

# Lung Ultrasound for Diagnosing Patients with Severe Dyspnea and Acute Hypoxic Respiratory Failure

MOHAMMAD ARABIAT, MD; ANDREW E. FODERARO, MD; ANDREW T. LEVINSON, MD, MPH

## ABSTRACT

Acute hypoxic respiratory failure can be caused by severe pneumonia, cardiogenic pulmonary edema (CPE), and acute respiratory distress syndrome (ARDS). Differentiating between these causes in critically ill patients can be challenging. Lung ultrasound (LUS) evaluation of acute respiratory failure has been developed and adopted only recently. LUS offers promise as a valuable clinical tool for the diagnosis and treatment of patients with severe dyspnea and acute hypoxic respiratory failure.

**KEYWORDS:** lung ultrasound, point-of-care ultrasound, pneumonia, cardiogenic pulmonary edema (CPE), acute respiratory distress syndrome (ARDS)

## INTRODUCTION

Acute respiratory failure is a common problem encountered on a daily basis caring for critically ill patients. While diagnostic imaging is commonly obtained in order to reach a diagnosis in a timely manner in the critically ill patient, some of the imaging techniques, including computed tomography (CT) and routine chest radiography (CXR), have significant drawbacks. These drawbacks include cost, radiation exposure, and the need for transportation across the hospital.

The increasing availability of point-of-care ultrasound equipment as well as technical expertise has opened a door into new areas of bedside diagnostics. Although lung ultrasound (LUS) is unlikely to replace commonly used imaging modalities, it has become a valuable tool in the care of the critically ill patients. LUS performed by the physician taking care of the patient allows for the direct correlation of imaging findings to the clinical presentation.

LUS has been shown to significantly reduce the number of chest radiographs and CT scans obtained in the ICU.<sup>1</sup> In addition, lung ultrasound has been shown to maintain diagnostic accuracy in differentiating various causes of acute respiratory failure, including pneumothorax, lung consolidation, and alveolar-interstitial syndrome.<sup>2</sup>

## BASIC LUNG ULTRASOUND

Air is a strong ultrasound beam reflector. Lung ultrasound depends on artifacts in the detection of different lung pathologies. The high frequency linear transducer (5–12 MHz) can be used to detect the pleural line and the lung parenchyma immediately below the pleural line. The low frequency microconvex or convex transducers (2–5 MHz) can be used to visualize the pleural line as well as deeper lung parenchyma. Current techniques for performing complete lung scanning using standard point-of-care ultrasound machines and transducers can be learned quickly and specific methods and protocols are well described in the literature.<sup>1</sup> Which transducer is best for lung ultrasound is currently controversial.<sup>3</sup>

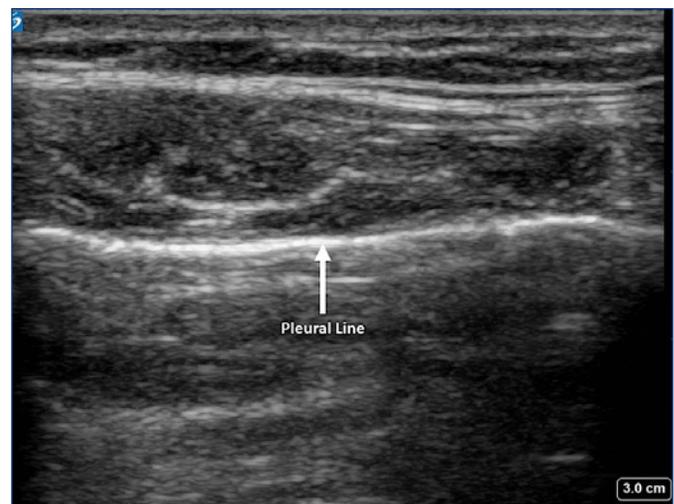
## NORMAL LUNG ULTRASOUND FINDINGS

Normal LUS findings include the Bat sign, lung sliding, A-lines, and B-lines.

The Bat sign occurs when, as the probe is placed longitudinally, the pleural line can be visualized as a horizontal hyperechoic line between the two adjacent ribs (Figures 1 and 2).

