Usefulness of ultrasound in the management of acute respiratory distress syndrome

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ABSTRACT

Acute respiratory distress syndrome (ARDS) is a life-threatening disease. Different imaging techniques have been used to diagnose and guide the ventilatory management of patients with ARDS. Chest ultrasound is a reliable tool to identify interstitial syndrome, lung consolidation, lung collapse, and pleural effusion. In addition, echocardiography is essential in the diagnosis of diastolic left ventricle dysfunction and the estimation of elevated ventricle filling pressures, which is necessary before diagnosing ARDS. Therefore, combining chest and heart ultrasound assessment is useful to diagnose ARDS and guide the ventilatory management of the disease. Available data in the literature suggest that protocol-based approaches should be implemented for the purposes of diagnosis and management.

Key Words: Acute respiratory distress syndrome, echocardiography, lung ultrasound

INTRODUCTION

Acute respiratory distress syndrome (ARDS) was first reported by Ashbaugh et al. as a life-threatening, severe, and refractory hypoxemia related to an acute alveolar and capillary damage.\(^1\) Its incidence ranges between 4.2 and 58 cases per 100,000 persons/year.\(^2-4\) The ARDS-related mortality is high and is reported from 36% to 44%.\(^3,5\) Therefore, the definition of ARDS has been regularly updated in order to improve and standardize the ventilatory and nonventilatory management.\(^6,7\) Common components of these different definitions include bilateral alveolar infiltrates that cannot be exclusively explained by either left ventricle dysfunction or fluid overload.\(^6,7\) Therefore, lung and cardiac imaging is important to establish the diagnosis of ARDS and, possibly, in evaluating the response to treatment. During the last few decades, chest X-ray and computed tomography (CT) of the chest have been widely used in patients with ARDS.\(^8\) Even though bedside chest X-ray is part of the diagnostic criteria for ARDS, several limitations exist.\(^8-11\) On the other hand, performing a CT chest requires moving the patient and is risky in severely hypoxemic patients.\(^10,12\) CT has been shown to be useful in identifying the distribution of the alveolar damage, assessing positive end-expiratory pressure (PEEP)-induced alveolar recruitment, and recognizing ventilator-induced lung injury.\(^8,12-14\)

Ultrasongraphy techniques are being increasingly used in the intensive care units (ICUs).\(^15\) These techniques are noninvasive and can be easily performed at the bedside. The current review addresses the usefulness of the technique for the management of patients with ARDS.

Diagnosis of acute respiratory distress syndrome

The definition of ARDS has been updated in 2012.\(^6\) Accordingly, the diagnosis of ARDS is based on clinical, radiological, and oxygenation criteria. The imaging criteria consist of bilateral opacities, not fully explained...
by effusion, lobar/lung collapse, or nodules. The ultrasound findings are closely correlated to the usual evolution of ARDS. In fact, the hallmark of the 1st week following pulmonary or extrapulmonary insult is the occupation of interstitial and alveolar space by protein-rich fluid. The proliferative phase follows the exudative phase and starts at the 2nd week with stabilization of the imaging findings. Starting from the 3rd week, the lungs evolve toward either fibrosis or resolution of the ARDS. Therefore, at the stage of interstitial syndrome with moderate aeration loss, lung ultrasound (LUS) shows vertical well-defined spacing lines starting from the pleural line and reaching the edge of the screen. These B1 lines reflect the thickening of the interlobular septa. In patients with significant aeration loss, these B lines become coalescent and are therefore labeled as B2 lines. Finally, lung consolidations with significant aeration loss appear as poorly defined hypoechoic areas, in which hyperechoic lines or pinpoint images related to air bronchogram can be identified. Heterogeneity is the hallmark of imaging abnormalities in ARDS. Therefore, these abnormalities should be screened bilaterally in 12 areas as previously described. Moreover, LUS has been shown to be useful to predict the onset of ARDS in several categories of patients such as those with chest trauma. The main differential diagnosis of ARDS is cardiogenic pulmonary edema. Several studies highlighted that LUS may be useful to make the distinction between these two conditions. In a prospective study including 58 patients (40 patients with pulmonary edema and 18 patients with acute lung injury or ARDS), Copetti and colleagues reported that alveolo-interstitial syndrome was found in all cases. However, pleural-line abnormalities, consolidation, spared lung areas, pleural effusion, and lung pulse sign were significantly more common in patients with noncardiogenic pulmonary edema.

Making the difference between acute respiratory syndrome and cardiogenic pulmonary edema based on LUS only is challenging. In fact, several studies mainly conducted in emergency departments suggest that most of the patients presenting with acute respiratory failure with B lines identified by LUS are diagnosed as cardiogenic pulmonary edema. In a prospective study conducted in a prehospital setting, Laursen et al. reported that in patients with acute respiratory failure, the identification of B lines had a sensitivity of 94.4% and a specificity of 77.3% to predict cardiogenic pulmonary edema. Therefore, several patients with ARDS and showing B lines on chest ultrasound might be mistakenly diagnosed as pulmonary edema. Therefore, combining LUS findings with echocardiography has been reported to be more useful in this regard. In fact, echocardiography is a useful tool to assess left ventricular diastolic function and left ventricular filling pressure and therefore can rule out elevated pulmonary artery occlusion pressure.

