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ORIGINAL ARTICLE

Decreased sensitivity of lung ultrasound limited to the anterior chest in emergency department diagnosis of cardiogenic pulmonary edema: a retrospective analysis

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Abstract
Purposes B-lines are vertical echogenic artifacts seen on lung ultrasound that allow bedside diagnosis of pulmonary edema. The BLUE protocol, published by Lichtenstein and Mezière, suggests that cardiogenic pulmonary edema is sufficiently ruled out in the ICU setting when B-lines are not predominant in the anterior chest (the B-profile). Our analysis sought to evaluate the sensitivity of the B-profile for ruling out pulmonary edema in the ED patient population.
Methods The ultrasound lung scans of patients with confirmed official diagnoses of acute decompensated heart failure (ADHF) from two ED databases were retrospectively analyzed. 170 acutely dyspneic patients had complete studies (130 from one database and 40 from the other). The scans were reviewed using the B-profile definition for ruling out pulmonary edema and comparing that to an alternate scanning protocol that includes ultrasound evaluation of the lateral and anterior chest.
Results Of the 170 ED patients with ADHF diagnoses, the B-profile missed 16.5% ($n = 28$) for a sensitivity of 83.5% (95% CI 77–89%). These 28 patients did not show anterior bilateral B-lines that fit the criteria for positive under the BLUE protocol. Moreover, 25% (7/28) of these missed patients had only lateral B-lines on their lung scans and B-lines would have been detected only by including scans of the lateral zones.
Conclusions Limiting the sonographic lung examination to the anterior chest areas only will miss cases of ADHF in the dyspneic ED patients. The BLUE protocol (B-profile) may need to be modified to include examination of the lateral chest as necessary for ED patients with ADHF.

Keywords Emergency ultrasound · Lung ultrasound · Chest sonography · Pulmonary edema

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Introduction

In recent years, emergency ultrasound has had a remarkable development, based on a change of thinking about the clinical role of sonography. Among the many clinical applications, lung ultrasound in the emergency setting has been one of the most actively studied as there is a very high level of research interest. This tool allows the treating physician to identify different causes of acute respiratory failure at the bedside. The practical success of this technique relies on its simplicity and discovery of the significance of easily recognizable sonographic artifacts [1, 2]. One of the most intriguing aspects of lung ultrasound is the analysis of echogenic vertical artifacts, named B-lines, which are the result of processes that cause interlobular septal thickening and an increase in extravascular lung water. In 1997, Lichtenstein et al. [3] showed that the identification of multiple B-lines in each hemithorax, correctly diagnosed diffuse interstitial syndrome (IS) in mechanically ventilated patients in the intensive care unit (ICU) with high accuracy (sensitivity 93%, specificity

93%). They then showed that ultrasound could distinguish cardiogenic dyspnea as B-lines in these patients are disseminated throughout both lung fields, which allows prompt differentiation from other common causes of respiratory failure, like exacerbation of COPD [4]. In 2006, our group applied the same sonographic technique to the emergency department (ED) setting, and found a similar diagnostic accuracy for lung ultrasound in identifying IS (sensitivity 86%, specificity 98%) [5]. However, there is likely more variability in the severity of illness of patients presenting to the ED with dyspnea and those in the ICU setting. ED patients with acute decompensated heart failure (ADHF) can have variable distribution and dissemination of B-lines. This variability may be caused by the fact that ED patients present wider degrees of pulmonary congestion and severity of disease. Moreover, localized B-lines can be visualized occasionally in normal lung and in condition of localized alveolar consolidations (pneumonia, contusion, infarct, and atelectasis) [6]. Therefore, a more comprehensive scanning protocol with a precise definition of the differentiation between positive and negative examinations for diffuse B-lines was needed for ED patients. We published one alternative which involved performing four scans per side (2 anterior and 2 lateral), and requiring at least two positive scans per side to diagnose diffuse IS [5]. This definition can, therefore, be positive even if B-lines are limited to the lateral chest areas.

