Journal of Cardiovascular Disease Research

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 11, 2023

A Study Of The Correlation Between Extravascular Lung Water And Lung Compliance In Mechanically Ventilated Patients - A Multicentric Study

Joshi Thomas[1], Rangraj Setlur[2], Parli Raghavan Ravi[3] and Dilip Kumar[1]

[1]Department of Anaesthesiology, Peoples Education Society University Institute of Medical Sciences and Research, Electronic City, Bangalore, Karnataka, India,
[2]Department of Anaesthesiology, Indian Naval Hospital Ship Asvini
[3]Senior Consultant Anaesthesiology, Sultan Qaboos Comprehensive Cancer Care and Research Centre, Muscat, Oman

Corresponding Author-Dr. Joshi Thomas,joshimthomas@gmal.com

ABSTRACT
Introduction: Decreased lung compliance in patients requiring ventilator management prolongs the duration of ventilation. This study tested the hypothesis that an increase in extravascular lung water assessed by lung ultrasound was negatively correlated with static lung compliance. **Materials and methods:**100 patients requiring mechanical ventilation for more than 48 hours for primarily respiratory reasons were studied in 4 tertiary care hospitals. Extravascular lung water was measured by sector wise counting of ultrasound B-lines at admission and after 48 hours using a uniform scoring protocol; static lung compliance was measured off the ventilator. A one-way linear regression between the extravascular lung volume score and static lung compliance was performed. A paired t-test was carried out to compare these variables at 48-hour intervals. **Results:** At both intervals, a negative correlation was seen between extravascular lung water scores and lung compliance. **Conclusion:** Increased extravascular lung water has a measurable effect on lung compliance and that measurement by lung ultrasound may be of value in management of the patient, as its detection would lead to measures to decrease extravascular lung water and improve lung compliance.

KEYWORDS: Ultrasound, extravascular lung water, static compliance, mechanically ventilated patient

INTRODUCTION
The usefulness of lung ultrasound for imaging various pulmonary conditions in the Intensive Care Unit, especially in the detection of Extravascular Lung Water (EVLW) has been increasingly recognized recently.[1] Accumulation of extra vascular lung water in normal lung tissue makes it more echo reflective giving rise to characteristic images on ultrasound.[2] The number of these images per field is proportional to the amount of extra vascular lung water. Extravascular lung water also decreases lung compliance, but the correlation between extravascular lung water and lung compliance has not been formally defined although it has been parenthetically mentioned in a recent article.[2]The quantification of a correlation between them would be clinically relevant, since decreased lung compliance prolongs the requirement of mechanical ventilation. If this decreased compliance is ascribable to increased extravascular lung water, therapeutic measures can be adopted to decrease extravascular lung water (fluid restriction and diuresis). This in turn would lead to increased lung compliance and reduce the duration of mechanical ventilation. This study is an effort to define these correlations.

AIM OF THE STUDY:
The aim of the study was to define the correlation of EVLW as measured by lung ultrasound and static lung compliance in mechanically ventilated patients. Establishing such a correlation would indicate and partially quantify the contribution of extravascular lung water to decreased compliance in mechanically ventilated patients which in turn leads to the prolongation of the duration of mechanical ventilation and increased patient morbidity and mortality.

MATERIALS AND METHODS:
Most of the ultrasound images of the interstitial pathology of the lung whether it is extravascular lung water expansion, oedema, interstitial inflammation or interstitial fibrosis are based on sonographic visual artefacts. An artefact is an erroneous interpretation of a signal by the ultrasonography machine. An interesting family of these artefacts is formed by so called ultra sound lung-comets (ULC) also known as ring down artefacts or B-lines (Figure 1). These are defined, in lung ultra sound, as linear vertical signals that emerge from the pleural line and extend through the entire lung fields. According to the biophysical model developed from in vitro and ex vivo

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 11, 2023

models [3,4] the origin of B-lines is not from a precise anatomic structure but rather from reflections of discrete air/fluid interfaces between collapsed, fluid-filled, and well-aerated alveoli. The appearance of B-lines corresponds to a progressive loss of air per volume of lung tissue with a corresponding increase in relative and absolute content of EVLW (from the normal 5% to overt pulmonary oedema). B-Lines have to be distinguished from normal artefacts which consist of 1 or 2 roughly horizontal, parallel lines visible at regular intervals below the pleural line. They have an identical vertical distance between 2 adjacent lines. These horizontal lines are known as ‘A’ lines and are considered normal. Literature exists comparing the utility of B-lines in detecting extravascular lung water when compared to previous reference standards- CT scan and thermodilution derived measures of extravascular lung water.[5,6,7] The convenience of using non-invasive, bed side ultrasound in comparison to invasive thermodilution measures or to shifting critically ill patients to the CT scan suite is a strong reason to consider its use routinely in ventilated patients.

