative final diagnosis. Sensitivity, specificity, accuracy, LR+, and LR– of the LuCUS protocol are 83% (95% CI = 67% to 93%), 83% (95% CI = 70% to 91%), 83% (95% CI = 74% to 89%), 4.8 (95% CI = 2.7 to 8.3), and 0.20 (95% CI = 0.09 to 0.42), respectively. Observed agreement for the LuCUS protocol was 93% between coinvestigators, and $\kappa = 0.82$ (95% CI = 0.70 to 0.95). 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. Sensitivity and specificity for detecting diastolic dysfunction were 100% (95% CI = 83% to 100%) and 47% (95% CI = 24% to 71%), respectively. Agreement between EPs and cardiology had a weighted kappa of 0.51 (95% CI = 0.35% to 0.66%).

Pre-US (Clinical Gestalt)

ADHF was listed amongst the top three etiologies in the differential diagnosis in 69 (70%) of 99 patients. Of these 69 patients, 34 (49%) had the criterion standard diagnosis of ADHF and 35 (51%) had alternative diagnoses (Figure 3). Thus, the sensitivity and specificity of clinical gestalt were 94 and 44%, respectively.

Post-US (LuCUS Protocol)

ADHF was listed as one of the top three etiologies in the differential diagnosis in 41 (41%) of 99 patients. Of these 41, 30 (73%) had the criterion standard diagnosis of ADHF and 11 (27%) had alternative diagnoses (Figure 2).

Table 2
Performance Characteristics for Diagnosing Acutely Decompensated Heart Failure

Characteristic	Sensitivity, % (95% CI)	Specificity, % (95% CI)	LR(+)	LR(–)
Clinical gestalt (pre-US)	94.4 (81–98)	44.4 (33–56)	1.7	0.12
LuCUS (post-US)	83.3 (67–93)	82.5 (70–91)	4.8	0.20
AIS and EF < 45%	34.3 (21–51)	96.8 (89–99)	10.9	0.67
B profile and EF < 45%	69.4 (53–82)	93.7 (84–97)	10.9	0.33
Pleural effusion and EF < 45%	79.4 (63–89)	98.4 (92–99)	51	0.21
Plethoric IVC and EF < 45%	70.6 (54–83)	81.5 (70–89)	3.8	0.36

AIS = alveolar interstitial syndrome; EF = ejection fraction; IVC = inferior vena cava; LR = likelihood ratio; LuCUS = lung and cardiac ultrasound.

Table 3
Patient Characteristics

Characteristic	ADHF (n = 36)	Total (n = 99)
Age (yr), mean ± SD (range)	57 ± 14 (34-91)	56 ± 13 (22-91)
Male sex	23 (63.9)	55 (55.6)
Medical comorbidities		
Congestive heart failure	23 (63.9)	40 (40.4)
COPD	12 (33.3)	43 (43.4)
Coronary artery disease	6 (16.7)	16 (16.2)
Hypertension	30 (83)	68 (68.7)
Lung cancer	1 (2.8)	10 (10.1)
Diabetes	11 (30.6)	29 (29.3)
Smoking	6 (16.7)	21 (21.2)
Vital signs		
Hypotension (sBP < 100 mm Hg)	3 (8.3)	5 (5.0)
Tachycardia (HR > 100 beat/min)	15 (41.7)	36 (36.3)
Tachypnea (RR > 20 beats/min)	16 (44.4)	44 (44.4)
Fever (>100.4°F)	0 (0)	0 (0)
Hypoxia (<92%)	4 (11.1)	12 (33.3)
Disposition		
ICU	3 (8.3)	9 (9.1)
Catheterization laboratory	0 (0)	1 (1)
Floor	26 (72.2)	64 (64.6)
Observation unit	4 (11.1)	9 (9.1)
Home	3 (8.3)	16 (16.2)
Final diagnosis		
ADHF		36 (36.3)
COPD		24 (24.2)
Pneumonia		10 (10.1)
Lung cancer		7 (7.1)
Pleural effusion		3 (3)
Noncardiogenic pulmonary edema		2 (2)
Pulmonary embolism		2 (2)
Acute coronary syndrome		1 (1)
Other		15 (15.1)

Values are number (%). ADHF = acutely decompensated heart failure; COPD = chronic obstructive pulmonary disease; HR = heart rate; ICU = intensive care unit; RR = respiratory rate; sBP = systolic blood pressure.

