Ultrasonographic Evaluation of the Pleura

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Abstract

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Pleural ultrasonography is useful to diagnose, monitor, and guide management of pleural disease. This article reviews the applications of ultrasonography to pleural disease.

Keywords

pleura, ultrasound, pleural ultrasonography

Introduction

Pleural ultrasonography is useful to identify and characterize pleural effusions and solid pleural lesions, to identify pneumothorax, and to guide pleural procedures. It can be easily performed by the clinician at the point of care.

The Accreditation Council of Graduate Medical Education stipulates that pleural ultrasonography is a mandatory component of pulmonary and critical care fellowship training in the United States.¹ The American College of Chest Physicians/La Société de Réanimation de Langue Française statement on competence in critical care ultrasonography includes pleural ultrasonography as a required component. Thoracic ultrasonography can be easily learned and applied with acceptable diagnostic accuracy.²⁻⁵ In this article, we focus in pleural ultrasonography. Other important aspects of thoracic ultrasonography, such as examination of the lung and diaphragm, are reviewed elsewhere.^{6,7}

Equipment Requirements

Many different types of 2-dimensional ultrasonography machines can be used to perform pleural ultrasonography. Most modern portable ultrasonography machines yield serviceable images with the added advantage of low cost and ease of use. A probe designed for echocardiography is useful for pleural ultrasonography, as its small size allows easy fit between rib interspaces. A low-frequency probe of phased array design with a frequency of 2 to 5 MHz is preferred. This allows penetration of the ultrasound beam to a depth permitting visualization of deep thoracic structures. High-frequency probes (5-10 MHz) are useful for detailed analysis of pleural surface morphology but have limited depth penetration. The inverse relationship between resolution and penetration should always be kept in mind when choosing the probe to be used.

Image Acquisition

The probe is held perpendicular to the chest wall with the probe marker orientated in the cephalad direction. The machine controls are adjusted for optimal gain and depth. In general, modern portable ultrasonography machines give optimal resolution, if the target structure is in the center of the screen. The probe is moved in longitudinal plane over the chest wall in order to form a scan line. The scan line consists of multiple views through adjacent intercostal spaces. The examiner performs multiple scan lines by moving the probe on the chest wall using an organized approach, in order to construct a 3-dimensional view of the thorax and pleural space by obtaining multiple 2-dimensional tomographic views. Sufficient coupling media and probe pressure are required to obtain adequate image quality. If a more detailed evaluation of the pleural line is needed, then the high-frequency probe can be used.

The pulmonary specialist has the advantage of examining the patient who is in a sitting position. This allows full examination of the thorax including the posterior area except in the subscapular region.⁸ The critical care specialist will usually examine the patient who is in supine position. This blocks easy visualization of the posterior thorax, which is problematic, as pleural effusion, under

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Pleural line Rib shadow A lines

Figure 1. Normal pleural line.

gravitational influence, will assume a dependent position. In the supine patient, the posterior lateral thorax may be visualized by pressing the probe into the mattress while angling the scanning plane in an upward direction. Alternatively, the patient can be turned into a lateral decubitus position, in order to expose the entire posterior chest wall. In rare cases, the critical care physician may elect to have the patient in a sitting position while being held by two assistants and being careful not to cause undue traction on the endotracheal tube and other indwelling devices.

The Pleural Line

In the fully inflated lung, the interface between the parietal and the visceral pleura is identified as the pleural line (Figure 1). In order to locate the pleural line, the probe position is adjusted such that the rib shadows are orientated on either side of the screen image, with the ultrasound beam extending into the thorax. The pleural line is identified approximately 0.5 cm deep to the periosteal reflection. In the normal lung, the pleural line moves in respirophasic and cardiophasic fashion referred to as lung sliding and lung pulse, respectively (Video 1 and Video 2). This movement results from the apposition of the visceral and parietal pleura and indicates, at the site of the examination, that there is no pneumothorax. Aerated lung is not visible as a distinct tissue structure due to the intense reflection of the ultrasound at the air-tissue interface that results from the large difference in the acoustic impedance and velocity of ultrasound between tissue and air. However, if a pleural effusion is interposed between visceral and parietal pleura, it is readily visualized, as fluid collections are well seen with ultrasonography.

