



Original Contribution

Bedside ultrasound of the lung for the monitoring of acute decompensated heart failure[☆]

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Abstract

Purposes: Multiple artifacts B lines (B+) at transthoracic lung ultrasound have been proposed as a sonographic sign of pulmonary congestion. Our aim is to assess B+ clearance after medical treatment in acute decompensated heart failure (ADHF) and to compare the usefulness of sonography with other traditional tools in monitoring resolution of pulmonary congestion.

Methods: Eighty-one patients with a diagnosis of ADHF were submitted to lung ultrasound and chest radiography at admission, and 70 of them underwent the same procedures as control group after 4.2 ± 1.7 days of medical treatment. The ultrasound examination was performed with 11 scans on as many anterolateral thoracic areas (6 on the right side and 5 on the left side). Then, we calculated a sonographic score counting the B+ scans and compared it with radiologic score for extravascular lung water, clinical, and plasma brain natriuretic peptide improvement.

Main Results: All patients showed B+ pattern at admission and significant clearing after treatment, with median number of 8 positive scans (range, 3–9 scans) vs 0 (range, 0–7 scans) ($P < .05$). Our sonographic score showed positive linear correlation with radiologic score ($r = 0.62$; $P < .05$), clinical score ($r = 0.87$; $P < .01$), and brain natriuretic peptide levels ($r = 0.44$; $P < .05$). Δ Sonographic score correlated with Δ clinical ($r = 0.55$; $P < .05$) and radiologic ($r = 0.28$; $P < .05$) scores.

Conclusions: B line pattern mostly clears after adequate medical treatment of ADHF and represents an easy-to-use alternative bedside diagnostic tool for clinically monitoring pulmonary congestion in patients with ADHF.

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1. Introduction

Acute decompensated heart failure (ADHF) is an emergency department (ED) problem, which has led to a growing interest among emergency physicians. Accurate assessment of effectiveness of medical treatment in reducing pulmonary congestion, which is a sign of elevated cardiac filling pressure, is a basic step in evaluating patients with ADHF. Most patients hospitalized for ADHF are not submitted to invasive hemodynamic measurements, and

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clinical improvement relies on change in physical findings, radiologic evaluation, and hormone levels. Physical findings of elevated filling pressure are often inadequate and rarely decisive to assess real clinical improvement when considered alone [1-3]. Chest x-ray (CXR) has long been a traditional procedure to assess pulmonary congestion, but interpretation of radiologic signs such as redistribution and interstitial edema are often questionable and subjective [4]. More recently, serial assessment of brain natriuretic peptide (BNP) or aminoterminal pro-BNP level has been proposed as a reliable tool to guide therapy decisions for these patients [5-7], yet their exact role is subject of increasing debate.

Vertical comet tail artifacts at lung ultrasound have been shown to be an easy-to-acquire bedside sign of diffuse alveolar-interstitial syndrome in the intensive care unit and ED [8,9]. These artifacts are named *B lines* and are related to small water-rich structures surrounded by air, as it happens in case of aerated lung with abnormal thickened interlobular septa and extravascular water [10]. The number of sonographic B lines correlates with both the radiologic estimate of extravascular lung water (EVLW) and findings at invasive measurement of pulmonary capillary wedge pressure [11-13]. The aim of our study was to assess the potential of B lines in monitoring the resolution of pulmonary congestion and clinical improvement of patients hospitalized for ADHF.

