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Pleural Ultrasonography

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Ultrasonography is a useful tool for physicians managing pleural diseases. It permits imaging of pleural effusion and other pleural pathology. In addition, ultrasonography has utility in the guidance of thoracentesis and various pleural interventions. This article reviews the field of pleural ultrasonography with emphasis on clinical applications.

Pleural ultrasonography physics

Medical ultrasonography uses ultrasound waves to create images of the body for diagnostic purposes and to guide procedures. Whether imaging the abdomen, heart, vascular structures, or pleura, the physical principles of ultrasonography are the same. The transducer sends out a brief pulse of high-frequency sound that penetrates the tissue. The sound waves are reflected back to the transducer, which serves as the sensor and the source of signal. Ultrasound is reflected at tissue boundaries and interfaces. The degree of reflection is determined by the acoustic impedance of the adjacent tissue. Acoustic impedance is related largely to tissue density, although the propagation velocity of sound through different tissues also is a factor. Another factor that influences the detection of an acoustic interface is the angle at which the sound beam strikes the interface of interest. Ultrasound undergoes refraction, scattering, and attenuation as it passes through tissue, all of which degrade image quality on examining deeper structures.

Ultrasound examination of the pleura is particularly influenced by the presence of ribs and aerated lung. In bone, there is nearly complete absorption of sound waves; this yields a shadowing artifact. Ribs completely stop transmission of ultrasound and block any view of structures deep to the rib in question. Air is a powerful ultrasound reflector. As a result, most of the ultrasound wave is reflected back from the lung surface if the lung is filled with air. It is impossible to view normally aerated lung with ultrasound. This point of reflection of air from the lung surface corresponds to the pleural surface. If the lung is not normally aerated, as in consolidation or atelectasis, it can be readily visualized [1].

Image artifacts are common in ultrasonography. Bone shadowing and lung air reflection artifacts are predictable problems with thoracic ultrasonography. Artifacts related to the beam itself, such as reverberation, mirroring, marginal, and scatter artifacts, may confuse the examiner. Enhancement, resolution, and beam-thickness artifacts are problematic. Translational artifacts that occur when the patient is breathing at a high respiratory rate may make it difficult to discern dynamic pleural movement. The reader is referred to a definitive text for a complete review of artifacts and their physical explanations [2]. The clinician-sonographer should consider the following issues related to artifact:

1. Obesity and edema degrade image quality. In this patient population, it is difficult to discern ultrasound interfaces and to judge the relative echogenicity tissue. Subcutaneous air causes intense reflection artifact and makes ultrasound examination difficult.

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2. Rib shadowing and lung aeration artifact are a constant challenge with pleural ultrasonography. Identification of the pleura–chest wall interface may be problematic because of near-field clutter.
3. Artifacts typically are visible in only one plane of scanning and often disappear or attenuate on changing probe angle. Artifacts often do not move with movement of adjacent body structures during the respiratory cycle; they are immobile or move with transducer movement.
4. Use of sufficient coupling medium between the skin and the transducer reduces some types of artifacts. Commercial ultrasound gel is effective. Water applied to the skin also is effective, although evaporative loss requires frequent re-application [3].

Discussion of the physics of ultrasonography must include a review of the controls of the ultrasound machine. With pleural ultrasonography, the operator needs to set the image marker on the screen in reference to the orientation of the transducer. Every ultrasound transducer has a groove or raised edge located on one side of the probe. Whichever direction the transducer indicator is pointed, it is projected to the side of the screen marker. The machine, by standard convention, should be set such that the image marker on the machine screen is to the left on the screen. This setup allows the operator to remain orientated to the anatomic axis of scanning, and it permits standardization of image projection for reporting purposes. In longitudinal scanning of the thorax, the probe always should be orientated such that the marker on the probe is pointed cephalad. This being the case, the cephalad direction always is projected to the left of the screen.

When the marker is set, the operator should set the appropriate gain. Machines allow for total gain setting, and most permit settings of individual gain levels within specific areas of the screen. Gain is adjusted so that the pleural and chest wall boundary is clearly visible and so that deeper structures of the image field are seen clearly, such as lung, liver, or spleen. The operator should set the machine for the proper depth penetration. Alteration of depth setting on the machine allows for more or less penetration of ultrasound waves for study purposes. Less penetration results in magnification of the image in the field. When the examiner wishes to visualize the actual pleural surface clearly, depth setting should be set for near-field magnification. This setting is important when examining the pleural surface for subtle findings, such as lung sliding. The depth setting should be increased to maximum when deeper structures that are crucial for defining the boundaries of a pleural effusion are relevant.

Transducer design is important to pleural ultrasonography. Higher frequency probes (7.5–10 MHz) generally are designed for vascular examination, but can be used for pleural ultrasonography. Their advantage is excellent resolution, but their disadvantage is poor penetration. The higher the frequency of the transducer, the better is its resolution, but the lower its penetration. In addition, most vascular probes are linear in design; in thin patients, this does not permit easy examination of the intercostal space in a longitudinal plane. High-frequency transducers have utility if the examiner wishes to do a detailed examination of the pleural surface, which is relatively close to the skin surface. The limited penetration of high-frequency probes prevents visualization of deeper structures, however, which are crucial in assessing pleural space pathology. Most general ultrasonography is performed with transducers with frequency of 3.5 to 5 MHz. Although there is a decline in fine resolution, penetration is superior so that deeper structures can be visualized. These probes are often of sector design so that they allow longitudinal scanning between interspaces in thin individuals. They may not allow detailed resolution of the individual parietal and visceral pleural surfaces. This has little relevance to the clinician, who is more interested in identifying the pleural lung interface and being able to observe structures deeper in the thorax and adjacent abdominal structures that are crucial to assessing pleural effusion and other pleural pathology and in guiding pleural interventions. The penetration and resolution of standard general ultrasound probes make them the ideal tool for pleural ultrasonography in clinical practice.