The paper by Lichtenstein and Mezière [7] on lung ultrasound in acute respiratory failure introduces the BLUE protocol (Bedside Lung Ultrasound in Emergency), which has the merit of providing some standardization of the sonographic criteria used in the management of dyspneic patients in the emergency setting. The study provides clear evidence of the relevance of bedside sonographic lung examination in acute respiratory failure, of which the authors themselves deserve enormous credit having produced much of the relevant research. The protocol represents a significant milestone in the efforts to standardize the lung ultrasound examination. However, the BLUE protocol explicitly states that the lateral chest areas do not need to be scanned when using ultrasound to diagnose pulmonary edema. Lichtenstein and Mezière examined 64 patients with cardiogenic pulmonary edema in the ICU and observed "anterior multiple B-lines on each side" (the B-profile) in 62 cases. The B-profile showed 95% specificity and 97% sensitivity for pulmonary edema. Based on these findings, the BLUE algorithm rules out the diagnosis of cardiogenic pulmonary congestion in acute respiratory failure when multiple B-lines are absent in the anterior chest areas on each side (Fig. 1).

Our hypothesis was that patients with cardiogenic acute dyspnea presenting to the ED may not always fit the B-profile and thus the test characteristics of the BLUE protocol in this patient population may differ from those of

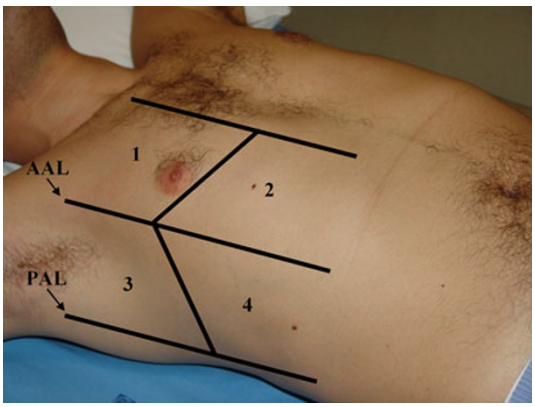

Fig. 1 The four chest areas considered in the lung ultrasound evaluation of patients with ADHF, retrospectively analyzed from the three studies [6, 8, 9]. *Areas 1* and *2* upper anterior and lower anterior, *areas 3* and *4* upper lateral and basal lateral. Each area was the same on right and left side. *AAL*, anterior axillary line; *PAL*, posterior axillary line

ICU patients. We present here a retrospective analysis of the distribution of B-lines in patients with a confirmed final diagnosis of ADHF enrolled in three previous studies at two different centers using the same eight-zone protocol which includes the lateral zones described previously.

Methods

We retrospectively analyzed the distribution of B-lines on 170 patients enrolled in the ED of two different Hospitals that were evaluating the accuracy of lung ultrasound to diagnose the etiology of acute dyspnea. All patients enrolled complained of acute dyspnea at presentation and had a confirmed diagnosis of ADHF without additional pulmonary diagnoses. Patient demographics are summarized in Table 1.

Study 1

From June 2004 to 2005, three hundred consecutive patients admitted from the ED to the Emergency Medicine unit (San Luigi Gonzaga University Hospital, Torino, Italy) had lung ultrasound performed within 48 h of admission (90% were performed within 12 h) [5]. Four anterolateral scans were performed on each hemithorax (Fig. 1). Forty-nine over 300 patients had a final diagnosis of ADHF and were eligible for inclusion in the retrospective review.

Study 2

From August 2005 and December 2006, 81 consecutive patients presenting to the ED with acute dyspnea and then admitted to the Emergency Medicine unit (San Luigi Gonzaga University Hospital, Torino, Italy) with a

Table 1 Demographics of patients analyzed from study 1 [5], study 2 [8] and study 3 [9] and total population of the retrospective analysis

	Study 1	Study 2	Study 3	Total
n	49	81	40	170
Average age, years (±SD)	64.0 ± 14.6	75.2 ± 11.6	76.5 ± 15.1	74.0 ± 13.6
Male/female	33/16	47/34	25/15	105/65

SD, standard deviation

diagnosis of ADHF had lung ultrasound performed on admission [8]. The scanning protocol included 11 antero-lateral scans (3 anterior and 3 lateral scans on the right, 2 anterior and 3 lateral scans on the left). All 81 patients were eligible for retrospective review.

Study 3

From December 2006 to June 2007, 94 patients who presented to the ED (Massachusetts General Hospital, Boston, USA) with acute dyspnea had lung ultrasound performed within 12 h of arrival (95% of the scans were done within 6 h) [9]. Four anterolateral scans were performed on each hemithorax (Fig. 1). Forty over 94 patients were ultimately diagnosed with ADHF and were eligible for inclusion in the retrospective review.

