American Journal of Emergency Medicine (2009) **27**, 71–75

The American Journal of Emergency Medicine

www.elsevier.com/locate/ajem

Brief Report

Identification of congestive heart failure via respiratory variation of inferior vena cava diameter☆,☆☆

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Received 8 August 2007; revised 11 January 2008; accepted 12 January 2008

Abstract

Introduction: Rapid diagnosis of volume overload in patients with suspected congestive heart failure (CHF) is necessary for the timely administration of therapeutic agents. We sought to use the measurement of respiratory variation of inferior vena cava (IVC) diameter as a diagnostic tool for identification of CHF in patients presenting with acute dyspnea.

Methods: The IVC was measured sonographically during a complete respiratory cycle of 46 patients meeting study criteria. Percentage of respiratory variation of IVC diameter was compared to the diagnosis of CHF or alternative diagnosis.

Results: Respiratory variation of IVC was smaller in patients with CHF (9.6%) than without CHF (46%) and showed good diagnostic accuracy with area under the receiver operating characteristic curve of 0.96. Receiver operating characteristic curve analysis showed optimum cutoff of 15% variation or less of IVC diameter with 92% sensitivity and 84% specificity for the diagnosis of CHF.

Conclusion: Inferior vena cava ultrasound is a rapid, reliable means for identification of CHF in the acutely dyspneic patient.

1. Introduction

Exacerbations of congestive heart failure (CHF) lead to respiratory distress or even respiratory failure and are associated with high morbidity and mortality [1-3]. Identification of volume overload as the cause of a patient's respiratory distress can be difficult particularly in patients with comorbid conditions such as chronic obstructive pulmonary disease (COPD) because physical examination is unreliable and no imaging or laboratory test is adequate [4]. Ultrasonographic measurement of a large respiratory variation of inferior vena cava (IVC) diameter has been shown to correlate with volume depletion in patients with septic shock [5,6] and may be useful in diagnosing volume overload. In this study, we sought to use decreased respiratory variation of IVC diameter as measured via bedside ultrasound to identify volume overload in patients with acute dyspnea.

2. Methods

2.1. Study population

Patients were enrolled from a single urban academic emergency department (ED) with an annual volume of

☆ This study was supported in part by the Department of Emergency Medicine, University of Massachusetts Medical School (Worcester, Mass).

☆☆ Preliminary data were presented at the Society for Academic Emergency Medicine National Conference 2006, San Francisco, CA.

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doi:10.1016/j.ajem.2008.01.002

75 000 patients. Patients presenting with a primary complaint of shortness of breath were eligible for inclusion. Exclusion criteria included age of younger than 18 years, pregnancy, liver transplantation, mechanical ventilation, or inability to consent for the study. In addition, patients were excluded if diuretics, bronchodilators, or vasoactive medicines were administered before enrollment.

2.2. Bedside ultrasound

Patients enrolled in the study received a limited ultrasound of their IVC before initiation of medical care in the ED. Ultrasound images were obtained immediately on patient arrival to the ED concordant with physician evaluation and nursing care. All decisions for laboratory testing, diagnostic imaging as well as therapeutic interventions were made by the ED attending who was blinded to the results of the IVC measurements.

Measurements of the IVC were made with a 3.5-MHz curvilinear probe on a portable ultrasound machine (SonoSite, Inc, Bothell, Wash). Images of the IVC were obtained from an anterior transabdominal approach. The transverse diameter of IVC was measured anterior to posterior immediately inferior to the confluence of the hepatic veins and the IVC with patients in 45° recumbent position. Measurements were taken at maximum diameter during expiration and minimum diameter during inspiration (see Fig. 1). Respiratory variation was then calculated as the difference between maximum and minimum divided by the maximum. All ultrasound images were recorded on medical-grade DVD for later review.

2.3. Diagnostic confirmation and other outcomes measurements

Primary outcome measure was diagnosis of CHF or alternate diagnosis. Final diagnosis was determined using previously published methods consisting of a standardized chart review performed independently by 2 physician investigators blinded to results of ultrasound measurements. [4]. Data were collected and recorded on preprinted data sheets (see Table 1 for listing of data points). Diagnoses were divided into 3 categories: (1) shortness of breath secondary to volume overload, (2) history of CHF but shortness of breath due to alternate pathology, and (3) shortness of breath due to alternative cause. For the purposes of statistical analysis, categories 2 and 3 were combined. In the event of a disagreement between the 2 investigators, a third investigator performed a standardized review of the patient records and categorized the patient as described above.