Identification and Characterization of Pleural Effusion

Identification and characterization of pleural effusion is an easy skill for the novice ultrasonographer to acquire.² A pleural effusion, unless loculated, will assume a dependent



Figure 2. Pleural effusion (simple).

location within the thorax and will have 3 characteristic features (Figure 2; Video 3):

- The pleural effusion will appear as a relatively hypoechoic space.
- The pleural effusion will be surrounded by typical anatomical boundaries, that is, the inside of the chest wall, the diaphragm, the surface of the compressed lung, and on occasion the pericardium.
- The pleural effusion will have typical associated dynamic findings, for example, diaphragmatic movement, lung flapping, or plankton sign.

Each of these 3 characteristics warrants separate discussion.

a. The hypoechoic space

Once the hypoechoic space, which represents pleural effusion, is confirmed to be pleural fluid by boundary identification and presence of dynamic findings, the examiner further characterizes the fluid. The volume of pleural effusion may be estimated by ultrasonography.^{9,10} While these methods are accurate, in our clinical practice we do not perform them on a regular basis. We prefer a qualitative estimate, small, moderate, or large in volume, as a more precise estimate of pleural effusion volume does not have major clinical utility.

The echogenicity of the pleural effusion may vary from being completely anechoic to a hyperechoic complexity. Pleural effusions that are anechoic are usually transudates, while pleural effusions that are exudates will usually have internal echogenicity.¹¹ The echogenicity will depend on the amount of protein or cells within the pleural effusion. Both infection and malignancy will result in pleural complexity manifested by the presence of strands, fronds, septations, or loculations within the pleural effusion^{11,12} (Figure 3; Video 4). A neglected long-standing empyema may result in loculations with thick immobile walls (Video 5), while an infected hemopneumothorax may become so echodense



Figure 3. Pleural effusion with loculations.



Figure 4. Plankton sign.



Figure 5. Hematocrit sign.

as to lack standard characteristics present in most pleural effusions. Ultrasonography is superior to chest computerized tomography (CT) in identifying the internal architecture of complex pleural effusions.¹³ The fluid component of a pleural effusion may have echogenicity that is characteristic of the presence of cellularity. For example, highly cellular fluid may exhibit a pattern of internal mobile echogenicity



Figure 6. Hemothorax.



Figure 7. Air bubbles in a pleural effusion, in this case caused by a bronchopleural fistula.

that is called plankton sign (Figure 4; Video 6). In the patient who is immobile for a period of time, the cellular component of a pleural effusion may, by gravitational effect, result in a clear interface with an anechoic fluid above and cellular component below that is termed the hematocrit sign (Figure 5; Video 7). Acute hemothorax from aortic injury or intercostal artery laceration results in a characteristic hyperechoic mobile effusion (Figure 6; Video 8). Air bubbles within pleural fluid, which may occur with esophagealpleural fistula, bronchopleural fistula, or a gas-forming infection will exhibit multiple mobile echogenic foci within pleural fluid that represent air bubbles (Figure 7; Video 9).

Malignant pleural effusions (MPE) often have echogenic elements within them but that are not diagnostic for malignancy.^{14,15} Discrete masses that are identified within the pleural effusion are highly suggestive of metastatic disease. These are often found on the diaphragm, presumably due to gravitational effect on the distribution of the metastatic cells within the pleural effusion (Figure 8; Video 10).

Figure 8. Metastatic masses over diaphragm.



FFF'

Diaphragm

Chest wal

Figure 9. Inverted diaphragm secondary to a large hemothorax caused by deceleration injury of the descending aorta.

Anatomical Boundaries

With the examiner holding the probe with the marker orientated in the cephalad direction, the chest wall will be located at the top of the screen. The thickness of the chest wall will vary depending on the patient's body habitus. It is an important measurement, as it determines how far a needle will have to penetrate before accessing the pleural effusion. As the examiner moves the transducer caudally in a scan line, the diaphragm becomes visible on the right side of the screen. The diaphragm is visualized as a hyperechoic curvilinear line with respirophasic movement (Figure 2; Video 3). With massive pleural effusion, the diaphragm may have a reversal of normal curvature (Figure 9; Video 11). Beneath the diaphragm, the liver or spleen appears as a homogenous echogenic tissue density structure. Subphrenic ascites with a pleural effusion outlines the diaphragm very clearly (Figure 10; Video 12). In planning needle trajectory for device insertion, it is essential that the diaphragm be identified. Inadvertent subphrenic device insertion may have serious consequences.



