Original Contribution

Diagnosing heart failure among acutely dyspneic patients with cardiac, inferior vena cava, and lung ultrasonography ☆,☆☆,★

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ABSTRACT

Background: Rapid diagnosis (dx) of acutely decompensated heart failure (ADHF) may be challenging in the emergency department (ED). Point-of-care ultrasonography (US) allows rapid determination of cardiac function, intravascular volume status, and presence of pulmonary edema. We test the diagnostic test characteristics of these 3 parameters in making the dx of ADHF among acutely dyspneic patients in the ED.
Methods: This was a prospective observational cohort study at an urban academic ED. Inclusion criteria were as follows: dyspneic patients, at least 18 years old and able to consent, whose differential dx included ADHF. Ultrasonography performed by emergency sonologists evaluated the heart for left ventricular ejection fraction (LVEF), the inferior vena cava for collapsibility index (IVC-CI), and the pleura sampled in each of 8 thoracic regions for presence of B-lines. Cutoff values for ADHF were LVEF less than 45%, IVC-CI less than 20%, and at least 10 B-lines. The US findings were compared with the final dx determined by 2 emergency physicians blinded to the US results.
Results: One hundred one participants were enrolled: 52% male, median age 62 (25%-75% interquartile, 53-91). Forty-four (44%) had a final dx of ADHF. Sensitivity and specificity (including 95% confidence interval) for the presence of ADHF were as follows: 74 (65-90) and 74 (62-85) using LVEF less than 45%, 52 (38-67) and 86 (77-95) using IVC-CI less than 20%, and 70 (52-80) and 75 (64-87) using B-lines at least 10. Using all 3 modalities together, the sensitivity and specificity were 36 (22-51) and 100 (95-100). As a comparison, the sensitivity and specificity of brain natriuretic peptide greater than 500 were 75 (55-89) and 83 (67-92).
Conclusion: In this study, US was 100% specific for the dx of ADHF.

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1. Introduction

Congestive heart failure (CHF) is a major public health concern. Approximately 5.7 million patients in the United States carry the diagnosis of CHF with lifetime incidence of 1 in 5 for individuals older than 40 years [1–5]. Heart failure is the most common hospital discharge diagnosis, and more Medicare dollars are spent for the diagnosis and treatment CHF than for any other diagnosis [1,6]. The Centers for Medicare and Medicaid Services has targeted heart failure as the disease most worthy of cost-effective management; however, providing cost-effective treatment requires rapid and accurate differentiation of CHF from other causes of dyspnea [7]. Acutely decompensated heart failure (ADHF) is also the most common cause of acute dyspnea among elderly patients in the emergency department (ED) [8]. Although early appropriate diagnosis and therapy are associated with a decreased mortality [8–11], ADHF is also the most common cause of death among dyspneic patients presenting to the ED [12].

Correctly diagnosing ADHF among acutely dyspneic patients in the ED to provide early appropriate treatment has proven challenging [8,10,13–18]. Traditional diagnostic modalities such as physical examination, plain radiographs, and laboratory studies have variable, and frequently limited, diagnostic utility. The signs and symptoms of ADHF are frequently nonspecific and highly variable as well [15,18–20], especially among the increasingly larger group of patients with coexisting respiratory illness such as chronic obstructive pulmonary disease (COPD). Plain chest radiographs have limited correlation with CHF exacerbation [21,22]; and although natriuretic peptides may lend weight to a suspected diagnosis, they are insufficiently accurate to confirm or exclude the diagnosis of ADHF [1,11,16,23] and have a

"gray zone" of values that have little diagnostic value at all [24]. Unfortunately, misdiagnosis is associated with an increase in morbidity and mortality among patients with ADHF [8–10]. Conversely, treatments for CHF have deleterious effects among patients with noncardiac causes of dyspnea that often present with the same primary physical findings [10,25].

If the diagnostic accuracy of decompensated heart failure is to be improved in the acute setting, a rapid tool that is more specific for the diagnosis of ADHF must be developed. Such a tool, if positive, would allow treating physicians to begin treating even the most unstable patients with ADHF before the traditional diagnostic tests are available for interpretation without the increased morbidity and mortality associated with misdiagnosis and mistreatment. Furthermore, in less critically ill patients, a highly specific test would aid in making the diagnosis of ADHF when traditional testing is equivocal or delayed. Echocardiography is commonly used to support the diagnosis of CHF, but comprehensive echocardiography is rarely available in the ED and is too time consuming for the acutely decompensating patient. However, limited bedside cardiac and lung ultrasonography (US) is becoming a standard tool in EDs and intensive care units (ICUs). Emergency point-of-care US is ubiquitous among emergency medicine residency training programs, and most emergency residents are graduating with proficiency in limited cardiac US since the American College of Graduate Medical Education began requiring procedural competency in point-of-care US in 2008 [26]. In addition, many emergency physicians (EPs) who graduated before this requirement, as well as many critical care physicians, have also learned limited cardiac US skills. There are 3 point-of-care US modalities that have potential utility in the diagnosis of ADHF: cardiac US (which gives direct visualization of ejection fraction) [27–34], inferior vena cava (IVC) US (a noninvasive method of estimating intravascular volume status), [35–45] and lung US (which can detect the presence of interstitial edema [IE]) [46–51]. Each of these modalities has been used alone in evaluating for the diagnosis of ADHF; however, when used alone, each one lacks the accuracy needed to definitively make the diagnosis among acutely dyspneic patients in an ED setting—a depressed left ventricular ejection fraction (LVEF) is present in chronic heart failure but does not indicate whether there has been an acute reduction in systolic function, and neither a plethoric IVC nor the presence of IE is specific to ADHF.

