Review Article

Lung ultrasound: Predictor of acute respiratory distress syndrome in intensive care unit patients

ABSTRACT

Purpose: The purpose of the study was to review and summarize current literature concerning the validation and application of lung ultrasound (LUS) in critically ill patients with acute respiratory distress syndrome (ARDS).

Materials and Methods: An extensive literature search was conducted using PubMed, Cochrane Review, Google Scholar, and Ohio State University Link based on the question if LUS should be considered a reliable investigational technique for ARDS diagnosis, treatment, and prognosis in pediatric and adult population.

Results: LUS has been successfully validated for facilitating early diagnosis and diagnosis of simultaneous lung conditions, predicting lung recruitment treatment effect, and evaluating the prognosis in ARDS patients. Whether lung US is a useful tool in the prediction of prone position and oxygenation response in patients with ARDS is conflicting.

Conclusions: LUS is a noninvasive, radiation-free, cheap, and easy to perform tool for critically ill patients with ARDS and might be a promising technique used in the Intensive Care Unit for ARDS management.

Key words: Acute respiratory distress syndrome; extravascular lung water indices; Intensive Care Unit; lung recruitment maneuvers; lung ultrasound; prone positioning oxygenation response

Introduction

Acute respiratory distress syndrome (ARDS) is characterized by diffuse alveolar damage associated with an increase in alveolar and capillary permeability, leading to interstitial and alveolar edema that requires mechanical ventilation. According to the Berlin definition, the diagnosis of ARDS is based on the onset of hypoxemia and bilateral chest opacities developed within 1 week from the initial symptoms.[1] ARDS is a common cause of mortality in the Intensive Care Unit (ICU); although the mortality rate is declining (while still 50%), the long-term morbidity is still considerable.[2-5] A cornerstone of treating patients affected by ARDS is mechanical ventilation, tailored to avoid ventilator-induced lung injury and lung collapse. Lung computed tomography (CT) scan can provide useful diagnostic information and assess the benefit of treatment. However, this procedure is done in a CT unit under cardiorespiratory monitoring with an increased risk to the patient.[6-9]

Diagnostic and lung exploratory ultrasound is a rapidly evolving technique used in the ICU environment, being considered noninvasive, radiation-free, cheap, and easy to

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perform.[10] Lung ultrasound (LUS) has been validated for hemodynamic management, pleural effusions, pulmonary edema, pneumothorax detection, parenchymal consolidation, and central vein catheter placement.[11-15] Li *et al*. used ultrasound in rabbits with ARDS to assess the efficacy of an alveolar recruitment maneuver. The authors concluded that LUS is an effective method of evaluating and guiding alveolar recruitment in ARDS rabbits.[16] Stefanidis *et al*. considered that lung sonography is a useful clinical tool for ARDS patients.[17] Prat *et al*. demonstrated that a simple and short LUS examination could predict prone position oxygenation response in ARDS patients.[18]

Materials and Methods

Based on this published evidence, we question if lung ultrasonography should be considered a reliable investigational technique for ARDS diagnosis, management, and prognosis in pediatric and adult population. We initiated a comprehensive review of literature using the following keywords: LUS, ARDS, ICU, recruitment treatment, prone positioning (PP), and extravascular lung water when accessing PubMed, Cochrane Review, Google Scholar, and Ohio State University Link.

Results and Discussion

Lung ultrasound and acute respiratory distress syndrome diagnosis

Lung ultrasound facilitates early diagnosis of acute respiratory distress syndrome

Several studies proved the advantage of LUS technique in the early diagnose of ARDS. Gargani *et al*. showed that LUS could detect extravascular lung water accumulation early during the oleic acid lung injury, in the presence of a normal PaO_2/FiO_2.[19] LUS can also predict trauma patients at risk of developing ARDS. Leblanc *et al*. performed chest radiography and LUS on 45 blunt trauma patients with ARDS. Lung contusion extent was quantified using a LUS score that was compared to CT scan measurements. The ability of the LUS score to predict ARDS was tested using the area under the receiver operating characteristic curve. The diagnostic accuracy of LUS versus combined clinical examination and chest radiography with CT scan as reference was tested in blunt trauma patients. The authors concluded that LUS could identify patients at risk for developing ARDS after suffering blunt trauma. A LUS score of 6 out of 16 was the best threshold to predict ARDS, with a 58% sensitivity and a 96% specificity. In addition, the diagnostic accuracy of LUS was higher than clinical examination combined with chest radiography.[20]