A-lines are horizontal single or multiple hyperechoic lines that are parallel to the pleural line and perpendicular to the

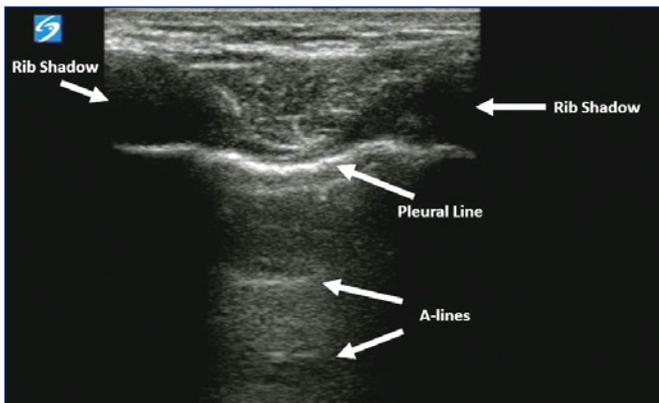
**Figure 1.** The pleural line is visualized as a horizontal hyperechoic line at the top of the image. This is the area where lung sliding can be seen on real-time imaging.



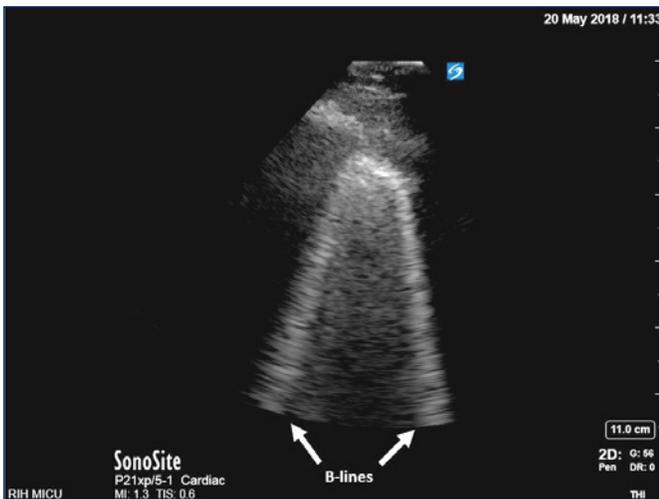
ultrasound beam. These lines represent repetitive reverberation artifacts of the pleura. Visualizing A-line confirms the presence of air, which can be alveolar or pleural in location (Figure 2).

Lung sliding is the movement of the parietal pleura against the visceral pleura. The absence of lung sliding can be the result of pleural separation from pneumothorax, or pleural adhesions due to lung pleurodesis or fibrotic lung disease, as well as non-vented lung from right main stem intubation or collapse.

**Figure 2.** "Bat sign" and A-lines: The bat sign is formed by the pleural line between the two adjacent ribs with hypoechoic areas below the ribs due to rib-shadow artifact. A-lines, seen below the pleural line, are horizontal single or multiple hyperechoic lines that are parallel to the pleural line and perpendicular to the ultrasound beam. These lines represent repetitive reverberation artifacts of the pleura. They are a normal finding in healthy lung.



**Figure 3.** B-lines: Vertical hyperechoic lines that originate from the interface of the pleura extend down to the bottom of the screen. B-lines represent a filling process of the interlobular septa, and can be seen in acute cardiogenic pulmonary edema (CPE), acute respiratory distress syndrome (ARDS), pneumonia and pulmonary fibrosis.



B-Lines are vertical hyperechoic lines that originate from the interface of the pleura, extend down to the bottom of the screen and move with lung sliding while effacing A-lines. Although the presence of two or less B-lines in a single view can be normal, they can also represent a pathologic process including a filling process of the interlobular septa, often seen in acute cardiogenic pulmonary edema, acute respiratory distress syndrome (ARDS), pneumonia and pulmonary fibrosis among others (Figure 3). These abnormal findings usually are represented by a higher number of B-lines in each ultrasound window view.