Lung Compliance: Compliance is the measure of the distensibility, or the ease with which the lungs can stretch during inhalation. The compliance reflects the ease with which the lungs inflate. The normal value of dynamic compliance is 30 - 40 ml/cm H_2O and that of static compliance is 40 – 60 mL/ cm H_2O. Increasing compliance means the lungs are easier to inflate. Decreasing compliance means the lungs are getting stiffer leading to increased resistance to inflation and consequently to the air entry. Dynamic compliance calculates lung distensibility based on both airway resistance and elastic resistance, while static compliance calculates lung distensibility based solely on the basis of elastic resistance. As static compliance is more reproducible [7,8] and has been used as the standard of measurement for most studies relating to ARDS, we decided to use this measure. The formula for its calculation is

Static Compliance (Effective Compliance) = Tidal Volume / (Plateau Pressure - PEEP).
Clinically, one obtains compliance for the patient as well as for the ventilator circuit. This requires that tidal volume be corrected to account for the compliance of the ventilator circuit being used and the gas volume that remains in the ventilator circuit after each breath. Tubing compliance factor (disposable tubing) is generally 2 to 4 ml per cm H_2O. However, the ventilators which were used in this study made an internal correction to compensate for the tubing compliance factor.

After approval from Institutional Ethics Committee for this study and after obtaining informed written consent, a multicentric trial was carried out in four tertiary care hospitals over a period of one year from March 2020 to Feb 2021. 100 patients admitted to the ICU receiving mechanical ventilation for more than 48hrs were enrolled in the study. Static lung compliance as read by the ventilator was recorded while the patient was placed on volume control ventilation and simultaneously, the patient’s Ultrasound Lung Comets score was obtained by performing transthoracic ultrasound of the lungs and summing the number of comets from each of the scanning spaces in the anterior right and left hemi-thoraces, from second to fifth intercostal spaces. This scan was repeated after 48 hours. Following the completion of the study, a one-way correlation coefficient was derived between the ULC score and changes in static compliance both at baseline and at 48 hours. At each scanning site the number of B-lines was determined and summed to yield the B-line score. The overall management of the patient was left to the discretion of the treating intensivist, but in general the ARDSNet protocol [9] was followed, and a conservative approach was taken to fluid management when the lung compliance was found to be low.

Inclusion Criteria:
Patients admitted to ICU requiring ventilator support for respiratory failure for more than 48 hours.

Exclusion Criteria:
1.Patients requiring less than 48 hours’ ventilator support, and those intubated primarily for airway protection, with no evidence of significant lung pathology.
2.Patients on whom ultrasound scanning could not be carried out without causing pain to the patient, viz. chest trauma and chest burns
3. Patients from whom or from whose relatives’ valid consent could not be obtained

Method of Collection of Data:
When a patient expected to receive mechanical ventilation for more than 48hrs was admitted in the ICU, a written consent was obtained from the relative, or the patient if the patient was awake enough to give consent. Depending on the clinical profile of the patient, therapeutic management carried out at the discretion of the treating physician with a ventilator strategy as per the ARDSNET guidelines. In general, a conservative approach was taken to fluid strategy. After placing the patient on volume control ventilation static compliance as read by the ventilator was recorded; in addition, the patient’s ultrasound lung comets (ULC) score were obtained by performing a transthoracic ultrasound of the lung and summing the number of comets from each of the

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 11, 2023

scanning spaces in the anterior right and left hemi-thoraces, from the second to fifth inter-costal spaces.[10] The study was repeated in each patient at admission and after 48 hours. There was no blinding carried out, since it was considered that depriving the clinician of static compliance data or a valid means of estimating extravascular lung water would be unethical.

Statistical Analysis: Statistical analysis was done by deriving a one-way correlation coefficient between the ULC score and the changes in the static compliance using standard linear regression. Secondary details noted were the duration of the ventilation and the final outcome. Paired t-test was carried out to compare variables in the same patient at 48hr intervals, especially between compliance values and B-line estimation.