Scanning technique

A Sonoline G50 mobile unit (Siemens, Malvern PA, USA) with a convex probe 3.5 MHz was used for Studies 1 and 2. A Micromaxx Sonosite portable unit with a 2–5 MHz curvilinear probe was used for Study 3. All sonographic examinations were performed by trained emergency physicians. Patients were lying in their position of comfort (supine or near-to-supine position). B-lines were identified in the lung scan zones as described above. Each scan zone was considered positive if it showed at least three B-lines with an observable distance between them of no more than 7 mm (multiple B-lines or B+, see Fig. 2). Only positive examinations for diffuse IS (examinations with at least two B+ scans per side) with regular lung sliding were considered in the analysis of B-lines distribution. The reader can refer to the previously published papers for a more detailed description of the materials and methods used for sonographic examination of the lung and diagnostic criteria of ADHF [5, 8, 9].

Retrospective analysis

We reviewed the database of each study as above and recalculated the positivity or negativity of the ultrasound examination using the B-profile definition. The BLUE protocol states that only anterior lung zones need to show "predominant bilateral B+ lines associated with lung sliding" to be considered B-profile. We classified B-profile for all the examinations showing at least one B+ sliding + anterior scan per side. Then, we calculated the accuracy of the B-profile definition for the patients with known ADHF in the three studies listed above and identified those ADHF patients who did not meet the B-profile definition.

Fig. 2 Positive lung scan for multiple B-lines (B+ pattern) from a dyspneic patient with acute decompensated heart failure. *Arrow*, pleural line; *asterisks*, B-lines

Results

Study 1

28.5% ($n = 14$) of the 49 patients selected did not show the B-profile. Thus, examining only the anterior areas, the sensitivity of the B-profile would inevitably drop to 71.4% (97% in the study of Lichtenstein and Mezière). Some patients showed B+ scans only in the lateral chest areas ($n = 3$; 6.4%).

Study 2

14.8% ($n = 12$) of 81 patients did not show the B-profile. The sensitivity of the B-profile would be 85%. In addition, some patients showed only lateral B+ scans ($n = 4$; 5.5%).

Table 2 Treatment regimen on patients with ADHF during hospital stay in study 1 [5] and study 2 [8], and corresponding B-profile pattern at bedside lung ultrasound

	Study 1	Study 2	Total Study 1 + study 2	Absence of B-profile Study 1 + study 2
Patients *n*	49	81	130	26
Only drugs (%)	39 (79.6)	60 (74.1)	99 (76.1)	26
C-PAP (%)	7 (14.3)	18 (22.2)	25 (19.2)	0
NIV (%)	3 (6.1)	2 (2.5)	5 (3.8)	0
IV (%)	0	1 (1.2)	1 (0.8)	0

C-PAP, continuous positive airway pressure; *NIV*, non-invasive ventilation; *IV*, invasive ventilation

Study 3

5% ($n = 2$) of 40 patients did not show the B-profile. 7.5% ($n = 3$) showed only one B+ scan in the anterior chest on each hemithorax.

When considering the total number of cases, we examined 170 dyspneic patients with confirmed ADHF and 16.5% ($n = 28$) of these diagnoses would be missed by sonography if we had examined only the anterior chest. The B-profile would show sensitivity of 83.5% (95% CI 77–89%). Seven patients (4.1%, 7/170) showed B+ scans only in the lateral chest areas, corresponding to 25% (7/28) of the group of patients misdiagnosed by the BLUE protocol. All the patients of study 1 and 2 who received C-PAP, invasive or non-invasive ventilation, showed sonographic pattern with B-lines spread all over the anterior and lateral chest (Table 2).

Discussion

Detection of pulmonary edema as a sign of ADHF is a crucial point in the bedside diagnostic process of acute respiratory failure. Lung ultrasound plays a decisive role in the prompt diagnosis of pulmonary edema due to artifacts identified as a result of an increase in extravascular lung water, and sonography is easy to implement and highly accurate [10–12]. To date, there is a general consensus on the technique of lung ultrasound targeted to detect B-lines and the meaning of lung sonographic artifacts. However, because the lung is a large organ and the examination consists of a set of multiple scans, we still lack an evidence-based consensus on how to define a positive examination. This point is crucial, especially with regards to standardizing the application of lung ultrasound in the ED. The BLUE protocol proposed by the paper of Lichtenstein and Mezière is a real contribution to the development of this consensus, but we have some concern on the criteria proposed to rule out cardiogenic pulmonary edema.