2. Methods

2.1. Study population

This was a prospective study conducted at San Luigi Gonzaga Hospital, Turin, Italy. Our institutional review board approved the study. All patients presenting to our ED between August 2005 and December 2006 with shortness of breath as a prominent complaint were submitted within a few minutes to routine examination that included CXR and lung ultrasound (phase 1). We enrolled 81 patients (mean age, 75.2 ± 11.6 years; 34 women and 47 men) consecutively admitted to our emergency medicine unit with established symptomatic ADHF. Patients were selected by the attending physician, blinded to lung ultrasound result, on the basis of history, symptoms, and routine testing. Diagnosis of admission was then confirmed by an independent cardiologist. In our institution, general sonographic examination, particularly focusing on lung analysis, is part of the routine examination of all critical situations. All patients gave their informed consent. Exclusion criteria were diagnoses of either any acute lung disease or chronic pulmonary fibrosis. Functional capacity was estimated according to the New York Heart Association (NYHA) functional classification [14]. Forty-one patients underwent plasma BNP assay by convenience sampling, based on

laboratory availability. Patients' characteristics and therapies during hospital stay are shown in Table 1. Physical examination recording, lung ultrasound, CXR, and plasma BNP assay were all repeated on the day of discharge or referral to another unit (phase 2, after 4.2 ± 1.7 days). All patients underwent transthoracic echocardiographic examination during hospital stay.

2.2. Chest x-ray

At admission, an anteroposterior CXR was performed in the radiology department. Depending on clinical condition, some patients were submitted to portable CXR ($n = 13$). The film was read by an independent radiologist blinded to ultrasound data and clinical diagnosis. Assessment of EVLW was performed through a previously validated radiologic score (RS; range, 0-111) incorporating consideration of variables described in Table 2 [15-17]. A control radiography and new film reading using the same techniques (patient decubitus and EVLW estimation) were performed at phase 2.

2.3. Lung ultrasound

The sonographic examination, consisting of 11 thoracic intercostal scans, was performed with patients in the supine

Table 1 Clinical features and treatment during hospital stay of 81 patients admitted for ADHF

Variables	
Age (y)	75.2 \pm 11.6
Male-female sex (n)	47:34
EF (%)	45.04 \pm 14.3
Heart disease, n (%)	
Atrial fibrillation	25 (31)
Hypokinetic	31 (38)
Ischemic	35 (43)
Dilated	15 (18)
Valvular	16 (20)
Hypertrophic	7 (8.6)
Cor pulmonale	7 (8.6)
Hypertension	53 (65)
Therapy, n (%)	
Diuretics	78 (96)
CPAP	18 (22)
Vasodilators	45 (56)
Anti hypertensive drugs	14 (17)
Oxygen	67 (83)
Vasoactive	5 (6.2)
Morphine	9 (11)
NIV	2 (2.5)
Bronchodilators	13 (16)
Invasive ventilation	1 (1.2)

Data are presented as mean \pm SD unless otherwise indicated. EF indicates ejection fraction; CPAP, continuous positive airway pressure; NIV, noninvasive ventilation.

Table 2 Radiologic score variables

Variables	Score		
	Mild	Moderate	Severe
Hilar vessels			
Enlarged	1	2	3
Increased in density	2	4	6
Blurred	3	6	9
Kerley lines			
A	4	8	
B	4	8	
C	4	8	
Micronoduli	4	8	
Widening of interlobar fissures	4	8	12
Peribronchial and perivascular cuffs	4	8	12
Extensive perihilar haze	4	8	12
Subpleural effusion	5	10	
Diffuse increase in density	5	10	15

or near-to-supine position, depending on clinical condition, using a G50 portable unit (Siemens, Malvern, PA), equipped with a convex 3.5-MHz transducer. Both in phases 1 and 2, the sonographers were blinded to CXR,

BNP level, and auscultation. The chest wall was individualized into 11 areas (3 anterior and 3 lateral on right side and 2 anterior and 3 lateral on left side), for each of which 1 scan was obtained. The anterior chest wall was delineated from the sternum to the anterior axillary line and was subdivided into upper, medium, and lower halves from clavicle to diaphragm. The lateral zone was delineated from the anterior to the posterior axillary line and was subdivided into upper, medium, and basal halves. On the left side, the anterior lower area scan was not performed because of cardiac interposition. The sonographic signs that were analyzed were the pleural sliding and the B line. The latter, roughly vertical, is a comet tail artifact that has 5 mandatory features: it arises from the pleural line, it is well defined like a laser beam, it spreads to the edge of the screen without fading, it erases A lines, and it moves with lung sliding [18]. Each individual scan was considered to be pathologic when it had at least 3 artifacts with an observable distance between them of no more than 7 mm (multiple B lines or B+ lines, see Fig. 1) [8]. The 11 studied chest areas could include more than 1 intercostal space with a number of possible positionings of the probe. We analyzed each zone by longitudinal scans, moving the