RESULTS

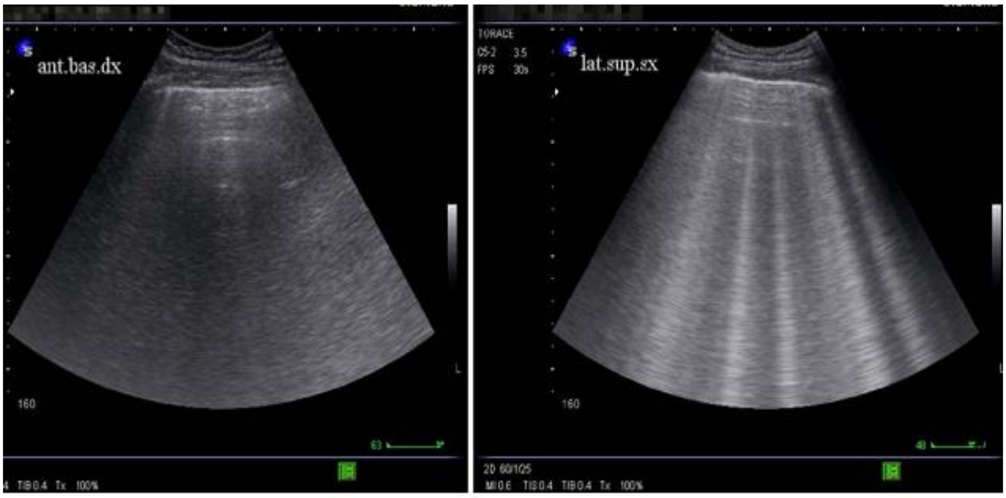

Fig. 1: On the left, normal ultrasound lung scan with horizontal hyper-echogenic lines (A-lines) regularly spaced due to reverberation of the lung wall. There is absence of vertical artefacts. On right, comet tail vertical artefacts fanning out from the lung-wall interface and spreading up to the edge of the screen. These are termed known as B lines. This image is from a patient with acute pulmonary oedema.

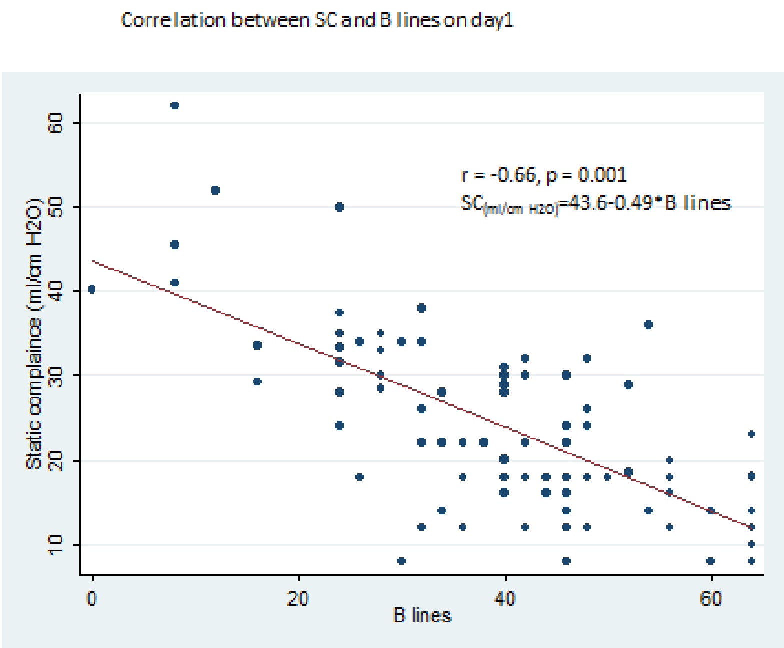

Fig 2: Co-relation between Static compliance and B Lines

Table 1: Patient Characteristics

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 11, 2023

Characteristics	Mean	Standard deviation	Median	Minimum	Maximum
Age	55.6	17.95	60.5	14	85
Weight	62.6	11.7	60	40	98
Male	**60**				
Female	**40**				

Table 2: T – Test Comparison of Means of Variables at Baseline and after 48 hours