Ultrasound machine requirements for pleural ultrasonography

Pleural ultrasonography may be performed with a simple two-dimensional ultrasound machine. Doppler capability is not needed. Machines designed in the early 1990s are adequate for imaging pleural effusion or other pleural pathology. Just as a simple older machine suffices, a sophisticated high-end cardiac ultrasound machine also can image the pleura. An ultrasound machine that is capable of abdominal or cardiac imaging has utility in examining the pleural space. As discussed in the physics section, standard sector transducers with frequency of 3.5 to 5 MHz are preferred for clinical pleural ultrasonography. Higher frequency probes give excellent image resolution of the normal pleura, but lack the penetration required to examine deeper structures that are required for clinical applications.

Many different ultrasound machines are available on the market. Many of these machines are capable of performing pleural ultrasonography. Some of the small, handheld ultrasound units of modern design may lack adequate near-field resolution, however, which is needed for pleural ultrasonography. With some of these units, the inside of the chest wall is not clearly visualized when there is a pleural effusion present. As a result, the depth of needle penetration required to access the effusion cannot be determined accurately for performance of thoracentesis. In addition, recent generation ultrasound machines use extensive imaging processing for image smoothing. This processing may make subtle findings, such as lung sliding, more difficult to observe. Paradoxically, older ultrasound machines may be more suitable for pleural ultrasonography because they lack extensive image processing. This being said, pleural ultrasonography is so straightforward that any machine used for general ultrasound purposes would provide a useful image. In purchasing an ultrasound machine, the clinician should test the device carefully for its intended application.

Normal pleura

Ultrasound examination of the normal pleura is easy to perform. When the probe is applied to an interspace in longitudinal scanning plane between adjacent ribs, the normal pleura appears as a bright, highly echogenic line interposed between the chest wall and the air artifact of the lung. With small movement of the transducer, the examiner may orientate the rib shadows, such that the pleural line is centrally located on the screen. The marker on the probe should be pointed toward the head of the patient so that the cephalad direction is projected to the left of the machine screen. By sliding the transducer along the chest wall in a longitudinal direction, adjacent interspaces can be examined. When a longitudinal scan line is completed, the probe may be moved laterally or medially to an adjacent position, and another longitudinal scan line may be created. In this fashion, the costal pleura may be mapped almost completely. To view the diaphragmatic pleura, a transhepatic approach permits avoidance of lung air. On the left side, the full extent of diaphragmatic pleura may be blocked by lung air. The mediastinal pleura generally is not visible via a transthoracic approach. A transesophageal probe allows visualization of some parts of the mediastinal pleura. This is a specialized technique and is not discussed further. Occasionally, consolidated lung or pleural effusion allows visualization of mediastinal pleural surfaces by virtue of acoustic wave transmission through the pleural effusion or the airless lung. The parietal pleura underlying rib may not be visible owing to rib shadowing. Breathing results in movement of the visceral pleura into the scanning field, however, allowing a complete examination of the visceral subcostal pleura. Approximately 70% of the pleural surface is accessible to ultrasound examination [4].

The normal pleura is 0.2 to 0.4 mm thick [5]. High-frequency probes may have sufficient resolution to allow visualization of the parietal and visceral pleura as separate linear structures that are closely opposed. The probes that are more commonly used for general ultrasonography application (3.5–5 MHz) may not offer sufficient resolution to separate the two pleural surfaces; rather, normal pleura appears as a single summation interface. The inability to visualize the separate pleural surfaces in the examination of normal pleura does not have any clinical relevance. Close apposition of the parietal and visceral pleura is normal. When a pleural effusion is present, the parietal pleura and the visceral pleura are separated. Only then are the two normal surfaces readily visualized by ultrasonography as two distinct echogenic structures when using a lower frequency probe.

A critical finding of the normal pleural examination is lung sliding. The examiner notes that the pleural line, interposed between the chest wall and the underlying aerated lung, has a mobile quality that cycles with respiration. This is called *lung sliding*. Careful observation also may reveal a subtle shimmering movement to the pleural line that coincides with cardiac pulsation; this is called *lung pulse*. The source of these movements of the pleural line is the visceral pleura moving or sliding along the parietal pleura. In spontaneously breathing patients, lung sliding is accentuated in the lower thorax because lung inflation is greatest in this area. Lung pulse may be accentuated most at pleural surfaces adjacent to the heart. Lung sliding and lung pulse are normal findings of the examination of the pleura. The identification of lung sliding indicates the absence of pneumothorax at the site of probe application [6]. Likewise, the presence of lung pulse excludes pneumothorax (Fig. 1) [7].