LUS helps differential diagnosis of patients with "white" lungs at standard chest X-ray, excluding conditions such as pleural effusions or cardiogenic pulmonary edema.[21] Sekiguch *et al*.'s study enrolled 134 patients (median PaO_2/FiO_2 ratio, 191 and interquartile range, 122–253). Combined cardiac and LUS assist in the early differential diagnosis of ARDS, cardiogenic pulmonary edema, and other causes of hypoxemic respiratory failure.[22] In clinical applications, Zhang *et al*. used lung ultrasonography to diagnose 11 patients with ARDS due to bird flu H7N9 infection. They showed that bedside ultrasound can be used to evaluate H7N9 avian influenza infection in patients with ARDS, providing a strong basis for adjusting the treatment plan for patients. Therefore, LUS could be useful for the timely monitoring of ARDS caused by the H7N9 virus in clinics,[23] especially in resource-scarce settings or situations such as future respiratory virus outbreaks or pandemics.[24]

Lung ultrasound helps to diagnose coexisting pathology in acute respiratory distress syndrome patients

As ARDS aggravates, lung consolidation, atelectasis, pleural effusion, and pneumothorax will develop. LUS can also accurately diagnose and assess the severity of lung simultaneous conditions. Xirouchaki *et al*. conducted a prospective study using a modified LUS protocol based on 42 mechanically ventilated patients scheduled for CT. Four pathologic entities were evaluated: consolidation, interstitial syndrome, pneumothorax, and pleural effusion. The study proved that LUS has a considerably better diagnostic performance than chest X-ray when identifying coexisting conditions.[14]

A semi-quantitative, simple, and noninvasive index of lung water accumulation can be assessed by LUS identifying B-lines (also called ultrasound lung comets).[25] Thickened interlobular septa generate B-lines 7 mm apart and are associated with interstitial edema, while ground-glass areas characterizing alveolar edema are generating B-lines ≤3 mm.[26] The number of B-line reflects the extent of pulmonary edema. Per Lichtenstein *et al*. "when 3 or more B-lines are seen, interstitial edema can be diagnosed with 97% sensitivity and 95% specificity."[27] Recently, a modified Berlin definition of ARDS has introduced LUS as a based tool to detect bilateral lung opacities and to assess incidence and outcomes of ARDS patients in resource-constrained settings.[1]

Lung ultrasound ability to predict treatment outcome in acute respiratory distress syndrome patients

Lung ultrasound ability to predict lung recruitment treatment effect in acute respiratory distress syndrome patients

Patients with ARDS invariably require mechanical ventilation to decrease the work of breathing and to improve oxygen transport. An improvement in oxygenation can be obtained by increasing positive end-expiratory pressure (PEEP), a strategy

that was proposed when ARDS was initially described in 1967.[28] Stefanidis *et al*. performed lung US in ten patients with ARDS to depict the nonaerated area in the dependent lung regions at different PEEP settings of 5, 10, and 15 cm H_2O. Sonographic assessment of the nonaerated lung area and arterial blood gas analysis were performed simultaneously at the end of each period. The results indicated that nonaerated areas in the dependent lung regions were significantly reduced when increasing PEEP, and these changes were associated with a subsequent increase in arterial oxygen partial pressure. According to the authors, lung sonography can detect the nonaerated lung area changes during a PEEP trial of patients with ARDS. Thus, transthoracic lung sonography might be considered a useful clinical tool during ARDS management.[17]

A prospective study, including 40 consecutive patients with ARDS, demonstrated that LUS can be used as a reliable tool for assessing PEEP-induced lung recruitment at the bedside. A significant correlation was found between the ultrasound reaeration score and PEEP-induced lung recruitment measured by pressure-volume curves. The authors considered that LUS is not the sole method for PEEP titration because its failure to assess PEEP-induced lung hyperinflation.[29] Same authors compared lung reaeration measured by bedside chest radiography, and LUS in patients with ventilator-associated pneumonia treated by antibiotics. The study concluded that chest radiography was inaccurate in predicting lung reaeration. LUS accurately estimates lung reaeration in patients with ventilator-associated pneumonia on antibiotic therapy.[30]

