Utility of bedside lung ultrasound for assessment of lung recruitment in a case of acute respiratory distress syndrome

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ABSTRACT

Lung recruitment maneuvers are rescue measures commonly used to improve oxygenation in severely hypoxemic patients with acute respiratory distress syndrome (ARDS), who fail to improve on standard treatment. After recruitment, appropriate level of positive end-expiratory pressure (PEEP) is applied to prevent alveolar de-recruitment during expiration. Computed tomography scan of thorax and quasi-static pressure-volume curves have played a pivotal role are important in the assessment of recruitment, but they have several limitations. Lung ultrasound (LUS), which is now easily available in nearly every Intensive Care Unit, could be an attractive alternative method for assessing lung recruitment. It is noninvasive, easily repeatable and is devoid of radiation hazards. We are presenting a case of 24-year-old female patient with moderate ARDS in whom bedside LUS was successfully used into assessing lung recruitment as well as into determining the appropriate level of PEEP.

KEY WORDS: Acute respiratory distress syndrome, bedside lung ultrasound, recruitment maneuvers

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INTRODUCTION

Mechanical ventilation (MV) with low tidal volume (TV) and high-positive end-expiratory pressure (PEEP) is conventional strategy for improving oxygenation in patients with acute respiratory distress syndrome (ARDS).[1] However, patients who fail to show improvement in oxygenation with standard therapy require frequent recruitment maneuvers with high pressures to achieve satisfactory opening of the collapsed alveoli.[2] Imaging has played a key role in the evaluation of lung recruitment since last three decades. The computed tomography (CT) scan thorax and quasi-static pressure-volume (PV) curve have played a pivotal role in the assessment of recruitment but have several disadvantages. CT cannot be performed routinely and repeated easily.[3] It also requires the patient to be transported outside the Intensive Care Units (ICUs) and is associated with significant radiation exposure. PV curve requires deep sedation, muscle paralysis, and expensive software on the ventilator.[4] The arterial oxygenation method has also been validated to detect the efficacy of recruitment. It is available in all ICUs and is easy to measure by performing arterial blood gas (ABG) analysis frequently with arterial catheter. However, it is an invasive procedure associated with complications such as hematoma, arterial thrombosis, and catheter-related infections. Repeated sampling also adds a significant cost burden to patients. Lung ultrasound (LUS) is now available in almost every ICU and is used routinely for the evaluation of pleural fluid, pulmonary edema, pneumothorax, and also for the diagnosis of pneumonia by measuring lung aeration score.[5,6] With the same principle, it has also recently been used to assess the lung recruitment with the application of

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PEEP.[7] LUS has the advantage of being noninvasive, safe with no radiation exposure, and easily repeatable. We are reporting a case of young female with severe ARDS, in whom bedside LUS was used successfully for assessing lung recruitment and for selecting an appropriate level of PEEP to prevent derecruitment during expiration.

