Commentary

Lung ultrasound in acute respiratory distress syndrome and beyond

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Provenance: This is an invited Commentary commissioned by the Section Editor Zhiheng Xu (State Key Laboratory of Respiratory Disease, Guangzhou Institute of Respiratory Disease, Department of Intensive Care, The First Affiliated Hospital of Guangzhou Medical University, Guangzhou, China).

Comment on: Haddam M, Zieleskiewicz L, Perbet S, *et al*. Lung ultrasonography for assessment of oxygenation response to prone position ventilation in ARDS. Intensive Care Med 2016;42:1546-56.

Submitted Dec 03, 2016. Accepted for publication Dec 09, 2016.
doi: 10.21037/jtd.2016.12.74
View this article at: http://dx.doi.org/10.21037/jtd.2016.12.74

Lung ultrasound is still a relatively new technology, albeit one that has rapidly grown in popularity since the initial description of ultrasonographic evaluation of the pleura in the 1960s (1) and of the lung parenchyma in the 1980s (2). Lung ultrasound facilitates rapid bedside assessment by a clinician, augments the physical exam, and offers superior diagnostic accuracy than a chest radiograph for certain conditions (3-6). Since air scatters sound waves, much of lung ultrasound involves the evaluation of visual artifacts resulting from sonographic data processing. The slight movement of the visceral pleura against the parietal pleura creates a shimmering appearance on the screen that has been described as "lung sliding", and effectively rules out a pneumothorax or pleural effusion at the site of examination. The faint reverberations between the skin and the mirror-like reflector of the pleura cause the machine to display repeating horizontal lines as the delayed return of sound waves create the impression that multiple pleural interfaces exist at regular depth intervals. These "A line" artifacts confirm the presence of air, dramatically decreasing the likelihood of a consolidation or pulmonary edema at that location. Fluid in the alveoli or interstitial thickening cause a different reverberation artifact, with the sound waves trapped within the small diameter of an alveolus creating a laser-like vertical "B line" from the pleural surface (7).

In animal studies B lines correlate well with areas of increased extravascular lung fluid, and lung ultrasound images have excellent correlation with computed tomography (CT) scan findings in humans (3,8). There are, however, some significant limitations to lung ultrasound. Visualization of pleura and lung parenchyma may be impaired by shadowing from ribs, and the patient must be positioned appropriately to evaluate all of the lung fields recommended by the international consensus statement on lung ultrasound (9). While B lines are very easy to capture and count (10), identifying the varying pathophysiological conditions that result in subtle differences in B line appearance is still an art under development (11). Also, lung ultrasound can only detect pathology that reaches the lung periphery, since even a thin layer of normal lung parenchyma (or pneumothorax) will completely scatter the sound waves before allowing visualization of any deeper findings (8). Despite these limitations, the richness of data rapidly attained at the bedside with lung ultrasound is exciting.

Lung ultrasound offers a variety of advantages, especially when integrated into the bedside evaluation of patients and combined with other ultrasound examinations (12). Unlike chest radiography and CT, there is no ionizing radiation exposure, and use of lung ultrasound may

Table 1 Selected pleuro-pulmonary conditions detectable by lung ultrasound

Disorder	Lung ultrasound findings	Reported performance	References
Pneumothorax	Absence of lung sliding, absence of B lines, lung point	Sensitivity: 89% [88–91], specificity: 99% [98–99], diagnostic OR: 993	(4)
Pleural effusion	Anechoic fluid with posterior acoustic shadowing above diaphragm	Sensitivity: 93% [89–96], specificity: 96% [95–98]	(21)
Pneumonia	B' profile, A/B profile, consolidation, irregular pleural surface, dynamic air bronchograms	Sensitivity: 94% [89–96], specificity: 96% [94–97], + LR: 16.8 (7.7–370), – LR: 0.07 (0.05–0.10)	(5,17)
COPD/asthma	A profile with lung sliding	Sensitivity: 89%, specificity: 97%	(5)
Pulmonary edema	Diffuse B lines with intact lung sliding	Sensitivity: 93% [82–98], specificity: 89% [79–95]	(16)
ARDS	Heterogeneous B lines, ± lung sliding, subpleural consolidation	Sensitivity: 93–98%, specificity:78–100%	(3,5)
Interstitial lung disease	B lines in affected zones, B-7 for fibrosis, B-3 for ground glass	Unknown	(18)

OR, odds ratio; LR, likelihood ratio; ARDS, acute respiratory distress syndrome.

reduce the use of these other imaging techniques (13,14). Furthermore, increasing evidence supports superior diagnostic performance of lung ultrasound over chest radiography, such as when evaluating a pleural effusion (15), ruling out a pneumothorax in trauma (4), differentiating volume overload from an exacerbation of obstructive lung disease (16), or diagnosing pneumonia (17). The list of diseases that can be readily evaluated with lung ultrasound continues to expand, and now includes interstitial lung diseases (18), postoperative atelectasis (19), and diffuse alveolar hemorrhage (20). A selection of conditions that can be identified by lung ultrasound is shown in the *Table 1*. In settings such as the emergency department or the intensive care unit the real-time information provided can be very useful for urgent clinical decision-making. As a battery powered, portable, durable, and versatile tool, lung ultrasound can serve as a useful diagnostic modality in a wide range of clinical environments, including those where resources are limited (22).