Figure 10. Subdiaphragmatic ascites and pleural effusion.



Figure 11. Atelectatic lung with air bronchogram.

A pleural effusion will result in compressive atelectasis of the lung. The atelectatic lung appears as a tissue density structure within the pleural effusion. Punctuate echoic foci will be present within the airless lung; these represent residual air collections in the bronchi¹⁶ (Figure 11). The interface between the atelectatic lung and pleural effusion is linear, whereas the interface between the compressed airless lung and adjacent normal aerated lung is irregular, termed "shag sign" (Figure 12; Video 13) and typically has multiple comet tail artifacts. This is an important differential point, as an echogenic pleural effusion and atelectatic lung may occasionally be difficult to differentiate, if there is a patient-specific problem with imaging quality. Identification of the visceral pleural surface of the atelectatic lung allows the examiner to avoid lung injury from needle insertion. When examining the left hemithorax, the pericardium or descending aorta may define an additional anatomic boundary that surrounds the pleural effusion (Figures 13 and 14; Videos 14 and 15).

b. Dynamic findings

There are a number of dynamic findings characteristic of pleural effusion.

HEAD

Atelectatic lung

Pleural effusion

Masses



Figure 12. Shag sign.



Figure 13. Pleural effusion with descending aorta.

1. Respirophasic movement of the diaphragm

The normal diaphragm moves in a caudal direction during inspiration (Video 16). If the diaphragm is paralyzed or in the case of massive pleural effusion with reversal of the curvature of the diaphragm, there will be paradoxical cephalad movement during inspiration (Video 17).

2. Movement of the atelectatic lung:

The airless tissue density lung that is identified within the pleural effusion moves in respirophasic and cardiophasic fashion. This has been termed "lung flapping" or the "jelly fish sign"¹⁷ (Video 18).

3. Movement of elements within the pleural effusion

Septations, loculation walls, and cellular elements within the effusion will move in respirophasic and cardiophasic fashion. If the patient is immobile for a period of time, cellular elements within the pleural effusion will sediment and form a distinct interface with anechoic characteristics clearly separated from the more echoic cellular component of the



Figure 14. Pleural and pericardial effusion.

effusion. This has clinical implications, as sampling above the interface will yield a cell count in the fluid that is very different than if the sample is drawn from the area where the cells have sedimented. If the examiner observes this phenomenon, patient movement will result in a more homogeneous distribution of the cellular elements.

Special Considerations

a. Ultrasonography to differentiate benign from MPE.

Malignant pleural effusions have many patterns of echogenicity,¹⁴ none of which are diagnostic for the presence of malignancy.¹⁵ Pleural fluid echogenicity, septations, or pleural nodularity, may be found in MPE but can also be found in infectious and non-MPE.¹⁸ Coexisting chest wall invasion, hepatic metastasis, or a peripheral lung lesion associated with pleural effusion is highly suggestive of MPE.¹⁸ Pleural ultrasonography may suggest the presence of malignancy, but its greatest value lies in its utility to guide thoracentesis and render definitive tissue diagnosis.

b. Ultrasonography to differentiate empyema from lung abscess

A complicated loculated empyema may be associated with pneumonia in the adjacent lung. The pleural complexity, which may include multiple septated collections of purulent material, is difficult to distinguish from a coexisting lung abscess. Chest CT is not as effective in identifying pleural complexity as is ultrasonography.¹³ Chest CT may not well differentiate lung abscess from empyema. Thoracic ultrasonography is useful to differentiate the two. With ultrasonography, lung abscess appears as an ovoid, hypoechoic lesion with irregular hyperechoic outer margins^{11,19} surrounded by consolidated lung (Figure 15). Ultrasonographic findings used to differentiate lung abscess from empyema are wall characteristics (smooth vs. irregular in empyema and