Variables	At Baseline	After 48 hrs	P – value
Systolic BP (mmHg)	105.15	106.64	0.3416
Diastolic BP (mmHg)	69.85	68.78	0.4010
Pulse per min	112.54	112.13	0.8165
Temperature (ºF)	99.33	99.29	0.6249
CVP (cm of H_2O)	12.66	13.40	0.0142
SpO_2 (%)	91.93	92.39	0.3606
Tidal volume (ml)	408.68	413.94	0.2007
Resp. Rate per minute	15.3	15.66	0.0490
PEEP (cm of H_2O)	9.57	9.62	0.7733
Pressure support(cm of H_2O)	15.4	15.02	0.0063
PaO_2	154.29	167.67	0.0793
PCO_2	41.35	45.86	0.1592
pH	7.29	7.29	0.9540
HCO_3	21.18	20.97	0.5729
B-lines	42.38	40.37	0.3812
Static compliance	22.69	21.586	0.237

The generic data for the patients who were studied is shown in Table 1. In Table 2 the measured parameters are shown at baseline and after 48 hours. The mean Systolic Blood pressure was 105.2 mmHg, the mean diastolic pressure 69.8 mmHg, the mean heart rate 112/mt and the mean temperature 99.3^0. This is consistent with the expectation that patients admitted to the ICU tend to be hypotensive, tachycardic and febrile. In the 87 patients in whom CVPs were measured, the average CVP was 12.67 cm H2O, the SpO2 was 92 %, and on the ventilator the average respiratory rate was 15.3 with a tidal volume of 409.6 and a PEEP of 9.57. Again, this was in keeping with the expectations that such patients would be ventilated with ARDSnet protocol low tidal volumes, and would require high levels of PEEP due to their underlying lung condition. Trends in static compliance and B-lines did not reach significance. However, when the Static compliance and B lines are correlated as shown for the baseline in Graph 1(Fig 2), both on admission and after 48 hours, a significant negative association was seen between static compliance and B lines. On admission, the regression formula was: -

$SC_{(ml/cm\ H20)}$ = 43.6- 0.49*B lines (R=0.66, p=0.001)
And after 48 hours the formula was
$SC_{(ml/cm\ H2O)}$ = 39.5- 0.44*B lines (r-0.86, p<0.001.)

Thus it was seen that on two separate regression curves, a decrease of one B line in the ultrasound scan was associated with approximately a 0.5cm increase in static compliance. The correlation coefficient was much higher after 48 hours, which was consistent with the expectation that extravascular lung water would have a more consistent contribution to the decrease in lung compliance after ARDS had set in.

DISCUSSION:

In our study, we have correlated the quantification of EVLW by a scoring system between the number of B-lines in a set of predefined sectors of the lung and static lung compliance. This was a multicentric study which recruited 100 mechanically ventilated patients admitted to adult ICUs in four major service hospitals. Patients were referred in our study if ventilated for more than 48 hours for pulmonary issues. Admission characteristics showed the standard mix of patients admitted to a mixed ICU, with a preponderance of patients admitted with sepsis from various sources. Admission investigations were notable for low mean PaO_2 / FiO_2 ratio of 154.4 with a standard deviation of 55.48, indicating that nearly all patients admitted fitted into the standard definition of ARDS on admission. On admission, the patients had a low static compliance (22.69 ± std deviation 10.58). which persisted after 48 hours.

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 11, 2023

On both measurements, there was a significant correlation between the number of B lines and the static compliance, with a negative correlation on both days, indicating that with a decrease in lung compliance, presumably due to increase in extravascular lung water, there was an increase in the number of B- lines.

The α intercepts on both days were similar, as was the β coefficient of the B- lines. The correlation coefficient was higher on the second measurement, possibly indicating that the effect of extravascular lung water on both the B-lines and static compliance had stabilized over 48hrs.

Zoltan Jambrik et al [10] studied 121 consecutive hospitalized patients (43 women and 78 men; aged 67 ±12 years) admitted to a combined cardiology- pneumology department (including cardiac intensive care unit) showed linear correlation between echocardiographic comet score and radiologic lung water score ($r = 0.78$, $p < 0.01$). Intra patient variations ($n = 15$) showed an even stronger correlation between changes in echocardiographic lung comet and radiologic lung water scores ($r = 0.89$; $p < 0.01$). D. Lichtenstein et al [11] conducted a prospective clinical study in 66 consecutive dyspnoeic patients, 40 with pulmonary edema and 26 with COPD. In addition, 80 patients without clinical and radiologic respiratory disorders were also studied. The sign studied was the comet-tail artifact arising from the lung wall interface, multiple and bilaterally disseminated to the anterolateral chest wall. They found a sensitivity of 100% and a specificity of 92% in the diagnosis of pulmonary edema when compared with COPD. Other studies [12,13,14,15] showed that B-lines provide 95% specificity and 97% sensitivity for pulmonary edema identification by bedside lung ultrasound in congestive heart failure and high-altitude pulmonary edema. The B-lines can be resolved significantly after treatment and suggested that the B-lines represent the existence of EVLW.