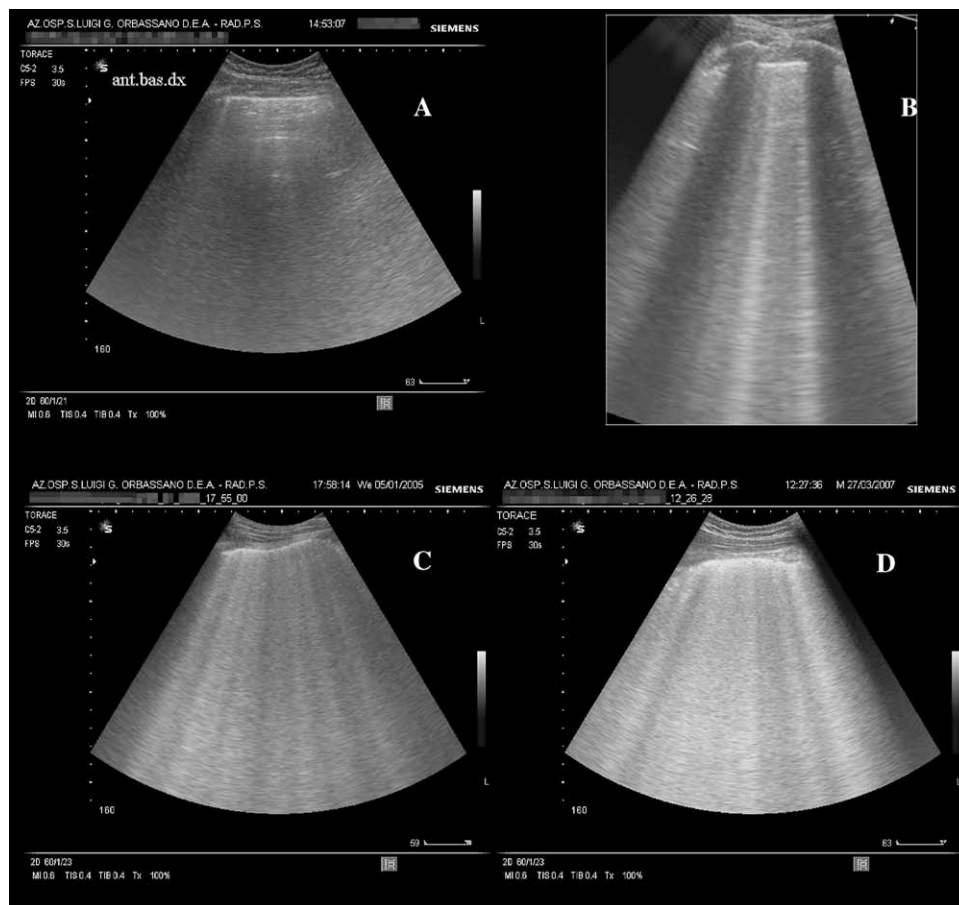


Fig. 1 A, Normal transthoracic ultrasound (US) lung scan with no vertical artifacts (comet tails or B lines). B, Longitudinal US lung scan for the detection of the pleural line between 2 adjacent ribs ("bat sign"). C, Oblique transthoracic US lung scan with B+ in a patient with ADHF. D, Multiple and large B lines that fuse ("shining" or "white" lung) in a patient admitted with ADHF and advanced pulmonary edema.

probe over the thorax wall in a sliding movement. Once the sonographic image of the pleural line was detected through location of the ribs and visualization of the “bat sign” (pleura line under 2 adjacent ribs, see Fig. 1B) [19], we turned the probe to obtain the intercostal scan with the maximum extension of the visible pleura (oblique scan, see Fig. 1C). When more than 1 intercostal scan was recordable in a thoracic area, we considered the most positive one (ie, the scan with the highest number of B lines). A sonographic score (SS) was then calculated, simply counting the number of positive scans obtained on each patient with (SS₁; range, 0-11) or without analysis of the laterobasal scans (SS₂; range, 0-9). Each image was recorded on a CD-ROM.