CASE REPORT

A 24-year-old previously healthy woman was admitted to the hospital with chief complaints of high-grade fever, generalized body ache, and decreased appetite for 5 days followed by breathlessness for 1 day. Her vital parameters on examination were as follows: pulse 140/min, blood pressure 110/70 mm Hg, respiratory rate (RR) 60/min, temperature 38.4°C (101°F), and pulse showing oxygen saturation of 60% on room air. Respiratory system examination revealed bilateral air entry with no adventitious sounds. Other systemic examination revealed no significant abnormality. She was found to have thrombocytopenia (50,000/cm^3). The serology of dengue and malaria showed negative results. Scrub typhus serology (IgM Elisa >1.5) was positive (normal cutoff value <0.5). Rest all laboratory investigations were within normal limit. Her chest radiography on the 1st day of admission showed bilateral infiltrates involving all zones suggestive of ARDS. The ABG showed pH of 7.51, PaO_2 of 23.1 mm Hg (3.1 kPa), $PaCO_2$ of 26.9 mm Hg (3.6 kPa), and alveolar–arterial gradient of 55 mm Hg (7.3 kPa) on room air. The diagnosis of moderate ARDS secondary to scrub typhus infection was confirmed as per Berlin criteria.[8] She was initially placed on Venturi mask with FiO_2 (fraction of inspired oxygen) 60%, but oxygenation could not be improved and her condition further worsened. Intubation and MV were initiated immediately to correct hypoxemia and reduce work of breathing. A radial arterial catheter was inserted for ABG sampling and arterial blood pressure monitoring. ABG analysis parameters were recorded after optimum calibration. She was placed on initial ventilator settings: FiO_2 1.00, volume control mode, constant-flow inflation, TV 300 mL (6 mL/kg of predicted body weight, baseline PEEP of 5 cm H_2O, and RR 35/min to keep $PaCO_2$ within normal limit). Repeat ABG revealed pH 7.49, PaO_2 102 mm Hg (13.6 kPa), $PaCO_2$ 28.3 mm Hg (3.8 kPa), and PaO_2/FIO_2 ratio 102. Lung mechanics parameters recorded at baseline were as follows: peak inspiratory pressure (Pinsp) 36 cm H_2O and plateau pressure (Pplat) 28 cm H_2O. Ultrasound examination was also performed simultaneously to assess baseline lung aeration, which was C pattern (consolidation = 3) at same ventilator setting. This severity of loss of aeration has been adopted from LUS scoring patterns as defined by Bouhemad *et al*.:[7] Normal aeration (N) = 0: the presence of lung sliding with A lines (horizontal repetitive artifacts originating from the pleural line) or fewer than two isolated B lines (vertical, comet-tail artifacts originating from the pleural line, long, hyperechoic, well-defined, dynamic, erasing A lines); moderate loss of lung aeration (B1) = 1: Multiple well-defined B lines 7 mm apart caused by thickened interlobular septa (interstitial edema); severe loss of lung aeration (B2) = 2: Multiple coalescent B lines <3 mm apart caused by ground-glass areas (alveolar edema) and lung consolidation (C) = 3: The presence of a tissue pattern characterized by dynamic air bronchograms. These patterns are represented pictorially in Figure 1. The patient was examined in the semi-recumbent position with 4 MHz frequency probe of bedside portable LUS (LOGIQe ULTRASOUND, BT 12; GE-Health Care, Philips, USA). The probe was positioned parallel to the rib on the dependent region at the left side of chest perpendicular to the skin and without angulation at the posterior axillary line in sixth ICS. PEEP was then increased to 12 cm H_2O for improving oxygenation; however, no significant response was observed as PaO_2 remained low (117 mm Hg-15.6 kPa) as well as LUS aeration pattern remained unchanged (C pattern) and FiO_2 could not be reduced to <60%. Fluid resuscitation was started along with hemodynamic monitoring. Two-dimensional echocardiography revealed normal ejection fraction and normal heart chambers. The recruitment maneuver was then performed with pressure control ventilation using stepwise increase in sustained inflation pressure starting from 30 cm H_2O and successively rising to 40 and 50 cm H_2O, applied for 50 s till PaO_2 + $PaCO_2$ is increased to 406.5 mm Hg (54.2 kPa). The recruitment maneuver was stopped at 50 cm H_2O as target of maximal recruitment strategy (PaO_2 + $PaCO_2$ ≥400 mm Hg-53.3 kPa) was achieved based on previous validated study.[9] The ABG analysis and ultrasound examination were performed simultaneously at different settings to estimate trends in change of oxygenation and LUS aeration patterns. The LUS aeration pattern at this point was N (normal = 0). It was followed by PEEP titration starting from highest set PEEP of 24 cm H_2O where other ventilator settings were adjusted

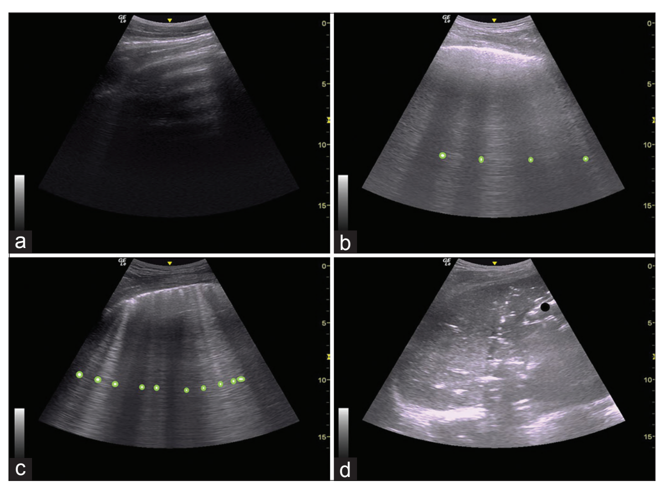

Figure 1: (a) N pattern (normal aeration): The presence of lung sliding with horizontal A lines; (b) B1 pattern (moderate loss of aeration): The presence of multiple well-defined B lines >7 mm apart-marked with dots; (c) B2 pattern (severe loss of aeration): The presence of multiple coalescent B lines <3 mm apart-marked with dots; (d) C pattern (consolidation): The presence of tissue pattern characterized by punctate lesions and dynamic air bronchograms