2.4. Statistical analysis

The diagnostic performance of a sonographic measurement of the respiratory variation of the IVC for discriminating CHF from non-CHF was assessed using a receiver operating characteristic (ROC) curve. The optimal cutoff value of respiratory variation of the IVC to diagnose CHF was chosen by analyzing the ROC curve for maximum sensitivity and specificity.

Approval for this study was obtained from University of Massachusetts Institutional Review Board, and written consent was obtained from all participants.

3. Results

Forty-six patients were enrolled over a 10-month period. Patients were enrolled in a convenience sample upon the availability of one of the study authors to perform the bedside ultrasound. Patient characteristics for each group are provided in Table 2. Twenty-nine percent of patients had a diagnosis of CHF as the etiology of their shortness of breath. There was no statistical difference between patients with CHF and patients without CHF with the exception of the presence of diabetes.

Ultrasound measurements of IVC respiratory variation differentiated CHF from non-CHF. Respiratory variation in IVC diameter averaged 9.6% in CHF and 46% in non-CHF ($P < .0001$). Absolute diameter of IVC (taken as the maximum diameter in expiration) was nondiagnostic (18 mm in CHF vs 15 mm in non-CHF, $P = .084$).

Receiver operating characteristic curve using respiratory variation of the IVC as diagnostic criteria for CHF produced an area under the curve of 0.96 and revealed 15% respiratory variation or less as the optimum cutoff (see Fig. 2). This cutoff value showed a sensitivity of 93% (95% confidence interval [CI], 76%-99%) and specificity of 84% (95% CI, 77%-88%) for CHF ($P < .0001$). A secondary analysis of the data showed that no patients in the CHF group had an absolute diameter of the IVC less than 10 mm. There were patients, however, in the non-CHF group with diameters of less than 10 mm and respiratory variation below the 15% cutoff value. If a 10-mm cutoff for absolute diameter is added to the diagnostic criteria for CHF, the specificity of the test increased to 91% (95% CI, 83%-93%).

Four patients were classified in category 2 (history of CHF but shortness of breath due to alternative cause). All 4 of these patients had BNP measurements greater than 100 μg/mL. Using test criteria of IVC diameter greater than 10 mm and respiratory variation of greater than 15% correctly, we identified all 4 patients as non-CHF.

4. Discussion

This study examined the utility of sonographic measurement of the IVC as a marker of volume overload in patients with acute shortness of breath. We found that respiratory variation of the IVC was highly sensitive and specific for the diagnosis of CHF.