**LUNG ULTRASOUND FEATURES OF PNEUMOTHORAX**

There are a variety of LUS findings associated with pneumothorax. The visualization of lung sliding accurately rules out pneumothorax at the site of the transducer, but its absence does not necessarily confirm it.<sup>4</sup> In addition, the point at which the two pleural linings detach from each other is called the "lung point." The identification of a lung point is a 100% specific for pneumothorax and 66% sensitive.<sup>4</sup> Finally, as B-line arise from the visceral pleura, the appearance of even a single B-line rules out pneumothorax at the site of the transducer.<sup>5</sup>

**ULTRASOUND FEATURES OF SEVERE PNEUMONIA AND PULMONARY EDEMA**

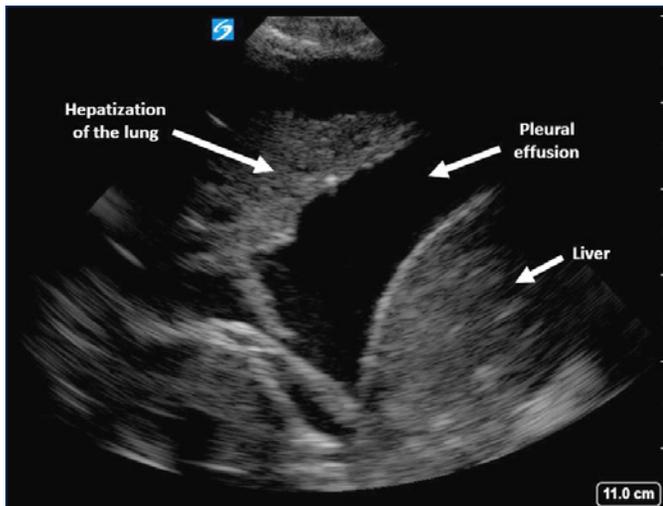
Lung ultrasound continues to grow as a tool for the evaluation of respiratory failure, including for the evaluation of common causes of dyspnea such as pneumonia and pulmonary edema. As discussed above, the normal lung findings include lung sliding, A-lines, and a small number of B-lines. When utilizing LUS to diagnose pneumonia and pulmonary edema, it is important to consider the etiologies for respiratory failure in these conditions.<sup>6</sup> Predominant findings found on LUS in patients with severe pneumonia and pulmonary edema include alveolar filling and interstitial or septal abnormalities.<sup>7</sup>

Findings in severe pneumonia on LUS include translobar alveolar consolidation (sonographic hepatization of the lung Figure 4), nontranslobar alveolar consolidation (shred or fractal sign), sonographic air bronchograms, alveolar-interstitial syndrome (AIS), and lung pulse.

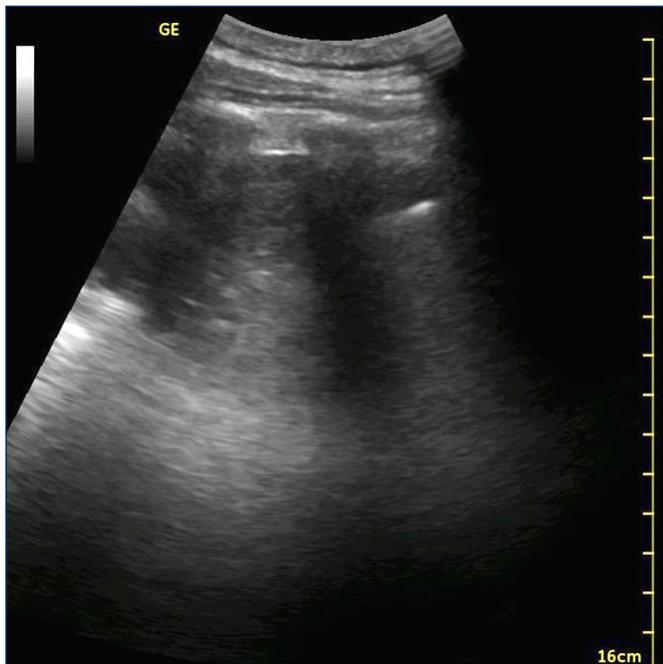
Translobar and nontranslobar pneumonia vary with the extent of disease. Translobar alveolar consolidation of the lung (sonographic hepatization of the lung) represents consolidation of an entire lobe or more (Figure 4). Nontranslobar alveolar consolidation (shred or fractal sign) represents less extensive pneumonia involving a localized area or sub-segment of a lobe of the lung (Figure 5). The differences in location and extent of consolidation result in unique ultrasound findings. With translobar pneumonia, sonographic

