Ultrasound for the Pulmonary Consultant

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ABSTRACT: Bedside ultrasonographic assessment of the lung and pleura provides rapid, noninvasive, and essential information in diagnosis and management of various pulmonary conditions. Ultrasonography helps in diagnosing common conditions, including consolidation, interstitial syndrome, pleural effusions and masses, pneumothorax, and diaphragmatic dysfunction. It provides procedural guidance for various pulmonary procedures, including thoracentesis, chest tube insertion, transthoracic aspiration, and biopsies. This article describes major applications of ultrasonography for the pulmonary consultant along with illustrative figures and videos.

KEYWORDS: lung ultrasonography, pleural ultrasound, thoracic ultrasound, lung sliding, diaphragm dysfunction

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Introduction

Lung ultrasonography has become an indispensible extension of bedside physical assessment and provides valuable information about lung and pleural structures and the ability to assess volume status. The bedside clinician is able to approach the dyspneic patient and rapidly come up with a differential diagnosis when guided by lung ultrasonography.[1] This is in large part due to the work of Dr Daniel Lichtenstein who has given us the foundation for lung ultrasonography.[2] In this article, we discuss the use of ultrasonography in diagnosing and managing common clinical conditions encountered by pulmonologists and the use of ultrasonography to guide common procedures performed by pulmonologists.

Equipment

A phased array transducer (frequency range 3.5–5.0 MHz) is used for examination of the thorax. A high-frequency linear vascular transducer (frequency range 7.5–10.0 MHz) is preferred for closer examination of the pleural surface and chest wall structures.[3] A high-frequency ultrasound probe improves resolution of superficial structures; however, this probe is not suitable for the analysis of deeper thoracic structures. Both transducers are available on the majority of portable ultrasound machines, thus increasing the ease of examination (Fig. 1).

The lung and pleural structures are assessed using B-mode, while M-mode is used to assess pleural movement. The latter mode assesses the movement of structures over time. Doppler assessment is not required for examination of the thoracic cavity.

Technique

Lung ultrasound is best performed with the patient sitting up; however, this may not be possible in hospitalized patients where it is generally performed in supine or lateral positions. A basic knowledge of ultrasound machine control is important for ideal image acquisition. In particular, the examiner should have a good understanding of depth, gain, and image orientation. The transducer (probe) is held longitudinally with the marker facing cephalad. The transducer is moved between intercostal spaces while holding it firmly and perpendicular to the chest wall. Multiple scan lines are performed by sliding the transducer from one intercostal space to another. The scan lines should be performed methodically in order to develop a three-dimensional model of the thorax by examining various ultrasound planes. At least four scan lines should be performed, including mid-clavicular, anterior axillary, mid-axillary, and posterior axillary and examining more areas as possible.

Normal Lung

In a normally aerated lung, one should see a bright shimmering echogenic linear structure representing the pleural line. The depth and gain should be reduced on the ultrasound machine to examine the pleural line. The movement of this line represents movement of the visceral pleura against the parietal pleura and occurs either with respiratory cycle or with cardiac cycle. This normal movement of pleural line is called *lung sliding* when it results from respiratory cycling and *lung pulse* when it occurs with cardiac cycling (Video 1,2). The presence of lung sliding or lung pulse excludes pneumothorax

Figure 1. A high frequency linear transducer is shown on the left and a phased array probe is shown on the right.

Table 1. Main features of A-lines and B-lines.

A-LINES	B-LINES
Horizontal on screen	Vertical on screen, Comet tail or laser like
Parallel to the pleural surface	Perpendicular to the pleural surface
Parallel to each other and equidistant from each other at any interval corresponding to the distance between skin surface and pleural surface	Arise from the pleural surface and spread up to the edge of the screen, moving with lung sliding and lung pulse. Effface A- lines
Represent reverberation artifacts of a normal aerated lung when in the presence of sliding lung	Represents interstitial pattern in the lung when >3 are present in a single examination field

at the point of the probe with a negative predictive value of 100%.[4,5] Refer to section on pleural ultrasonography for a detailed review of pleural morphology and detection of pneumothorax.

Once lung sliding is confirmed, lung morphology should be assessed next by increasing the depth on the ultrasound machine. A normal aerated lung has a reverberation artifact known as A-line pattern (Fig. 2 and Table 1). The presence of an A-line predominant pattern bilaterally over the anterior chest suggests the absence of cardiogenic pulmonary edema as it has been found to indicate a pulmonary capillary wedge pressure (PCWP) of <18 mmHg.[6] Elevated PCWP produces another ultrasound artifact known as B-lines (Fig. 3, Video 3, and Table 1). These are also referred to as comet tail artifacts and represent the presence of an alveolar-interstitial syndrome.[7] However, it is common to see a few B-lines at the base of a normal lung. The presence of more than three B-lines in a single ultrasound examination field is considered significant and suggests alveolar interstitial syndrome, which may be from elevated PCWP, interstitial lung disease, or infectious etiology. The term *lung rockets* is used when diffuse B-lines are seen in a single scan field (Video 3). B-lines should start at the pleural line, move with the pleural line, come down to the edge of the screen, appear hyperechoic, and efface A-lines.

