REVIEW

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Lung Ultrasound as a Monitoring Tool

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Lung ultrasound has proven to be useful in detecting pneumothorax, interstitial syndrome, and lung consolidation. It is easily applied at the bedside, in real-time, and free of radiation hazards. Recently, the use of lung ultrasound has moved from a diagnostic tool to a monitoring tool for lung aeration quantification. This article reviewed the use of lung ultrasound in monitoring acute pulmonary edema, acute respiratory distress syndrome, and pneumonia, and how it could be used to monitor changes during the application of mechanical ventilation or other treatments for respiratory failure.

Keywords: Ultrasonography; Monitoring; Lung; Extravascular Lung Water

Introduction

Over the last two decades, lung ultrasound (LUS) has emerged as a useful, radiation-free imaging technique that can be quickly done at the bedside to assess patients in the intensive care unit (ICU) or emergency department. An international evidence-based recommendations for point-of-care LUS suggested the use of LUS to diagnose pneumothorax, interstitial syndrome and lung consolidations[1] and its use has been expanded to neonatal and pediatric critical care setting[2]. Increasing evidence supports superior diagnostic performance of LUS compared to bedside chest X-ray in critically ill patients[3,4]. Recently, the use of LUS has moved from being a diagnostic tool to a monitoring tool for lung aeration quantification. LUS may be used to monitor various pulmonary disease such as acute pulmonary edema, acute respiratory distress syndrome (ARDS), and pneumonia[1,5].

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Quantification of LUS Findings

A controlled human model undergoing whole lung lavage showed that different states of lung aeration can be reliably detected by changes in LUS findings[6]. A progressive loss of aeration results in the switch from A-lines to B-pattern. A more severe loss of aeration responds as increasing number of B-lines that coalesce and a complete loss of aeration is shown as a tissue-like pattern in LUS[7]. The most frequently used approach is the LUS score, which is a semi-quantitative scoring system of four steps of progressive loss of lung aeration (Table 1). LUS score is calculated as the addition of scores in designated regions. The most popular method is dividing the lungs into 12 standard areas. Each hemithorax is divided into six areas by identifying anterior and posterior axillary lines and dividing each hemithorax in to upper and lower region. LUS scores can range from 0 (all areas well aerated) to 36 (all areas are consolidated)[5,8].

Acute Pulmonary Edema

Cardiogenic pulmonary edema is characterized by the homogenous distribution of multiple B-lines in all areas. LUS have been proven to be effective in the quantification of extravascular lung water and is comparable to more invasive methods[9-11]. LUS has also shown that diuretic therapy or continu-

Table 1. Lung ultrasound scores

Score	Characteristics
0	Normal aeration or maximum of two isolated B-lines
1	Moderate loss of aeration with three or more well-defined B-lines
2	Severe loss of aeration with coalescent B-lines
3	Complete loss of aeration with a tissue-like pattern

Table 2. Ventilator-associated pneumonia lung ultrasound score (VPLUS)

VPLUS	Parameter
1	Purulent secretions
1	≥2 areas with subpleural consolidations
2	≥1 area with dynamic linear air-bronchogram
2	Positive direct gram-stain result or culture results of endotracheal aspirate

ous positive airway pressure in acute cardiogenic pulmonary edema is followed by decrease in the number of B-lines, suggesting that dynamic changes in the extravascular lung water can be monitored using LUS[12,13]. Tailored LUS-guided diuretic treatment of pulmonary congestion has also been associated with improved outcomes of patients with heart failure[14]. It is interesting to note that although natriuretic peptides are more frequently used for diagnosis and prognostication of acute cardiogenic pulmonary edema, their value as a guide for treatment has not yet been demonstrated[15].

Acute Respiratory Distress Syndrome

Although the differential diagnosis of ARDS and cardiogenic pulmonary edema using LUS remains challenging, certain findings such as pleural line abnormalities, spared areas, consolidations may be used to distinguish the two diseases[16]. The regional LUS score of patients with ARDS correlated well with tissue density assessed with quantitative computed tomography[17].