hepatization is apparent, which represents acoustic impedance to ultrasound waves due to alveolar filling from inflammatory exudates, which gives an appearance similar to that of the liver. The less extensive nontranslobar pneumonia has areas of alveolar filling adjacent to areas of normal aerated lung. The LUS findings of hypoechoogenic regions separated by an irregular line from normal lung findings result

**Figure 4.** Translobar alveolar consolidation of the lung with sonographic hepatization of the lung. The lung at the top of the screen is surrounded by a pleural effusion. At the bottom of the screen is the dome of the diaphragm and below that the liver. The appearance of the lung in this patient with lobar pneumonia appears similar to that of the liver.



**Figure 5.** Shred sign found in non-translobar pneumonia: In this image there is a relatively normal area of hypoechoogenic lung on the lower right and abnormal consolidated area on the lower left.



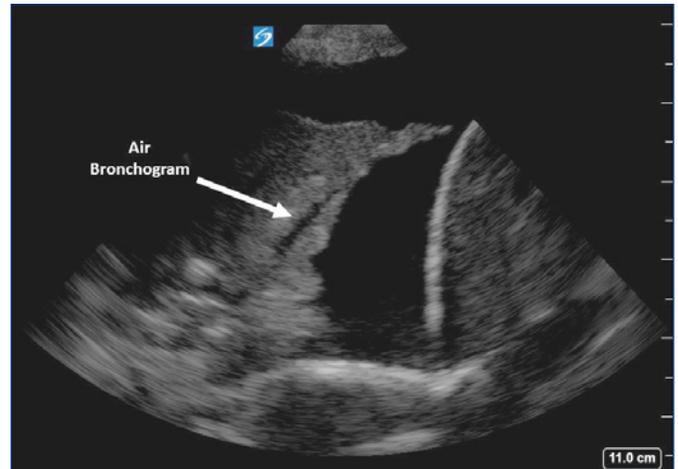
in the “shred” sign. The stark difference between hypoechoic and normal areas create a linear abnormality which can resemble a shredded piece of paper, which is why it is termed the shred sign.<sup>8</sup>

Other findings of pneumonia on ultrasound can be found in both trans and nontranslobar pneumonia. Sonographic air bronchograms appear similar to those seen on other radiographic techniques (Figure 6), including chest computed tomography scans. The air-filled bronchi become visible due to surrounding alveolar filling. Another finding which can be seen, especially in early pneumonia, is Alveolar Interstitial Syndrome (AIS), which is interstitial edema, represented by B lines (Figure 7).

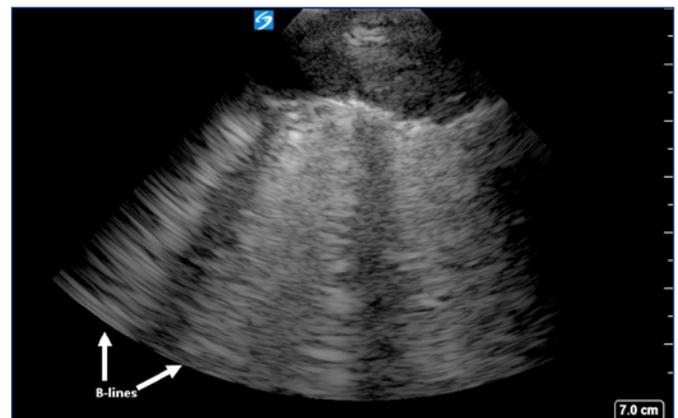
Combining the above findings with a history of infectious respiratory symptoms is suggestive of pneumonia. There are multiple studies that have shown LUS to be comparable or even more accurate than chest X-ray in diagnosing pneumonia when compared to computed tomography as the gold standard.<sup>9</sup>