Recently, there has been speculation that a combination of the 3 US modalities might yield a tool that is useful in making the diagnosis of ADHF among acutely dyspneic patients in the ED setting. One report has suggested that a focused US examination consisting of point-of-care cardiac, IVC, and lung examinations would be "an ideal tool to rule in or rule out the diagnosis of CHF"; however, this report has no data to support this assumption [52]. Only 1 case report has been published as evidence that this "Triple Scan" could potentially be used to identify the etiology of acute dyspnea in the ED [53]. Another recent study, performed by cardiologists, demonstrated that an echocardiogram, including valvular and IVC interrogation, combined with lung US is more accurate than lung US alone in distinguishing cardiac from noncardiac etiologies of dyspnea [54]. Accordingly, we set out to assess the accuracy of point-of-care US in making the diagnosis of ADHF among acutely dyspneic patients in the ED setting by combining all 3 modalities (cardiac, IVC, and lung US). We also performed a secondary analysis to determine if the combination of any 2 of the 3 modalities would perform as well as all 3 together.

2. Materials and methods

2.1. Study design

This was a prospective convenience sample of adult patients designed to assess the accuracy of EP-performed point-of-care cardiac, IVC, and lung US in the diagnosis of ADHF among dyspneic patients in the ED. The University of Pennsylvania Human Research Committee Institutional Review Board approved this study.

2.2. Study setting

The study was performed in the ED of an urban academic tertiary care facility with an annual ED census of 55,000. The ED is a primary teaching site of an emergency medicine residency program and an emergency US fellowship.

2.3. Study population

Adult patients were eligible for inclusion if they presented to the ED with acute dyspnea and if the treating attending physician felt that CHF exacerbation was part of the differential diagnosis after the history and physical examination but before any testing being completed. A convenience sample of patients was enrolled when 1 of the 5 clinical investigators was present in the ED. Participants were identified by the treating physician, a brain natriuretic peptide (BNP) laboratory study was ordered, and then written informed consent was obtained by one of the clinical investigators. Clinical investigators did not enroll their own patients when they were on a clinical shift to ensure that the sonologist performing the scans remained blinded to the clinical data; if one of the clinical investigators was acting as the treating physician during a clinical shift and desired to have one of his or her patients enrolled, another one of the investigators enrolled the patient and performed the scans. Patients were excluded if they were younger than 18 years or unable to consent.

2.4. US evaluations

Ultrasonographic evaluations were performed by 1 of 5 clinical investigators who were blinded to the clinical data provided by the treating physician. Investigators were not privy to the details of the patients' clinical course, laboratory values, or other diagnostic information either. The investigators performing the US studies were either emergency US fellows or emergency US fellowship trained. Scans were performed using a 1- to 5-MHz phased array transducer for the limited cardiac US and either a 3- to 5-MHz curvilinear transducer or the phased array probe for the B-line assessment (Siemens G-60, Acuson X-300 [both Siemens AG, Munich, Germany] or Sonosite M-Turbo [Sonosite Inc, Bothell, WA]).

Ultrasonographic results were recorded using a standardized data collection form. The US measurements included LVEF, IVC maximum diameter (IVCDmax), IVC minimum diameter, calculated IVC collapsability index (IVC-CI), as well as the number of B-lines present in each of the 8 thoracic zones used in the lung US examination (Fig. 1). The US data were entered at the bedside while measurements were being made. Details regarding the acquisition of US images are as follows:

2.4.1. Cardiac US
Limited cardiac US involved examination of the heart in 4 standard views when available (sometimes limited by habitus or dressings): parasternal long-axis, parasternal short-axis, subxyphoid 4-chamber, and apical 4-chamber views [55]. Left ventricular ejection fraction was visually estimated as the reduction in the cross-sectional area of the left ventricle viewed in the short axis as previously described [27,28,56–58].

2.4.2. Inferior vena cava US
Evaluation of the IVC involved examination at a level approximately 2 cm distal to the junction of the hepatic veins [57,59]. Sonographic views of the IVC were obtained either in the epigastric window or via the right intercostal spaces through the hepatic
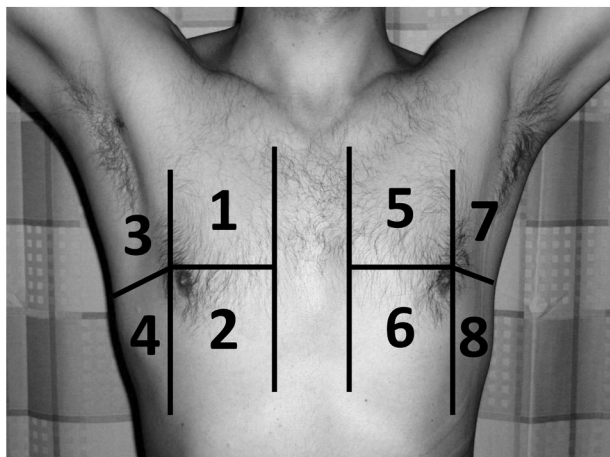
Fig. 1. The 8 thoracic zones considered in the B-pattern scoring method. Dividing lines include the sternum medially, the anterior axillary line dividing medial and lateral zones, and the posterior axillary line laterally. The third intercostal space divides the superior and inferior zones. Reproduced with permission from the American Institute of Ultrasound in Medicine.

window. The choice of sonographic window was determined by availability (limited by dressings, wounds, bowel gas, or habitus) and sonologist preference. Scans were performed in both the longitudinal and transverse orientations. Longitudinal images were used to make the measurements and calculations found in the results of our study, and transverse views were also measured to verify that the longitudinal scan was in the IVC midline. Maximal measurements were made during expiration, and minimal measurements were made during inspiration. The IVC-CI was calculated according to the standard formula: IVC-CI = (IVCDmax − IVC minimum diameter)/(IVCDmax).