In a prospective study including 134 patients with hypoxic acute respiratory failure, Sekiguchi et al. reported that moderate-to-severe left ventricle function impairment, a minimal inferior vena cava diameter above 23 mm, and left-sided pleural effusion are in favor of cardiogenic pulmonary edema rather than ARDS in patients with bilateral B lines. In the group of patients with diastolic function assessment, the authors reported that ARDS is more likely in patients with E/e’ ratio ≤8.3.

**Ultrasound and ventilator management**

Lung protective strategies have been shown to be associated with improved outcome and less complications in patients with ARDS. Accordingly, low tidal volume should be delivered to all patients and high PEEP should be applied in patients with moderate-to-severe ARDS. Prone position should be attempted in patients with severe ARDS. The selection of the best level of PEEP has been challenging. Several studies have suggested that the level of PEEP might be adjusted according to the oxygenation parameters, whereas others suggested that it should be based on lung mechanics (lung compliance, plateau pressure, pressure–volume curve, and stress index). Imaging techniques, mainly chest CT, were also used to assess the effect of increasing the PEEP level on alveolar recruitment or overdistension. In the last decade, LUS has become a seductive method that can be taken as a surrogate of CT in this regard. In a prospective study including thirty patients with ARDS and ten patients with acute lung injury, Bouhemad et al. reported that LUS can be a useful tool to assess lung aeration after increasing PEEP level. Moreover, the assessment of the anterior, lateral, and posterior lung areas showed that the benefit from PEEP was mainly observed in the lower part of the anterior and lateral lungs as well as the upper and posterior part of the lungs. Total or partial reaeration of the consolidated lung was seldom observed and was more likely to occur in the lower parts of the lungs. Similarly, Rode et al. reported a significant positive correlation between the required PEEP to recruit subpleural consolidation and the lower inflection point identified on the pressure–volume curve. A significant correlation between the lung reaeration assessed by LUS and oxygen partial pressure has been also reported.

The improvement of lung aeration can also be achieved by recruitment maneuvers. Recent data suggest that LUS can be helpful to evaluate the effect of these maneuvers. In an experimental study, Li et al. reported that ultrasound-guided recruitment maneuver strategy results in significant improvement of lung reaeration when compared to oxygenation-guided strategy.

**Ultrasound and hemodynamic management**

Applying a high level of PEEP is a cornerstone of the open-lung ventilation strategy that has been shown to be...
Fluid management in patients with ARDS is challenging. Based on the results of a large randomized controlled trial, it has been shown that conservative fluid management is associated with significant increase of ventilator-free days. However, applying a strict conservative fluid management is usually difficult in patients with ARDS and hypovolemic status. In fact, one previous experimental study has shown that recruitment maneuver in hypovolemic pigs was associated with a significant decrease in the left end ventricular volume as well as the cardiac output. This negative effect was counterbalanced by improving the volemic status. Similarly, implementing this strategy in patients with septic shock who always require fluid resuscitation is challenging. In this regard, by using LUS, Caltabeloti et al. assessed the effect of fluid loading in patients with moderate-to-severe ARDS associated with septic shock in 36 patients. The authors reported a persistent worsening of the lung aeration despite transient improvement of the cardiac output and the oxygenation parameters. Therefore, bedside ultrasound assessment is a useful technique to assess the effect of fluid resuscitation on both hemodynamic status and lung condition, especially in a selected group of patients. In fact, the re-analysis of large randomized controlled trials data showed that the following two subphenotypes of ARDS can be identified: subphenotype 1 characterized by mild inflammatory response, in which mortality can be reduced with liberal fluid resuscitation, and subphenotype 2 characterized by increased inflammatory markers (interleukin 8, interleukin 6, and tumor necrosis factor r1), acidosis, shock, and vasopressor requirement, in which liberal fluid resuscitation is potentially harmful and associated with significant worsening of the outcome. Whether echocardiographic and LUS studies can be helpful to differentiate these two subphenotypes needs to be investigated.

Protoceol approach for acute respiratory distress syndrome

During the last few decades, protoceol sonography approaches have been established to improve ultrasound-based diagnostic strategies. The Bedside Lung Ultrasound in Emergency protocol has been elaborated to get an ultrasound-based systematic approach in patients admitted to the emergency departments with acute respiratory failure. The protocol includes different profiles including the B profile suggesting pulmonary edema. However, it does not provide enough criteria to make the difference between cardiogenic pulmonary edema and acute respiratory distress. Fluid Administration Limited by Lung Sonography protocol has been developed to add more details about basic echocardiography findings and to guide fluid resuscitation therapy accordingly. Similarly, there are no specific recommendations for the diagnosis of ARDS. Based on the Berlin definition of ARDS, combining clinical and imaging findings could be the best option in patients with hypoxemic acute respiratory failure. Therefore, the combination of LUS findings suggesting pulmonary edema with echocardiographic findings ruling out left ventricular dysfunction and increased left ventricular filling pressure could be useful to diagnose ARDS.

CONCLUSION

Ultrasound techniques are noninvasive and reproducible imaging tools that can be performed at the bedside. Currently available data in the literature suggest that these techniques are useful in patients with ARDS as they can help to establish the diagnosis, to optimize the ventilation settings, and to avoid hemodynamic compromise. Combining LUS and echocardiography is more helpful for the management of patients with acute respiratory syndrome.

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Conflicts of interest
There are no conflicts of interest.

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