The other major cause of respiratory failure which can be

**Figure 6.** Dense translobar consolidation with air-bronchogram with surrounding pleural effusion.



**Figure 7.** B-lines in a patient with pneumonia with alveolar-interstitial syndrome (AIS).



evaluated by LUS is left-sided heart failure with resultant pulmonary edema. Using the common LUS findings of A lines and B lines can help to differentiate pulmonary edema from normal aerated lung. Left-heart failure results in a combination of interstitial and septal edema, alveolar filling, and pleural effusions related to increased hydrostatic pressure.<sup>10</sup>

The LUS findings that are predominate in pulmonary edema are >2 B-lines in multiple lung fields. These B-lines are generally vertical, well defined, and extend from the pleural line with movement with lung sliding.<sup>11</sup>

### DIAGNOSING ETIOLOGIES OF SEVERE DYSPNEA WITH LUS

Acute dyspnea, especially in patients with comorbidities, is an extremely challenging clinical diagnosis to make, even for the experienced clinician. Multiple studies have found that chest radiograph, clinical examination, and the use of N-terminal pro-brain-type natriuretic peptide for differentiating between various etiologies of dyspnea are often quite inaccurate, with corresponding sensitivities of 50–60%. Treating patients for multiple possible causes (aka “triple therapy,” giving diuretics, antibiotics, and steroids) can be quite costly for the healthcare system as a whole and have significant negative side effects for individual patients.

Differentiating cardiogenic from non-cardiogenic pulmonary edema can be especially diagnostically challenging. Multiple studies have shown that brain-type natriuretic peptide (BNP), NT-proBNP, chest radiograph, and common physical examination findings are inaccurate for identifying and excluding patients with CPE, with sensitivities and specificities ranging from 50% to 60%.<sup>12</sup> In addition, meta-analyses show that BNP is inconclusive for ruling out acute CPE.<sup>13</sup>

LUS has been recently shown to be a very useful tool in helping to diagnose the etiology of dyspnea in non-critically ill patients. In one recent study of 152 patients admitted to a medical floor with a diagnosis of dyspnea, a definitive diagnosis was made by blinded reviewers of all available clinical evidence. Lung US and pro-BNP levels were obtained on admission and at 48 hours. The study found that Lung US findings (8 or more B-lines on LUS) was significantly better than utilizing BNP to diagnose CHF as the cause of dyspnea in patients admitted to the medical floor.<sup>14</sup> Another recent study in internal medicine patients examined 150 patients also admitted to the medical wards with acute dyspnea. Utilizing a blinded reviewer with access to the complete medical record as the “gold standard”, the study examined the predictive value of LUS findings compared to clinical exam and CXR findings alone to differentiate respiratory and cardiogenic etiologies for the patient’s dyspnea. The authors concluded that LUS greatly improved the accuracy of the clinical diagnosis of patients admitted to the general wards with acute dyspnea. The study also found that LUS diagnostic accuracy for the diagnosis of pneumonia was better than

chest X-ray.<sup>15</sup> A recent systematic review also found that lung ultrasound using B-lines had high sensitivity and specificity in the diagnosis of acute cardiogenic pulmonary edema.<sup>11</sup> Finally, a study in emergency department patients presenting with acute dyspnea found that LUS combined with point-of-care cardiac ultrasound was more sensitive for the diagnosis of heart failure; however, a standard evaluation without LUS was better in the diagnosis of COPD/asthma and PE.<sup>16</sup>

### DIFFERENTIATING SEVERE PNEUMONIA, CARDIOGENIC PULMONARY EDEMA, AND ARDS WITH LUS

Differentiating between severe pneumonia, CPE, and ARDS remains a diagnostic challenge in critically ill patients. LUS has been shown in many studies to have better predictive value than usual clinical practice in differentiating the causes of acute respiratory failure.<sup>11,14,15,17</sup>

Identification of pleural effusions on ultrasound can help differentiate CPE from ARDS. At the bedside, the use of ultrasound is more sensitive than chest radiograph for this identification.<sup>18</sup> The ultrasound finding of bilateral pleural effusions, especially if they are large, can be a rapid and effective diagnostic tool and in combination with interstitial syndrome can be suggestive of CPE from left-sided heart failure.