Figure 15. Lung abscess.

lung abscess, respectively) and lesion shape (lenticular vs. ovoid in empyema and lung abscess, respectively); however, these findings are associated with high interobserver variability.²⁰ Identification of blood flow using color Doppler in the pericavitary consolidation is useful for identifying lung abscess without interobserver variability²⁰ (Video 19). Lung abscess is characterized by abundant branching and twisted blood vessels in the surrounding pericavitary lung. In the areas of compressive atelectasis that are adjacent to the empyema, there will be no blood flow detected by color Doppler.

Pleural Morphology

When the visceral and parietal pleura are apposed, they cannot be visualized as two separate anatomical structures without the use of a very high-frequency probe, which is not available for clinical use. The movement and morphology of the pleural line are well visualized with the linear high-frequency vascular probe, while deeper thoracic structures such as pleural effusion and consolidated lung are imaged with a low-frequency phased-array probe. If there is a pleural effusion, both parietal and visceral pleura may be seen as distinct anatomical structures; as they are not apposed one to the other. Presence of a pleural effusion allows the examiner to identify pleural abnormalities selective to either the parietal or the visceral pleura. A wide variety of pleural processes that result in pleural effusion will involve either or both surfaces. For example, malignant disease may cause pleural nodularity or discrete adherent masses (Figure 8; Video 10); pleural fibrosis, identified as pleural thickening that is focal or diffuse, may involve either of the pleural surfaces; and infections of the pleural space may result in pleural thickening or nodularity.

The normal pleural line, which is composed of visceral and parietal pleura in full apposition, is seen with ultrasonography as a smooth hyperechoic horizontal line that moves in respirophasic and cardiophasic fashion. The presence of air within the thoracic cavity will produce a reverberation



Figure 16. Pleural line in congestive heart failure.

artifact called A-lines. They appear as one or more horizontal hyperechoic lines deep to the pleural surface that are equidistant from one to another. They are typical for normal aerated lung⁶ (Figure 1; Video 1). In normal individuals, a few comet tail artifacts are found over the lower lateral chest wall interspaces. Comet tail artifacts that are designated as B-lines are hyperechoic vertical lines that start at the pleural line, move with the pleura line, reach the bottom of the machine screen, efface A-lines, and flare out as they approach the lower screen area. They are produced when the ultrasonography wave encounters a subpleural process, such as thickened lobular septae, subpleural hydrostatic edema, or inflammatory foci, that is, an alveolar interstitial syndrome.

Underlying lung disease will alter the pleural line when it affects the visceral pleural surface. Assessment of the pleural morphology using pleural ultrasonography is helpful to differentiate common pulmonary diseases involving the pleura. The presence of a thick (>2 mm) and irregular pleural line is indicative of a primary lung disease, whereas smooth pleural line suggests cardiogenic pulmonary edema (Figure 16; Video 20). Both processes are associated with B-lines. Acute lung injury will produce an irregular and thick pleural line with subpleural consolidations, multiple bilateral comet tail artifacts, and reduced or absent lung sliding²¹ (Figure 17; Video 21). Patients with interstitial lung disease will have a thickened irregular pleural line with multiple comet tail artifacts often with lower lobe predominance²² (Figure 18; Video 22). Subpleural abnormalities, representing granulomas (due to sarcoidosis or silicosis), rheumatic nodules, or pulmonary metastasis are detected with pleural ultrasonography.²² Pulmonary embolism produces characteristic ultrasound findings. Initially, pulmonary emboli will result in homogeneous hypoechoic subpleural smooth-margined lesions without air bronchograms. These are thought to be secondary to pulmonary infarctions. Following a period of time, these subpleural abnormalities become echodense, wedge-shaped with serrated margins, and have an air bronchogram in the center of the lesion. Pulmonary infarctions are



Figure 17. Pleural line in acute lung injury.