A common artifact seen on lung ultrasonography is *mirror image* artifact. It is seen when there is a highly reflective surface (ie, diaphragm) in the path of a primary beam, which reflects the beam at an angle. The ultrasound assuming that the waves are traveling in a straight line creates a virtual object, which mimics a true object on the other side of the reflective surface. For example, this would create a mirror image of the

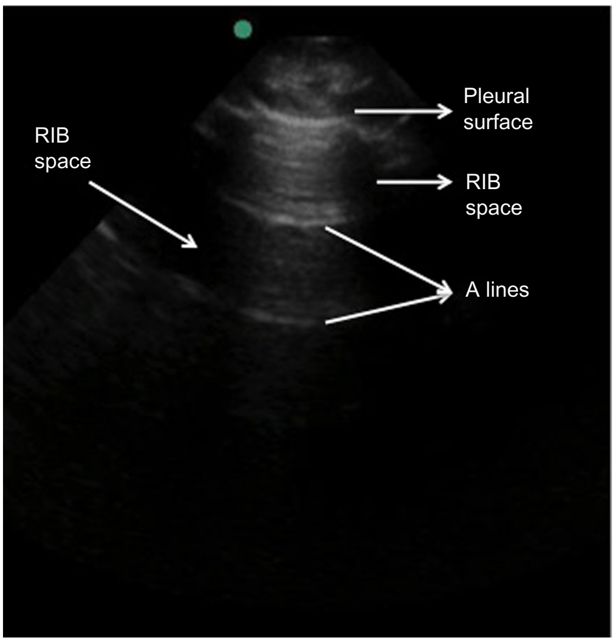

Figure 2. A lines on lung ulrasound.

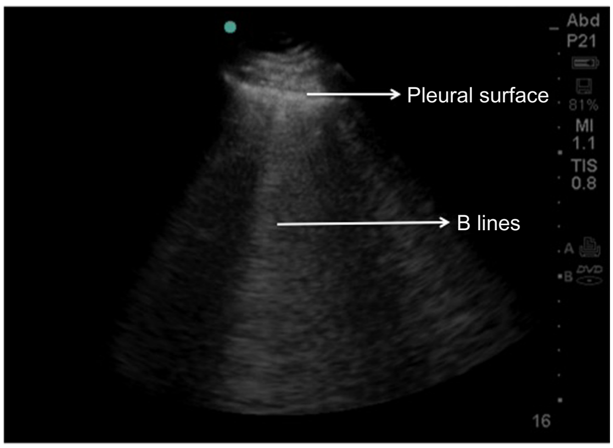

Figure 3. Profuse B lines.

liver on the opposite side of the diaphragm on the right. The mirror image is usually more hypoechoic and blurred than the original structure.[8]

Lung Consolidation

Lung consolidation pattern appears very differently than A-line pattern. The lung looks like liver and has a tissue density but is cephalad to the diaphragm. The consolidation pattern results in the formation of air bronchograms, which can be visualized on lung ultrasound as punctate echogenic foci. If they are dynamic in nature, ie, move with respiratory cycle, it is more likely to represent a consolidation of infectious origin (Video 4).[9] Using the ultrasound, the location and volume of consolidation can be mapped out. The ultrasound aids in examining areas that may be missed on chest X-rays, especially on supine, rotated films, routinely obtained in the hospitalized patients with limited mobility. The irregular, shaggy border between consolidated and normally aerated lung is known as "shred sign" (Fig. 4).[10] Subpleural consolidations are usually accompanied by pleural irregularities.

Atelectasis

Atelectasis has a pattern similar to lung consolidation with a tissue density and an echogenicity similar to that of liver or spleen. Air bronchograms may or may not be observed, when observed these are usually static, ie, do not move with respiratory cycle and are in contrast to dynamic air bronchograms seen in lung consolidation (Videos 4 and 5).[9] An elevated diaphragm can also be seen. A lung pulse can be seen in atelectasis, especially in acute atelectasis.[11]

A common example is postright mainstem intubation; on examining the left anterior chest wall, loss of lung sliding will be seen but with diffuse B-lines signifying atelectasis.

Lung Abscess

An abscess in the lung can be visualized within areas of consolidation using the ultrasound. They appear as masses with irregular borders of varying echogenicity with both anechoic and echogenic areas representing tissue necrosis (Video 6). Peripherally located abscess usually abut the pleural surface at an acute angle. An abscess not adjacent to the chest wall and surrounded by aerated lung will not be seen with lung ultrasound.