Most often, pleural ultrasonography is goal directed. A chest radiograph or chest CT scan identifies an abnormality that can be characterized further by

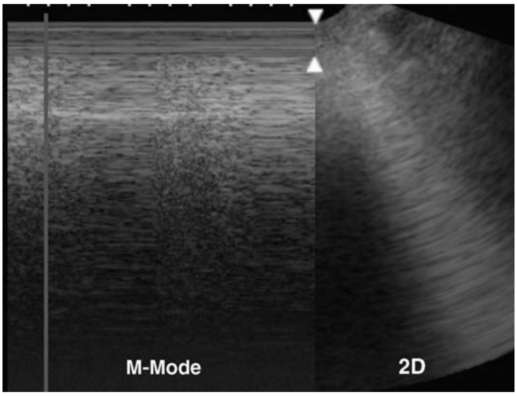

Fig. 1. Composite image of M-mode tracing and two-dimensional image of lung obtained through an intercostal space. Although a bright pleural reflection is not present in this image, the immobile chest wall between the arrows can be readily distinguished from the moving air artifact below. This "lung sliding" can be documented only on static images by using M-mode, but is readily visible during dynamic imaging. The presence of lung sliding excludes pneumothorax in the area of probe contact.

thoracic ultrasonography. In addition to examining the area of abnormality, a complete ultrasound examination of the costal pleura can be accomplished rapidly. For a complete examination of the costal pleura, the patient should be in an upright position with hands on head and arms abducted. This position enlarges the interspaces for better probe placement. The examiner can examine the pleura and underlying lung by moving the transducer along sequential longitudinal scan lines. If an area of abnormality is identified, the examiner can return to it for more detailed examination with the patient in a comfortable position. The anterior and lateral thorax of the supine patient may be examined using the same mapping technique.

The normal pleura should appear as a bright echogenic line interposed between the chest wall and the underlying lung. Lung sliding is a dynamic feature of normal pleural ultrasonography. Methodical examination of multiple adjacent interspaces results in a complete ultrasound evaluation of the costal pleura.

Pleural disease and pleural ultrasonography

Pleural effusions are seen easily with pleural ultrasonography. In addition, many types of less common pleural pathology may be identified.

Pleural effusion

Identification of pleural effusion is a straightforward application of pleural ultrasonography. Ultrasonography is ideally suited to the identification of fluid collections throughout the body because fluid is relatively echo-free compared with other body tissues. Taking advantage of this fact, the sonographer may readily identify pleural effusions of even small size. A minimum of 150 mL of pleural effusion is required for detection by standard upright chest radiography [8]. Effusions of 5 mL can be identified with careful pleural ultrasonography of the costophrenic angle in patients in the upright position [9]. Pleural ultrasonography is superior to standard upright chest radiography and supine chest radiography for detecting pleural effusion [9,10]. Identification of pleural effusion by pleural ultrasonography obviates the need for lateral decubitus chest radiographs, which commonly are ordered to verify pleural effusion after standard chest radiograph. Compared with chest CT scan, pleural ultrasonography has excellent performance characteristics in identifying pleural effusions in supine patients [11].

Identification of a pleural effusion with pleural ultrasonography in a patient who is in an upright position is straightforward. An important capability of pleural ultrasonography is identifying pleural effusions in a supine, critically ill patient on ventilatory support. Readers are well aware of the severe limitations of standard supine chest radiographs in the ICU. Penetration, rotation, and distance magnification artifacts are a consistent problem with these types of films. Also, pleural effusions accumulate in dependent fashion in the thorax, which results in a common problem, wherein thoracic opacities seen on standard supine chest radiographs in the ICU, particularly opacification in the lower chest region, derive from a summation of pleural effusion, compressed lung, and parenchymal lung disease. This nonspecific pattern of opacification is common in this type of chest radiograph. Pleural ultrasonography is able to characterize accurately the cause of the radiographic abnormality seen in the typical ICU chest radiograph. Ultrasonography can distinguish between pleural effusion and any contribution of abnormal lung aeration that contributes to the radiographic abnormality [11]. Pleural effusions are correlated closely with CT scan of the chest in this patient population.

A free-flowing effusion seeks a dependent position in the thorax by gravitational effect. Aerated lung assumes a nondependent position relative to the pleural effusion. Patient position determines where the pleural effusion is found by the sonographer. The predictable position of the effusion in a dependent position is a major advantage when the patient is scanned in an upright position; as a result, pleural ultrasonography is best accomplished with the patient in an upright position. Pleural ultrasonography is more difficult to perform in a supine patient, such as a critically ill patient whose hemodynamic status and multiplicity of support devices prohibit an upright position. In the supine position, the effusion is dependent and layers posteriorly with the lung assuming a nondependent or anterior position in the thorax. Unless the pleural effusion is very large and distributed laterally in the chest, the bed blocks easy viewing of smaller pleural effusions owing to the dependent position of the fluid. The examiner can place the transducer in the posterior axillary line and push down on the bed while angling the probe toward the center of the body; this permits visualization of smaller dependent effusions and defines ultrasound findings of coexisting lung disease. This probe position does not allow for a safe thoracentesis approach because the operator lacks adequate clearance from the bed to perform safe needle insertion.

If routine pleural ultrasonography identifies a pleural effusion that requires thoracentesis on clinical grounds, the examiner must be skilled in safely positioning a supine critically ill patient to find a safe path for thoracentesis. Several options are effective. In positioning a critically ill patient for thoracentesis, one team member must be assigned to monitor the airway if the patient is intubated. Unplanned extubation is always a risk when moving critically ill patients. One option is to bring the thorax to a near-vertical position using the bed controls. This position results in the pleural effusion collecting in the inferior thorax. Gentle adduction of the ipsilateral arm rotates and lifts the chest wall off of the bed, which may allow visualization of the pleural effusion by ultrasonography. This maneuver requires careful monitoring of the endotracheal tube position and an assistant to hold the patient's position during the thoracentesis. Patients who are hemodynamically unstable may not tolerate this position. An alternative to achieve pleural ultrasonography in a critically ill patient for the purpose of safe thoracentesis is to roll a supine patient to a full lateral decubitus position with the target hemithorax in the upper position. This position frequently allows good visualization of the pleural effusion and a suitable field for thoracentesis. Finally, for very unstable patients, carefully sliding a supine patient to the edge of the bed such that part of the hemithorax is exposed allows detection and sampling of small pleural effusions. To protect the patient, the authors use a sling made of bed sheets to hold the patient's body in place and prevent any possibility of the patient falling out of bed. The operator may choose to sit on the floor to perform the thoracentesis. These three techniques permit identification of a safe point for needle insertion that allows sufficient clearance with sterile technique for safe thoracentesis. Loculated pleural effusions or pleural masses that are anterior or lateral in position do not require any special positioning methods in a supine patient and are readily visualized with standard scanning technique.

