Research Article

Transthoracic ultrasound assessment of B-lines for identifying the increment of extravascular lung water in shock patients requiring fluid resuscitation

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Abstract

Introduction: Several studies have shown that the number of B-lines was related to the amount of extravascular lung water (EVLW). In our study, we aimed to demonstrate the magnitude of the incremental B-lines in shock patients with positive net fluid balance and the association with gas exchange impairment. **Materials and Methods:** We performed trans-thoracic ultrasound at admission (T_0) and at follow-up period (T_{FL}) to demonstrate the change of B lines (ΔB-lines) after fluid therapy. We compared the total B-line score (TBS) at T_0 and T_{FL} and calculated the Pearson's correlation coefficient between the ΔB-lines and PaO_2/FiO_2 ratio. **Results:** A total of 20 patients were analyzed. All patients had septic shock. Net fluid balance was + 2228.05 ± 1982.15 ml. The TBS at T_0 and T_{FL} were 36.6 ± 23.73 and 63.80 ± 29.25 ($P < 0.01$). The ΔB-lines along anterior axillary line (AAL) correlated to the ΔTBS ($r = 0.90$, $P < 0.01$). The ΔB-lines along AAL had inverse correlation to PaO_2/FiO_2 ratio ($r = -0.704$, $P < 0.05$). The increase of B-lines ≥ 10 was related to the decrease of PaO_2/FiO_2 ratio. The inter-observer reliability between two ultrasound readers was high ($r = 0.92$, $P < 0.01$). **Discussion:** The number of B-lines increased in shock patients with positive net fluid balance and correlated to impaired oxygenation. These data supported the benefit of ultrasound for assessing the EVLW.

Keywords: extravascular lung water, lung comet, lung leakage, lung ultrasound, sonographic B-line

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Introduction

Extravascular lung water (EVLW) is an important predictor for mortality in critically ill patients. A study of intensive care unit (ICU) by Sakka *et al*. demonstrated higher value of EVLW in non-survivors than survivors.[1] Likewise, Craig *et al*. found that EVLW index was a predictor of mortality in acute lung injury.[2]

Theoretically, EVLW is measured by the double indicator technique.[3] Recently, EVLW measurement using single indicator technique by the trans-pulmonary thermo dilution method has been proposed[4-6] and good correlation has been observed between double and single indicator techniques.[7] However, the latter still requires an invasive procedure that may cause complications.

Intensive care ultrasound is a non-invasive device that can be used for assessing lung water. B-lines acquired by lung ultrasound associate with EVLW.[8] The study conducted by Soldati *et al*. demonstrated the presence of B-lines in most cases of acute heart failure.[9] They are prominent when the lung parenchyma has accumulated extra-vascular fluid. According to the algorithm of bedside lung ultrasound in emergency protocol, the B-lines provide 95% specificity and 97% sensitivity for pulmonary edema identification.[10] In congestive heart failure and high altitude pulmonary edema, the B-lines can be resolved significantly after treatment.[11,12] In addition, Noble *et al*.[13] confirmed the significant reduction of the B-lines after body fluid removal by

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hemodialysis. These data suggested that the B-lines represent the existence of EVLW.

This study was aimed to demonstrate, by transthoracic ultrasound, how the B-lines were changed in shock patients receiving net positive fluid balance (increase of EVLW). The second objective was to find the correlation between gas exchange impairment and the change of the B-lines after positive fluid balance causing lung interstitial edema.

Materials and Methods

We conducted a prospective, observational study from July 2010 to December 2010. We consecutively enrolled shock patients admitted to medical ICU of a university hospital. The inclusion criteria were patients at age ≥18 years old with the presence of shock and requiring fluid therapy. The shock syndromes were defined by mean arterial pressure <65 mmHg with evidence of poor tissue perfusion. The exclusion criteria were patients with pleural diseases, post-operative heart or lung surgery, those unable to perform ultrasound and those who refused to sign a consent form. In patients with mechanical ventilation, the tidal volume was set as 8-10 ml/kg and kept constant throughout the study period. Positive end-expiratory pressure was set according to the lung problem. The FiO_2 was adjusted to keep PaO_2 in normal range. The transthoracic ultrasounds were performed by an experienced physician. The first ultrasound was performed at admission to assess the baseline number of the B-lines. The repeated ultrasound was performed within 48 h to assess the number of the B-lines after fluid resuscitation. The patient's characteristics, hemodynamic data, PaO_2/FiO_2 ratio (P/F ratio), chest radiographic score and total fluid volume were recorded at the same time as performing transthoracic ultrasound.