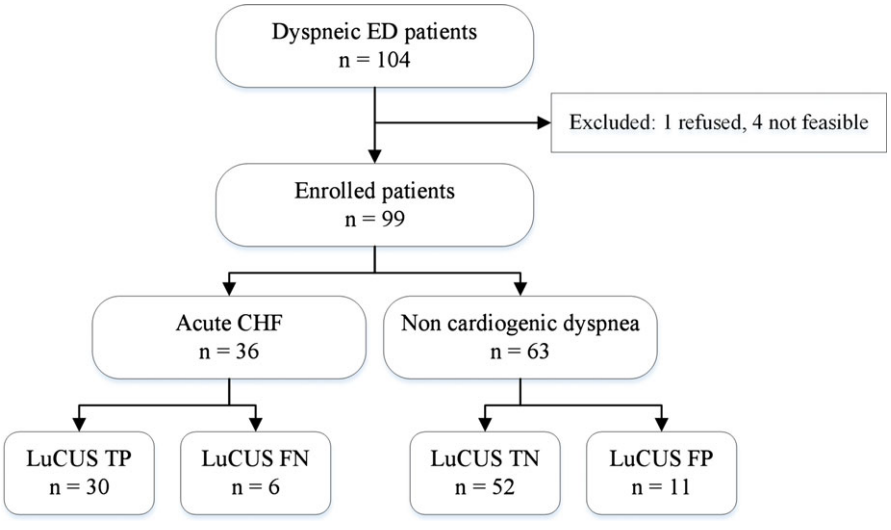

Figure 2. Patient flow through study, from enrollment to LuCUS (post-US) findings. CHF = congestive heart failure; FN = false negative; FP = false positive: LuCUS = lung and cardiac ultrasound; TN = true negative; TP = true positive.

Comparison of Pre- to Post-US

Of the initial 69 patients thought to have ADHF pre-US, 30 (43%) were found to have ADHF post-US and on final diagnosis; four (6%) were found to have a final diagnosis of ADHF but an alternative post-US diagnosis; eight (12%) were felt to have ADHF post-US but not on final diagnosis (Figure 3). US correctly eliminated ADHF from the differential diagnosis in 27 (39%) patients who were found to have alternative final diagnoses. No additional patients who were initially thought to have

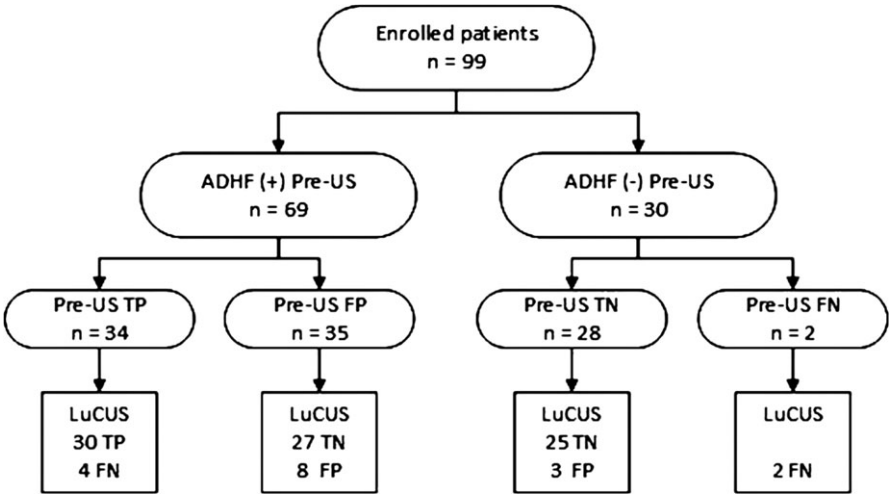

Figure 3. Patient flow through study, comparing clinical gestalt (pre-US) diagnosis to criterion standard diagnosis and LuCUS (post-US). ADHF = acutely decompensated heart failure; FN = false negative; FP = false positive; LuCUS = lung and cardiac ultrasound; TN = true negative; TP = true positive.

alternative diagnoses pre-US were identified as having ADHF post-US.