Lung Tumors

The ultrasound can be used to evaluate lung masses adjacent to the pleural surface. They usually appear as hypoechoic areas with normally aerated lung cephalad and caudad to the mass (Fig. 5 and Video 7).[12] Peripheral pulmonary metastases can appear as subpleural echogenic foci. Lung ultrasound is a particularly useful tool in evaluating for chest wall invasion, with Bandi et al.[13] showing higher sensitivity and specificity than chest CT using ultrasound for this purpose. Color Doppler flow signals can be used to differentiate between benign and malignant lesions as well.[14,15]

Acute Interstitial Syndrome

The presence of diffuse B-lines on several scan fields defines the ultrasonographic alveolar interstitial syndrome (Video 3).[7] The major causes of the interstitial syndrome include acute cardiogenic pulmonary edema, acute noncardiogenic pulmonary edema (acute lung injury/acute respiratory distress syndrome), and interstitial pneumonia. Lung ultrasound can aid in distinguishing between these three causes, and the differentiating features are summarized in Table 2. The study of pleural morphology and presence of subpleural consolidations mainly guide in distinguishing between these entities (Video 8). M-mode ultrasonography can be used

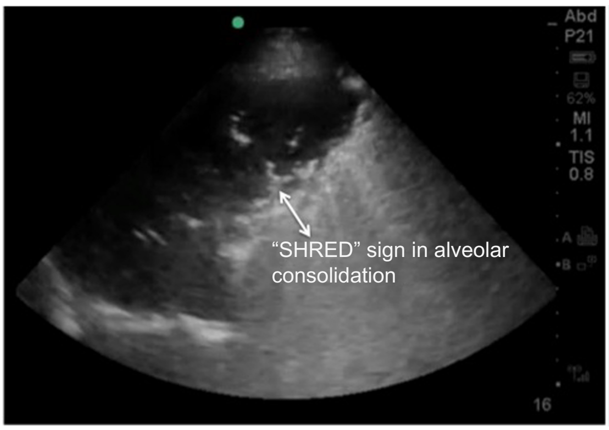

Figure 4. Lung consolidation with "Shred Sign" seen on ultrasound.

Figure 5. Lung mass seen on ultrasound.

to differentiate between the causes of alveolar interstitial syndrome and is currently being studied.[16]

Assessing Lung Recruitment Using Ultrasonography

Determination of optimal positive end expiratory pressure (PEEP) level in acute lung injury/acute respiratory distress syndrome (ALI/ARDS) remains challenging. Lung ultrasonography can be successfully used to titrate PEEP using lung aeration morphology in ALI/ARDS.[17] Lung morphology assessment in ALI/ARDS shows multiple or diffuse B-lines or consolidated pattern. On increasing the PEEP level, lung ultrasonography should be performed to detect loss of B-lines or loss of consolidation pattern. An optimal PEEP level can be determined by loss of B-lines and return of A-line predominance. The risk of over distention should be kept in mind during this uptiration of PEEP as lung ultrasonography cannot assess over distention.

Pneumothorax

Ultrasonography provides rapid and accurate assessment of pneumothorax. As discussed earlier, lung sliding or lung pulse (Videos 1 and 2) seen in the anterior lung fields bilaterally effectively rules out large pneumothorax as the cause of respiratory distress with a sensitivity of 95.3% and a negative predictive value of 100%.[4] However, the absence of lung sliding or lung pulse does not always indicate the presence of pneumothorax (specificity <80%) (Table 3).[5,18]

The presence of B-lines also rules out pneumothorax as these are generated by the visceral pleura.[19] It is important to note that in the case of pneumothorax, the pleural line visualized on ultrasound represents only the parietal pleura since the interposed air prevents visualization of the visceral pleura.

The most specific sign of pneumothorax is the presence of a lung point (Videos 9 and 10).[20] Lung point is the interface between normal lung sliding (or pathological B-lines) and pneumothorax pattern (absence of lung sliding with exclusive A-lines) that is seen during real time scanning and can be confirmed using M-mode (Figs. 6 and 7). During exhalation, a pneumothorax pattern is apparent, but during inspiration, a fleeting appearance of lung sliding is seen. This interface is the lung point and marks the location of the pneumothorax. The finding of lung point is 100% specific for pneumothorax but is only 66% sensitive.[20]

The location of lung point correlates with the size of the pneumothorax and correlates with the need for chest tube insertion.[20] An anterior lung point correlates with a small pneumothorax and is usually of limited clinical significance. However, a lung point that is located more laterally or posteriorly is usually indicative of a larger and more symptomatic pneumothorax that frequently requires intervention. Lung point is less likely to be detected if the pneumothorax is large with complete lung collapse because there is less likely to be apposition between the visceral and parietal pleura.

Ultrasound is more sensitive than traditional chest radiography at detecting a small pneumothorax.[5,21,22] As stated earlier, in a supine patient, air will distribute anteriorly, thus

Table 3. Causes of absent lung sliding besides pneumothorax.

