Current Problems in Diagnostic Radiology 46 (2017) 305–316

ELSEVIER

Current Problems in Diagnostic Radiology

journal homepage: www.cpdrjournal.com

Thoracic Ultrasound: Technique, Applications, and Interpretation

Suraj H. Rambhia, MD*, Catherine A. D'Agostino, MD, Ali Noor, MD, Robert Villani, MD, Jason J. Naidich, MD, John S. Pellerito, MD

Department of Radiology, North Shore University Hospital, Northwell Health, Manhasset, NY

Thoracic ultrasound is used at the bedside in emergency and critical care settings. Advantages of ultrasound include rapid real-time, low-cost, diagnostic information that can direct patient care without the use of ionizing radiation. We describe methods on how to perform lung ultrasound, with the intent to educate the radiologist who might otherwise be relatively unfamiliar with thoracic sonography. We describe and depict the normal sonographic appearance of lung anatomy. We also show the sonographic appearance of a wide range of lung and pleural pathologies such as pneumonia, pneumothorax, as well as lung and pleural masses. We review various lines and signs described in the literature, such as A-lines, B-lines, the stratosphere sign, and the bat-wing sign. Finally, we correlate our findings with chest x-ray and computerized tomography to emphasize the anatomy.

Teaching Points

(1) Lung ultrasound is a valuable tool used by sonologists who practice largely in the emergency and critical care settings. Radiologists are beginning to increase their awareness of the growing role and importance of lung ultrasound as a bedside tool, as well as in the ultrasound suite as a means of directly probing the lung or characterizing pathology seen incidentally on abdomen, neck, or chest wall sonography.

(2) Proper technique can involve either curved or linear probes based on patient's body habitus and need superficial vs deep penetration into the lung. Combined B-mode and M-mode coupled with patient's clinical evaluation is imperative to performing a diagnostic examination.

(3) The presence of air in the lung results in reverberation artifacts called A-lines and B-lines that can both be seen in normal and pathologic settings. Although other types of lines and signs are described in the literature, recognizing the role of A-lines and B-lines in normal and abnormal pathology can help establish a foundation for understanding lung ultrasound.

(4) Formalized lung ultrasound protocols, such as BLUE and FALLS, have been established to allow for rapid assessment of patients in critical settings and provide clinical guidance at the bedside. These entities include dynamic evaluation to assess for fluid resuscitation of a patient in shock and multifaceted approach for evaluating of pulmonary embolism.

(5) Lung ultrasound can also be used for guidance of therapeutic procedures such as thoracocentesis as well as diagnostic procedures such as lung and pleural biopsies in real time.

Introduction

Thoracic ultrasound is a point-of-care tool used at the bedside in emergency and critical care settings to assess and triage patients with a wide variety of pulmonary pathologies. Specifically, lung and pleural ultrasound techniques have been developed to provide rapid real-time, low-cost, diagnostic information that can direct patient care without the use of ionizing radiation.[1-5] Several studies have described the value of lung ultrasound in select clinical situations compared to conventional thoracic imaging modalities such as chest radiographs and computed tomography (CT).[1-4] The clinical indications for lung and pleural ultrasound include, but are not limited to, dyspnea, hypercapneic or hypoxemic respiratory failure, undifferentiated shock, suspicion for pneumothorax, assessment of volume status, assessment of pleural effusions, evaluation for the presence of alveolar consolidation, diaphragmatic function, abnormal blood gas, trauma (FAST), pleural-based masses, as well as planning and guidance for an invasive thoracic procedure (Table). Often neglected, when performing dedicated ultrasound examinations of the abdomen, chest wall, or heart, is the lung that can be surveyed for evidence of pathology such as pneumonia, edema, chronic interstitial changes, pleural pathology, and pneumothorax.[4-6] Furthermore, increased use of lung ultrasound at the bedside has led to the development of collaborative guidelines to standardize lung ultrasound technique and provide uniform framework for a vast array of clinical entities around the world.[7]

Our approach for this discussion is to provide the reader with a guide for lung and pleural ultrasound image analysis. Here, we present an overview of the basics of lung ultrasound, describing normal and pathologic findings. We acknowledge and draw from the published literature that has been amassed by our emergency, critical care, and radiology colleagues. Their contributions provide the basis for dedicated lung and pleural ultrasound for a number of

* Reprint requests: Department of Radiology, North Shore University Hospital, Northwell Health, 300 Community Dr, Manhasset, NY 11030.

E-mail address: srambhia13@northwell.edu (S.H. Rambhia).

http://dx.doi.org/10.1067/j.cpradiol.2016.12.003

Table
Clinical indications for thoracic ultrasound

Dyspnea
Hypercapneic or hypoxemic respiratory failure
Undifferentiated shock
Suspicion for pneumothorax
Assessment of volume status
Assessment of pleural effusions
Evaluation for the presence of alveolar consolidation
Diaphragmatic function
Abnormal blood gas
Trauma (FAST)
Pleural-based lesion evaluation
Planning or guidance for an invasive thoracic procedure

clinical applications. This information also improves detection and recognition of incidental findings that can be seen on ultrasound examinations of the neck, chest, and abdomen.