Treatment Prior to US

Twelve patients were treated with positive pressure ventilation, nitroglycerin, and/or furosemide prior to US, with an average of 21 minutes (range = 3 to 30 minutes) between treatment and US. All 12 patients had pre-US diagnoses of ADHF. Of these 12 patients, nine (75%) were found to have ADHF post-US and on final diagnosis, and three (25%) had alternative final and post-US diagnoses (two had COPD, one had noncardiogenic pulmonary edema).

Changes in Clinical Management Based on LuCUS

The LuCUS protocol led to 70 individual changes in management among 47 (47%) patients. This included 42 patients with changes in treatment plan, 12 patients with changes in disposition (e.g., admitted to a cardiology service vs. medicine), eight patients with changes in level of care (e.g., telemetry, intensive care unit, or catheterization lab), and eight patients who received new consults. Of the 42 patients with changes in treatment, 39 (93%) received correct disease-specific treatment (evidenced by concordance between post-US diagnosis and final diagnosis). In three of the 42 patients (7%), treatment changes were made based on US findings, but in these three the post-US diagnosis and final diagnosis differed. This included one patient with a final diagnosis of COPD where albuterol was initially discontinued as the patient was thought to have ADHF post-US, and discontinuation of fluids in two patients felt to have noncardiogenic pulmonary edema on US who were later found to have pneumonia and lung cancer as their final diagnoses, respectively.

big miss

Fifty-one of 99 patients (51%) had pre-US differential diagnoses that included both ADHF and COPD. Of these 51 patients, 25 (49%) had changes in ED-administered medications. These results are summarized in Table 4. As a result of the use of the LuCUS protocol, 24 of 25 of these patients (96%) received correct disease-specific treatment (final diagnosis and post-US diagnosis were concordant). Only one patient, with both a pre-US and a final diagnosis of COPD, incorrectly had albuterol discontinued as a result of the LuCUS protocol indicating ADHF.

The LuCUS protocol took a mean ± SD total time of 12 ± 4 minutes to complete; the lung portion took an average of 6 minutes, and the cardiac portion, including IVC, took 6 minutes. This time started when the first images were acquired.

DISCUSSION

Dyspnea is a common complaint in the ED, and rapidly identifying the cause can pose a challenge for clinicians. In this study we found that the LuCUS protocol improved diagnostic accuracy over clinical gestalt alone, including a significant improvement in specificity. Clinical gestalt had equivalent sensitivity to the LuCUS protocol for diagnostic accuracy, perhaps due to ADHF being overdiagnosed. This is illustrated by the fact that over 50% of the patients thought to have ADHF based on clinical gestalt (pre-US) were ultimately found to have alternative criterion standard diagnoses.

The LuCUS protocol had six false-negative results. Two of these patients were thought to have atrial fibrillation as the primary etiology of dyspnea pre-US, the LuCUS protocol found mixed diagnoses, defined as two etiologies contributing equally to the patients' clinical symptoms. In these two cases, ADHF was one of the two etiologies, so these US were coded as "mixed" diagnoses and not as ADHF alone. However, both of these patients were treated appropriately with diuresis. If these US had been coded as ADHF instead of mixed diagnoses, the sensitivity would have improved from 83% to 89% (95% CI = 75% to 95%).

Eleven patients had false-positive US. Of these, eight were thought to have pre- and post-US diagnoses of ADHF, meaning that they had both the clinical and the

Table 4
Treatment Changes in Patients With Pre-US Differential Diagnosis Including Both ADHF and COPD