2.4.3. Lung US

There are a number of sonographic artifacts that may appear at the pleural surface; however, the primary artifact of interest when examining for IE is the presence of B-lines (in the past, these artifacts have also been referred to as *comet tail artifacts* or *lung comets*).

We followed a scanning protocol that was originally described by Volpicelli et al and has been used by other investigators in ED and ICU settings [49,60,61]. The transducer was placed on the chest wall, perpendicular to the ribs; and 8 predefined thoracic zones were interrogated to a depth of 15 cm (Fig. 1).

Two methods of counting B-lines have been described. We used both methods of counting so that they can be compared. In the first method, initially described by Volpicelli et al [62], the goal is to determine how many of the 8 thoracic zones have 3 or more B-lines (B-pattern). Because *diffuse IE* has been defined as 2 or more zones bilaterally that demonstrate the B-pattern, we used a bilateral B-pattern count (BBPC) for this first method. The other method of quantifying B-lines includes counting the total number of B-lines present rather than identifying spaces with the presence of the B-pattern; the total number of B-lines in the entire thorax is then summed and can be referred to as a *B-line count* (BLC) [48,49,63–65]. We used a BLC of all 8 zones for this second method.

2.5. Cutoffs

Cutoff values for LVEF, IVC-CI, and BLC were determined from the optimal cutoff value for identifying ADHF among a pilot group of 20 patients using receiver operating characteristic (ROC) curve analysis. These cutoffs were used because there are no established standard cutoff values for diagnosing ADHF using any of these US modalities. The cutoffs were as follows: LVEF less than 45%, IVC-CI less than 20%,

and BLC at least 10. The BBPC cutoff was 2 or more bilateral B-pattern positive zones as previously described [62].

2.6. Clinical data

Clinical data were entered onto a separate standardized data collection form at the time of enrollment by the treating physician who was blinded to the US results. Clinical data included the patients' age and sex, presenting symptoms, medical history, and physical examination findings as listed in Table 1. The BNP level was entered once it had resulted from the laboratory.

2.7. Statistical analysis

Each participant was diagnosed as either having a primary diagnosis of ADHF or not having ADHF (ADHF+ or ADHF−) via medical record review that was performed after each participant had been discharged from the hospital. Participant medical records were independently reviewed by 2 EPs who were blinded to the US results. Reviewers had the entire electronic medical record available to them including the ED note, laboratory results (including BNP), plain radiographs and final radiology reads, comprehensive echocardiography results, and discharge summaries. Admission notes, consultation notes, and daily progress notes were not available in the electronic record; however, a synopsis of these was present in the discharge summary. In the case of reviewer disagreement, a third EP independently reviewed the medical record and served as a tiebreaker. For medical record reviews, there was no standard abstraction form. This expert physician consensus with medical record review analysis served as our criterion standard and is similar to the criterion standard used in prior CHF investigations [61,66,10,67]. Patients who may have had CHF as a secondary or contributing diagnosis were not identified because the treatment of the few patients whose CHF is contributing only partially, if any, to their dyspnea differs greatly from that of patients whose dyspnea is primarily caused by ADHF. Based on the criterion standard diagnosis of physician consensus and each of the 3 independent diagnostic tests, LVEF, IVC-CI, and BLC, with predetermined optimal cutoff values determined, 2 × 2 contingency tables were constructed; and sensitivity, specificity, positive predictive value (PPV), and negative

Table 1
Characteristics of enrolled participants

Characteristic	Total, N = 101	ADHF+, n = 44	ADHF−, n = 57
Demographics			
Mean age (y) (25th-75th interquartile)	62 (53-91)	63 (53-91)	62 (52-88)
Male (%)	52 (51)	25 (56)	27 (47)
Symptoms (%)			
Shortness of breath	101 (100)	44 (100)	57 (100)
Chest pain	31 (31)	11 (25)	20 (35)
Orthopnea	50 (50)	32 (73)	18 (32)
Paroxysmal nocturnal dyspnea	19 (19)	11 (25)	8 (14)
Medical history (%)			
CHF	52 (51)	33 (75)	19 (33)
COPD	29 (29)	9 (20)	20 (35)
Asthma	19 (19)	5 (11)	14 (25)
Both CHF & COPD	18 (18)	8 (18)	10 (18)
Diabetes	33 (33)	19 (43)	14 (25)
Tobacco use	32 (32)	13 (30)	19 (33)
Prior myocardial infarction	28 (28)	15 (34)	13 (23)
Renal failure	19 (19)	10 (23)	9 (16)
Physical signs (%)			
Rales	36 (36)	18 (41)	18 (32)
Wheezing	25 (25)	7 (16)	18 (32)
Jugular venous distention	22 (22)	16 (36)	6 (11)
Lower extremity edema	48 (48)	29 (66)	19 (33)
S3/S4 gallop	14 (14)	9 (20)	5 (9)

Table 2
Detection of ADHF with single variables and with combinations of 2 and all 3 variables

Variable(s)	Specificity (95% CI)	Sensitivity (95% CI)	PPV (95% CI)	NPV (95% CI)
LVEF <45%	74 (62-85)	77 (65-90)	69 (57-82)	81 (70-92)
IVC-CI <20%	86 (77-95)	52 (38-67)	74 (59-90)	70 (59-81)
B-lines ≥10	75 (64-87)	70 (52-80)	67 (53-81)	74 (63-85)
B-lines & IVC-CI	97 (92-100)	39 (24-53)	90 (76-100)	67 (57-77)
B-lines & EF	93 (86-100)	52 (38-67)	85 (72-99)	72 (61-82)
IVC-CI & EF	98 (95-100)	48 (33-62)	96 (87-100)	71 (61-81)
All 3	100 (95-100)	36 (22-51)	100 (77-100)	67 (57-77)

predictive value (NPV) were calculated for each diagnostic test to assess performance of each test independently. In addition, the same statistical measures of performance were calculated for each pairwise comparison of the 3 tests, with cases defined by a positive classification of test pairs. Lastly, the performance of the 3 tests combined with cases only defined by an overall 3-way positive classification was assessed by sensitivity, specificity, PPV, and NPV. Interrater agreement between the 2 physician raters was determined using a nonweighted Cohen κ. The number of patients who met the cutoffs for all 3 US modalities were compared with their final diagnosis to determine how specific the tool is in making the diagnosis of ADHF.