Identification of a large free-flowing effusion in a thin echogenic patient is straightforward (Fig. 2). A patient who is less echogenic, such as a very muscular, obese, or edematous patient, and a patient who

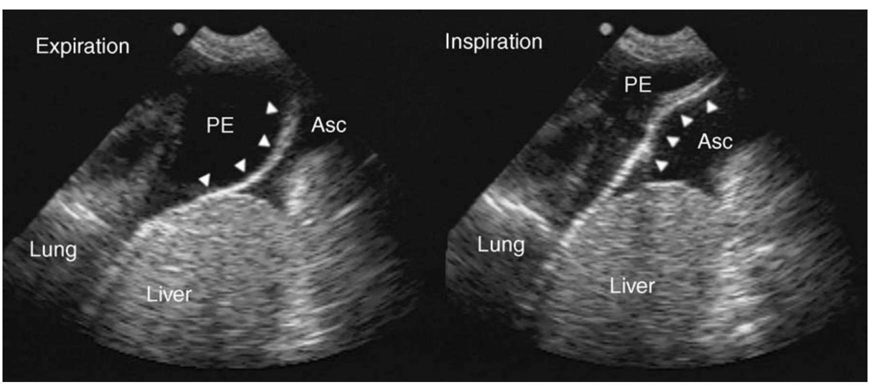

Fig. 2. Images of a hepatic hydrothorax and ascites (Asc) taken during expiration and inspiration. The diaphragm (*arrowheads*) moves cephalad during inspiration. This "paradoxical" diaphragmatic movement is commonly associated with severe dyspnea reversible with thoracentesis. The images also illustrate the importance of identification of the diaphragm before thoracentesis. Failure to do so may result in inadvertent puncture of the ascites. PE, pleural effusion.

is supine because of critical illness with only a small or moderate effusion is more challenging, particularly if thoracentesis is required. Across a continuum of difficulty, the principles of pleural ultrasonography for identification and sampling of a pleural effusion are the same. The three key findings that indicate the presence of a pleural effusion are as follows:

1. The operator should seek unequivocal identification of structures that define the boundaries of pleural anatomy and, in particular, the boundaries of any pleural effusion. This requires clear identification of the diaphragm and subdiaphragmatic organs, the liver on the right and the spleen on the left; identification of the chest wall and in particular its inner border; and identification of lung that is clearly distinguished from the pleural effusion.
2. The sonographer must identify whether a pleural effusion exists within the pleural space. A characteristic feature of pleural effusion is that it is relatively echo-free, and that it is demarcated by the usual anatomic boundaries—the lung, chest wall, and diaphragm.
3. The examiner must identify dynamic changes that are characteristic for pleural effusion.

With the probe held in the longitudinal plane and applied in the interspace, the operator notes two rib shadows, the upper rib on the left and the lower rib on the right of the screen with the inside of the chest wall visible about 5 mm below the origin of the rib shadows. With the patient in a seated position, the best starting position is to examine the posterior chest. In the supine patient, the posterior axillary line is most appropriate. The diaphragm is seen as a curvilinear structure that moves with the respiratory cycle. To confirm identification of the diaphragm, it is important to identify the liver or the spleen as structures that are clearly subdiaphragmatic (see Fig. 2). Rarely, a complex cellular pleural effusion has echogenicity that is similar to the liver or spleen; distinction between the two is crucial. When identified, a pleural effusion appears as a relatively echo-free space above the diaphragm with dynamic movement of the diaphragm occurring with the breathing cycle. The inside of the chest wall is not observed to undergo dynamic change because it is a relatively rigid structure. Underlying lung has a homogeneous gray aeration pattern or appears as a compressed tissue density structure owing to the compressive effect of the adjacent pleural effusion.

The airless lung frequently undulates spontaneously as it floats within the pleural effusion. The undulation of compressed lung is common in moderate-to-large pleural effusions and is termed *lung flapping* or the *jellyfish sign*. Smaller pleural effusions may not cause sufficient compression of the lung to yield these specific signs. Rather, the lung adjacent to the pleural effusion appears with tissue density. Dynamic changes in smaller effusions may include aerated lung that moves into the scanning field to obscure partially the pleural effusion and adjacent compressed lung during inspiration; this is called the *curtain sign*. Airless lung is common with pleural effusions secondary to compressive effect and has an ultrasound density similar to tissue. The term *sonographic hepatization of lung* has been applied to this finding of tissue-density airless lung (Fig. 3). Frequently, at the interface of the effusion and the visceral pleural line, there is a characteristic air artifact called *comet tail* that extends into the adjacent lung. By definition, comet tails start at the pleural interface, move with pleural movement, are sharp-bordered, and extend to the edge of the ultrasound screen. They indicate alveolar-interstitial lung abnormality [12] and often occur in conjunction with a curtain sign. M-mode ultrasound examination of the pleural surface often shows a "sinusoid" sign that is an indication of dynamic movement of the pleural surface within the fluid-filled pleural space [13].