Post (LuCUS) Diagnosis	Final Diagnosis	Treatment Change
ADHF	ADHF	Discontinued albuterol
ADHF	ADHF, viral myocarditis	Discontinued albuterol
ADHF	ADHF	Discontinued albuterol
COPD	COPD	Discontinued diuresis
ADHF	ADHF	Discontinued albuterol
ADHF	COPD	Discontinued albuterol
ADHF + ACS	ADHF, A-fib RVR	Started diuresis, stopped albuterol
COPD	COPD	Discontinued diuresis
ADHF	ADHF	Discontinued albuterol
NCPE + PNA	ARDS + PNA	Started IVF
Tamponade	Tamponade	Started IVF, Catheterization Lab
COPD	COPD	Discontinued diuresis
ADHF	ADHF	Discontinued albuterol
ADHF	ADHF	Discontinued albuterol
COPD	COPD	Discontinued diuresis
COPD	COPD	Discontinued diuresis
ADHF + ACS	ADHF, A-fib RVR	Discontinued albuterol
COPD	COPD	Discontinued diuresis, started albuterol
ADHF	ADHF	Discontinued albuterol
NCPE	Renal failure	Dialysis
COPD + PNA	PNA	Discontinued diuresis
COPD	COPD	Discontinued diuresis
ADHF	ADHF	Discontinued albuterol
ADHF	ADHF	Discontinued albuterol
COPD	COPD	Discontinued diuresis

ACS = acute coronary syndrome; A-fib = atrial fibrillation; ADHF = acutely decompensated heart failure; ARDS = acute respiratory distress; COPD = chronic obstructive pulmonary disease; LuCUS = lung and cardiac ultrasound; NCPE = noncardiogenic pulmonary edema; PNA = pneumonia; RVR = rapid ventricular response.

sonographic appearance of ADHF and were treated as such. These eight patients had final diagnoses that included renal failure with noncardiogenic pulmonary edema, atrial fibrillation, pulmonary hypertension with interstitial lung disease, and sternal fracture with pulmonary contusion. There are several factors that could explain why these patients were found to be false positives. First, the etiology of their dyspnea on initial presentation may have been multifactorial, including, in addition to their final diagnoses, ADHF. This is supported by the fact that in each of these cases, the patient had a history of ADHF and positive lung findings on US. Thus, their clinical and sonographic appearances were consistent with ADHF, while the root causes of their dyspnea (at the index visit) were not related to their underlying cardiac condition. Second, because ADHF is a dynamic process,[29] it is possible these patients had evidence of ADHF in the ED and improved prior to admission after receiving proper treatment. These findings illustrate the limitations of the criterion standard used for diagnosing ADHF in this study. If, for example, these eight patients truly had ADHF, specificity would have improved from 83% to 95% (95% CI = 87% to 98%).

The LuCUS protocol had a large effect on acute clinical management, which is highly important as disease-specific therapies for acutely dyspneic patients improve outcomes.[2] Almost half of the patients enrolled had changes in ED-administered medications, changes in level of care, and new consultations. Thirty-nine of 42 patients (93%) received correct disease-specific treatment. Only one patient had disease-specific treatment (albuterol) discontinued in error based on false-positive US findings of ADHF.

In the subset of patients thought to have both ADHF and COPD pre-US, 24 of 25 (96%) received correct disease-specific treatment post-US. Based on clinical gestalt, 12 of these 25 patients (48%) were thought to have COPD and thus were treated with beta agonists and steroids; after LuCUS-diagnosed ADHF, beta agonists were correctly discontinued. Final diagnoses confirmed that these patients had ADHF, not COPD.

This protocol not only differentiated patients with ADHF versus COPD, but it also identified alternative causes of dyspnea requiring very different treatment. For example, one patient thought to have ADHF based on clinical gestalt was diagnosed post-US with a large pericardial effusion with early tamponade physiology and was taken immediately for drainage.

The findings of the LuCUS protocol are similar to other previous studies that investigated the utility of bedside US for diagnosing ADHF. However, there are several aspects of our study that make it unique. The study by Kajimoto et al.[17] differs from ours in that their protocol was performed by trained cardiologists, thus limiting its use by EPs. Also, we included patients treated for ADHF prior to US to allow for better real-world application. The results of our study show that our protocol can be accurately applied in this subset of patients. We also evaluated the direct effect of US findings on acute management of dyspneic patients and found that the LuCUS protocol led to correct disease-specific treatment in the vast majority of treated patients.