Figure 18. Pleural line in interstitial lung disease.

often found in the posterior lower lobes with a size ranging from 5 to 70 mm¹⁹ (Figure 19; Video 23). Malignant disease that is adjacent to the pleural surface results in peripheral echogenic subpleural nodules with strong color Doppler signals because of high vascularization.²³

A disease process that involves the parietal pleura will alter the morphology of the pleural line. Chest wall invasion by a pleural or lung malignancy has characteristic features on ultrasonography, such as disruption of the pleural line or adjacent chest wall and lack of respirophasic or cardiophasic movement of the pleura. Ultrasonography of the pleura is superior to chest CT for the detection of chest wall invasion by tumor.²⁴ Identification of chest wall invasion or malignant subpleural nodules may be limited if a rib blocks the examination.

Ultrasonographic findings of pleural mesothelioma include diffuse pleural thickening or hypoechoic mass with irregular borders,²⁵ irregular thickening of the pleural line with associated micronodules, and moderate to large pleural effusion.²⁶ Benign pleural lesions have a trapezoidal



Figure 19. Pulmonary infarct.



Figure 20. Benign pleural lesion.

shape with acute angles between the lesion and the chest wall, irregular borders,²⁵ and are associated with small pleural effusion (Figure 20). Differential diagnosis includes pleural plaques of different etiologies, lipomas, and chondromas.^{25,27}

Pneumothorax

Ultrasonography is superior to chest radiography for detection of pneumothorax following thoracentesis and transbronchial biopsies,²⁸ for timing the removal of chest tubes following resolution of pneumothorax,²⁹ and for the evaluation of trauma patients. Volpicelli has defined a simple protocol to diagnose pneumothorax.³⁰

Pneumothorax results in the loss of lung sliding and lung pulse, as there is no apposition of the visceral and parietal pleura surfaces. The presence of lung sliding, lung pulse, or B lines rules out pneumothorax at the intercostal space evaluated, since to produce these findings, there must complete apposition of both visceral and parietal pleura. Lung point is a specific finding for pneumothorax³¹ and is found

in the anterolateral aspect of the thorax in the supine patient. When pneumothorax occurs, the pneumothorax airspace will generally distribute into the nondependent anterior thorax, while the partially deflated lung will assume a posterior position. The lung point is found where the partially deflated lung interfaces with the pneumothorax space. The examiner identifies lung point at this interface by observing movement of the aerated lung in and out of the pneumothorax space (Video 24). The size and resolution of pneumothorax can be monitored by following serial examinations of the lung point.²⁹

To evaluate for pneumothorax, the patient is examined in the supine position, which favors distribution of the pneumothorax to a nondependent anterior chest area.³⁰ Multiple interspaces can be examined rapidly in order to rule out pneumothorax with high level of certainty.

The presence of lung sliding, lung pulse, or B lines rules out pneumothorax. The absence of lung sliding suggests the possibility of pneumothorax, as absence of lung sliding may be found in apnea, pleurodesis, atelectasis, severe acute lung injury, and unilateral main stem bronchial intubation. Identification of lung sliding is difficult at the lung apex and in patients with severe tachypnea. Patients with severe respiratory distress who have marked inspiratory intercostal contraction may have the appearance of lung sliding when it is not actually present. The presence of B lines rules out pneumothorax, as B lines are produced at the visceral pleural surface. In cases where lung sliding or lung pulse is difficult to identify, the presence of B lines is useful in excluding pneumothorax at the site of the transducer position. In general, lung sliding and lung pulse are present simultaneously. Main stem bronchial intubation, atelectasis, apnea, and small tidal volume breathing while on ventilatory support will result in lung pulse without lung sliding.

The ultrasonographic evaluation of pneumothorax has utility for the evaluation of the patient with dyspnea and sudden decompensation of the patient on mechanical ventilatory support. It has special application for the clinician who performs pleural interventions, where there is risk of pneumothorax. For this application, the clinician checks for pneumothorax before and after the procedure. The loss of lung sliding postprocedure, when it was present prior to the intervention, indicates procedure-related pneumothorax with high degree of certainty.

Pleural Ultrasonography for Procedure Guidance

Guidance of Device Insertion

Pleural ultrasonography allows the clinician to identify a safe trajectory for needle insertion into the pleural effusion, whether for simple diagnostic thoracentesis or to guide device placement into the pleural space. The incidence of complications from ultrasound-guided thoracentesis is low.³²⁻³⁴



Figure 21. Pseudopleural effusion.

