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Diagnostics

Resolution of sonographic B-lines as a measure of pulmonary decongestion in acute heart failure

Jennifer L. Martindale, MD *

Department of Emergency Medicine, SUNY Downstate/Kings County Hospital, Brooklyn, NY 11203

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ABSTRACT

Objective noninvasive measures of dyspnea in patients with acute heart failure are lacking. In this review, we describe lung ultrasound as a tool to estimate the degree of pulmonary congestion in patients presenting with acute heart failure and to monitor therapeutic efficacy. Serial semiquantitative measures of sonographic B-lines in acute heart failure patients can be converted to pulmonary edema scores obtained at admission and hospital discharge. These scores provide prognostic information for short-term clinical outcomes. Lung ultrasound has the potential to measure changes in pulmonary edema during acute heart failure management and improve risk stratification.

1. Introduction

Dyspnea is the most common complaint prompting acute heart failure (AHF) patients to seek emergency care [1,2]. Improvement in dyspnea is an important clinical goal in the management of AHF, and it serves as a primary end point in therapeutic trials. As a surrogate marker of clinical improvement, however, change in dyspnea severity may be an inadequate measure of response to therapy for several reasons. Dyspnea is subjective, and language used to describe dyspnea is subject to cultural and racial differences [3]. The most prevalent instruments used to measure dyspnea, visual analog and Likert scales, have poor interscale reliability [4–6]. A more objective and direct measure of the primary pathophysiologic derangement underlying dyspnea could help clinicians more accurately assess clinical improvement and readiness for discharge in AHF patients.

Pulmonary congestion is most often the primary cause of dyspnea in AHF patients. The chest radiograph is the conventional tool used for identifying pulmonary congestion in acutely dyspneic patients. Radiographic signs of pulmonary congestion, however, are insensitive [7], subject to high interobserver variability [8], and slow to improve with changes in pulmonary capillary wedge pressure. Lung ultrasound identifies pulmonary congestion with high sensitivity and is helpful in discriminating AHF from other causes of dyspnea in emergency department (ED) patients [9,10]. In the presence of extravascular pulmonary fluid, vertical hyperechoic artifacts called B-lines arise from the pleural line and extend to the bottom of the screen. When distributed diffusely, B-lines represent cardiogenic pulmonary congestion. Beyond its diagnostic value, lung ultrasound may be useful as a tool that can semiquantitatively measure AHF severity. A higher density of B-lines has been shown to correlate with other measures of AHF severity including pulmonary capillary wedge pressure [11], echocardiographic evidence of diastolic dysfunction [12], and natriuretic peptide levels [13]. Serial measures of B-lines have also been shown to decrease in response to AHF treatment [12,14,15]. This article describes current approaches to measuring sonographic pulmonary congestion and the available evidence supporting roles for lung ultrasound in monitoring response to therapy and predicting clinical outcomes.

2. Discussion

The potential of lung ultrasound as a tool to objectively measure the resolution of pulmonary edema in AHF patients during treatment has not been fully realized. Attributes that make lung ultrasound a potential modality for monitoring therapeutic progress include its feasibility, ease of use by novice sonographers [16], the short time required for imaging and analysis (<5 minutes), and its ability to reflect changes in pulmonary edema in real time.

2.1. Scanning protocols

Lung ultrasound is performed by obtaining longitudinal scans of the intercostal space with phased array or curvilinear probes set to a depth of approximately 15 cm. Scanning protocols for quantifying B-lines differ by the number and designation of anatomical thoracic zones scanned. The most common and exhaustive protocol is based on scanning 28 lung zones (Fig. 1A) [11,12,15,17–20]. The right hemithorax is scanned from the second to the fifth intercostal spaces

* Department of Emergency Medicine, SUNY Downstate Medical Center, 450 Clarkson Ave, Brooklyn, NY 11203. Tel.: +1 718 270 4580.
E-mail address: martindale.jen@gmail.com.

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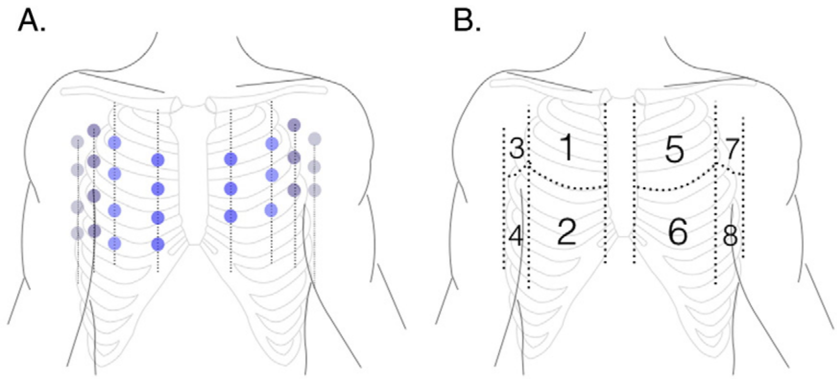

Fig. 1. A, The 28-zone scanning protocol. The second to fourth intercostal spaces on the left hemithorax and second to fifth intercostal spaces on the right hemithorax are scanned at the parasternal, midclavicular, anterior axillary, and midaxillary lines. B, The 8-zone scanning protocol. The third intercostal space divides upper and lower zones of the chest and the anterior axillary line divides the anterior and lateral zones in each hemithorax.