PHYSIOLOGY	EXAMPLES	ASSOCIATED FINDINGS
1. Reduced movement of air into lung	Right mainstem intubation Mucous plug Foreign Body Tumor in mainstem bronchus Pneumonectomy	Complete atelectasis Presence of lung pulse
2. Impaired lung inflation	Extensive pneumonia Severe ARDS Acute lung fibrosis	Alveolar consolidation B lines
3. Pleural symphysis	History of pleurodesis Inflammatory or malignant pleural disease	Thickened pleura Associated pleural effusion
4. Apnea	Ventilator disconnect	Lung pulse B lines

Table 2. Differentiating features on lung ultrasound of various causes of alveolar interstitial syndrome.

	ACUTE CARDIOGENIC PULMONARY EDEMA	ACUTE LUNG INJURY/ACUTE RESPIRATORY DISTRESS SYNDROME	INTERSTITIAL PNEUMONIA
Clinical course	Acute or acute on chronic	Acute	Acute, subacute or chronic
B-lines	Multiple B lines bilaterally and diffusely especially in the anterior lung fields	Multiple, scattered diffuse B lines bilaterally. Can be heterogeneous with spared areas	Heterogeneous distribution, more at bases usually
Pleural surface morphology	Regular, smooth	Irregular	Irregular
Subpleural consolidations	Absent	Present	Either
Pleural effusions	Usually present and bilateral	Either	Usually absent
Echocardiogram	Abnormal	Normal initially	Can have signs of right ventricular dysfunction/ pulmonary hypertension if long standing

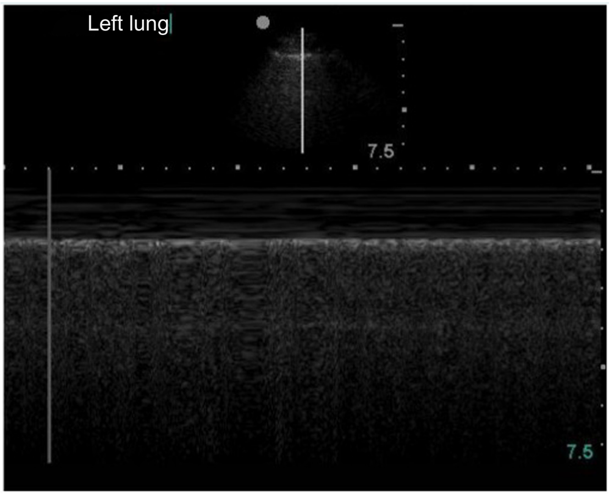

Figure 6. M mode showing "Seashore" sign seen with lung sliding.

allowing detection by ultrasound, which is likely to be missed by a supine radiograph. The use of ultrasound for the detection of pneumothorax is currently part of the extended focused assessment with sonography for trauma and has been shown to be superior to supine radiographs for the detection of occult pneumothorax.[23]

Pleural Ultrasonography

Pleural ultrasonography allows the evaluation of pleural effusions, pleural-based lesions, and guidance during pleural procedures, including thoracentesis. Pleural ultrasonography is performed with the same phased-array probe (3.5–5 MHz) and settings as for lung ultrasonography with the transducer marker pointing cephalad. This allows standardization during image projection as cephalad is always located to the left of the ultrasound machine screen/monitor.[24] Gain and depth are adjusted appropriately so that the chest wall and pleura are clearly visible. Depth may then be adjusted for near-field magnification of pleural anatomy as necessary. Higher frequency probes (7.5–10 MHz), such as the vascular probe, can be used for pleural evaluation, their main limitation being poor penetration.

Pleural ultrasonography has been shown to be superior to supine radiographs in detecting pleural effusions, with comparable performance to computed tomography scans.[25,26] Since pleural fluid typically accumulates in dependent areas, evaluation is straightforward in the upright patient. However, pleural ultrasonography may be more challenging in critically ill patients who have hemodynamic instability and are connected to numerous support devices, making the upright or lateral decubitus position difficult to obtain.[24] The operator is required to position the probe laterally and reach beyond the posterior axillary line, pointing to the ceiling as much as possible in order to visualize the dependent lung regions where pleural fluid and atelectasis will be found.[27]

When evaluating a pleural effusion, it is imperative to identify the key anatomic landmarks that surround the relatively echo-free space. These include the chest wall, diaphragm, underlying abdominal organ (liver or spleen), and dynamic motion of the consolidated lung with inspiration (Fig. 8). This collapsed lung is frequently seen undulating within the pleural effusion; this is termed "lung flapping" or the "jellyfish sign" (Video 11). In pleural effusions with cellular debris, one will find a "plankton" sign, in which the debris is agitated by cardiac or respiratory motion. In loculated pleural effusions, thick strands will be seen oscillating within the pleural space, also due to cardiac or respiratory motion (Fig. 9).

The size of the pleural effusion should be estimated based on where the effusion is found during ultrasonography. A small effusion will only be detected posteriorly in the supine patient, and the larger the effusion, the more anterior it will be detected.