3. Results

Over a 12-month period, 101 patients were enrolled. The mean age was 62 years, and the numbers of male and female patients were almost equal. Forty-four of the participants had a final diagnosis of ADHF. Interrater agreement between physician raters for the diagnosis of ADHF was near-perfect: $\kappa = 0.97$ (95% confidence interval [CI], 0.94-0.99). The demographics and clinical characteristics of participants diagnosed as ADHF+ and ADHF− are listed in Table 1. Among the 57 ADHF− patients, the final diagnoses were as follows: pneumonia (n = 10), COPD (n = 8), renal failure (n = 5), and asthma (n = 4); there were an additional 20 patients with unique diagnoses such as malignant pleural effusion, pericardial tamponade, sepsis, laryngospasm, pulmonary fibrosis, and others.

The specificity for the diagnosis of ADHF using all 3 US modalities was 100% (95% CI, 95-100). The specificity of LVEF, IVC-CI, or B-lines alone is listed in Table 2. Using a combination of 2 modalities, the specificities for the diagnosis of ADHF were as follows: B-lines and IVC-CI, 97% (95% CI, 92-100); B-lines and EF, 93% (95% CI, 86-100); or IVC-CI and EF, 98% (95% CI, 95-100) (Table 2). The specificity of BNP greater than 500 pg/mL was 83% (95% CI, 67-92).

The specificity and sensitivity of a BBPC alone and in combination with the other 2 US modalities in making the diagnosis of ADHF are listed in Table 3.

4. Discussion

We set out to assess the test characteristics of point-of-care US in making the diagnosis of ADHF among acutely dyspneic patients in the

ED when cardiac, IVC, and lung modalities are combined. Our findings suggest that point-of-care US is perfectly predictive in making the diagnosis of ADHF in an ED population.

The clinical role of US has changed rapidly and drastically over the past 2 decades, as technology has allowed portable US machines with ever-improving image quality to be developed. The most dramatic change has been in the emergency and critical care settings where bedside US by the clinician caring for the patient has proven to rapidly render immediately interpretable, reproducible, and noninvasive answers to time-sensitive questions without requiring an unstable patient to leave the department or be subjected to unnecessary irradiation. Ultrasonography has proven to be so useful that the American College of Graduate Medical Education requires all emergency medicine residents to demonstrate procedural competency in bedside US as a core skill in their specialty training [26].

When limited cardiac US (including a standard IVC assessment) indicated the presence of ADHF, no other testing was needed for confirmation in this study. The *2008 Emergency Ultrasound Guidelines* published by the American College of Emergency Physicians defines the limited cardiac US performed by EPs as an ability to assess for pericardial effusion and evidence of tamponade, presence of cardiac activity, general cardiac contractility, and the central venous volume status [68,69]. These cardiac US guidelines have subsequently been accepted as reasons for EPs to perform and interpret limited cardiac US in the ED by the American Society of Echocardiography [34]. This study only required the clinician sonologist to assess for contractility and central venous volume status. In this study, the combination of LVEF, IVC-CI, and B-lines was 100% specific in making the diagnosis of ADHF; however, the combination of LVEF and IVC-CI alone performed equally well, which allows these findings to be generalizable to EPs who have the limited cardiac US skills suggested by the American College of Emergency Physicians.

One question that arises from the results of this study is whether B-lines should play any role at all in the diagnosis of ADHF because the combination of limited cardiac and IVC US (LVEF and IVC-CI) performs just as well at making the diagnosis without their inclusion. A review of the results suggests that they are not necessary for making the diagnosis of ADHF, but may be of use in some instances. B-lines in combination with IVC-CI also perform about as well as LVEF + IVC-CI or all 3 modalities combined; indeed, there is no significant difference between these 3 different combinations of US modalities. If a patient has difficult cardiac windows, then B-lines and IVC-CI could reasonably be used as an alternative because the pleura is a superficial structure that is much simpler to visualize than the heart.

In this study, US was very specific in making the diagnosis of ADHF. With the use of US, the treating clinician can be very confident that the diagnosis is correct, which is important when beginning therapies that are potentially deleterious if the diagnosis is incorrect. However, the sensitivities demonstrate that US only makes the diagnosis less than half the time. At first glance, these findings may seem to contrast with studies that have demonstrated that US for B-lines alone has excellent diagnostic accuracy in detecting IE [46,49,50,62] or that IVC-CI alone has both an excellent sensitivity and specificity for the diagnosis of decompensated heart failure [44]. However, diffuse IE is not always cardiogenic in nature. In 1997, Lichtenstein et al [46] showed that, among patients in the ICU, most of whom were mechanically ventilated, B-lines had a sensitivity of 93% and a specificity of 93% in diagnosing diffuse IE; however, in this group, only 37 of the 121 patients with IE were diagnosed with acute cardiogenic pulmonary edema. A study among an ED population showed similar results with a sensitivity of 86% and a specificity of 98% for the diagnosis of diffuse IE; this group reported that 59 of the 75 patients diagnosed with diffuse IE had ADHF [60]. Other disease states that were reported as causing diffuse IE on US include adult respiratory distress syndrome, multilobar pneumonia, interstitial pneumonia, exacerbation of chronic interstitial lung disease, and

Table 3
Detection of ADHF using BBPC alone and in combination with other variables