The evaluation of the patient suffering from the acute respiratory distress syndrome (ARDS) is of particular interest in light of the high mortality associated with this condition. The original description of the ultrasonographic appearance of ARDS by Lichtenstein described diffuse B line artifacts, which unfortunately overlapped with the appearance of cardiogenic pulmonary edema (5). This problem is not unique to ultrasound, as the radiographic pattern of ARDS on chest radiograph is also indistinguishable from cardiogenic pulmonary edema. While this can create challenges in the use of lung ultrasound to diagnose ARDS (23), there are certain findings that may allow the skilled user to distinguish the two entities (24). Lung ultrasound may also inform epidemiological investigations of the prevalence of ARDS in locations where radiography or CT is not available or easily accessible (25).

A large multi-center trial showed that prone positioning decreases mortality in ARDS (26). While prone positioning is also known to improve oxygenation in ARDS, the actual mechanism of improvement in mortality is not clearly understood (27). Theoretically, the bulk of the benefit comes from aeration of atelectatic portions of the lung that are recruited when no longer gravitationally dependent. Identifying which patients would benefit most from prone positioning would be advantageous. Currently, the gold standard for assessing regional atelectasis is a CT scan, but it is limited by costs, risks of transportation, and radiation exposure. In a recent study, Haddam *et al.* evaluated whether lung ultrasound could predict which patients with ARDS would most improve their gas exchange after prone positioning (28). They serially evaluated the lung abnormalities seen on ultrasound in each of 12 lung zones before, during, and after prone positioning in order to calculate discrete regional and global aeration scores at each timepoint, change in discrete scores (reaeration scores) with change in positioning, and to categorize patients with focal ARDS. The authors found that there was no correlation between aeration scores at baseline or in the reaeration scores with an oxygenation response after prone positioning. Furthermore, there were no differences in global reaeration scores based on the focal or non-focal distribution of ARDS.

There are several possible explanations for these null associations. First, the scoring system used may be problematic for the specific question addressed, as B lines—which, along with sonographic evidence of dense consolidation, were used to reflect increasingly abnormal lung parenchyma—are reflective of a diverse set of pathologies including pulmonary edema, pneumonia, or multiple processes other than atelectasis (7). Second, changes in the appearance of B lines, which would alter the reaeration score, could be due to changes in aeration, hyper-aeration, or extra-vascular lung fluid. Third, although lung ultrasound has been shown to correlate well with CT findings in ARDS (3), it can be challenging to define focal or diffuse patterns, especially if the pathology does not reach the periphery. Fourth, since the authors used the highest lung score for each of the 12 lung zones they evaluated, even a diffuse pattern may include considerable heterogeneity, as reported in previous studies of lung ultrasound and ARDS (24). Finally, even if lung ultrasound successfully detected changes in aeration, prior studies utilizing CT have shown that aeration changes are not sufficient to identify which patients will have improvements in gas exchange (29).

The results of the study suggest that the mechanism for improvement in gas exchange with prone positioning is a complex process involving both perfusion and aeration—as has been suggested by other analyses of the physiologic mechanisms in play during prone positioning—not simply reaeration of previously dependent tissue alone (30). Perhaps more importantly, the study continues the important process of defining the utility and performance of ultrasound in the evaluation of specific clinical questions about lung disease. In the future this will allow more effective studies to be performed in circumstances where radiography and CT imaging are not available or feasible.

A remaining challenge is how best to integrate lung ultrasonography into clinical practice. While several studies have demonstrated the diagnostic utility of lung ultrasound, using the modality to predict clinical responses—such as in the study by Haddam *et al*.—may be more difficult. Presently there is marked variability in the clinical utilization of lung ultrasound, ranging from extensive sonographic examinations of patients with respiratory symptoms to use of the tool only for procedural guidance. Notably, in contrast to many technological advances in medicine, lung ultrasound may increase the amount of time that the clinician spends with the patient. This secondary effect may result in additional benefits. Overall, the portability, real-time information provided, and absence of radiation of the modality, along with decreasing costs and ongoing improvements in the technology, increase the likelihood that lung ultrasound will become an essential tool for the evaluation of pulmonary disease in the years ahead.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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Cite this article as: Baston C, West TE. Lung ultrasound in acute respiratory distress syndrome and beyond. J Thorac Dis 2016;8(12):E1763-E1766. doi: 10.21037/jtd.2016.12.74