The study was approved by the institute's Human Research Committee Institutional Review Board and followed the National Helsinki Committee guidelines. All patients or their next of kin gave written informed consent.

To assess the B-lines, we used commercially available portable device; Sonosite M-turbo (Sonosite Inc.; Bothell, WA, USA) 10-15 MHz probe. The B-lines were defined as vertical echogenic, wedge-shaped, dynamic lines with narrow origin starting from the pleural line and extending to the edge of the screen [Figure 1]. We assessed the B-lines of patients in the supine position by taking the ultrasound probe initially from the second intercostal space (ICS) to the fifth ICS on bilateral hemithorax along the mid-clavicular line (MCL), anterior axillary line (AAL) and mid-axillary line (MAL) respectively and to the fourth ICS only for assessment along the MCL of left hemithorax. We adjusted the image depth to the deepest level before recording. All images were saved as video files and renamed in codes set by the operator. A total of 23 10-s interval video files was obtained per patient and sent to two observers in two separate file sets for interpretation.

The video files were independently interpreted by two observers who were blinded from the patient data, to verify the number of B-lines. If the numbers of B-lines counted by two observers were not concordant, the consensus number would be used. The inter-observer correlation between two independent observers in a set of 14 consecutive cases was very high ($r = 0.92$, $P < 0.01$). The numbers of B-lines were finally derived as: (1) Total B line score (TBS) calculated by the sum of all B lines in all 23 points of assessment, (2) B + area defined as the number of points of assessment containing at least three B-lines; and (3) ΔB-lines calculated by the differences of a number of B-lines at follow up period (T_{FL}) and at admission (T_0). Chest radiography was done at the same time point as ultrasound procedure. We used radiologic score (RS) to assess EVLW.[14,15] The RS was scored by an experienced chest radiologist, who was blinded from the patient data. The score ranged from 0 to 111 as shown in Table 1.

Patient characteristics, TBS, B + area, chest RS and fluid volume were expressed as the mean value ± standard deviation or percentage. Comparison of ultrasonographic data between two points of time were analyzed by paired sample *t*-test. Correlations between changing of B line and three variables including the amount of fluid replacement volume, oxygenation and RS were analyzed by Pearson's correlation. A $P \leq 0.05$ was considered as statistical significance. The statistical analysis was performed using SPSS software version 15.0.

Figure 1: The characteristics of B line

Results

We enrolled 27 patients into this study. Six patients were excluded. Five of those expired and the other developed pneumothorax before performing the second ultrasound. So we had 21 patients with completion of two transthoracic ultrasounds. Among those patients, one video clip file was damaged. Thus the data from 20 patients were finally analyzed [Figure 2].

The baseline characteristics were shown in Table 2. The TBS at T_0 and at T_{FL} were 36.6 ± 23.73 and 63.80 ± 29.25 (P < 0.01). The number of B-lines along MCL, AAL and MAL at T_{FL} significantly increased from T_0 [Table 3]. The B + area increased from 6.50 ± 5.69 at T_{0-}12.30 ± 6.39 at T_{FL} (P < 0.01).

The Pearson's correlation coefficients between the ΔB-lines and the ΔTBS along MCL, AAL and MAL were 0.759 (P < 0.01), 0.90 (P < 0.01) and 0.487 (P < 0.05) respectively. As shown in Figure 3, we found a significant correlation between the changing of PaO_2/FiO_2 ratio and ΔB-lines only at AAL (r = −0.704, P < 0.05). The correlation between the ΔTBS and ΔRS was not observed (r = 0.002, P > 0.05) as well as that between ΔTBS and the volume of net fluid balance [Table 4]. Approximately 120 ml of positive net fluid balance caused the increase of one B-line.