ARDS affects children with an incidence of 12 cases/100,000 person-years with under-recruited lungs owing to inflammatory edema. Lung recruitment maneuvers are challenging and often performed by the critical care physicians and pediatric intensivists when CT or pulmonary mechanic measurements are not easily accessible.[31,32] Recently, lung ultrasonography has been applied successfully in critical care patients aiming to obtain reliable, fast, and continuous evaluation.[33] Santuz *et al*. reported a case of 2-month old infant with severe ARDS and lung recruitment maneuver assisted by LUS. This is the first report of a successful lung recruitment maneuvers using LUS in pediatric ARDS.[34] Sameshima *et al*. described a case of US-guided lung recruitment procedure applied in an infant with severe ARDS and advocated that the lung US-guided recruitment maneuvers in infants are a feasible and safe procedure.[35]

Lung ultrasound ability to predict prone positioning response in acute respiratory distress syndrome patients

PP has been accepted as one of the important therapeutic strategies for ARDS patients.[36] Several studies have shown that PP could improve oxygenation,[37,38] reduce ventilation-induced lung injury, and decrease mortality.[39,40] However, the method may involve risks of unintended extubation and hemodynamic disturbance.[41] It is important to assess the effectiveness of PP in patients with severe ARDS and to predict whether these patients can benefit from the procedure. Prat *et al*. assessed whether lung US is a useful tool in prediction of PP oxygenation response in patients with ARDS. According to their prospective study, 19 ARDS patients were assessed for at least 12 h[42] with six different ultrasonography windows. Patients were classified into two groups (responders/non responders) according to their oxygenation response to PP. The normal aspect of the anterobasal regions, evaluated by LUS, was significantly associated with the oxygenation response ($P = 0.0436$), with a positive predictive value equal to or near 100%.[18] A similar study showed that the PP LUS examination protocol can be used to predict PP potential and assess prognosis in patients with ARDS.[43]

A multicenter prospective study included 51 adult patients with severe and moderate ARDS and used LUS to assess oxygenation response to PP ventilation. LUS was performed at four time points, 1 h before (baseline) and 1 h after turning the patient to PP, 1 h before and 1 h after turning the patient back to the supine position. Regional lung aeration changes and ultrasound reaeration scores were assessed at each time. The authors reported negative results that oxygenation response after PP was not correlated with a specific LUS pattern.[44]

Lung ultrasound evaluates the prognosis of patients with acute respiratory distress syndrome

An early assessment of the severity of ARDS and identification of coexisting conditions are essential to implement the treatment and to improve the prognosis. Based on prospective data, Li *et al*. indicated that LUS had a positive correlation with the following "traditional parameters" used to assess the severity and prognosis of ARDS: Acute Physiology and Chronic Health Evaluation II score, Sequential Organ Failure Assessment score, and Clinical Pulmonary Infection Score. The authors concluded that LUS can be a valuable tool when evaluating the changes in pulmonary ventilation associated with ARDS, the severity, prognosis, and prediction of mortality in ARDS patients.[45]

The prognostic value of extravascular lung water indices for patients with ARDS is widely accepted.[46] Patients with high indexed EVLI have the more serious lung injury and a worse prognosis. Significant positive linear correlations between LUS and EVLW were found by a recent published prospective study. The authors concluded that LUS is a

simple and economic approach for predicting the prognosis of ARDS patients and can serve as a diagnostic marker of this disease.[47]

The limitations of lung ultrasound for acute respiratory distress syndromepatients

When applying LUS in ARDS patients, several limitations should be considered. First, the presence of draining tube and multicatheter can interfere with the appropriate placement of the transducer and reading of the result. Second, obesity may prevent clear imaging of targeted body area because of the rib cage thickness. Third, the technique's efficiency is limited in patients with subcutaneous emphysema or large thoracic dressings. Finally, subjectivity must be considered when interpreting the LUS according to the providers' skills and experience.[48]

Conclusions

The limitations of LUS are not essential when considering its diagnosis and prognosis capabilities for patients with ARDS. It is an easily available, user-friendly, and cost-effective medical technique that involves no ionizing radiation. It is complementary to bedside chest X-ray and reduces the need to use a CT scan. LUS is a helpful tool used to diagnose, treat, and predict the prognosis of ARDS patients.

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Conflicts of interest

There are no conflicts of interest.

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