to maintain Pplat below 30 cm H_2O. The PEEP was then lowered stepwise by 2 cm H_2O after every 10 min. The ABG analysis was performed at each level of PEEP with simultaneous LUS examination. The PEEP titration was continued till 14 cm H_2O, where decrease by >10% of maximally achieved PaO_2 + $PaCO_2$ was observed, i.e., 357.3 mm Hg (47.6 kPa). The LUS also revealed some derecruitment or loss of aeration at this point and B1 = 1 pattern was recorded. These changes are demonstrated in Table 1 as well as pictorially in Figure 2a-j. The patient again underwent re-recruitment to maintain oxygenation; however, this time LUS was used primarily to guide recruitment maneuver as well as titration of appropriate level of PEEP and simultaneous oxygenation parameters were also noted by the ABG analysis at each level of set PEEP. The findings of the ABG analysis were blinded to the operator performing LUS. A similar trend was observed with improvement in LUS aeration score during recruitment maneuver, i.e., conversion from C pattern at baseline PEEP (5 cm H_2O) to N pattern at continuous positive airway pressure (CPAP) of 50 cm H_2O. The LUS also detected derecruitment at PEEP of 14 cm H_2O during appropriate level of PEEP titration as conversion to B1 pattern from N pattern was observed. The corresponding changes in oxygenation (PaO_2 + $PaCO_2$) values were 172.9 (23.1 kPa), 411.8 (54.9 kPa), and 352.2 mm Hg

Table 1: Serial oxygenation parameters and corresponding lung ultrasound scores in our patient with acute respiratory distress syndrome undergoing recruitment as well as appropriate level of positive end-expiratory pressure titration

PEEP setting (cm H_2O)	FiO_2 (%)	PaO_2 in mm Hg (kPa)	$PaCO_2$ in mm Hg (kPa)	PaO_2 + $PaCO_2$ in mm Hg (kPa)	LUS pattern	LUS score
Baseline PEEP (5)	100	114 (15.2)	41.9 (5.6)	155.9 (20.8)	C	3
RM with CPAP (30)	100	140 (18.7)	42.9 (5.7)	182.9 (24.4)	C	3
RM with CPAP (40)	100	286 (38.1)	47 (6.3)	333 (44.4)	B2	2
RM with CPAP (50)	**100**	**340 (45.3)**	**66.5 (8.9)**	**406.5 (54.2)**	**N**	**0**
PEEP (24)	100	349 (46.5)	62.2 (8.3)	411.2 (54.8)	N	0
PEEP (22)	100	342 (45.6)	60.4 (8.1)	402.4 (53.7)	N	0
PEEP (20)	100	343 (45.7)	59.9 (8)	402.9 (53.7)	N	0
PEEP (18)	100	339 (45.2)	55.2 (7.4)	394.2 (52.6)	N	0
PEEP (16)	100	335 (44.7)	52.8 (7.1)	387.8 (51.8)	N	0
PEEP (14)	**100**	**311 (41.5)**	**46.3 (6.2)**	**357.3 (47.7) - fall by >10% from that of CPAP 50 cm H_2O**	**B1 (loss of aeration)**	**1**

PEEP: Positive end-expiratory pressure, LUS: Lung ultrasound, RM: Recruitment maneuver, CPAP: Continuous positive airway pressure, kPa- Kilopascal (The level of PEEP and corresponding LUS score and oxygenation is marked in bold)