Table 1: Radiologic score for assessment of EVLW

Variables	Score		
	Mild	Moderate	Severe
Hilar vessel 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	
Micro-nodules	4	8	
Widening of interlobar fissure	4	8	12
Peribronchial cuff	4	8	12
Extensive perihilar haze	4	8	12
Subpleural effusion	5	10	
Diffuse increase in density	5	10	15

EVLW: Extravascular lung water

Table 2: Patient characteristics

Characteristics	Patients (N=20)
Gender (n/%)	
Male	10/50
Female	10/50
Age (mean±SD, year)	64.1±11.6
Septic shock (n/%)	20/100
Pneumonia (n/%)	5/20
ARDS (n/%)	1/5
MAP (mean±SD, mmHg)	
Pre volume expansion	70.3±10.4
Post volume expansion	78.5±15.7
Vasopressor (n/%)	16/80
Albumin (mean±SD, g/dl)	21.3±5.3
Cr (mean±SD, mg/dl)	1.97±1.3
On mechanical ventilator (n)	12
All fluid intake (mean±SD, ml)	4796.60±1846.49
Net fluid balance (mean±SD, ml)	2228.05±1982.15
Net fluid balance per one B line change (mean±SD, ml)	118.77±134.42
Time between 1st and 2nd ultrasound (mean±SD, h)	31.2±8.92

SD: Standard deviation; ARDS: Acute respiratory distress syndrome; MAP: Mean arterial pressure

Discussion

The study by Lichtenstein *et al.* demonstrated the presence of B line either in pulmonary edema or interstitial fibrosis and concluded that the B-lines could be used for diagnosis of alveolar interstitial syndrome.[16] The retrospective study by Soldati *et al.* found that almost 70% of patients with positive results of B-line by lung ultrasound developed acute pulmonary edema.[9] Valpicelli and the team showed the reduction of the B + area after diuretic treatment of acute decompensated heart failure.[11] Similarly, the percentage of B-line decreased after hemodialysis.[13] As a result of this, the presence of B-line suggests the presence of interstitial disease of the lungs mostly caused by pulmonary edema that means an increase of EVLW. In addition, the decrease of intravascular volume, reduction of EVLW, leads to the decrement of the B-lines. Thus change of B-lines seems to be associated with the change of EVLW.

The present study shows the relationship between the B-lines and net positive fluid balance, probably causing

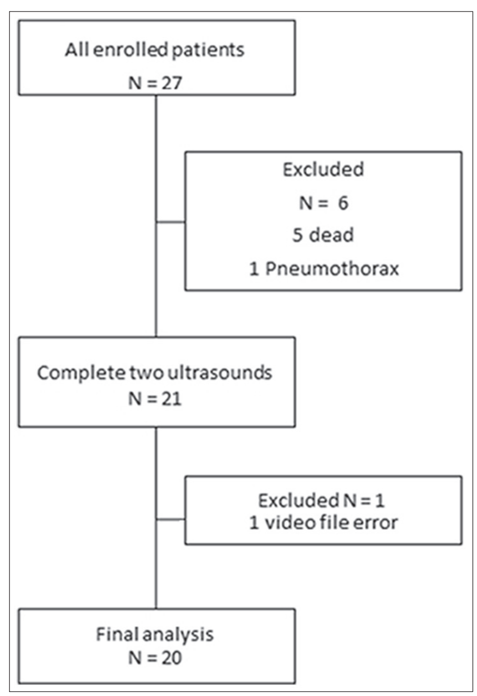

Figure 2: Patients enrolment flow chart

the change of lung water, as in the previously mentioned studies but in a different way. We have found a significant increase of the B-lines in all patients with positive fluid balance. This result suggests that the incremental B-lines are caused by a rise of EVLW. We noted that the increase of B-lines is prominent along the AAL area. This finding supports the best value of the correlation coefficient between the B-lines at this area and the TBS observed in this study. We hypothesized that the fluid leakage into the lungs predominantly occurred along this area as the Kerley B lines seen in the chest radiography of early heart failure.

Five patients with pneumonia and one patient with acute respiratory distress syndrome (ARDS) were enrolled into this study. Pneumonia and ARDS patients might have contributed to the relationship between the Δ PaO_2/FiO_2 ratio and Δ B-lines at all area. However, only two of five pneumonia cases requiring mechanical ventilation were included in the analysis of correlation. Not necessarily as interstitial edema may be either due to increased intravascular volume or due to capillary permeability. The capillary permeability index has not been measured in this study nor has these findings being correlated with left atrial pressure. As mentioned net positive balance is not the only cause of EVLW. This also increases with increased capillary permeability. Thus, in terms of fluid management, the increase of B-lines in septic shock with pneumonia or ARDS is still a warning sign for carefully titrating fluid loading.