The echogenicity of the pleural effusion must be carefully evaluated, as it may give a clue to the underlying etiology. Understanding the terminology of echogenicity is

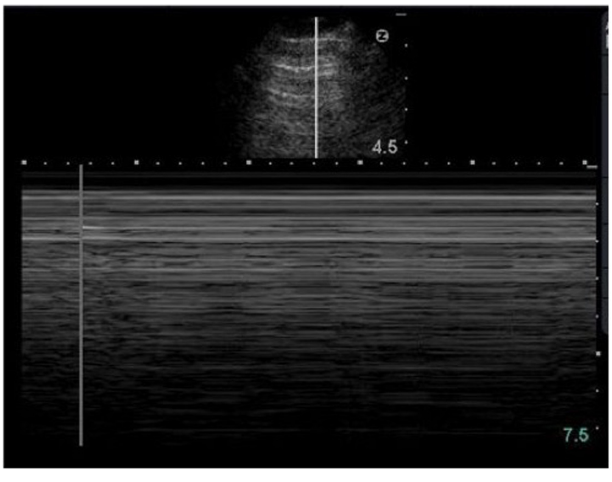

Figure 7. Stratosphere sign seen on M-mode in absent lung sliding.

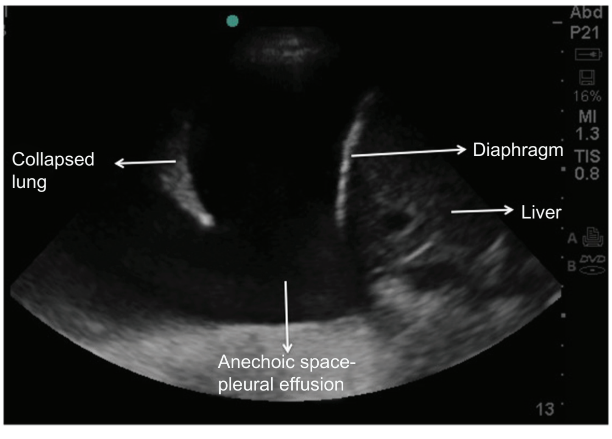

Figure 8. Pleural effusion with typical anatomical boundaries.

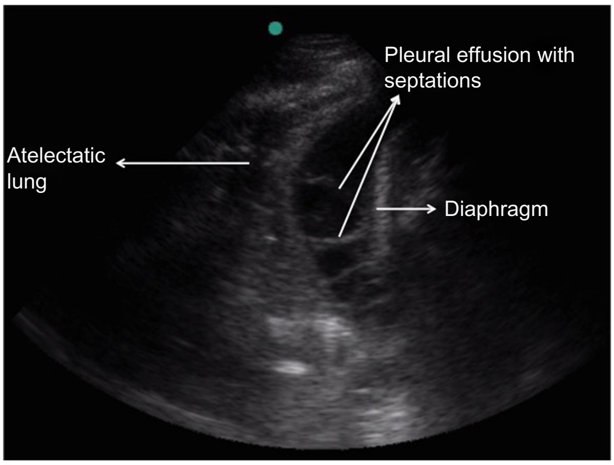

Figure 9. Complex pleural effusion with septation.

important. An anechoic effusion has no echogenicity within, a complex nonseptated pattern has evidence of complexity within the fluid but no fibrin strands or septations, a complex septated pattern has fibrin strands and septations within, and the homogenously echogenic pattern has evenly distributed hypoechoic density within the effusion (Figs. 8–10).[28,29] Although initial studies demonstrated that all transudative effusions are anechoic, a subsequent study revealed that transudative effusions may be either anechoic or complex nonseptated but never complex septated or homogenously echogenic.[28,29] On the contrary, exudative effusions may have any of the four patterns described. Homogenously echogenic patterns are characteristic of hemothorax (Fig. 10) or empyema, while sonographic evidence of pleural nodules (Fig. 11), associated parenchymal lesions, or pleural thickening is associated with exudative effusions. In patients with suspected malignant pleural effusion, findings consistent with malignancy include pleural thickening greater than 1 cm, pleural nodularity, and diaphragmatic thickening greater than 7 mm.[30]

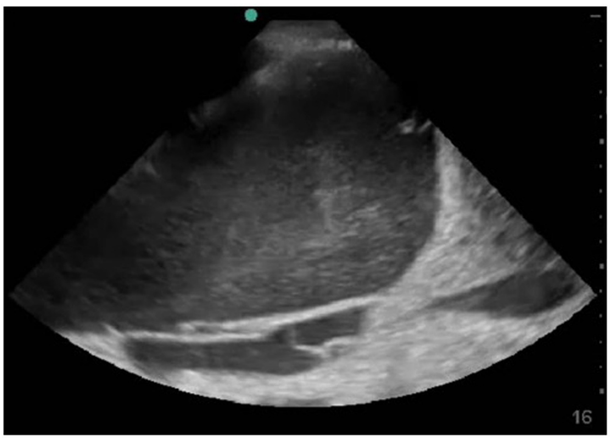

Figure 10. Echogenic Material with layering consistent with a hematocrit sign in hemothorax.