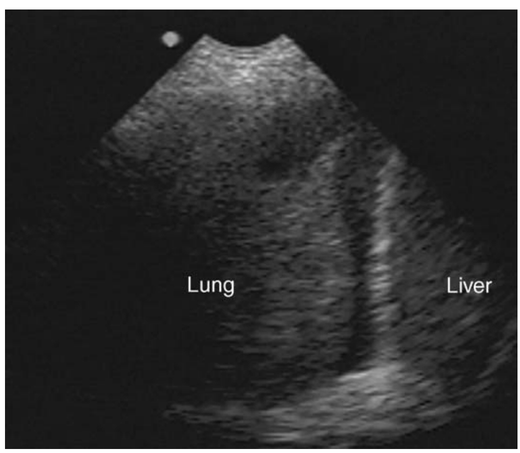

Fig. 3. Image of collapsed lung and normal liver with virtually identical echogenicity. This characteristic of collapsed lung has been named *hepatization* of lung. The bright band between lung and liver represents the diaphragm, and the dark area is a hypoechoic pleural effusion.

Box 1. Findings of importance to pleural sonography

Dynamic signs confirming the presence of pleural liquid

1. Lung flapping (jellyfish sign): Oscillating movement of collapsed lung in a pleural effusion
2. Swirling debris (plankton sign): Debris agitated by cardiac or respiratory motion in a pleural effusion
3. Undulating movements: Strands or fronds agitated by cardiac or respiratory motion in a pleural effusion

Pneumothorax

1. Lung sliding: Periodic movement of the pleural interface relative to chest wall as observed in two-dimensional mode. Indicates the absence of pneumothorax
2. Seashore sign: Equivalent of lung sliding in M-mode, used for documentation of lung sliding on static images
3. Stratosphere sign: Parallel lines representing chest wall and air reverberation artifact in M-mode, documents absence of lung sliding on static images

Miscellaneous

1. Comet tails: Air artifact consisting of a mobile ray-like effect emanating from the pleural surface and extending to the outer edge of the image. Role in pleural ultrasonography is mainly for the identification of air containing lung
2. Curtain sign: Refers to intermittent obscuration of underlying organs by intervening air-filled lung, also has been used to describe the moving air interface in a hydropneumothorax or lung abscesses
3. Hematocrit sign: Refers to the rare layering effect sometimes seen in hemothorax or other highly cellular effusions, the effusion is separated into two phases of different echogenicity

In searching for these three elements that are characteristic of a pleural effusion (Box 1), a relatively echo-free space with characteristic boundaries that undergoes characteristic dynamic changes, the examiner will need to move the probe widely over the thorax. A limited interspace examination is never sufficient to confirm the presence or absence of pleural effusion or to characterize fully the signs that are essential for its identification.

Beyond its simple identification, pleural ultrasonography allows characterization of a pleural effusion. The examiner should attempt to report features of the effusion as follows:

1. *Volume of the effusion*. The simplest approach for estimating the volume of a pleural effusion identified by pleural ultrasonography is a strictly qualitative approach. Based on the opinion and experience of the examiner, the pleural effusion is designated as small, moderate, or large. No particular rules apply to this definition. The advantage of this approach is extreme simplicity. Its inherent inaccuracy is obvious. Another approach to estimating volume is to measure the thickness of the pleural effusion. This method has an inherent problem because the thickness of pleural effusion depends on transducer position. Eibenberger et al [14] reported a correlation between thickness and actual volume of the effusion. In this study, ultrasound methods were more accurate than estimates derived from standard chest radiography. Several authors have used more complex strategies to account for the complex geometry of the pleural space in developing methods of determining the volume of the pleural effusion by ultrasound. It is possible to estimate accurately the volume of a pleural effusion by using these methods [15].
2. *Echogenicity*. The examiner should characterize the echogenicity of the pleural effusion (Box 2). Transudates do not have constituents that serve as ultrasound reflectors and are echo-

free (anechoic). Swirling echoes, strands, fronds, or septations may be visible in exudates, and effusions with these findings are described as being heterogeneously echogenic. Highly cellular exudates, such as hemothorax or empyema, may show homogeneous echogenicity. Most effusions characterized by homogeneous or heterogeneous echogenicity are exudates. Exudative effusions also may be anechoic, however, whereas transudates are uniformly anechoic [16]. Swirling is suggestive of a cellular exudative effusion, such as associated with malignancy, but may occur with a transudate [17]. Increased density of the effusion reduces dynamic changes that are characteristic of pleural effusions, making ultrasound identification difficult. Effusions that are highly cellular may yield an obvious bilayer effect such that the more dependent part of the effusion is frankly echogenic as cells collect in dependent fashion by gravitational effect below an echogenic fluid component of the effusion. This is termed the *hematocrit sign*. If the patient has been immobile for a time, this interface can be quite distinct and suggests the presence of a hemothorax or a purulent pleural effusion.

3. *Stranding or septation*. Complex patterns of fibrinous stranding and frank septations are visualized easily by pleural ultrasonography (Fig. 4). These are found commonly in parapneumonic effusions and suggest the presence of complicated parapneumonic effusion or empyema [18]. Loculated effusions are readily detected by pleural ultrasonography as circular fluid collections that are separated one from the other by thick-walled echogenic structures. Isolated loculations may be located anywhere in the pleural space and are characterized by their atypical position and lack of movement with change of body position. They require careful ultrasound examination to confirm their location. When located, they may be drained under ultrasound guidance if clinically indicated. Pleural ultrasonography is superior to chest CT scan in visualizing septations with a pleural effusion [19]. Even with contrast enhancement, a chest CT scan is unable to clearly define stranding or septations in the pleural space.

Solid pleural abnormalities

Fluid within the pleural space is characteristically relatively nonechogenic. A variety of pleural diseases cause echogenic abnormalities within the pleural space, which are characterized as solid pleural abnormalities. Some of these may coexist with pleural effusions.