We demonstrated the association between the ΔB-lines along AAL and ΔP/F ratio. The reason why the ΔP/F ratio correlates only to the ΔB-lines along this area is probably because most of all increased B-lines (ΔB-lines), occurring after fluid therapy, are present in this area. Therefore, the ΔB-lines along AAL contribute to hypoxemia rather than the others. The information in Figure 3 suggests

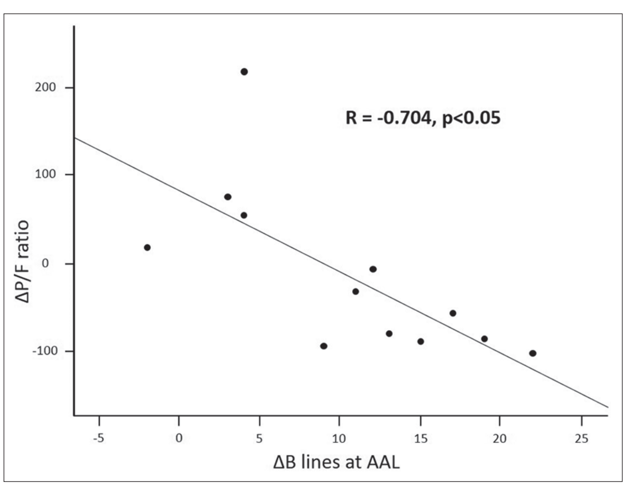

Figure 3: The correlation between the ΔB lines at anterior axillary line and the ΔP/F ratio

that the ΔB-lines more than 10 adversely affect patients due to the deterioration of P/F ratio. This finding is reasonable. Because the volume of net fluid balance per one incremental B-line is approximately 120 ml [Table 2], the positive net fluid balance ≥ 1200 ml. usually affects P/F ratio in clinical practice.

We have not found a linear correlation between the amount of net fluid balance and the ΔB-lines. This is because the impairment of pulmonary vascular permeability is different among sepsis patients and hence the individual degree of pulmonary leakage depends not is variable. As expected, there is no correlation between change of radiographic scores and that of ΔB-lines. This result is concordant with the previous study by Bruce *et al.* that showed similar output.[17]

However, the present study has some limitations. First, we did not measure the actual EVLW. So we could not know which specific numbers of the B-lines were associated to significant lung leakage. Secondly, we did not measure the cardiac function at the first and second ultrasound, thus care must be taken when interpreting some data such as the amount of fluid per one B line.

Conclusion

We conclude that the increase of B-lines is present in septic patients with net positive fluid balance and suggest that it probably occurs from the increase of EVLW.

Table 3: Comparison of data between the 1st and 2nd ultrasound

Parameters	Number of B-line at the 1st U/S (mean±SD)	Number of B-line at the 2nd U/S (mean±SD)	*P* value
MAP (mmHg)	66.82±12.71	77.91±15.78	0.115
PEEP (cmH_2O)	4.28±4.36	4.39±4.41	0.331
P/F ratio	258.66±96.18	244.45±74.46	0.615
TBS	36.60±23.73	63.80±29.25	<0.01
MCL	13.10±9.01	21.20±10.13	<0.01
AAL	12.90±8.54	22.35±10.13	<0.01
MAL	10.90±8.30	15.50±8.43	<0.01
B+area (range 0-23)	6.50±5.69	12.30±6.39	<0.01

PEEP: Positive end-expiratory pressure; P/F ratio: PaO_2/FiO_2 ratio; TBS: Total B-line score; MCL: Mid-clavicular line; AAL: Anterior axillary line; MAL: Mid-axillary line; SD: Standard deviation; MAP: Mean arterial pressure

Table 4: Correlation coefficient (*r*) between Δ B line and three variables namely fluid balance, oxygenation and radiographic score

???	TBS (*r*)	B+area (*r*)	MCL (*r*)	AAL (*r*)	MAL (*r*)
Fluid balance	0.146	−0.259	−0.157	0.051	0.072
Oxygenation (P/F ratio)	−0.456	−0.300	−0.113	−0.704*	0.371
Radiologic score	0.002	0.023	0.101	0.101	0.106

**P*<0.05. P/F ratio: PaO_2/FiO_2 ratio; TBS: Total B-line score; MCL: Mid-clavicular line; AAL: Anterior axillary line; MAL: Mid-axillary line

The change in B-lines along the AAL may be useful for assessment of the overall B-lines in clinical practice because they correlate well with the TBS. We suggest that further fluid therapy should be prescribed carefully in case of the increase of B-line, especially more than 10 lines, in combination with the deterioration of oxygenation.

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