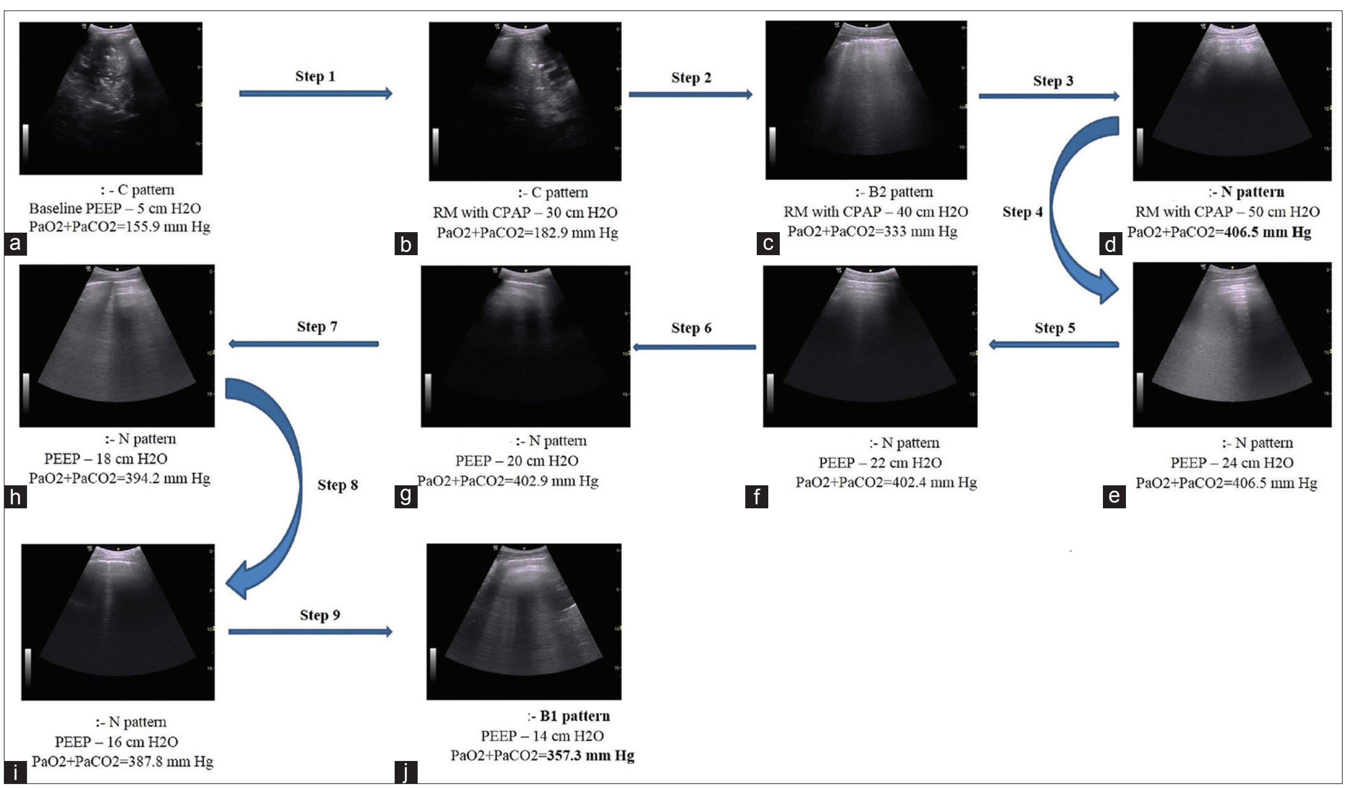

Figure 2: (a-j) Arterial oxygenation parameters with corresponding lung ultrasound aeration patterns (pictorial view) in our patient with ARDS undergoing recruitment as well as appropriate level of positive end-expiratory pressure titration at different positive end-expiratory pressure settings

(47 kPa) at baseline PEEP, recruitment maneuver with CPAP 50 cm H_2O, and PEEP of 14 cm H_2O, respectively. These findings, including pictorial illustrations, are summarized in Table 2 and Figure 3a-l. The probe was placed in the same position for the assessment of aeration pattern at all settings. Similar changes were also detected in the same position in the contralateral right lung. The patient was again re-recruited, and PEEP was finally set at appropriate level of 16 cm H_2O, i.e., 2 cm higher than the level of derecruitment PEEP to maintain quality of care. The LUS at this point of time revealed N pattern. These findings show significant agreement as well as good correlation between oxygenation parameters and LUS aeration patterns during recruitment maneuver as well as appropriate level of PEEP titration, as shown in Figures 4a and b ($r = 0.732$, $P = 0.02$). There was further improvement in oxygenation parameters during course of illness as the patient got extubated after 4 days of admission. She was discharged after 1 week of extubation in a stable general condition.