Variable(s)	Specificity (95% CI)	Sensitivity (95% CI)	PPV (95% CI)	NPV (95% CI)
≥2 B+ zones	91 (83-99)	34 (20-49)	74 (54-94)	65 (54-75)
≥2 B+ zones & IVC-CI	97 (92-100)	16 (5.1-27)	78 (51-100)	60 (50-70)
≥2 B+ zones & EF	100 (92-100)	23 (10-35)	100 (66-100)	63 (53-73)
All 3	100 (92-100)	16 (7.1-31)	100 (56-100)	61 (50-70)

pulmonary tuberculosis. To our knowledge, the only other study that has used IVC-CI to diagnose ADHF demonstrated a sensitivity of 92% and a specificity of 84%. This sensitivity is much higher than our IVC-CI data, but still lacks the specificity needed to be confident with the diagnosis [44]. The improved performance of IVC-CI by this group was likely due to a CHF population that was much more acutely ill than ours. Their group reported an average IVC-CI of 9.6% among the CHF cohort compared with our CHF cohort that had an average IVC-CI of 17%, suggesting that our CHF population suffered from less intravascular volume overload. These observations are important because they point out that more than one US modality is needed to make the diagnosis of CHF. They also suggest that, among more severely decompensated patients, the sensitivity of the US findings is likely to be increased.

To increase the diagnostic accuracy and utility of the B-line examination, we modified the Volpicelli protocol to produce a BLC. In the protocol described by Volpicelli et al, the goal is to determine how many of the 8 thoracic zones have the B-pattern. However, the B-pattern method may not perform as well in the ED where the severity of pulmonary edema from CHF is often not as marked as in the ICU [61]. One ED study revealed that the optimal cutoff for identifying ADHF using an ROC curve analysis is one or more B-pattern positive zones bilaterally [61]. Pilot data for our study plotted on an ROC curve were almost identical with these previous ED data, suggesting that the optimal cutoff for diagnosing ADHF among an ED cohort is lower than the arbitrary cutoff previously suggested by Volpicelli et al in diagnosing diffuse IE. Using the same pilot data, when we compared the ROC curves for a BLC compared with a BBPC, a BLC for the 8 zones had a greater area under the curve than a BBPC for predicting the presence of ADHF. For these reasons, we decided to use both a BLC, as it may be more accurate, as well as a more traditional BBPC in our study. In addition, for the busy EP who may be constrained by time, using a BLC will often be advantageous because there are sometimes 10 B-lines in a single intercostal space; instead of having to scan at least 4 intercostal spaces, as is required by the BBPC, 1 or 2 rib spaces may suffice.

We also point out that using a BBPC instead of a BLC produces results with equal specificity in making the diagnosis of ADHF; however, the sensitivities suffer when using a BBPC in making the diagnosis of ADHF. This is likely due to the BBPC requiring the patient to have more findings than the BLC. By forcing the patient to have at least 2 B-pattern positive zones bilaterally to qualify as diffuse IE, the patient must have a BLC of at least 12, which is higher than our BLC cutoff of 10. The more B-lines you require the patient to have, the more specific the study will be at the expense of sensitivity. Similarly, simply requiring the patient to have at least 4 B-pattern positive zones results in a sacrifice of sensitivity, as several of our patients in decompensated CHF had fewer than 4 positive zones.

The findings of this study would most likely affect the clinical outcome of patients with more severely decompensated heart failure where incorrect treatments are more detrimental; however, further studies are needed to more precisely characterize which population of acutely dyspneic patients will benefit most from the rapid and correct diagnosis of ADHF using US early in their ED management. Our findings assume that the US examinations can be performed rapidly; and although our study did not measure the time it took to perform the US examinations, prior literature demonstrates that a point-of-care cardiac US (including both LVEF and IVC-CI) and B-line assessment both take less than 5 minutes to perform [63,70].

4.1. Limitations

The sample size of this study is relatively small. A larger prospective study would be necessary to validate our cutoffs as diagnostic criteria for ADHF. However, this is currently the only study that has combined the 3 US modalities in the ED setting to assess whether they actually can be considered "an ideal tool to rule in or rule out the diagnosis of CHF" [52].

In this study, there was no attempt to identify patients with isolated diastolic heart failure using US. The evaluation of diastolic dysfunction was intentionally excluded because this is a skill set that is not typically learned by most EPs and would make the results much less generalizable. Similarly, because valvular examination is not typically part of the limited cardiac US skills learned by EPs, there was no attempt to evaluate whether a diminished IVC-CI was due to intravascular overload or valvular regurgitation. Although these intentional exclusions may affect the sensitivity of the study slightly, they would not affect the specificity, which is the important finding in our study; and their exclusion makes the results much more generalizable.

Although US examinations were performed as close to patient arrival as possible, it is possible that US results were affected by treatment that was initiated in the prehospital setting. Again, any prehospital administered medications would have the effect of decreasing the sensitivity but not the specificity of the test.

The design of this study leaves open the possibility for selection bias by using a convenience sample; however, a convenience sample was the only feasible way to enroll patients so that all 3 US modalities could be performed by investigators with similar scanning ability. With 5 investigators available to perform the scans, at least one of the scanning investigators was usually available in the ED at all times—if one of them was not available, it was usually during an overnight shift. Furthermore, there is the possibility of expectation bias because all 3 US modalities were performed by a single investigator. We attempted to minimize bias by blinding the investigators to all clinical data; however, if an investigator noted that a participant had a low EF while performing the cardiac examination, he or she may have inadvertently measured the IVC with a lower IVC-CI with the expectation that the participant had ADHF. Although the investigators were blinded to clinical data, they could not practically be blinded to the clinical condition of the patient they were scanning.