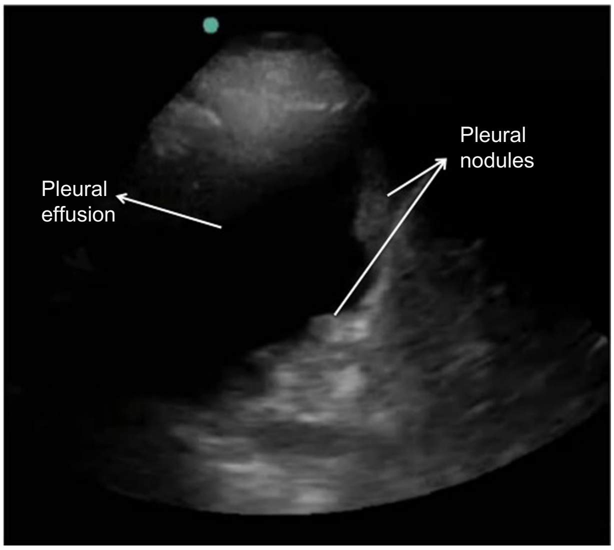

Figure 11. Image showing pleural nodules and a pleural effusion in a patient with metastatic lung cancer.

Ultrasonography for Thoracic Procedural Guidance

Thoracentesis/chest tube insertion. Ultrasound-guided thoracentesis or chest tube insertion is now standard-of-care, and the authors exclusively use ultrasound to guide access of the pleural space. Ultrasound-guided thoracentesis has been proven to have a significantly lower risk of pneumothorax (3%) compared to conventional thoracentesis (18%).[31,32]

In a consensus statement by the American College of Chest Physicians, it was recommended that the first objective in procedural guidance is identification of a pleural effusion with the typical anatomic boundaries and dynamic findings as discussed above.[33] Fluid must be characterized by its echogenicity, and the presence of strands, debris, septations, or hematocrit sign must be identified. A semiquantitative assessment should be made prior to drainage. Also, evaluation of the diaphragm is important as an inverted hemidiaphragm is consistent with a symptomatic pleural effusion with significantly elevated pleural pressure.[34] Pre- and postprocedural assessments of lung sliding should be performed to rule out pneumothorax, often not requiring postprocedural radiograph, especially in the spontaneously breathing patient.[35]

A special consideration is the mechanically ventilated patient in the supine position. Due to high risk of tension pneumothorax from iatrogenic pneumothorax in these patients, ultrasound-guidance is important to ensure pleural access with a safe window, such that there is no risk of puncturing the visceral pleura.[24] Thoracentesis in the mechanically ventilated patient has been repeatedly demonstrated to be safe when ultrasound guidance is utilized.[36–38] Patient positioning may include the lateral decubitus position or the supine position, as long as there is adequate visualization of the pleura.

As with nonultrasound-guided thoracentesis, a path for needle insertion along with the superior rib margin must be identified to avoid the neurovascular bundle that rides along the inferior rib margin. The site identified with ultrasound should be marked, and the angle at which the probe was positioned must be memorized by the operator so as to ensure access into the pleural space at the site desired.[24] This also allows the procedure to be performed without real-time ultrasound guidance with no increased risk for complications. Site preparation and thoracentesis should be performed soon after the site is marked and confirmed with ultrasound so as to minimize patient motion. It is also important to note the depth required for pleural access, understanding that the depth may be underestimated due to pressure applied with the probe, especially in obese and edematous patients.[3]

Ultrasound guidance is also useful for other pleural procedures, including chest tube placement for complicated parapneumonic effusions or empyema, tunneled intrapleural catheter placement for malignant pleural effusions, medical thoracoscopy, and mechanical septolysis.[24] Use of real-time ultrasound guidance may be useful to confirm guidewire or chest tube insertion (Video 12). In patients with empyema or complicated parapneumonic effusions who require insertion of tissue plasminogen activator and dornase, sequential pleural ultrasonography can give insight into the effectiveness of treatment in clearing the pleural infection, especially when used in conjunction with computed tomography. The benefit of pleural ultrasound in these settings is its superiority over chest radiography in the characterization of pleural anatomy and lack of radiation exposure.[3]

Transthoracic aspiration/biopsy. As discussed in the earlier section, ultrasound can detect pleural- and lung-based lesions that abut the chest wall. These can be accessed by the pulmonologist under ultrasound guidance. Both fine needle aspiration biopsies and cutting needle biopsies can be performed using lung ultrasonography with high degrees of sensitivities and specificities.[39,40] As with all procedures with a risk of pneumothorax, it is recommended to assess for lung sliding before and after the procedure. A peripheral lung abscess can also be drained using ultrasound guidance for either diagnostic or therapeutic purposes as determined by the clinician.[41]

Diaphragm dysfunction. Ultrasound has been increasingly used for diaphragm dysfunction assessment and can be used to assess structural and functional changes in the diaphragm. Performing diaphragmatic ultrasound is simple, and multiple studies have shown that there is minimal interoperator variability and good reproducibility.[42]

A 3.5–5 MHz phase array probe is used to look for the movement of diaphragm. A linear 6–13 MHz probe is used to assess diaphragmatic thickness and thickening ratios.