2.4. Echocardiography

Echocardiographic examinations were performed at rest by an independent cardiologist during hospital stay and within 3 days from admission. The left ventricular volume and ejection fraction were measured according to the American Society of Echocardiography and adjusted for body surface area [20].

2.5. Brain natriuretic peptide assay

Brain natriuretic peptide concentration in blood samples was measured by immunoradiometric assay at phases 1 and 2, using a commercially available kit (Shionoria BNP, Schering, Gif-sur-Yvette, France) and established methodology.

2.6. Clinical score

A clinical score (CS) was arbitrarily calculated using the classic signs and symptoms of decompensated heart failure [21]. Each clinical sign or symptom was assigned a value of 1 or 0 (present or absent). The clinical parameters evaluated were lower extremity edema, pulmonary rales and wheezing, jugular venous distension, orthopnea, high respiratory rate (>25 breaths per minute), and low pulse oxymetric saturation (<90%). New York Heart Association class was added to the score (range, 1-10).

2.7. Statistical analysis

Continuous variables are expressed as mean values \pm SD or number and percentage of positivity. Scores are expressed as median with range (upper and lower limits). Comparisons between measurements were performed using the paired Wilcoxon *W* test. The difference (Δ) between scores and BNP levels measured at phase 1 and phase 2 were correlated by the Spearman analysis. A *P* value of less than .05 was considered statistically significant. The statistical analysis was performed using statistical software (Statsoft, Inc, 2004, version 6, Tulsa, Okla).

3. Results

The feasibility of the lung ultrasound examination for the diagnosis of diffuse B+ lines was 100%, and the required time never exceeded 3 minutes. Phase 2 examination could not be performed in 11 cases because of patient's death (6 cases) or refusal (5 cases). Seventy patients completed the 2 phases of the study (41 with BNP measurements). The feasibility of the study was 86%.

Table 3 shows the diagnosis of all individual clinical parameters included in the clinical score. In the 70 patients who completed the study, the median calculated CS was 8 (range, 4-10) at phase 1 and 1 (range, 1-5) at phase 2 (*P* < .05, *W*). All patients showed diffuse B+ patterns at admission. Table 4 shows the number of positive scans in the 11 individualizable thoracic areas at phases 1 and 2. All the areas showed significant clearing of B lines after treatment (*P* < .001, *W*). Some scans were still positive after treatment, with the higher percentage in the laterobasal areas (29%). The total number of positive scans at phases 1 and 2 were 682 (88.5%) and 94 (12.2%; *P* < .001, *W*), respectively. The median SS₁ (10 [range, 5-11] vs 1 [range, 0-9]), the median SS₂ (8 [range, 3-9] vs 0 [range, 0-7]), the median RS (12 [range, 0-40] vs 0 [range, 0-16]), and the mean plasma level of BNP (534.1 \pm 333.8 vs 289.6 \pm 276.0) were significantly higher at phase 1 (*P* < .001, *W* for all). Table 5 shows the calculated scores from each radiologic parameter.