Table 2: Serial lung ultrasound scores and corresponding oxygenation parameters in the same patient with acute respiratory distress syndrome undergoing recruitment as well as appropriate level of positive end-expiratory pressure titration

PEEP setting (cm H_2O)	FiO_2 (%)	LUS pattern	LUS score	PaO_2 in mm Hg (kPa)	$PaCO_2$ in mm Hg (kPa)	PaO_2 + $PaCO_2$ in mm Hg (kPa)
Baseline PEEP (5)	100	C	3	131 (17.5)	41.9 (5.6)	172.9 (23.1)
RM with CPAP (30)	100	C	3	144 (19.2)	42.9 (5.7)	186.9 (24.9)
RM with CPAP (40)	100	B2	2	293.2 (39.1)	47 (6.3)	340.2 (45.4)
RM with CPAP (50)	**100**	**N**	**0**	**345 (46)**	**66.8 (8.9)**	**411.8 (54.9)**
RM with CPAP (60)	100	N	0	364.7 (48.7)	68.5 (9.1)	433.2 (57.8)
PEEP (24)	100	N	0	356 (47.5)	64.5 (8.6)	420.5 (56.1)
PEEP (22)	100	N	0	351 (46.8)	65.2 (8.7)	416.2 (55.5)
PEEP (20)	100	N	0	343 (45.7)	61.9 (8.3)	404.9 (54)
PEEP (18)	100	N	0	339.4 (45.2)	62.2 (8.3)	401.6 (53.5)
PEEP (16)	100	N	0	338 (45.1)	61.8 (8.2)	399.8 (53.3)
PEEP (14)	**100**	**B1 (loss of aeration)**	**1**	**293.9 (39.2)**	**58.3 (7.8)**	**352.2 (47) - fall by >10% from that of CPAP 50 cm H_2O**
PEEP (12)	100	B2	2	290.6 (38.7)	47.2 (6.3)	337.8 (45)

PEEP: Positive end-expiratory pressure, LUS: Lung ultrasound, RM: Recruitment maneuver, CPAP: Continuous positive airway pressure, kPa- Kilopascal (The level of PEEP and corresponding LUS score and oxygenation are marked in bold)