Benign and malignant tumors may involve the pleura. Pleural tumors, such as benign mesotheliomas, lipomas, chondromas, or thoracic splenosis, are rare diseases and not commonly found during pleural ultrasonography. They often are delineated by a distinct capsule and are echogenic. They are not seen to invade adjacent tissue planes, although this may be difficult to exclude with pleural ultrasonography. Pleural ultrasonography would not be a means to render a definitive diagnosis based on its nonspecific ultrasound morphology, although pleural ultrasonography can be used to guide biopsy of the lesion. Pleural malignancy may be primary, as in malignant mesothelioma, or metastatic. Pleural ultrasound findings of malignant mesothelioma include hypoechoic thickening of the pleural surface often with irregular or unclear borders (Fig. 5). It can cover large areas of the pleura and be nodular in character. Invasion of the chest wall and diaphragm can be discerned with ultrasonography. Pleural metastatic disease characteristically occurs with a coexisting pleural effusion. The presence of an ultrasound window through the pleural effusion makes the detection of pleural metastatic disease straightforward. Metastatic tumors are generally hypogenic to moderately echogenic and frequently multiple. They can assume a variety of shapes, such as circular, nodular, hemispheric, or broad-based. Frondlike protrusions may be present. Their size varies, and a characteristic feature is their

Box 2. Ultrasound characterization of pleural effusion

1. Anechoic (simple) effusion: Complete absence of internal echoes, black uniform appearance
2. Homogeneously echogenic (complex) effusion: Diffuse internal echoes, gray uniform appearance, occasionally may be seen in dependent parts of an effusion as a result of gravity acting on cellular constituents of an effusion (hematocrit sign)
3. Inhomogeneously echogenic (complex) effusion: Debris, strands, fronds, septations

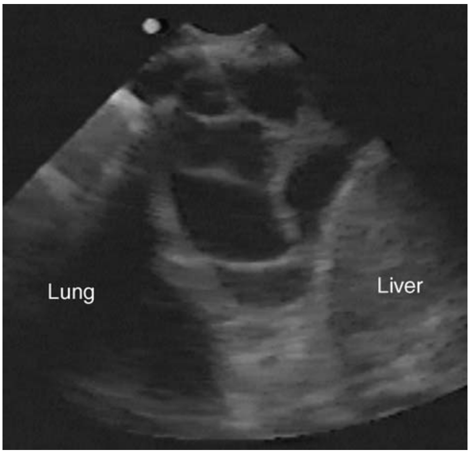

Fig. 4. Complex septate pleural effusion. Although typical for complicated parapneumonic effusion or empyema, this case actually represents spontaneous hemorrhage into a preexisting pleural effusion.

multiplicity. Chest wall or diaphragmatic invasion may be apparent as a disruption of normal tissue interfaces and by visualization of direct extension of the metastatic tumor into adjacent structures (Fig. 6).

Inflammatory diseases of the pleural space, particularly diseases involving infection, are well visualized by pleural ultrasonography. Pleuritis yields characteristic findings on pleural ultrasonography. The parietal pleura is thickened and hypoechoic. The visceral pleura also may be thickened. Underlying lung may show consolidative changes in the subpleural area. As the pleuritis progresses, stranding within the pleural effusion may develop. Pleural ultrasonography identifies undulating, threadlike bands that float freely in the pleural effusion. In the later stage of pleuritis, these bands may thicken and divide the effusion into fluid-filled cavities. A complex network of septa then develop. Complicated parapneumonic effusions or true empyemas often have this septate pattern, with the pleural effusion that collects in each cavity being variably echogenic owing to accumulation of cellular debris (see Fig. 4). A densely echogenic but homogeneous empyema may have echogenicity similar to a subdiaphragmatic spleen or liver and not manifest with a septated pattern. This type of dense empyema does not exhibit dynamic changes that are important means of identifying pleural effusion. When this problem is a consideration, the sonographer should be especially attentive to clear identification of the position of the diaphragm before attempting a drainage procedure.

Pleural fibrosis may be the nonspecific end result of pleural injury. Its ultrasound pattern is characterized by obvious pleural thickening at the area of fibrosis. The echogenicity of pleural fibrosis varies. It may be hypoechoic, which makes distinction from small pleural effusion problematic. A finding that favors fibrosis is absent respiratory movement of the lung pleural interface. One of the few indications for color Doppler in pleural ultrasonography is to aid in distinguishing pleural fibrosis from a small pleural effusion [20]. Pleural fluid provides a color Dopp-

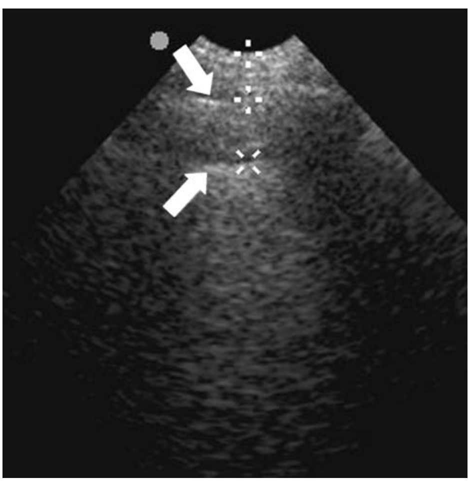

Fig. 5. Hypoechoic area interposed between chest wall and lung (between *arrows*). The distances have been marked for subsequent core biopsy. This echo pattern is not specific for mesothelioma, but can be seen in other malignancies and with pleural fibrosis or plaque.