Considering all examinations (n = 81 at phase 1 and n = 70 at phase 2), positive linear correlations were found between SS₂ and RS (*r* = 0.62; *P* < .001), between SS₂ and CS (*r* = 0.87; *P* < .001), and between RS and CS (*r* = 0.66; *P* < .05). *P* < .001). In 82 examinations, SS₂ also correlated with BNP levels (*r* = 0.44; *P* < .05). The BNP levels at admission showed a significant linear negative correlation with systolic dysfunction as measured at echocardiography (*r* = -0.37; *P* < .05). The difference between phases 1 and 2

Table 3 Number of patients admitted for ADHF showing each clinical variable, at admission (phase 1) and control (phase 2) (n = 70)

Variables	Phase 1, n (%)	Phase 2, n (%)	<i>P</i> (<i>W</i>)
Lower extremity edema	35 (50)	2 (2.9)	<.001
Pulmonary rales/wheezing	59 (84)	3 (4.3)	<.001
Jugular venous distention	15 (21)	1 (1.4)	<.001
Orthopnea	63 (90)	3 (4.3)	<.001
High respiratory rate (>25 breaths per minute)	50 (71)	0	<.001
Low pulse oxymetric saturation (<90%)	44 (62)	3 (4.3)	<.001
NYHA class			
I	0	20 (28)	
II	1 (1.4)	42 (60)	
III	10 (14)	8 (11)	
IV	59 (84)	0	

Table 4 Positive ultrasound lung scans in the 11 individualizable thoracic areas at admission (phase 1) and control (phase 2) in 70 patients admitted for ADHF

Thoracic area	Phase 1 ^a	Phase 2 ^a	<i>P</i> (<i>W</i>)
Anterior superior right	51 (73%)	3 (4.3%)	<.001
Anterior medium right	54 (77%)	2 (2.9%)	<.001
Anterior basal right	65 (93%)	4 (5.7%)	<.001
Lateral superior right	64 (91%)	5 (7.1%)	<.001
Lateral medium right	67 (96%)	10 (14%)	<.001
Lateral basal right	68 (97%)	21 (30%)	<.001
Anterior superior left	52 (74%)	6 (8.6%)	<.001
Anterior medium left	58 (83%)	6 (8.6%)	<.001
Lateral superior left	63 (90%)	6 (8.6%)	<.001
Lateral medium left	70 (100%)	11 (16%)	<.001
Lateral basal left	70 (100%)	20 (29%)	<.001

^a Data are presented as number of positive scans and percentage.

(Δ) of the SS_1 with Δ RS was not significant ($r = 0.18$; $P =$ not significant [NS]). Δ SS_1 significantly correlated with Δ CS ($r = 0.49$; $P < .05$). A better correlation was found comparing Δ SS_2 with Δ RS ($r = 0.28$; $P < .05$) and Δ CS ($r = 0.55$; $P < .05$). Δ SS_1 and SS_2 were not significantly correlated with Δ BNP levels ($r = 0.28$ and $r = 0.29$, respectively; $P =$ NS for both).

4. Discussion

Previous studies have clarified the significance of vertical artifacts B lines at lung ultrasound. When B lines are multiple and diffuse in more than 1 scan on each thoracic side, they have been shown to predict diffuse alveolar-interstitial syndrome either in the intensive care unit or ED [8,9]. B lines are useful to distinguish different causes of dyspnea and are highly sensitive in diagnosis of ADHF [22,23]. Moreover, a quantitative relationship of this sign with pulmonary wedge pressure and EVLW measured through invasive techniques in the cardiology consultation setting has been recently shown [12,13]. On this basis, it has been reasonable to speculate about a possible role of ultrasound in predicting the effects of medical treatment on pulmonary congestion in patients hospitalized for ADHF. In everyday practice, this prediction relies particularly on change in physical signs and serial CXRs. Lung ultrasound evaluation of B+ lines has a number of practical advantages over these methods. It is an easy-to-use and recordable technique that provides numerical data, and it is free from radiation and allows for a high inter- and intraobserver reproducibility [8,9,24]. On the contrary, radiologic manifestations of congestion are not always easy to detect, especially in the emergency setting and difficult reading because of poor quality films [25,26]. The BNP levels showed a good correlation with echocardiographic detection of low ejection fraction and NYHA classification in our

patients and other studies [27,28], but the role of hormonal serial assessment in monitoring clinical improvement of patients with ADHF is still unclear.