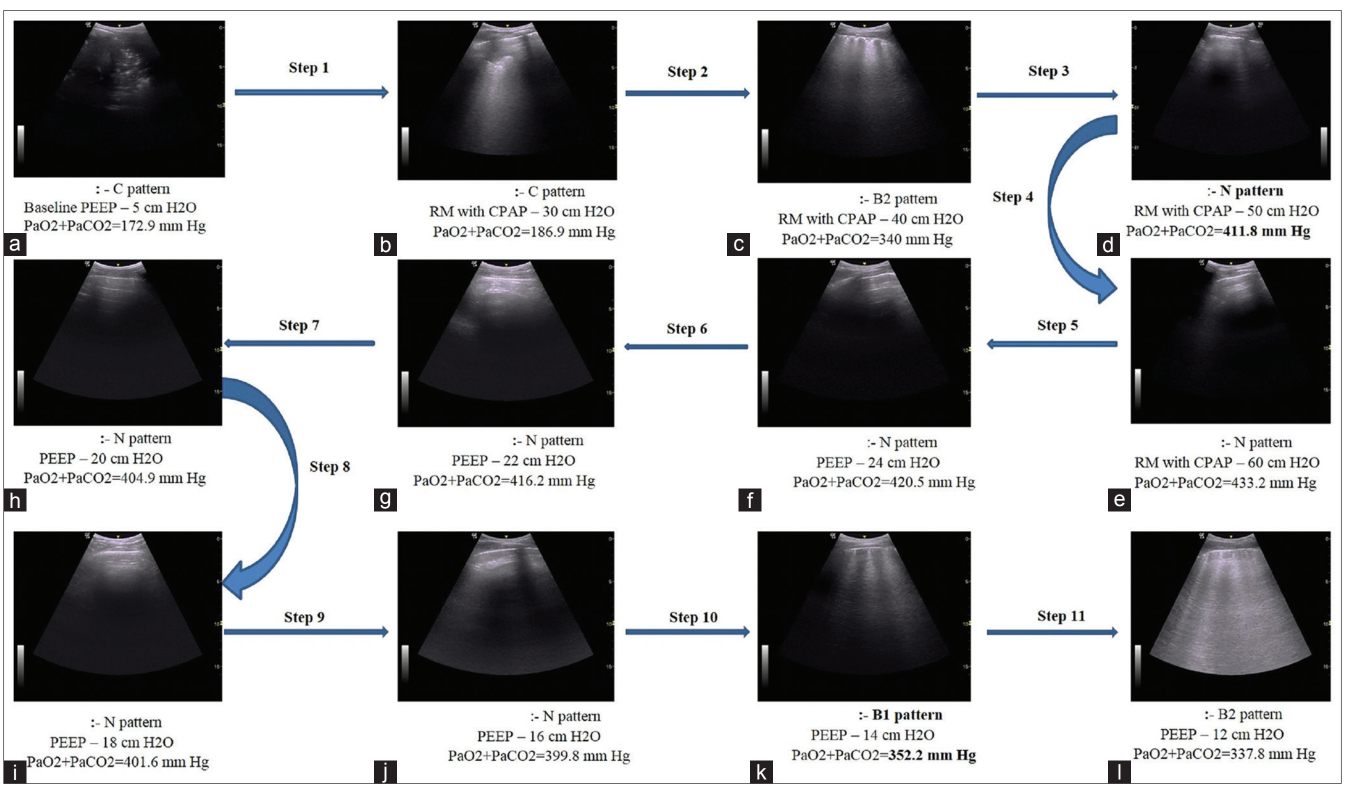

Figure 3: (a-l) Lung ultrasound aeration patterns in our patient with acute respiratory distress syndrome undergoing recruitment as well as appropriate level of positive end-expiratory pressure titration with corresponding arterial oxygenation parameters at different positive end-expiratory pressure settings

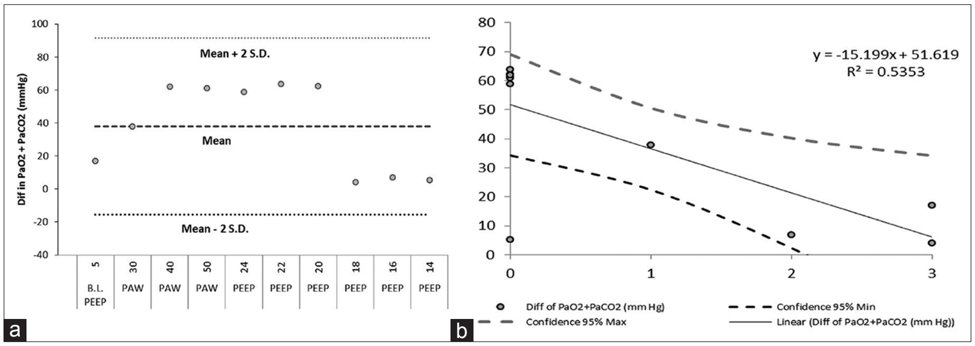

Figure 4: (a) Bland and altman plot for difference in PaO_2 + $PaCO_2$ calculated at two different times from Tables 1 and 2, with the representation of the limits of agreement (dotted line), from 1.96 s to + 1.96 s. (b) Prediction of differences of PaO_2 + $PaCO_2$ by lung ultrasound aeration patterns with significant correlation (r = 0.732, P = 0.02) with all values lying between upper and lower confidence limit