LUS can be used in different clinical context of patients with ARDS. The application of extracorporeal membrane oxygenation (ECMO) to patients with severe ARDS is increasing and its extended use in patients with less severe hypoxemia may be associated with favorable outcomes[18]. LUS may be used to monitor ARDS patients on ECMO[19,20] in which bedside chest X-ray reveals only minimal information. It may also be used to assess aeration changes in ARDS patients, but there are contradictory results on its use in assessing positive end-expiratory pressure (PEEP) induced lung recruitment[17,21]. Moreover, improved aeration shown by LUS may not have a linear correlation with the improvement in oxygenation after prone positioning of ARDS patients[22,23]. Another limitation of LUS in patients with ARDS is that LUS cannot detect PEEP-induced lung hyperinflation.

Pneumonia

Ventilator-associated pneumonia (VAP) is one of the common complications of mechanical ventilation and is associated with prolonged ICU duration and increased medical costs. With the development of VAP, the normal LUS pattern is gradually substituted with focal areas of interstitial syndrome. With the aggravation of VAP, spaced B-lines increase in number and turn into coalescent B-lines and are often associated with subpleural consolidations[24]. Consolidations with a dynamic air-bronchogram (Supplementary Video S1) or subpleural consolidations in LUS may be useful for the diagnosis of VAP[25]. However, the diagnosis of VAP is challenging because LUS of patients under mechanical ventilation often presents severe loss of aeration from various etiologies not associated with infection[26]. VAP lung ultrasound score (Table 2) of more than 2 points identified VAP with 71% sensitivity and 69% specificity and its area under curve was higher than the Clinical Pulmonary Infection Score (0.743 vs. 0.574)[25]. A single center randomized controlled trial showed that daily LUS screening for VAP in patients with purulent sputum was associated with longer ventilator free days compared to the control group using a combination of chest X-ray and clinical findings[27]. Also, VAP was diagnosed earlier and was less severe at the time of diagnosis in the LUS screening group.

Weaning from Mechanical Ventilation

The risk of complications associated with mechanical ventilation, increases with the duration of ventilator support. Patients requiring prolonged mechanical ventilation is at risk for increased medical cost and morbidity[28]. Given the risks associated with delayed or unsuccessful extubation, new methods are needed to assist with the weaning process. Changing from positive pressure ventilation to spontaneous breathing is often associated with significant lung derecruitment. In patients who successfully passed spontaneous breathing trial (SBT), changes in LUS scores are predictive of extubation success or failure[29]. In this study by Soummer et al.[29], LUS was more accurate than B-type natriuretic peptide in identifying patients at higher risk for postextubation distress. LUS before and after SBT was also useful in diagnosing weaning-induced pulmonary edema[30]. However, another study showed that LUS before SBT failed to predict SBT failure[31] which highlights the fact that not one method should be used in isolation to make decisions regarding critically ill patients. Although out of scope of this review, ultrasound of the heart, diaphragm and pleura may also be useful in detecting obstacles to successful extubation[32,33].

Monitoring Response to Treatment

LUS can be used to monitor aeration changes derived from treatment or procedure. The utilization of high-flow nasal cannula (HFNC) has continued to increase in various diseases and clinical situations[34-36]. Although strict monitoring of patients on HFNC is recommended to avoid delays in intubation and worse clinical outcomes[37], monitoring methods and definitive signs to diagnose HFNC failure needs further research. LUS scores promise in this respect as it reflects positive changes in patients treated with HFNC oxygen therapy for blunt chest trauma[38] and postextubation atelectasis in children[39].

Limitations

LUS evaluation has several limitations. LUS is operator-dependent and requires training for acquisition of adequate images and correct interpretation. LUS cannot distinguish normal aeration from hyperinflation. It is difficult to assess patients with subcutaneous emphysema, subcutaneous edema, and large thoracic dressings or drains. Also, central lung lesions surrounded by normal lung parenchyma cannot be detected using LUS.

The traditional method of semiquantifying lung aeration also has limitations. The method of visualizing the pleura between the ribs helps identify the pleura but the view is limited by the width of the intercostal space which varies greatly among patients. Focal subpleural consolidations frequently seen in ARDS might lead to overestimation of aeration loss. To overcome these limitations, modified LUS score has been suggested[40] but needs further validation.

Conclusion

LUS is a simple, valuable bedside technique with numerous potentials as a monitoring tool. It can be used to monitor lung aeration changes in acute pulmonary edema, pneumonia, ARDS. It can also be used during mechanical ventilation and treatment for respiratory failure to monitor changes and response.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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Supplementary Material

Supplementary material can be found in the journal homepage (http://www.e-trd.org).

Supplementary Video S1. Video of dynamic air-bronchogram.

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