Specifically with regard to ARDS, the currently widely used Berlin definition requires 3 central criteria: “(1) Occurrence within 1 week of a known clinical insult or new or worsening respiratory symptoms; (2) bilateral opacities on chest imaging not fully explained by effusions, lobar/lung collapse, or nodules; and (3) respiratory failure not fully explained by cardiac failure or fluid overload, and need objective assessment (e.g., echocardiography) to exclude hydrostatic edema if no risk factor present.” Imaging to fulfill the second criterion is traditionally by CT scan and/or chest radiograph.<sup>19,20</sup>

Specific findings on LUS, such as bilateral opacities not fully explained by effusions, lobar or lung collapse, or nodules, may suggest the diagnosis of ARDS.<sup>21</sup> Other findings suggestive of ARDS include multiple bilateral lung regions with 2 or more B lines or bilateral consolidations.

One study found significantly increased diagnostic accuracy for ARDS using LUS as the imaging modality compared with chest radiograph, when thoracic CT scan was used as the gold standard.<sup>22</sup> Another study that compared chest radiograph and LUS found they were both equally useful in the identification of ARDS using the Berlin definition, although LUS was more accurate in predicting mortality.<sup>23</sup>

### CONCLUSION

Diagnosing the cause of acute respiratory failure in a critically ill patient can often be quite challenging, even for skilled providers. LUS is rapidly being adopted as a complementary

modality to conventional thoracic imaging techniques for critically ill patients with dyspnea or acute hypoxic respiratory failure. LUS can help elucidate rapidly the etiologies of acute respiratory failure and severe dyspnea. There is growing evidence for the use of LUS to help differentiate cardiogenic pulmonary edema, ARDS, and pneumonia.

### Acknowledgment

We are grateful to Taro Minami, MD, for his review of our ultrasound images.