DISCUSSION

This case report demonstrated the utility of bedside LUS in assessing lung recruitment as well as in determining the appropriate level of PEEP required to prevent derecruitment in patients with severe ARDS. The LUS has been used for similar indications previously also by various authors in different case reports and observational studies but with a heterogeneity in methodological approach as well as investigation used for comparison.[6,7,10-22] Few studies have been described in Online supplementary material. ARDS is a condition characterized by diffuse alveolar as well as lung capillary damage, interstitial edema, and alveolar flooding leading to increased lung water. This can cause alveolar collapse and consolidation, especially of dependent lung; and decreased lung aeration, leading to poor compliance accompanied by ventilation-perfusion mismatch.[1] The LUS can detect increased interstitial and alveolar fluids in patients with ARDS by examination of artifacts known as B lines.[23] It is characterized by the presence of three or more discrete laser-like vertical hyperechoic reverberation artifacts that arise from the pleural line (previously described as 'comet tails'), extend to the bottom of the screen without fading, and move synchronously with lung sliding. These B lines correlate well with the ultrasound interstitial syndrome. A scoring system has been proposed to assess lung recruitment by LUS in ARDS.[7] Most cases of ARDS occur because of various systemic etiologies resulting in the production of inflammatory exudate, which lead to the collapse of lungs because of distal airways closure, especially in basal or dependent areas. These areas are subjected to a superimposed hydrostatic pressure of overlying upper or nondependent lung under the influence of gravity and the effect increases from sternal to vertebral regions in supine position. This sternovertebral gradient results in heterogeneous collapse of dependent regions of lung even though the lung is uniformly involved in ARDS. Recruitment of these collapsed areas is essential to improve oxygenation by early positive pressure through application of either PEEP or recruitment maneuver. The gold standard CT scan has significantly contributed in understanding the pathophysiology of ARDS and the regional distribution of lung aeration with recruitment maneuver.[3] Bedside LUS can directly evaluate effectiveness of recruitment. This was shown by Bouhemad *et al*.[6] as they observed a highly significant correlation between CT and LUS reaeration score before and after antibiotic therapy in 30 patients with ventilator-associated pneumonia. Subsequently, they observed a change in LUS score before and after recruitment maneuver that was quantified on the basis of reaeration scoring system: 1 point, from multiple B lines to normal, from coalescent B lines to multiple B lines, and from consolidation to coalescent B lines; 3 points, from coalescent B lines to normal or from consolidation to multiple B lines; and 5 points, from consolidation to normal.[7] Thereafter, other studies also assessed recruitment maneuver under direct guidance with bedside LUS with successful outcome.[11-14] Few studies used alternative approach to assess recruitment by LUS.[15,16] Stefanidis *et al*.[15] observed that reduction in the nonaerated areas of dependent lung regions in 10 patients with ARDS as estimated by the LUS was associated with significant improvement in oxygenation during incremental PEEP titration trial. Tusman *et al*.[24] has proposed an algorithm for assessing recruitment maneuver as well as appropriate level of PEEP titration by the LUS to conduct and personalize recruitment maneuver in a real-time way at the bedside. There is requirement of uniform approach by framing systematic LUS-guided lung recruitment protocol available for daily clinical practice.