Our study demonstrates a consistent negative correlation between extravascular lung water as measured by counting B-lines on the ultrasound and static lung compliance. The presence of a consistent and reproducible correlation indicates that ultrasound assessment of extravascular lung water may be of value in guiding fluid therapy in patients who require ventilator support and whose lung compliance may be reduced by the presence of increased extravascular lung water.

Summarizing, our study emphasizes that lung ultrasound is an accurate method for assessment of lung water and permeability at the bedside. EVLW has been repeatedly suggested to improve ARDS-Definition. This was well recognized by the experts creating the Berlin-Definition. However, they argued that inclusion of EVLW was “infeasible based on the lack of availability of transpulmonary thermodilution” in most patients with ARDS. Consequently, estimation of lung water based on B-lines could be the “missing link” to include EVLW or its estimate in future definitions of ARDS.

REFERENCES:

1. Enghard P, Rademacher S, Nee J, et al. Simplified lung ultrasound protocol shows excellent prediction of extravascular lung water in ventilated intensive care patients. Crit Care. 2015;19:36.
2. Zhao Z, Jiang L, Xi X, et al. Prognostic value of extravascular lung water assessed with lung ultrasound score by chest sonography in patients with acute respiratory distress syndrome. BMC Pulm Med. 2015;15:98.
3. Ma H, Huang D, Guo L, et al. Strong correlation between lung ultrasound and chest computerized tomography imaging for the detection of acute lung injury/acute respiratory distress syndrome in rats. J Thorac Dis. 2016;8(7):1443-8.
4. Sweeney, RM, McAuley, DF. Acute respiratory distress syndrome. Lancet. 2016;388(10058):2416–2430.
5. Jozwiak, M, Teboul, JL, Monnet, X. Extravascular lung water in critical care: recent advances and clinical applications. Ann Intensive Care. 2015;5(1):38.
6. Picano, E, Pellikka, PA. Ultrasound of extravascular lung water: a new standard for pulmonary congestion. Eur Heart J. 2016;37(27):2097–2104.
7. Mayr, U, Karsten, E, Lahmer, T, et al. Impact of large volume paracentesis on respiratory parameters including transpulmonary pressure and on transpulmonary thermodilution derived hemodynamics: a prospective study. PLoS One. 2018;13(3):e0193654.
8. Tagami, T, Ong, MEH. Extravascular lung water measurements in acute respiratory distress syndrome: why, how, and when? Curr Opin Crit Care. 2018;24(3):209–215.
9. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. The Acute Respiratory Distress Syndrome Network. N Engl J Med. 2000;342(18):1301-8.
10. Jambrik Z, Monti S, Coppola V, et al. Usefulness of ultrasound lung comets as a non radiologic sign of extravascular lung water. Am JCardiol 2004; 93:1265 – 70

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 11, 2023

11. Lichtenstein, DA . Lung ultrasound in the critically ill. Ann Intensive Care. 2014;4(1):1.
12. Giovanni Volpicelli, Alessandro Mussa, Giorgio Garofalo, Luciano Cardinale, Giovanna Casoli, Fabio Perotto, Cesare Fava, Mauro Frascisco. "Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome." American Journal of Emergency Medicine 2006; 24, 689–696.
13. Pongdhep Theerawit, Nutchanart Touman, Yuda Sutherasan, and Sumalee Kiatboonsri. "Transthoracic ultrasound assessment of B-lines for identifying the increment of extravascular lung water in shock patients requiring fluid resuscitation". Indian Journal of Critical Care Medicine, Year: 2014,Volume:18, Issue: 4,Pages :195-199
14. Balzer, F, Menk, M, Ziegler, J, et al. Predictors of survival in critically ill patients with acute respiratory distress syndrome (ARDS): an observational study. BMC Anesthesiol. 2016;16(1):108.
15. Vikram Mukherjee,Deepak Pradhan, Bhisov Jhakarav. Lung ultrasound B lines correlate well static compliance in a mechanically ventilated patient. Critical Care 2020 ;4 (Supplement 584)