The LuCUS protocol included four unique elements that differ from prior protocols: 1) we included patients treated for ADHF before US; 2) we used a bilateral B-profile, rather than AIS, as a potential indicator of ADHF; 3) we evaluated for pleural effusions; and 4) we assessed and graded diastolic dysfunction. We chose to include patients who had been treated less than 30 minutes prior to US as we thought this was more applicable to daily practice, as patients may be treated by emergency medical services or other front-end providers prior to initial evaluation by EPs. We found the LuCUS protocol to be 100% accurate in this subset of patients. These results suggest that we can apply this protocol in patients who have been treated for heart failure within 30 minutes.

Using B-profiles and/or pleural effusions as potentially indicative of ADHF allowed us to apply our protocol to a much larger group of patients than previous similar studies. While it is well established that the presence of AIS is fairly sensitive for detecting ADHF,[3,8,10,14] it is possible to have ADHF without AIS. By using this definition, we found a bilateral B profile and ejection fraction < 45% improved sensitivity for detecting ADHF by 35% (69% vs. 34%, 95% CI = 11% to 53% for the difference) compared to AIS with ejection fraction < 45%.

Although previous literature would support the conclusion that pleural effusions do not improve diagnostic performance,[10] we chose to include pleural effusions as part of the protocol, as we hypothesized that their inclusion may improve the protocol's overall accuracy, especially after commencement of treatment. We found the presence of a pleural effusion combined with an ejection fraction < 45% to be 98% specific for ADHF, with a LR+ of 51.

why?

Even though we were able to detect diastolic dysfunction 100% of the time, there was only moderate agreement between EPs and cardiologists for grading the level of dysfunction. Its assessment in our study did not lead to substantive improvements in recognition of ADHF, as only two of the 36 patients (5%) with final diagnoses of ADHF had isolated diastolic dysfunction. However, we believe evaluation of diastolic function represents an area for future investigation, as patients with isolated diastolic dysfunction will present to the ED in ADHF and are likely to benefit from early recognition of this as the etiology of their dyspnea.

This study has shown that EP sonographers with extensive US experience can make an accurate diagnosis of ADHF, more accurate than clinical gestalt alone, and this in turn can improve patient care. Future directions for this research would include assessing a modified protocol with less experienced sonographers to further validate the results and to improve its generalizability.

LIMITATIONS

This study has several limitations that could limit its generalizability. We enrolled a convenience sample of patients at a single institution, which may have introduced selection bias, as one of the expert sonographers needed to be available for enrollment. In addition, despite being powered to detect a clinically significant improvement in accuracy, the overall sample size was small.

The criterion standard for diagnosing ADHF is comprehensive echocardiography in combination with clinical symptoms and therapeutic response. Due to limited resources, however, not all patients enrolled in the study had comprehensive echocardiograms. If it was performed, it was often not completed in a rapid manner, sometimes not occurring until days after admission, thereby limiting its utility as a criterion standard. For our study, the working criterion standard was the final diagnosis determined by two blinded independent expert reviewers. This methodology introduces a potential source of bias because the results of the bedside US, directly or indirectly, may have been included in patients' ED charts, thereby influencing the chart reviewer's determination of final diagnosis. However, this model has served as criterion standard in multiple previous heart failure studies,[1,11,30–32] and we feel that the risk for bias is minimal because experience at our institution is that documentation of EP US results for heart failure is an infrequent practice.

Furthermore, sonographers may have been biased as they could not be blinded to the physical appearance of patients. However, we believe that this would be of minimal significance as patients were covered; we did not perform a physical examination; and clinical gestalt, including physical assessment, has been proven to be unreliable for determining etiology of dyspnea.[18,33] Also, brain natriuretic peptide levels were not analyzed for this study, as not enough patients had levels available, although it was not a requirement for enrollment, as its use in the acute setting is not as well supported.[34] Last, this study was designed as an expert-level study, with future goals of prospective validation using less experienced sonographers.

CONCLUSIONS

Our findings indicate that the lung and cardiac ultrasound protocol, when performed by an experienced emergency physician-sonographer in the assessment of ED patients with undifferentiated dyspnea, may accurately identify acute decompensated heart failure in dyspneic ED patients and increase the rate of correct, disease-specific treatment decisions. This protocol has better diagnostic accuracy than clinical gestalt alone and increases physician confidence in the diagnosis.

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