The US examinations in this study were performed by emergency US fellows or fellowship-trained physicians. It is possible that cardiac images obtained by non–fellowship-trained EPs may be more technically limited than those obtained for this study, thus limiting the generalizability of the study. However, the cutoff values for evaluating LVEF and IVC-CI in this study are simple enough that EPs with proficiency in limited cardiac US can use these criteria. Some residency training programs do not expect their graduates to be able to determine a specific ejection fraction (eg, <45%); rather, they are taught to determine whether cardiac contractility is hyperdynamic, normal, diminished, or severely diminished. Our cutoff for diagnosing CHF was an LVEF of less than 45%, which is the upper limit of diminished; so even EPs that have learned this categorical method should be able to use the methods outlined in this study. Assessment for B-lines is a newer modality that may not be taught at all emergency medicine residency training programs yet; however, our study shows that an assessment for B-lines may be useful but not necessary in making the diagnosis of ADHF.

The lack of a true criterion standard is a limitation among CHF studies where a diagnosis must be reached because all accepted standards include a subjective analysis. However, the high agreement between our raters indicates that subjective differences were minimal.

5. Conclusions

In ED patients with a suspected diagnosis of ADHF, the diagnosis is made almost certain when the LVEF is less than 45% and the IVC-CI is less than 20%; the presence of 10 or more B-lines adds to the specificity of the diagnosis.

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References

[1] American Heart Association. Heart disease and stroke statistics—2009 update. Dallas, TX: American Heart Association; 2009.

[2] Hunt SA, Abraham WT, Chin MH, Feldman AM, Francis GS, Ganiats TG, et al. 2009 focused update incorporated into the ACC/AHA 2005 guidelines for the diagnosis and management of heart failure in adults: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines: developed in collaboration with the International Society for Heart and Lung Transplantation. Circulation 2009;119(14):e391–479.

[3] McMurray JV, Adamopoulos S, Anker SD, Auricchio A, Bohm M, Dickstein K, et al. ESC guidelines for the diagnosis and treatment of acute and chronic heart failure 2012. Eur Heart J 2012;33:1787–847.

[4] McCullough PA, Philbin EF, Spertus JA, Kaatz S, Sandberg KR, Weaver WD. Confirmation of a heart failure epidemic: findings from the Resource Utilization Among Congestive Heart Failure (REACH) study. J Am Coll Cardiol 2002;39(1):60–9.

[5] Redfield MM. Heart failure—an epidemic of uncertain proportions. N Engl J Med 2002;347(18):1442–4.

[6] Massie BM, Shah NB. Evolving trends in the epidemiologic factors of heart failure: rationale for preventive strategies and comprehensive disease management. Am Heart J 1997;133(6):703–12.

[7] O'Connell JB, Bristow M. Economic impact of heart failure in the United States: a time for a different approach. J Heart Lung Transplant 1994;13(4):S107–12.

[8] Ray P, Birolleau S, Lefort Y, Becquemin MH, Beigelman C, Isnard R, et al. Acute respiratory failure in the elderly: etiology, emergency diagnosis and prognosis. Crit Care 2006;10(3):R82.

[9] Bales AC, Sorrentino MJ. Causes of congestive heart failure: prompt diagnosis may affect prognosis. Postgrad Med. 1997;101(1):44–9, 54–6.

[10] Maisel AS, Krishnaswamy P, Nowak RM, McCord J, Hollander JE, Duc P, et al. Rapid measurement of B-type natriuretic peptide in the emergency diagnosis of heart failure. N Engl J Med 2002;347(3):161–7.

[11] Mueller C, Scholer A, Laule-Kilian K, Martina B, Schindler C, Buser P, et al. Use of B-type natriuretic peptide in the evaluation and management of acute dyspnea. N Engl J Med 2004;350(7):647–54.

[12] Bordin P, Da Col PG, Peruzzo P, Stanta G, Guralnik JM, Cattin L. Causes of death and clinical diagnostic errors in extreme aged hospitalized people: a retrospective clinical-necropsy survey. J Gerontol A Biol Sci Med Sci 1999;54(11):M554–9.

[13] McCullough PA, Nowak RM, McCord J, Hollander JE, Herrmann HC, Steg PG, et al. B-type natriuretic peptide and clinical judgment in emergency diagnosis of heart failure: analysis from Breathing Not Properly (BNP) Multinational Study. Circulation 2002;106(4):416–22.

[14] Morrison LK, Harrison A, Krishnaswamy P, Kazanegra R, Clopton P, Maisel A. Utility of a rapid B-natriuretic peptide assay in differentiating congestive heart failure from lung disease in patients presenting with dyspnea. J Am Coll Cardiol 2002;39(2):202–9.

[15] Lien CT, Gillespie ND, Struthers AD, McMurdo ME. Heart failure in frail elderly patients: diagnostic difficulties, co-morbidities, polypharmacy and treatment dilemmas. Eur J Heart Fail 2002;4(1):91–8.

[16] McCullough PA, Duc P, Omland T, McCord J, Nowak RM, Hollander JE, et al. B-type natriuretic peptide and renal function in the diagnosis of heart failure: an analysis from the Breathing Not Properly Multinational Study. Am J Kidney Dis 2003;41(3):571–9.

[17] Gehlbach BK, Geppert E. The pulmonary manifestations of left heart failure. Chest 2004;125(2):669–82.

[18] Jorge S, Becquemin MH, Delerme S, Bennaceur M, Isnard R, Achkar R, et al. Cardiac asthma in elderly patients: incidence, clinical presentation and outcome. BMC Cardiovasc Disord 2007;7:16.

[19] Rihal CS, Davis KB, Kennedy JW, Gersh BJ. The utility of clinical, electrocardiographic, and roentgenographic variables in the prediction of left ventricular function. Am J Cardiol 1995;75(4):220–3.