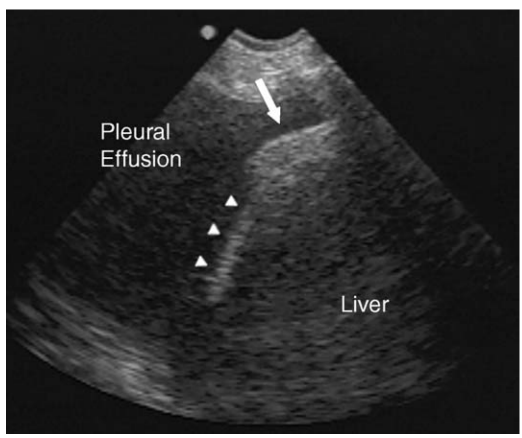

Fig. 6. Metastatic disease on the diaphragmatic pleura (*arrow*). The diaphragm (*arrowheads*) appears intact in this case. Metastasis may invade the diaphragm, and this may be visible with ultrasonography.

ler signal as small reflectors within the fluid move. Color signal from pleural fibrosis is generally absent. It is impossible to distinguish pleural fibrosis from neoplastic disease of the pleura with ultrasonography (see Fig. 5). Pleural calcification within areas of pleural fibrosis is difficult to distinguish because of underlying aerated lung artifact.

Pneumothorax

Pleural ultrasonography is an excellent means for excluding pneumothorax. The presence of sliding lung indicates that there is no possibility of pneumothorax at the site of the examination. The examiner can assess rapidly for sliding lung over a wide area of the thorax effectively excluding pneumothorax (see Fig. 1) [6]. The presence of lung pulse or comet tail artifact is another means of excluding pneumothorax [7,21]. Ultrasonography has special application to patients who are positioned in a supine position because standard chest radiographs may miss an anteriorly situated pneumothorax. For evaluation of pneumothorax, pleural ultrasonography is superior to standard chest radiography in critically ill patients and similar in performance to chest CT scan in this population [22]. The absence of lung sliding or lung pulse is strong, but not absolute, evidence for the presence of pneumothorax [6,7]. Inadequate visualization, pleural symphysis, or nonexpanding lung may cause absent lung sliding without pneumothorax. The presence of lung sliding is a useful finding because it excludes pneumothorax absolutely. The value of sliding lung in pleural ultrasonography is in the emergency evaluation of critically ill patients. Another application is in routine use for invasive procedures that have risk of iatrogenic pneumothorax, such as transbronchial biopsy, subclavian vein cannulation, and thoracentesis. Patients may be examined before and immediately after the procedure to exclude pneumothorax promptly. This greatly reduces the need for postprocedure chest radiographs.

Ultrasound-guided thoracentesis and other pleural interventions

Ultrasound-guided thoracentesis is a valuable technique that can be mastered easily by the pulmonary critical care medicine clinician. It is associated with a very low risk of pneumothorax. A special application is in patients who are on mechanical ventilatory support. Supine chest radiographs do not permit determination of a safe thoracentesis site; iatrogenic pneumothorax in a patient on positive-pressure mechanical ventilatory support is particularly dangerous because there is a high risk of tension pneumothorax. Numerous reports of ultrasound guidance for thoracentesis using two-dimensional ultrasonography have been published since 1982 with a low rate of pneumothorax. A report by Jones et al [23] described 941 thoracenteses in nonintubated patients with a pneumothorax rate of 2.7%. Several studies have addressed the safety of ultrasound-guided thoracentesis in patients requiring mechanical ventilatory support [24–27]. Lichtenstein et al [28] reported 45 procedures in this patient population with a pneumothorax rate of 0%. Mayo et al [29] reported 232 procedures with a pneumothorax rate of 1.3% in a population of patients who were on mechanical ventilatory support. These two reports have interest to pulmonary critical care medicine clinicians because all procedures were performed by nonradiologists. This is strong support for the concept that pleural ultrasonography is a skill that is readily and appropriately acquired by nonradiologists. Findings of thoracentesis in critically ill patients had an impact on their clinical management [30,31]. There is no study that compares the rate of pneumothorax with and without ultrasound guidance of thoracentesis. Diacon et al [32] addressed this issue by comparing standard physical examination and chest radiographs with ultrasonography to identify the best site for thoracentesis. Their results indicate superiority of ultrasound over standard physical examination and chest radiographs for determination of the best site of thoracentesis.

To perform ultrasound-guided thoracentesis, the patient must be positioned properly. Proper positioning with a clear field of action is essential for success. Positioning is a challenge in critically ill patients. The operator likewise must be positioned for ease of operation; this includes orientating the ultrasound machine for easy viewing throughout the procedure and clearing monitoring and support devices from the area of interest in the cluttered environment of the ICU. When all of this is accomplished, the examiner determines the best site, angle, and depth of needle penetration to perform thoracentesis. The site is marked. The needle inserter memorizes the angle of needle penetration. After preparation of the site, needle insertion is performed at the marked point with the insertion assembly held at the same angle as was the probe. The thoracentesis is performed immediately after the ultrasound study without any patient movement because movement may cause shift of the effusion in relationship to the planned insertion site. The shortest possible time should be allowed between the scan and needle insertion so that the operator maintains a clear memory of probe angle. The authors have no formal lower limit for thickness of effusion below which thoracentesis cannot be attempted. Incursions of the lung or the diaphragm during the respiratory cycle into the ultrasound window are specific contraindications to thoracentesis. Unequivocal positive identification of the diaphragm and underlying spleen or liver is required to avoid puncture of these organs.

A dangerous error of the inexperienced sonographer is to mistake the liver or spleen for an echogenic effusion with potentially catastrophic consequence on thoracentesis attempt. This error may be perpetuated if the examiner falsely identifies the curvilinear aspect of Morison's pouch as the diaphragm, when in fact it lies between the liver and kidney. Meticulous attention to clear identification of the diaphragm avoids this error.