### References

- Oks M, Cleven KL, Cardenas-Garcia J, et al. The effect of point-of-care ultrasonography on imaging studies in the medical ICU: a comparative study. *Chest*. 2014;146(6):1574-1577.
- Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest*. 2008;134(1):117-125.
- Lichtenstein DA. Current Misconceptions in Lung Ultrasound: A Short Guide for Experts. *Chest*. 2019;156(1):21-25.
- Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung sliding. *Chest*. 1995;108(5):1345-1348.
- Lichtenstein D, Meziere G, Biderman P, Gepner A. The comet-tail artifact: an ultrasound sign ruling out pneumothorax. *Intensive Care Med*. 1999;25(4):383-388.
- Lichtenstein D, Meziere G, Seitz J. The dynamic air bronchogram. A lung ultrasound sign of alveolar consolidation ruling out atelectasis. *Chest*. 2009;135(6):1421-1425.
- Lichtenstein DA, Lascols N, Meziere G, Gepner A. Ultrasound diagnosis of alveolar consolidation in the critically ill. *Intensive Care Med*. 2004;30(2):276-281.
- Biswas A, Lascano JE, Mehta HJ, Faruqi I. The Utility of the "Shred Sign" in the Diagnosis of Acute Respiratory Distress Syndrome Resulting from Multifocal Pneumonia. *Am J Respir Crit Care Med*. 2017;195(2):e20-e22.
- Ye X, Xiao H, Chen B, Zhang S. Accuracy of Lung Ultrasonography versus Chest Radiography for the Diagnosis of Adult Community-Acquired Pneumonia: Review of the Literature and Meta-Analysis. *PLoS One*. 2015;10(6):e0130066.
- Lichtenstein DA, Meziere GA, Lagoueyte JF, Biderman P, Goldstein I, Gepner A. A-lines and B-lines: lung ultrasound as a bedside tool for predicting pulmonary artery occlusion pressure in the critically ill. *Chest*. 2009;136(4):1014-1020.
- Al Deeb M, Barbic S, Featherstone R, Dankoff J, Barbic D. Point-of-care ultrasonography for the diagnosis of acute cardiogenic pulmonary edema in patients presenting with acute dyspnea: a systematic review and meta-analysis. *Acad Emerg Med*. 2014;21(8):843-852.
- Wang CS, FitzGerald JM, Schulzer M, Mak E, Ayas NT. Does this dyspneic patient in the emergency department have congestive heart failure? *JAMA*. 2005;294(15):1944-1956.
- Lam LL, Cameron PA, Schneider HG, Abramson MJ, Muller C, Krum H. Meta-analysis: effect of B-type natriuretic peptide testing on clinical outcomes in patients with acute dyspnea in the emergency setting. *Ann Intern Med*. 2010;153(11):728-735.
- Vitturi N, Soattin M, Allemand E, Simoni F, Realdi G. Thoracic ultrasonography: A new method for the work-up of patients with dyspnea. *J Ultrasound*. 2011;14(3):147-151.
- Perrone T, Maggi A, Sgarlata C, et al. Lung ultrasound in internal medicine: A bedside help to increase accuracy in the diagnosis of dyspnea. *Eur J Intern Med*. 2017;46:61-65.
- Zanobetti M, Scorpiniti M, Gigli C, et al. Point-of-Care Ultrasonography for Evaluation of Acute Dyspnea in the ED. *Chest*. 2017;151(6):1295-1301.
- Mantuani D, Frazee BW, Fahimi J, Nagdev A. Point-of-Care Multi-Organ Ultrasound Improves Diagnostic Accuracy in Adults Presenting to the Emergency Department with Acute Dyspnea. *West J Emerg Med*. 2016;17(1):46-53.
- Abraham AG, Althoff KN, Jing Y, et al. End-stage renal disease among HIV-infected adults in North America. *Clin Infect Dis*. 2015;60(6):941-949.
- Force ADT, Ranieri VM, Rubenfeld GD, et al. Acute respiratory distress syndrome: the Berlin Definition. *JAMA*. 2012;307(23):2526-2533.
- Komiya K, Ishii H, Murakami J, et al. Comparison of chest computed tomography features in the acute phase of cardiogenic pulmonary edema and acute respiratory distress syndrome on arrival at the emergency department. *J Thorac Imaging*. 2013;28(5):322-328.
- Corradi F, Brusasco C, Pelosi P. Chest ultrasound in acute respiratory distress syndrome. *Curr Opin Crit Care*. 2014;20(1):98-103.
- Lichtenstein D, Goldstein I, Mourgeon E, Cluzel P, Grenier P, Rouby JJ. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. *Anesthesiology*. 2004;100(1):9-15.
- See KC, Ong V, Tan YL, Sahagun J, Taculod J. Chest radiography versus lung ultrasound for identification of acute respiratory distress syndrome: a retrospective observational study. *Crit Care*. 2018;22(1):203.

### Authors

Mohammad Arabiat, MD, Division of Pulmonary, Critical Care and Sleep Medicine, Warren Alpert Medical School of Brown University, Rhode Island Hospital and the Miriam Hospital, Providence, RI.

Andrew E. Foderaro, MD, Division of Pulmonary, Critical Care and Sleep Medicine, Warren Alpert Medical School of Brown University, Rhode Island Hospital and the Miriam Hospital, Providence, RI.

Andrew T. Levinson, MD, MPH, Division of Pulmonary, Critical Care and Sleep Medicine, Warren Alpert Medical School of Brown University, Rhode Island Hospital and the Miriam Hospital, Providence, RI.

### Correspondence

Andrew T. Levinson, MD, MPH  
 Assistant Professor of Medicine  
 Miriam Hospital  
 164 Summit Avenue, Suite 227  
 Providence, RI 02906  
 401-793-4501  
[andrew\\_levinson@brown.edu](mailto:andrew_levinson@brown.edu)