Initially, two-dimensional mode is used to visualize diaphragm, and then its motion can be assessed by applying M-mode, In two-dimensional mode, the probe is placed below the right costal margin in the mid-clavicular line, or in the right anterior axillary line, and is directed medially, cephalad, and dorsally. While visualizing diaphragm on the right side, lung and liver are used as acoustic window, and on the left, spleen and lung act as acoustic window. Using this technique, diaphragm moves toward the probe during inspiration.

On M-mode, diaphragmatic ultrasonography is performed using a subcostal approach, and a sinusoidal waveform is obtained representing movements of diaphragm during inspiration and expiration. Maximal displacement of diaphragm (in centimeters) during inspiration can be measured (Fig. 12). Time (in seconds) required to reach maximal contraction can be also obtained. Using time required to contract and knowing the displacement contraction velocity can be used. Also other parameters, such as contraction velocity (centimeter per second) can be calculated (Fig. 12).

Using M-mode at the site of apposition, diaphragmatic thickness during inspiration and expiration can be obtained. Using these measurements, thickening fraction can be measured (thickening fraction = thickness at end inspiration − thickness at end expiration/thickness at end expiration).

Diaphragmatic Ultrasonography in Clinical Practice

Diaphragmatic paralysis. Fluoroscopy has been traditionally used for assessing diaphragmatic paralysis. However, diaphragmatic ultrasonography is rapidly replacing this as it does not involve moving the patient to the radiology suite or exposing the patient to ionizing radiation. Also, diaphragm structure and movement can be better visualized on ultrasound. Diaphragmatic excursion (displacement of diaphragm during inspiration) can be used to evaluate a paralyzed diaphragm. Normal values of diaphragmatic excursion in healthy individuals were reported to be 1.8 ± 0.3, 7.0 ± 0.6, and 2.9 ± 0.6 cm for males and 1.6 ± 0.3, 5.7 ± 1.0, and 2.6 ± 0.5 cm for females during quiet, deep breathing, and voluntary sniffing, respectively.[42] A paralyzed

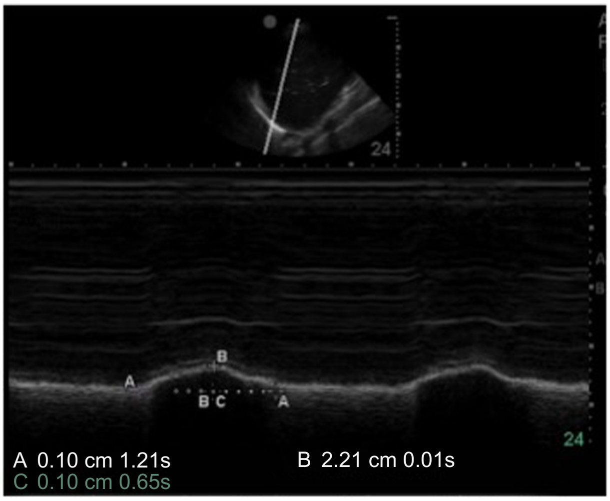

Figure 12. M-mode assessment of diaghram. "A" represents total duration of inspiration and expiration. "B" represents maximal displacement of diaphragm at the end of inspiration also known as diaphragmatic excursion. "C" represents time taken by diaphragm from start of inspiration to end of inspiration. As shown above diaphragmatic excursion is B = 2.21 cm. Contraction velocity is calculated by following formula. Contraction velocity = B/C = 2.21/0.65 = 3.4 cm/second.

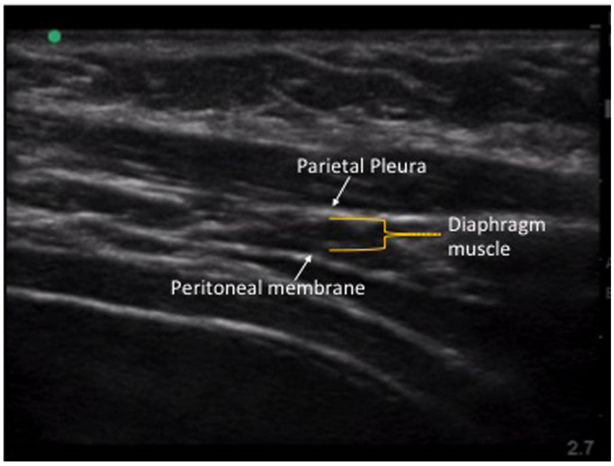

Figure 13. Diaphragm at zone of apposition.

diaphragm tends to move paradoxically (cephalad or away from the probe) or does not move at all during sniff test on M-mode.