The strength of our case report is that we have compared arterial oxygenation parameters with the LUS scores and found strong correlation in their values when both modalities were used independently. However, the LUS cannot detect hyperinflation of nondependent areas of the lung due to overtitration resulting in barotrauma. The selection of the appropriate PEEP level should not only consider optimizing lung recruitment but also focus on limiting hyperinflation.[25] A new method such as electrical impedance tomography can fulfill these requirements but is expensive, not commonly used and evidence regarding its utility is not well defined. In conclusion, this case highlights the usefulness of bedside LUS in the assessment of RM as well as appropriate level of PEEP titration. However, properly designed studies involving a large number of patients are required before it can be recommended for routine use in clinical practice. The LUS may become the primary means for diagnostic evaluation of patients with ARDS in the future.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given her consent for her images and other clinical information to be reported in the journal. The patient understand that name and initials will not be published and due efforts will be made to conceal identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Acute Respiratory Distress Syndrome Network, Brower RG, Matthay MA, Morris A, Schoenfeld D, Thompson BT, *et al*. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med 2000;342:1301-8.
2. Gattinoni L, Caironi P, Cressoni M, Chiumello D, Ranieri VM, Quintel M, *et al*. Lung recruitment in patients with the acute respiratory distress syndrome. N Engl J Med 2006;354:1775-86.
3. Malbouisson LM, Muller JC, Constantin JM, Lu Q, Puybasset L, Rouby JJ, *et al*. Computed tomography assessment of positive end-expiratory pressure-induced alveolar recruitment in patients with acute respiratory distress syndrome. Am J Respir Crit Care Med 2001;163:1444-50.
4. Lu Q, Constantin JM, Nieszkowska A, Elman M, Vieira S, Rouby JJ, *et al*. Measurement of alveolar derecruitment in patients with acute lung injury: Computerized tomography versus pressure-volume curve. Crit Care 2006;10:R95.
5. Lichtenstein D. Lung ultrasound in the critically ill. J Med Ultrasound 2009;17:125-42.
6. Bouhemad B, Liu ZH, Arbelot C, Zhang M, Ferarri F, Le-Guen M, *et al*. Ultrasound assessment of antibiotic-induced pulmonary reaeration in ventilator-associated pneumonia. Crit Care Med 2010;38:84-92.
7. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby JJ, *et al*. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. Am J Respir Crit Care Med 2011;183:341-7.
8. ARDS Definition Task Force, Ranieri VM, Rubenfeld GD, Thompson BT, Ferguson ND, Caldwell E, *et al*. Acute respiratory distress syndrome: The Berlin definition. JAMA 2012;307:2526-33.
9. Borges JB, Okamoto VN, Matos GF, Caramez MP, Arantes PR, Barros F, *et al*. Reversibility of lung collapse and hypoxemia in early acute respiratory distress syndrome. Am J Respir Crit Care Med 2006;174:268-78.
10. Lichtenstein D, Goldstein I, Mourgeon E, Cluzel P, Grenier P, Rouby JJ, *et al*. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. Anesthesiology 2004;100:9-15.
11. Algieri I, Mongodi S, Chiumello D, Mojoli F, Cressoni M, Via G, *et al*. CT scan and ultrasound comparative assessment of PEEP-induced lung aeration changes in ARDS. Crit Care 2014;18:P285.
12. Shen P, Luo R, Gao Y, Wang J, Zhang M. Assessment of positive end-expiratory pressure induced lung volume change by ultrasound in mechanically ventilated patients. Zhonghua Jie He He Hu Xi Za Zhi 2014;37:332-6.
13. Li DK, Liu DW, Long Y, Wang XT. Use of lung ultrasound to assess the efficacy of an alveolar recruitment maneuver in rabbits with acute respiratory distress syndrome. J Ultrasound Med 2015;34:2209-15.
14. Du J, Tan J, Yu K, Wang R. Lung recruitment maneuvers using direct ultrasound guidance: A case study. Respir Care 2015;60:e93-6.
15. Stefanidis K, Dimopoulos S, Tripodaki ES, Vitzilaios K, Politis P, Piperopoulos P, *et al*. Lung sonography and recruitment in patients with early acute respiratory distress syndrome: A pilot study. Crit Care 2011;15:R185.
16. Rode B, Vučić M, Siranović M, Horvat A, Krolo H, Kelečić M, *et al*. Positive end-expiratory pressure lung recruitment: Comparison between lower inflection point and ultrasound assessment. Wien Klin Wochenschr 2012;124:842-7.
17. Tsubo T, Sakai I, Suzuki A, Okawa H, Ishihara H, Matsuki A, *et al*. Density detection in dependent left lung region using transesophageal echocardiography. Anesthesiology 2001;94:793-8.
18. Tsubo T, Yatsu Y, Suzuki A, Iwakawa T, Okawa H, Ishihara H, *et al*. Daily changes of the area of density in the dependent lung region – Evaluation using transesophageal echocardiography. Intensive Care Med 2001;27:1881-6.
19. Tsubo T, Yatsu Y, Tanabe T, Okawa H, Ishihara H, Matsuki A, *et al*. Evaluation of density area in dorsal lung region during prone position using transesophageal echocardiography. Crit Care Med 2004;32:83-7.
20. Gardelli G, Feletti F, Gamberini E, Bonarelli S, Nanni A, Mughetti M, *et al*. Using sonography to assess lung recruitment in patients with acute respiratory distress syndrome. Emerg Radiol 2009;16:219-21.
21. Lu X, Wu DQ, Gao YZ, Zhang M. Lung ultrasound predicts acute respiratory distress syndrome in patients with paraquat intoxication. Hong Kong J Emerg Med 2017;24:275-81.
22. Tang KQ, Yang SL, Zhang B, Liu HX, Ye DY, Zhang HZ, *et al*. Ultrasonic monitoring in the assessment of pulmonary recruitment and the best positive end-expiratory pressure. Medicine (Baltimore) 2017;96:e8168.
23. Lichtenstein D, Mézière G, Biderman P, Gepner A, Barré O. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med 1997;156:1640-6.
24. Tusman G, Acosta CM, Costantini M. Ultrasonography for the assessment of lung recruitment maneuvers. Crit Ultrasound J 2016;8:8.
25. Rouby JJ, Lu Q, Goldstein I. Selecting the right level of positive end-expiratory pressure in patients with acute respiratory distress syndrome. Am J Respir Crit Care Med 2002;165:1182-6.