Scanning Technique

Ultrasound of the lungs presents several challenges secondary to rib shadowing and limited penetration through air-filled lung parenchyma. Because of these challenges, lung ultrasound scanning uses a meticulous targeted approach. We maximize coverage with 5 major positions on the chest wall: upper anterior, lower anterior, lateral thorax in the mid-axillary line, upper posterior, and lower posterior medial to the scapular margin (Fig 1A). Standard curvilinear or high-frequency linear probe is positioned in either sagittal, transverse, or intercostal (oblique) position. Sagittal or transverse or intercostal probe orientation allows for optimization of the image with a given lung window (Fig 1B). When positioned in a rib interspace, mild pressure can be placed to splay the ribs and allow for optimization of the window. This allows for maximal coverage as the transducer is moved over the chest wall. High-frequency linear probes can also be used to provide increased definition of the chest wall anatomy, which includes the intercostal musculature, rib margins, and pleural anatomy (Fig 2).

Evaluation for pleural-based pathology is simultaneously performed at each of the 5 positions with attention to the apposition of the visceral and parietal pleura. Normal apposition of the visceral and parietal pleura results in a phenomenon termed "lung sliding." Pathology of the pleura, which can be seen using either curvilinear phased array or high-frequency linear transducers, includes pleural effusion, pleural thickening, and pleural irregularity. As a general rule, pleural effusions tend to localize dependently, and so the dynamic evaluation of pleural fluid as a patient changes from a supine to decubitus position can allow for rapid assessment of complexity of an effusion.

A combination of probe placement, probe selection, B-mode, M-mode, and clinical evaluation is used for complete thoracic ultrasound assessment. B-mode sonography is used for general visualization of pulmonary pathology. M-mode sonography allows for observation of dynamic changes of the chest wall and pleural surface oscillating at a different rate than the lung parenchyma. For example, a normal lung, demonstrating lung sliding on B-mode, will have a characteristic appearance on M-mode.

Lung Ultrasound Findings: Normal and Abnormal

Lung Sliding

Understanding of normal thoracic ultrasound anatomy begins with understanding the anatomy of the chest wall. As noted earlier, high-frequency linear transducers will provide increased definition of the intercostal musculature, rib shadows, and the pleural line, often producing the characteristic "bat-wing" sign (Fig 2). High-frequency transducers, while providing high superficial resolution, will often not penetrate deeper into the lung parenchyma. For this reason, a lower-frequency curved array probe is often used for providing a wider window with increased depth.[5] The normal lung will demonstrate sliding of the visceral and parietal pleura, which can be seen in real-time with standard cine clip recording. Presence of lung sliding has high specificity for the exclusion of pneumothorax[8,9] and can be readily visualized in real-time with standard cine clip recording (Video Clip 1). However, although the absence of lung sliding in the setting of trauma is highly sensitive for the presence of pneumothorax, the absence of lung sliding has been described in other pathologies such as total lung atelectasis, pleuroparenchymal adhesions, one-lung intubation, and subpleural blebs or bullae.[10]

A-Lines and B-Lines

Use of a deeper-penetrating curved array probe at 4-5 MHz to interrogate a normal lung produces a characteristic line pattern, which is the result of acoustic reverberation artifact of normally aerated lung. The so-called A-line pattern presents as several echogenic parallel lines emanating deep to the pleural surface. The distance between the "A-lines" is equal to the skin to pleural surface distance (Fig 3). Normal A-line pattern of the lung is presented in contrast with contralateral large pleural effusion in a patient with lung adenocarcinoma (Fig 4). The absolute lack of A-line reverberation artifact of the contralateral lung in Figure 4 is due to the lack of aeration, what we often refer to as atelectasis. In contrast, dynamic loss of A-line pattern with expiration is seen in pneumothorax and has been described as the "lung point" sign. In this process, the partially aerated, partially collapsed lung comes into and out of view of a fixed transducer providing the clinician with an intermittent A-line pattern in the field of view. The M-mode counterpart to the "lung point" sign is referred to as the "stratosphere sign."

B-lines, also described as "lung-rockets," emanate perpendicularly from the pleural surface and in isolation, can be seen in normal aerated lung as well. However, with increasing number, generally above 3 per interspace, suspicion for alveolar-interstitial lung process rises (Fig 5).[4,11-14] A gradual change in the characteristic line pattern from parallel A-lines to perpendicular lines known as "B-lines" is seen in patients who transition from having "dry-interlobular septa" (A-line predominant pattern) to "wet-interlobular septa" (B-line predominant pattern). Intensive care unit-based studies in mechanically ventilated patients have demonstrated that patients with A-line predominant pattern have a 93% positive predictive value for a pulmonary capillary wedge pressure (PCWP) less than 13 mm Hg and an even higher 97% positive predictive value for PCWP less than 18 mm Hg.[14,15] For this reason, an A-line predominant pattern is correlated with a PCWP less than 18 mm Hg,[15] and a patient with an alveolar-interstitial syndrome will often show a transition from A-lines to B-lines more dependently.

Along these lines, lung ultrasound has been reported as a way of diagnosing neonatal respiratory distress syndrome early on, before chest radiographic findings.[7,16] A case of a newborn premature infant with respiratory distress syndrome is presented (Fig 6) with chest x-ray comparison. Normal A-line pattern is seen primarily of the right upper lung; however, change in the lung parenchymal line pattern from A-lines to B-lines is noted of the right lower lung, likely representing dependent interstitial edema.