along parasternal, midclavicular, anterior axillary, and midaxillary lines. The left hemithorax is scanned from the second to the fourth intercostal spaces along the same vertical lines. The time required for performing this 28-zone scan has been reported to range from less than 3 minutes [12,17] to 10 to 15 minutes [18], but this approach may be more challenging to incorporate into routine clinical practice. A simpler protocol is based on scanning 8 thoracic lung zones (4 anterior and 4 lateral, as described by Volpicelli [21]) (Fig. 1B). Anatomical zones in this protocol are defined by vertical lines through the sternum, anterior axillary line, and posterior axillary line and by horizontal lines through the clavicle, third intercostal space, and the diaphragm. The presence of 3 or more B-lines in an intercostal space is considered pathologic and defines the corresponding anatomical zone as positive. For diagnostic purposes, a positive lung ultrasound demonstrating diffuse pulmonary edema is defined by the presence of at least 2 bilateral positive lung zones [20].

Body positioning may affect the severity and distribution of B-lines, as B-lines have shown to be more numerous in the supine position compared to an upright position [22]. Whether B-line scores obtained in supine patients [12,15,23,24] apply to those obtained in severely dyspneic heart failure patients unable tolerate recumbent positioning is unknown.

2.2. Quantifying B-lines

B-lines are defined as discrete hyperechoic vertical lines [25]. The most prevalent method of quantifying B-lines is to sum the number of discrete B-lines in an intercostal space [11,17–19]. The sum total of scores obtained from all thoracic zones yields an overall B-line score. In the setting of severe pulmonary edema, counting B-lines becomes less straightforward because B-lines fuse together (Fig. 2). An intercostal space may be occupied entirely by a single, wide hyperechoic B-line extending from the pleural line when coalescence is complete, producing an image described as “white lung” [26]. Assuming that B-line fusion represents a more severe form of pulmonary edema, information is likely lost by regarding fused lines the same as discrete lines. One alternative approach discussed by Volpicelli et al [20] to quantifying the fused B-line is to estimate the percentage of intercostal space filled with confluent B-lines and dividing this percentage by 10. This number is then added to any additional discrete B-lines visualized in the intercostal space. This may be a more reliable method described for quantifying B-line severity. The interclass correlation coefficient for quantifying B-lines on lung ultrasound has been shown to be highest (interclass correlation coefficient, 0.89; 95% confidence interval [CI], 0.87-0.91) when confluent B-lines are counted as the percentage of rib space filled and added to any other B-lines visualized in a single static image [27].

The simplest method as described by Volpicelli et al [23] of quantifying B-line severity is based on the sum of the number of positive lung zones. A positive lung zone is defined by a minimum of 3 B-lines per intercostal space.

2.3. Resolution of sonographic B-lines

Lung ultrasound offers a real-time assessment of pulmonary congestion. Serial lung ultrasound can capture rapid changes in pulmonary congestion. Several studies performed in patients with end-stage renal disease have demonstrated that lung ultrasound can detect dynamic changes in B-lines in response to volume removed during a single hemodialysis session [18,28–31]. Most of the patients in these studies who were found to have sonographic pulmonary congestion before hemodialysis [18,28,29,31] were asymptomatic, suggesting that lung ultrasound detects subclinical pulmonary congestion.

B-lines clear in response to inpatient treatment of AHF. In a cohort of 100 patients admitted for AHF, B-line scores obtained using the sum of individual B-lines across 28 lung zones significantly improved before hospital discharge (48 ± 48 vs 20 ± 23; $P < .0001$) [15]. In an earlier study by Frassi et al [12], a similar decrease in B-lines during AHF hospitalization was observed in a group of 70 patients whose New York Heart Association functional classification improved by at least 1 point (42 to 15; $P < .0001$). In patients whose heart failure worsened or failed to clinically improve, B-line scores were not significantly

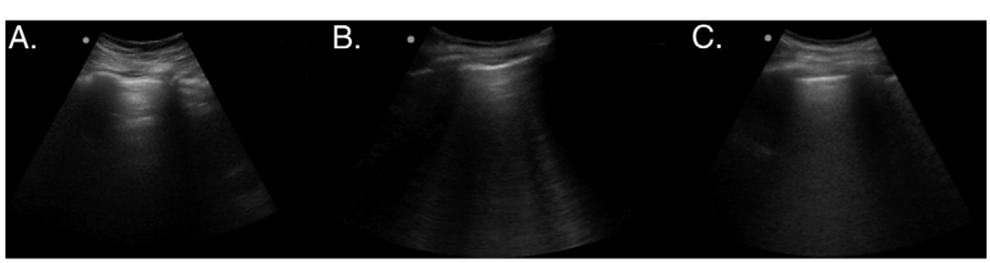

Fig. 2. Lung ultrasound clips showing varying degrees of pulmonary edema in a single intercostal space. A, Normal lung. B-lines are absent. Horizontal lines called A-lines run parallel to the pleural line. B, Pulmonary edema. Several discrete B-lines extend from the pleural line to the bottom of the screen. C, Severe pulmonary edema. B-lines have coalesced into a single hyperechoic band extending from the pleura.