Retrospective evaluation of distribution of B-lines in patients with ADHF in the ED setting shows that the B-profile (predominant B-lines in the anterior chest) proposed in the BLUE protocol would have missed a significant proportion of diagnoses. The exact meaning of the word "predominant" in terms of number of scans is not well specified in the BLUE protocol. In our analysis, we considered a positive B-profile pattern even those with only one positive scan on each side, which is not "predominant" in the real sense of the term (2/4 scans). If we had not included these patients, the number of missed diagnoses would be even greater and the sensitivity of the B-profile lower. We suggest two possible explanations to this discrepancy between the B-profile definition and the eight-zone technique used in these ED based studies.

The first explanation may be that Lichtenstein and Mezière mainly studied severe degrees of respiratory failure in ADHF. Criteria for admission to the ICU usually includes refractory hypoxemia, bilateral alveolar infiltrates on chest roentgenogram and severe respiratory distress. In these conditions, the interstitial and alveolar edema is probably extended to the whole lung, despite the effects of gravity and vascular distribution. Our patients presented to the ED with more varying degrees of acute dyspnea. The milder forms of pulmonary edema could be detected by sonography only in some chest areas and artifacts are not necessarily symmetric in the anterior wall. It has been shown that progression of pulmonary edema follows a gravitational gradient and in the early phase it involves the basal lobes [13]. Moreover, we should take into consideration co-morbidities which frequently occur in elderly patients and the possible asymmetric distribution of increased pressure edema due to morphologic changes in the lung parenchyma in COPD [13]. In study 1 and study 2 patients receiving C-PAP or ventilation support showed B-lines all over the anterior and lateral chest areas, being probably representative of the most severe degrees of illness in the ED (Table 2).

The second explanation could be related to a different timing of the sonographic examinations. Performing lung ultrasound after patients have been submitted to medical and ventilatory treatment could be confounding, because it has been shown that B-lines significantly clear during hospital stay in patients admitted for ADHF [8]. In study 1, we performed the examination in 12 h time following admission in the vast majority of cases (90%), while the BLUE protocol was applied within 20 min [7]. A wide range of time line may explain different B-lines patterns in the studies analyzed. However, study 2 and study 3 did not suffer from this bias, because ultrasound was immediately performed during first examination. Moreover, lung ultrasound should be accurate enough to detect pulmonary congestion, thus allowing the correct diagnosis, even on patients examined after initiation of therapy, as often happens in the ED daily practice in case of delayed presentation after home self-treatment or in case of patients treated during transport by the territorial emergency service.

Limitations

We referenced our retrospective analysis on trials spanned over few years, and change in technology could have had an effect as well as the use of different ultrasound machines and probes. However, the method used by the personnel of the three institutions involved (Paris, Boston, Torino) was strictly the same. We do not know the effect of different probes and machines on the visualization of B-lines, but we believe that the influence of technology may be very small, even if specifically designed studies should be performed to draw conclusions about this issue.

Another limitation of this retrospective analysis is the lack of stratification of the severity of illness in study 3, and the lack of a systematic comparison of B-lines patterns with the severity of disease in the group of patients not showing the B-profile in study 1 and study 2. We can only say that all the patients of the latter two studies who received C-PAP and ventilation support, invasive or not, showed the B-profile and positivity of all the lateral areas for multiple B-lines. A complete comparison of groups of patients stratified for severity of illness with ultrasound B-lines patterns would be extremely useful to confirm that patients misdiagnosed by the BLUE protocol were those with the milder forms of ADHF. However, the purpose of our analysis was only to demonstrate that an oversimplified method (i.e. exclusion of lateral chest scans) shows lower sensitivity when applied to ED patients with ADHF. Whether this flaw is linked to the limitation of B-profile in detecting even the milder forms of ADHF can only be speculated.

Finally, retrospective analysis did not allow calculation of specificity and likelihood ratios. To determine the accuracy of the BLUE protocol in ED patients with ADHF a blinded prospective observational study with appropriate reference gold standard will be necessary.

Conclusions

Limiting the sonographic lung examination to the anterior chest areas only may miss cases of ADHF in the dyspneic ED patients. Lung ultrasound scanning protocols (e.g. the BLUE protocol based on the B-profile) may need to be modified to include examination of the lateral chest areas as necessary for ED patients with variable degrees ADHF. In contrast, performing sonographic examination limited to the anterior chest would be probably adequate for ruling out cardiogenic pulmonary edema on critically ill patients in the ICU.

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Conflict of interest None.

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