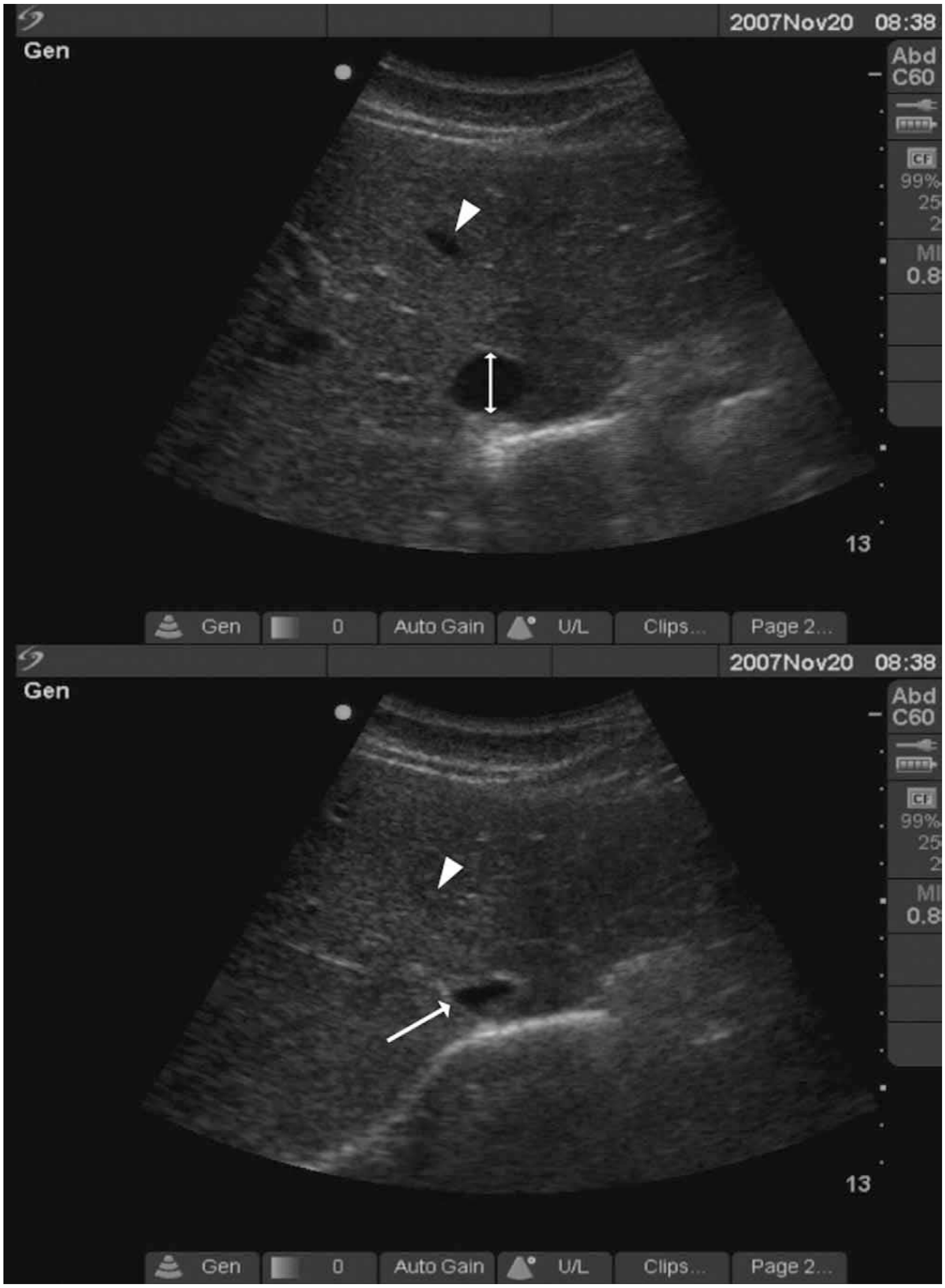

Fig. 1 Inferior vena cava diameter changes with respiratory cycle. Inferior vena cava imaged in the same patient without movement of the ultrasound probe. The top image demonstrates maximum AP diameter during expiration with measurement taken as demonstrated by the arrow. Hepatic veins are also seen in this view (arrowhead). The bottom image shows collapse of the IVC (arrow) during inspiration, which has also led to collapse of hepatic veins (arrowhead).

The diameter of the IVC is dynamic and changes with changes in intrathoracic pressure. During inspiration, intrathoracic pressure decreases thereby increasing venous return and causing collapse of the IVC. During expiration, increase in intrathoracic pressure decreases venous return and leads to increase in diameter of the IVC. The changes in IVC diameter with respiration reflect the elasticity of this capacitance vessel. In cases of CHF, volume overload dilates the IVC to the limits of its elasticity such that the increase in pressure during expiration leads to minimal increase in diameter. Therefore, despite the wide variation between individual patients in absolute diameter of IVC, volume overload can be assessed by observation of decreased change with the respiratory cycle.

Measurements of IVC diameter have been shown to trend with changes in volume status in patients with renal failure [7] as well as heart failure [8,9]. Absolute diameter decreases with progressive diuresis in CHF and with

Table 1 Standardized chart review data points

History of CHF
Hospital discharge diagnosis of CHF
Echocardiogram evidence of CHF
BNP >100
Chest x-ray evidence of CHF
Paroxysmal nocturnal dyspnea
Jugular venous distention
Rales
S3 gallop
Elevated central venous pressure
Hepatojugular reflux
Weight loss >4.5 kg in 5 d with treatment
Improvement with diuresis or dialysis