Safe pleural access requires the following steps:

- Identification of pleural effusion as described previously.
- b. Identification of safe trajectory for needle insertion. This requires avoidance of anatomic structures such as subdiaphragmatic organs, heart, vascular structures, and the visceral surface of the atelectatic lung. Positive identification of the diaphragm is particularly important to avoid hepatic or splenic injury. A common error that is made by the inexperienced operator is to misidentify the splenorenal or hepatorenal recess as the diaphragm (Figure 21; Video 25). These recesses are curvilinear, and the spleen or liver may be mistaken for an echogenic effusion. It is important to identify both the kidney and the overlying spleen or liver in order to avoid this hazardous error. If there is concern of aberrant intercostal vessel position, the operator may examine the proposed needle trajectory with a high-frequency vascular probe using color Doppler in order to exclude this possibility.
- c. Identification of depth for needle insertion. This is performed by measuring the distance between the skin surface and the inside of the chest wall, so the operator is aware of the distance required to enter the pleural space. In the edematous or obese patient, firm pressure of the transducer on the skin surface may cause indentation of the skin resulting in underestimation of the depth required for device insertion; as, with removing the transducer compression, the skin rebounds thereby increasing the distance required for access. The distance between the skin and the visceral pleural surface of the atelectatic lung is measured. This defines the depth of needle insertion that will predictably penetrate the pleural surface.
- d. Identification of appropriate angulation of the insertion device. The angle of needle insertion duplicates



Figure 22. Wire within pleural effusion.

the angle of the probe used to identify the best trajectory for pleural access. The following two ultrasonographic approaches for pleural device insertion can be used: (1) real-time visualization of the device entering the pleural space and (2) a mark and stick approach. Regardless of method of device insertion, no change in patient positioning after preprocedural ultrasonographic imaging is essential to avoid complications.

e. Identification of wire or catheter position. The operator may choose to identify the position of the guidewire or catheter in the pleural space³⁵ (Figure 22; Video 26 and Figure 23; Video 27).

Guidance of Pleural Biopsy

Ultrasonography may be used to guide biopsy of solid pleural lesions. Ultrasonography-guided pleural biopsy is as accurate as CT-guided pleural biopsy with the advantage of decreased cost, procedure time, and complications.³⁶ In cases where medical thoracoscopy was not feasible due to challenging pleural anatomy or severely ill patients, ultrasonography pleural biopsy was an effective alternative.³⁷ Probe design with a central hole for needle insertion may have special application for pleural biopsy under ultrasonography control.^{38,39}

Medical Thoracoscopy

Pleural ultrasonography is useful as an adjunct to medical thoracoscopy. In the presence of pleural effusion, it allows for identification of a safe site, depth, and angle for trocar insertion.⁴⁰ Ultrasonography can be used to facilitate thoracoscopy in the absence of pleural effusion.⁴¹ In this case, the proposed entry site is examined for the presence of lung sliding and to rule out pleural adhesions or thickening that would preclude device insertion. The trocar is inserted at the site



Figure 23. Chest tube within pleural effusion.

where there is lung sliding to reduce the risk of injuring the underlying lung.

Limitations

Patient-related factors such as obesity, heavy musculature, chest wall edema, difficulty in positioning, or chest wall dressing may degrade image quality. The presence of subcutaneous emphysema blocks transmission of ultrasound waves. Competence in pleural ultrasonography requires training. The learning curve is short, with small inter- and intraobserver variability.^{2,4} The identification of pneumothorax may require a longer training period.⁸

Conclusion

Pleural ultrasonography is useful for identification and characterization of pleural effusions. It allows for safe device insertion into the pleural space. It is a valuable adjunct for the management of pleural disease and is easy to master with a short period of training. This technology is safe, reproducible, and available at the point of care, and after an initial investment, it is relatively inexpensive.

Authors' Note

This work in original and all authors meet the criteria for authorship, including acceptance of responsibility for the scientific content of the manuscript. This article is not under consideration in any other journal, and all the authors have read and approved the content of the manuscript.

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