Our data show that lung ultrasound monitoring documents clinical improvement of patients hospitalized for ADHF at least equally well than serial radiologic EVLW estimates or hormonal levels. Changes in ultrasound patterns showed also a linear correlation with changes in radiologic EVLW. Thus, given that in the present ultrasound era, the use of a simple black and white unit is expanding, there is no reason to avoid the application of a more favorable and nonionizing technique in the follow-up of patients admitted for ADHF.

Our sonographic score correlated well also with BNP levels, but the change between phases 1 and 2 (Δ score and Δ BNP) did not. This latter observation could be explained by the fact that hormonal status is less informative about resolution of pulmonary congestion.

In our study, we suggest the use of a simple lung ultrasound score, which consists of counting the positive thoracic areas. This tool satisfies the need to supply numeric references. Even if this method is rougher than counting all the single vertical artifacts in many scans [11-13,24], it provides a very easy-to-acquire data in the emergency setting. There are at least 3 arguments to prefer our method of scoring: (1) it is not dependent from a retrospective analysis of frozen images, because 1 of the 5 characteristics of B lines is that they are dynamic (movement with sliding); (2) it is much easier to acquire, especially in the emergency setting; and (3) it is always detectable, even in case of advanced alveolar-interstitial edema characterized by scans with multiple and large B lines that fuse giving the appearance of what we named “shining” or “white lung” (see Fig. 1D).

The effectiveness of our SS in monitoring pulmonary congestion and clinical status improves when the laterobasal scans are excluded from the count. This is in agreement with

Table 5 Total score from each radiologic variable calculated at admission (phase 1) and after treatment (phase 2) in 70 patients admitted for ADHF

Variables	Phase 1	Phase 2	<i>P</i> (<i>W</i>)
Hilar vessels			
Enlarged	55	25	<.05
Increased in density	10	0	<.05
Blurred	105	12	<.05
Kerley lines			
A	72	8	<.05
B	148	24	<.05
C	12	8	NS
Micronoduli	12	16	NS
Widening of interlobar fissures	64	20	<.05
Peribronchial and perivascular cuffs	188	40	<.05
Extensive perihilar haze	80	12	<.05
Subpleural effusion	120	35	<.05
Diffuse increase in density	45	10	NS

previous studies in which 21% to 28% of laterobasal areas of the chest still show B+ lines in normal lungs (unpublished personal data) [8,29]. For this reason, our suggestion is to limit the examination to 9 thoracic areas, thus excluding the laterobasal scans.

5. Limitations

Our study has 2 major limitations. First of all, it lacks comparison of sonographic data with wedge pressure and computed tomography pulmonary scan. However, our aim was to compare ultrasound with standard methods used in the every day practice. Moreover, there are some studies proving that the accuracy of EVLW evaluation through traditional chest radiography is similar to computed tomography [30]. Another limitation is that we excluded patients with lung diseases, thus reducing the possibility of false positive sonographic patterns (B lines not linked to high EVLW). Diffuse B lines have low specificity because they do not necessarily imply a cardiogenic origin of the interstitial syndrome. They are detected also in the areas surrounding alveolar consolidations due to pneumonia or lung cancer, or in case of chronic interstitial lung diseases and permeability pulmonary edema (unpublished personal data) [8,9]. However, the aim of the present study was to validate the use of lung ultrasound as a method to assess the change of pulmonary congestion due to hydrostatic edema in the follow-up of selected patients admitted with ADHF. In patients with lung diseases, persistence of B lines during diuretic treatment could have the added diagnostic value of predicting interstitial involvement not linked to cardiogenic edema.

6. Conclusion

Lung ultrasound is a reliable tool to assess and monitor pulmonary congestion. In ADHF, increased lung arterial pressure causes fluid extravasation into the pulmonary interstitium and alveoli. Not only can this be heard at auscultation and seen at CXR but can also be observed at lung ultrasound as vertical B lines or comet tail artifacts, a fairly new finding. Searching for such sonographic artifacts is a simple approach that can be proposed as a bedside method to monitor clinical effects of medical therapy in ADHF. It has many advantages and could replace other traditional tools.

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