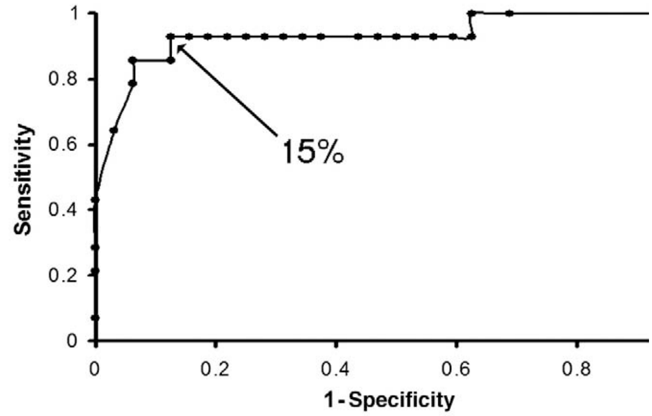

Fig. 2 Receiver operating characteristic curve. Respiratory variation of IVC diameter showed good diagnostic accuracy with area under curve of 0.96.

hemodialysis in renal failure [10]. Inferior vena cava diameter has also been shown to decrease after blood donation in healthy volunteers [11]. While helpful, the need for trending measurements makes IVC diameter a poor diagnostic technique for patients where baseline diameter is not known. The wide variation from individual to individual of IVC diameter [12,13] makes isolated measurements difficult to interpret as a true marker of volume status.

Recent research in critical care has shown that respiratory variation in IVC diameter can be used to predict volume responsiveness in patients with septic shock [5,6]. Patients with wide variation in IVC diameter with respiratory cycle were found to be more responsive to fluid therapy than those with smaller variations. Use of this respiratory variation has advantages of eliminating the need for baseline or trending measurements, and offers a noninvasive means to ascertain volume status quickly and at the patient's bedside. Brennan et al [14] recently compared IVC measurements to right atrial pressure in patients undergoing right heart catheterization and correlated IVC collapsibility with right atrial pressure. Although they found decreased respiratory variation to be predictive of elevated right atrial pressure, their optimum cutoff was identified at 40%, markedly greater than our cutoff of 15%. There are 2 possible explanations for the differences in our cutoff values. First, patients in the Brennan study had already received treatment and were at least partially diuresed before the ultrasound. As fluid was removed the respiratory variation would increase. Secondly, patients in the Brennan study were positioned for catheterization in a recumbent position, whereas most patients in our study were imaged in a semirecumbent position due to inability to lie flat. This reflects the difference in volume status after diuresis. It is also possible that a cutoff of 40% detects all patients with increased right heart pressures but a cutoff of 15% detects patients with elevated heart pressures who are symptomatic.

Table 2 Patient characteristics

	CHF	Not-CHF	*P*
Total no. of patients	14	32	
Average age (y)	69	62	.19
Male (%)	71	59	.52
Admitted (%)	86	74	.47
Coronary disease (%)	50	24	.094
Hypertension (%)	50	47	1.0
Diabetes (%)	57	18	.013
CHF (%)	36	18	.26
COPD (%)	21	44	.20
Asthma (%)	14	29	.47
Renal insufficiency (%)	36	12	.10

COPD indicates chronic obstructive pulmonary disease.

In our study, 15% respiratory variation or less of IVC diameter was highly sensitive and specific for the diagnosis of CHF. The test's specificity was further increased by the addition of a 10-mm cutoff for absolute diameter of IVC. Although absolute diameter of IVC in itself was nondiagnostic, patients with small IVC diameter posed a challenge for measurement of respiratory variation as it approached the limits of resolution of the imaging technique. Data published by Brennan et al [14] likewise supports the use of 10 mm as a cutoff for diagnosis of elevated right atrial pressure. As no patient diagnosed with CHF had an IVC diameter less than 10 mm in our study, we feel this cutoff is a reasonable addition to the test criteria.

4.1. Limitations

There were several limitations in our study. More men than women were enrolled in the study, and in particular, more men were ultimately diagnosed with CHF (71%). This may be due simply to chance or reflect the higher prevalence of cardiovascular disease in men than women [15]. Differences in patient groups and sex bias may be explained by our small sample size of 48 patients. This sample size was chosen after interim analysis revealed good diagnostic accuracy with area under ROC curve of 0.96. This remains, however, a small study, and certainly, future studies may be warranted to confirm our results in larger, more uniform populations. Another limitation of the technique that is difficult to quantify is the potential confounder of conditions such as tricuspid regurgitation. One would reason that this would lead to false positive tests in using this technique to diagnose CHF. We did not have echocardiogram data on all the patients in our study so we cannot speak to its bearing on our study population.

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