[20] Mueller C, Frana B, Rodriguez D, Laule-Kilian K, Perruchoud AP. Emergency diagnosis of congestive heart failure: impact of signs and symptoms. Can J Cardiol 2005;21(11):921–4.

[21] Herman PG, Khan A, Kallman CE, Rojas KA, Carmody DP, Bodenheimer MM. Limited correlation of left ventricular end-diastolic pressure with radiographic assessment of pulmonary hemodynamics. Radiology 1990;174(3 Pt 1):721–4.

[22] Collins SP, Lindsell CJ, Storrow AB, Abraham WT, Scientific Advisory Committee ADHERE. Prevalence of negative chest radiography in the emergency department patient with decompensated heart failure. Ann Emerg Med 2006;47(1):13–8.

[23] Wright SP, Doughty RN, Pearl A, Gamble GD, Whalley GA, Walsh HJ, et al. Plasma amino-terminal pro-brain natriuretic peptide and accuracy of heart-failure diagnosis in primary care: a randomized, controlled trial. J Am Coll Cardiol 2003;42(10):1793–800.

[24] Coste J, Pouchot J. A grey zone for quantitative diagnostic and screening tests. Int J Epidemiol 2003;32(2):304–13.

[25] Packer M, Cohn JN. Consensus recommendations for the management of chronic heart failure. On behalf of the membership of the advisory council to improve outcomes nationwide in heart failure Am J Cardiol 1999;83A(2):1A–38A.

[26] Accreditation Council for Graduate Medical Education. Emergency medicine guidelines. Available at: http://www.acgme.org . Accessed June 29, 2012.

[27] Amico AF, Lichtenberg GS, Reisner SA, Stone CK, Schwartz RG, Meltzer RS. Superiority of visual versus computerized echocardiographic estimation of radionuclide left ventricular ejection fraction. Am Heart J 1989;118(6):1259–65.

[28] Mueller X, Stauffer JC, Jaussi A, Goy JJ, Kappenberger L. Subjective visual echocardiographic estimate of left ventricular ejection fraction as an alternative to conventional echocardiographic methods: comparison with contrast angiography. Clin Cardiol 1991;14(11):898–902.

[29] Moore CL, Rose GA, Tayal VS, Sullivan DM, Arrowood JA, Kline JA. Determination of left ventricular function by emergency physician echocardiography of hypotensive patients. Acad Emerg Med 2002;9(3):186–93.

[30] Randazzo MR, Snoey ER, Levitt MA, Binder K. Accuracy of emergency physician assessment of left ventricular ejection fraction and central venous pressure using echocardiography. Acad Emerg Med 2003;10(9):973–7.

[31] Jones AE, Tayal VS, Kline JA. Focused training of emergency medicine residents in goal-directed echocardiography: a prospective study. Acad Emerg Med 2003;10(10):1054–8.

[32] Kobal SL, Atar S, Siegel RJ. Hand-carried ultrasonography improves the bedside cardiovascular examination. Chest 2004;126(3):693–701.

[33] Manasia AR, Nagaraj HM, Kodali RB, Croft LB, Oropello JM, Kohli-Seth R, et al. Feasibility and potential clinical utility of goal-directed transthoracic echocardiography performed by noncardiologist intensivists using a small hand-carried device (SonoHeart) in critically ill patients. J Cardiothorac Vasc Anesth 2005;19(2):155–9.

[34] Labovitz AJ, Noble VE, Bierig M, Goldstein SA, Jones R, Kort S, et al. Focused cardiac ultrasound in the emergent setting: a consensus statement of the American Society of Echocardiography and American College of Emergency Physicians. J Am Soc Echocardiogr 2010;23(12):1225–30.

[35] Natori H, Tamaki S, Kira S. Ultrasonographic evaluation of ventilatory effect on inferior vena cava configuration. Am Rev Respir Dis 1979;120(2):421–7.

[36] Moreno FL, Hagan AD, Holmen JR, Pryor TA, Strickland RD, Castle CH. Evaluation of size and dynamics of the inferior vena cava as an index of right-sided cardiac function. Am J Cardiol 1984;53(4):579–85.

[37] Otto CM. Textbook of clinical echocardiography. 3rd ed. Philadelphia, PA: Elsevier Saunders; 2004. p. 157.

[38] Feissel M, Michard F, Faller JP, Teboul JL. The respiratory variation in inferior vena cava diameter as a guide to fluid therapy. Intensive Care Med 2004;30(9):1834–7.

[39] Yanagawa Y, Nishi K, Sakamoto T, Okada Y. Early diagnosis of hypovolemic shock by sonographic measurement of inferior vena cava in trauma patients. J Trauma 2005;58(4):825–9.

[40] Lyon M, Blaivas M, Brannam L. Sonographic measurement of the inferior vena cava as a marker of blood loss. Am J Emerg Med 2005;23(1):45–50.

[41] Kircher BJ, Himelman RB, Schiller NB. Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. Am J Cardiol 2005;66(4):493–6.

[42] Gunst M, Ghaemmaghami V, Sperry J, Robinson M, O'Keeffe T, Friese R, et al. Accuracy of cardiac function and volume status estimates using the bedside echocardiographic assessment in trauma/critical care. J Trauma 2008;65(3):509–16.

[43] Stawicki SP, Braslow BM, Panebianco NL, Kirkpatrick JN, Gracias VH, Hayden GE, et al. Intensivist use of hand-carried ultrasonography to measure IVC collapsibility in estimating intravascular volume status: correlations with CVP. J Am Coll Surg 2009;209(1):55–61.

[44] Blehar DJ, Dickman E, Gaspari R. Identification of congestive heart failure via respiratory variation of inferior vena cava diameter. Am J Emerg Med 2009;27(1):71–5.