The authors routinely perform thoracentesis with freehand technique after marking of the site for needle insertion. It is not necessary to observe the needle in real time with the ultrasound transducer. Although this observation is possible, it complicates the procedure because it requires use of a sterile probe cover and an additional assistant. Real-time needle guidance is not required for safety purposes, as has been shown in a large study of ultrasound-guided pericardiocentesis [33]. Before and after ultrasound-guided thoracentesis, it is appropriate to check for sliding lung. This check permits prompt diagnosis of any procedure-related pneumothorax and avoids the need for postprocedure chest radiographs.

A common problem in performing ultrasound-guided thoracentesis is transducer compression artifact [34]. A probe pressed firmly to the skin indents the skin. The distance between skin surface and the pleural effusion is measured with the probe compressing the skin. On removal of the probe from the skin surface, however, the skin rebounds, assuming its normal configuration; and the actual distance between skin and pleura is greater than that measured during skin indentation. This artifact is especially problematic with patients in severe edema states, where a firmly applied probe may indent the skin several centimeters. The operator needs to be aware of this common problem and recognize that needle insertion may require a greater depth of penetration than was actually measured.

A variety of pleural interventions may be performed using ultrasound guidance. These include insertion of large-bore chest drainage devices, insertion of long-term indwelling drainage catheters for management of malignant effusions, mechanical septal lysis, and guidance of pleural biopsy. Ultrasonography also can assist in access site selection for pleuroscopy. The principles of inserting large-bore drainage devices into a pleural effusion are similar to the performance of a thoracentesis. The best site for insertion is determined by standard criteria, but the operator may choose to use real-time ultrasound guidance to place the device into the appropriate position. Ultrasound guidance requires the use of a sterile probe cover and an assistant to hold the probe during the procedure. If a wire is being used to insert the catheter, its position can be ascertained by ultrasonography (Fig. 7). Likewise, the catheter can be directed into the appropriate position if a trocar-based system is used. If the pleural space is air-filled, the position of the drainage device is impossible to determine owing to air artifact. The main application of ultrasonography in the case of an air-filled pleural space is to locate a safe site for chest tube insertion in reference to diaphragmatic position and possible pleural symphysis.

Ultrasound guidance of pleural biopsy is possible [35]. The forceps is introduced into the pleural space and guided to the pleural-based lesion under real-time ultrasound guidance.

Mechanical septolysis is an application to which pleural ultrasonography is ideally suited. Complex septate effusions present a therapeutic challenge. Ideally, it is advantageous to disrupt them to achieve adequate drainage of the pleural space because

Fig. 7. Hardware may be imaged in real time with ultrasonography. Guidewires, as in this image, are particularly echogenic and can be visualized easily before introducing dilators or catheters. Needles and other hardware are at times more difficult to visualize, but even smooth needles generally have a bright echo at their tip.

thrombolytics may not be effective in this situation. If a trocar-based catheter is introduced into a pleural space that has a multiseptated effusion, pleural ultrasonography allows the operator to break down the walls of the septa with mechanical lysis. The procedure is performed under direct ultrasound guidance and consists of targeting individual walls of septa and breaking them apart with gentle movement of the trocar and catheter assembly. After lysis of multiple septa has been achieved, the catheter is left in the space after removal of the trocar. The authors have had success in mechanical septolysis using this technique under direct real-time ultrasound guidance.

Box 3. Basic skills and technique for ultrasound-guided thoracentesis

1. Identification of anatomic boundaries characteristic of a pleural effusion
   - Inner border of the chest wall
   - Diaphragm with identification of underlying liver or spleen
   - Underlying lung
2. Dynamic changes of the anechoic space characteristic of a pleural effusion
   - Movement of the diaphragm with respiratory cycle
   - Movement of lung (lung flapping, jellyfish sign, curtain sign)
   - Mobile echoic material within the anechoic space (plankton sign)
3. Identification of a site for needle insertion that permits sterile technique and adequate syringe-needle clearance for thoracentesis
4. Stable patient and operator position
5. Site, angle, and depth of needle insertion determined by ultrasonography that avoids any risk of needle injury to the lung, diaphragm, intercostal vessels, or other critical structure throughout the respiratory cycle
6. Thoracentesis performed in standard fashion immediately after ultrasound examination without any patient movement between the ultrasound examination and needle insertion

Training in pleural ultrasonography

Training in ultrasonography requires factual knowledge of the field, skill in image acquisition, and skill in image interpretation (Box 3):

1. *Factual knowledge*. This article provides an overview of the field of pleural ultrasonography. To introduce ultrasonography into clinical practice, the authors recommend reviewing a standard textbook and atlas of chest ultrasonography [2].
2. *Image acquisition*. Implicit to clinical application of pleural ultrasonography is that the physician personally performs the study, interprets the results, and applies them to the problem at hand. This being the case, the physician scanner must be skilled in image acquisition. Image acquisition in pleural ultrasonography is a relatively straightforward task, suitable for an autodidactic approach, provided that image interpretation skills have been acquired. An operator familiar with the concepts and interpretation of ultrasound images of the chest achieves proficiency in a short time.
3. *Image interpretation*. A large anechoic effusion is not a challenge to a trainee with even minimal experience. The challenges of poor image quality, complex echo patterns, and risks inherent to procedure guidance require that the trainee be prepared for difficult image interpretation. Articles and textbooks display only static images and are not adequate for full training in image interpretation. As always, the trainee learns the most from hands-on training with an experienced thoracic ultrasonographer. The shortcomings of static imagery in textbooks can be overcome, however, by using archived and commented video clips. The authors currently are using this approach in their respective fellowship training programs, in addition to hands-on training [36].

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