Diaphragmatic weakness. In patients with diseases, such as amyotrophic lateral sclerosis, critical illness polyneuromyopathy, and muscular dystrophies, measuring changes in the thickness of the diaphragm can help assess any weakness or atrophy of the diaphragm. In normal individuals, diaphragmatic thickness at zone of apposition ranges between 1.8 and 3 mm at functional residual capacity (FRC) (Figs. 13 and 14).[43] Thickness of diaphragm varies widely from individual to individual. Often chronic diaphragmatic paralysis can lead to atrophy of diaphragm and decrease its thickness.[44] In such situations, calculating $\Delta tdi = (tdiTLC - tdiFRC)/tdiFRC$ (where Δtdi is the change in diaphragm thickness, tdiTLC is the diaphragm thickness at total lung capacity, and tdiFRC is the diaphragm thickness at FRC) can be useful. A Δtdi

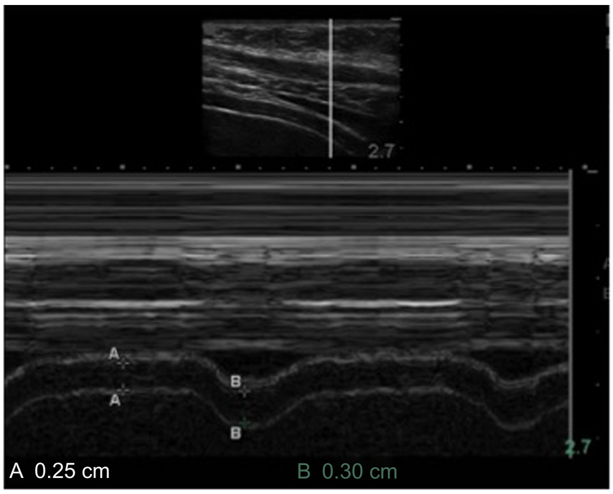

Figure 14. M-mode assessment of diaphragm at the zone of apposition. "A" represents diaphragmatic thickness during expiration which in this case is 2.5 mm. "B" represesnts diaphragmatic thickness during inspiration which in this case is 3 mm.

of less than 20% is suggestive of diaphragmatic weakness or paralysis.[44]

Training Curve for Ultrasonography

A steep leaning curve and training feasibility are potential barriers to thoracic ultrasonography.[45] However, focused training programs along with the development of an ultrasonography curriculum can enhance utilization.[46,47] Using a focused training program, Begot et al.[47] showed that after 15 studies novice medical residents were able to identify pleural effusions with good agreement with experts. Competency in lung ultrasound of trainees can be assessed by developing objective tools.[48] Additionally, simulation models that have greatly enhanced safety and accelerated learning curves for various procedures can be used to train ultrasound-guided thoracic procedures.[49,50]

Conclusion

Lung ultrasound is an invaluable tool for the bedside pulmonologist. The major findings are lung sliding, A-line pattern, B-line pattern, and consolidation pattern. When the clinician uses ultrasound in conjunction with clinical assessment, the findings obtained help in assessing volume status, ruling out pneumothorax, and diagnosing various other clinical conditions rapidly and noninvasively. There is no radiation exposure to the patient, and the examination is easily repeatable. Pleural ultrasonography aids in weaning, helps differentiate the cause of interstitial pattern, and is of use for procedural guidance. Thoracic ultrasonography as a whole provides valuable information that aid in the diagnosis and management of patients.

Author Contributions

Conceived and designed the experiments: AC, MM. Wrote the first draft of the manuscript: AC, MM, PC. Contributed to the writing of the manuscript:AC, MM, PC, MN. Agree with manuscript results and conclusions: AC, MM, PC, MN. Jointly developed the structure and arguments for the paper: AC, MM. Made critical revisions and approved final version: AC, MM, MN. All authors reviewed and approved of the final manuscript.

Supplementary Materials

Video 1 and 2. Lung sliding is demonstrated, which represents normal movement of the visceral pleura against the parietal pleura with respiratory cycling.

Video 3. Demonstration of multiple B lines on lung ultrasound. In this video, the patient has diffuse B lines present on lung ultrasound, also known as lung rockets.

Video 4. Lung consolidation pattern is demonstrated along with presence of dynamic air bronchograms, which are represented by punctate echogenic foci moving with respiratory cycling.

Video 5. Lung consolidation pattern without mobile air bronchograms. In this case, patient had a mucous plug causing atelectasis.

Video 6. Peripherally based lung abscess as seen on lung ultrasound with both anechoic and echogenic areas representing tissue necrosis.

Video 7. A large lung mass as seen on ultrasound. In this case, the patient had metastatic renal cell cancer to the lung.

Video 8. Irregular pleural surface is seen along with multiple B lines suggestive of a non cardiogenic cause of alveolar interstitial syndrome.

Video 9. Demonstrates presence of a lung point, which is a specific sign of pneumothorax as seen on lung ultrasound. It represents the interface between normal lung sliding and absent lung sliding.

Video 10. Absent lung sliding is seen with A lines suggestive of a pneumothorax.

Video 11. Lung Flapping or Jellyfish sign is demonstrated representing atelectatic lung seen undulating within a pleural effusion.

Video 12. A guidewire is seen in place within a pleural effusion using real time ultrasonography during the placement of an indwelling pleural catheter for a malignant pleural effusion.

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