[45] Nagdev AD, Merchant RC, Tirado-Gonzalez A, Sisson CA, Murphy MC. Emergency department bedside ultrasonographic measurement of the caval index for noninvasive determination of low central venous pressure. Ann Emerg Med 2010;55(3):290–5.

[46] Lichtenstein D, Meziere G, Biderman P, Gepner A, Barre O. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med 1997;156(5):1640–6.

[47] Picano E, Frassi F, Agricola E, Gligorova S, Gargani L, Mottola G. Ultrasound lung comets: a clinically useful sign of extravascular lung water. J Am Soc Echocardiogr 2006;19(3):356–63.

[48] Jambrik Z, Monti S, Coppola V, Agricola E, Mottola G, Miniati M, et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. Am J Cardiol 2004;93(10):1265–70.

[49] Agricola E, Bove T, Oppizzi M, Marino G, Zangrillo A, Margonato A, et al. "Ultrasound comet-tail images": a marker of pulmonary edema: a comparative study with wedge pressure and extravascular lung water. Chest 2005;127(5):1690–5.

[50] Lichtenstein D, Meziere G. A lung ultrasound sign allowing bedside distinction between pulmonary edema and COPD: the comet-tail artifact. Intensive Care Med 1998;24(12):1331–4.

[51] Lichtenstein DA, Mezière GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. Chest 2008;134(1):117–25.

[52] Nagdev A, Mantuani D, Bailey C. 'Triple Scan' for diagnosis of ADHF. ACEP News 2012;31(9):17–8.

[53] Mantuani D, Nagdev A. Three-view ultrasound to differentiate acute decompensated heart failure from chronic obstructive pulmonary disease. Am J Emerg Med 2013 [epub ahead of print].

[54] Kajimoto K, Madeen K, Nakayama T, Tsudo H, Kuroda T, Abe T. Rapid evaluation by lung-cardiac-inferior vena cava (LCI) integrated ultrasound for differentiating

heart failure from pulmonary disease as the cause of acute dyspnea in the emergency setting. Cardiovasc Ultrasound 2012;1(10):49.

[55] Reardon RF, Joing SA. Cardiac. In: Ma OJ, Mateer JR, Blaivas M, editors. Emergency ultrasound. 2nd ed. New York: McGraw-Hill; 2008. p. 109–48.

[56] Stamm RB, Carbello BA, Mayers DL, Martin RP. Two-dimensional echocardio-graphic measurement of the left ventricular ejection fraction: prospective analysis of what constitutes an adequate determination. Am Heart J 1982;104(1):136–44.

[57] Rich S, Sheikh A, Gallastegui J, Kondos GT, Mason T, Lam W. Determination of left ventricular ejection fraction by visual estimation during real-time two-dimen-sional echocardiography. Am Heart J 1982;104(3):603–6.

[58] Shahgaldi K, Gudmundsson P, Manouras A, Brodin LA, Winter R. Visually estimated ejection fraction by two dimensional and triplane echocardiography is closely correlated with quantitative ejection fraction by real-time three dimensional echocardiography. Cardiovasc Ultrasound 2009;7:41–7.

[59] Jue J, Chung W, Schiller NB. Does inferior vena cava size predict right atrial pressures in patients receiving mechanical ventilation? J Am Soc Echocardiogr 1992;5:613–9.

[60] Volpicelli G, Mussa A, Garofalo G, Cardinale L, Casoli G, Perotto F, et al. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. Am J Emerg Med 2006;24(6):689–96.

[61] Liteplo AS, Marill KA, Villen T, Miller RM, Murray AF, Croft PE, et al. Emergency thoracic ultrasound in the differentiation of the etiology of shortness of breath (ETUDES): sonographic B-lines and N-terminal pro-brain-type natriuretic peptide in diagnosing congestive heart failure. Acad Emerg Med 2009;16(3):202–10.

[62] Volpicelli G, Cardinale L, Garofalo G, Veltri A. Usefulness of lung ultrasound in the bedside distinction between pulmonary edema and exacerbation of COPD. Emerg Radiol 2008;15(3):145–51.

[63] Bedetti G, Gargani L, Corbisiero A, Frassi F, Poggianti E, Mottola G. Evaluation of ultrasound lung comets by hand-held echocardiography. Cardiovasc Ultrasound 2006;4:34.

[64] Fagenholz PJ, Gutman JA, Murray AF, Noble VE, Thomas SH, Harris NS. Chest ultrasonography for the diagnosis and monitoring of high-altitude pulmonary edema. Chest 2007;131(4):1013–8.

[65] Noble VE, Murray AF, Capp R, Sylvia-Reardon MH, Steele DJR, Liteplo A. Ultrasound assessment for extravascular lung water in patients undergoing hemodialysis, time course for resolution. Chest 2009;135(6):1433–9.

[66] Tung RH, Camargo Jr CA, Krauser D, Anwaruddin S, Baggish A, Chen A, et al. Aminoterminal pro-brain natriuretic peptide for the diagnosis of acute heart failure in patients with previous obstructive airway disease. Ann Emerg Med 2006;48(1):66–74.

[67] Januzzi Jr JL, Camargo Jr CA, Anwaruddin S, Baggish AL, Chen AA, Krauser DG, et al. The N-terminal Pro-BNP investigation of dyspnea in the emergency department (PRIDE) study. Am J Cardiol 2005;95(8):948–54.

[68] American College of Emergency Physicians. Emergency ultrasound guidelines. Available at: http://www.acep.org; 2008. Accessed June 29, 2012.

[69] Society for Academic Emergency Medicine. Ultrasound position statement. Available at: http://www.saem.org. Accessed June 29, 2012.

[70] Andersen GN, Haugen BO, Graven T, Salvesen O, Mjølstad OC, Dalen H. Feasibility and reliability of point-of-care pocket-sized echocardiography. Eur J Echocardiogr 2011;12(9):665–70.