

Thoracic Ultrasonography in the Critically Ill

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Introduction

With the advances in technology and improvements in cost, many ICUs have the capability to rapidly perform bedside thoracic ultrasonography (US), which has been typically performed by an intensivist team that may consist of advance care providers, residents, fellows and/or attending physicians. This allows for the rapid detection of either fluid or air within the pleural cavity with great accuracy. However, while it has become an integral part of management in many ICUs, it remains operator-dependent, and a detailed knowledge of the fundamentals of US and thoracic pathology is necessary to truly appreciate its benefits. Extensive literature has been published on thoracic US that validates both its diagnostic and therapeutic abilities [1, 2].

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Basic Concepts of Thoracic Imaging

Anatomy

Knowledge of normal pleural anatomy is necessary to be able to accurately interpret US images. The pleural cavity is enclosed between parietal pleura, which lines the chest wall, and visceral pleura lining the lung tissue. The layers of chest wall include skin, subcutaneous fat and fascia, muscles of shoulder girdle over anterior—superior aspect, muscles of abdominal wall over anterior—inferior aspect, muscles of back posteriorly, intercostal muscles interspersed with ribs and costal cartilages, parietal pleural, pleural cavity, visceral pleural and lung tissue (Table 2.1 and Fig. 2.1).

The skin, superficial tissue and muscles allow for passage of US waves, however, cast variable degrees of reflection depending on the tissue density. This differential reflection results in a layered appearance. Ribs will completely block

Table 2.1 Layers of chest wall

Skin
Subcutaneous fat
Superficial fascia
Muscles—shoulder girdle, abdominal wall, back
Intercostal muscles interspersed with ribs and costal cartilages
Parietal pleural
Pleural cavity
Visceral pleural
Lung tissue

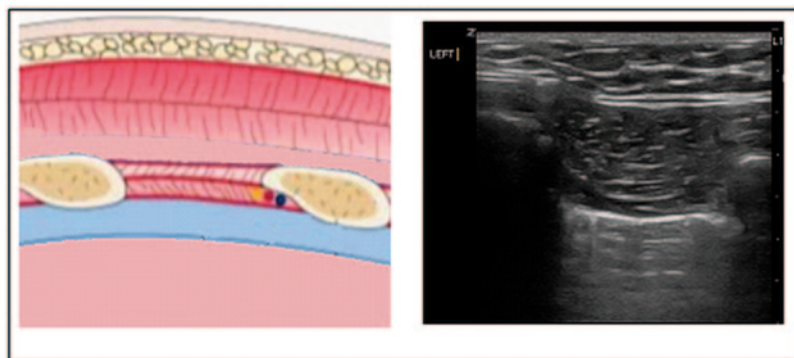


Fig. 2.1 Layers of chest wall

the US waves and create an acoustic shadow. Hence, to image the lung and pleura, it is essential to place the transducer probe between rib spaces and avoid the ribs (Fig. 2.2). This is often one of the more difficult aspects for the inexperienced ultrasonographer to learn, but is critical to obtaining images of the necessary quality.

Air contained in alveoli impedes passage of US waves and creates reverberation at the junction of visceral pleura, resulting in a bright-appearing line that slides along with the lung during breathing cycle directly beneath the layers of chest wall. When air or fluid is present in the pleural cavity, it separates visceral pleura from the chest wall, disrupting this normal sliding. Fluid of whatever type will collect in the dependent areas, which are the posterior costophrenic recess in the upright position, along the lateral chest wall in lateral decubitus position and lateral

costophrenic recess in the supine position. Air, on the other hand, will rise to apices with the patient in the upright position and along the anterior chest wall in the supine position. Thoracic US can be done in any position; however, the supine position is most common in the critically ill patient. Abducting the arm above the head can improve access to the lateral thoracic wall, which is particularly useful while performing interventions on thoracic cavity.

The probe should be gently placed in the intercostal acoustic window of the located area. The initial plane should be longitudinal, with the long axis of the probe parallel to the long axis of the patient's body. This plane allows visualization of at least two ribs and the corresponding intercostal space. The survey of thoracic cavity is carried in a systematic fashion, from anterior to posterior direction. The anterior zone is lined by sternum, clavicle, anterior axillary line and costal margin. This zone gives maximum yield for detection of pneumothorax. The lateral zone lies between anterior and posterior axillary lines. The posterior zone, lying behind the posterior axillary line, is difficult to assess in a supine patient as the probe is often limited by the bed. If the clinical condition allows, then the patient should be turned to other side with probe facing upside down to achieve comprehensive imaging.

The transducer frequency used in thoracic US varies from 3.5 to 10 MHz. A 2- to 5-MHz curvilinear probe allows visualization of the deeper structures and the sector scan field allows a wider field of view through a small acoustic window.



Fig. 2.2 Probe position for pneumothorax detection

The chest wall, pleura, and lungs may be quickly surveyed with the curvilinear probe. Once an abnormality has been identified, a high-resolution 7.5- to 10-MHz linear probe can be used to provide detail [3]. Both B and M mode are useful for thoracic US. Doppler imaging has limited application in thoracic imaging, but one possible use is to detect blood vessels within the needle tract while accessing pleural space.

Normal Lung and Pleural Imaging

All lung signs arise at the level of pleura. The signs can be described as either static or dynamic [4]. The usual static artifact is a horizontal, hyperechoic line, parallel to the pleural line, at an interval that is exactly the interval between skin and pleural line. This artifact is called the US A-line. Another static artifact is called the US B-line. These are vertical lines, arising from the pleural line, spreading up to the edge of the screen without fading and are synchronized with lung sliding. The B-line is also called a “comet tail” artifact. Figure 2.3 When several B-line are seen in single lung scan then this pattern is called the “lung rocket.” Another kind of vertical artifact, again a comet-tail, is well defined and spreads up to the edge of the screen without fading. However,

this artifact does not arise from the pleural line but from superficial layers of the chest wall, NOT the pleura. These line erase pleural lines and are called the E line, E for emphysema, and are seen in subcutaneous emphysema.

Lung sliding is a basic dynamic sign. Lung sliding shows the sliding of the visceral pleura against the parietal pleura. In experienced hands, one second scanning is suffice to detect lung sliding [4]. It is more prominent at lung bases compared to apices. Common pitfalls, which prevent detection of sliding, include a low-frequency probe and application of dynamic noise filters. Lung sliding is best characterized on M-mode scanning and creates a so-called “seashore” sign (Fig. 2.4 and Video 2.1).

Apnea or complete lack of lung ventilation, like main stem intubation, replaces the sliding with “lung pulse,” which is the transmittance of cardiac impulse through the lung tissue towards the probe [5]. The lung pulse on M-mode scanning is synchronized with cardiac rhythm.

Pneumothorax

The diagnosis of pneumothorax can be made rapidly and precisely using US. The ultrasonographic identification of pneumothorax involves

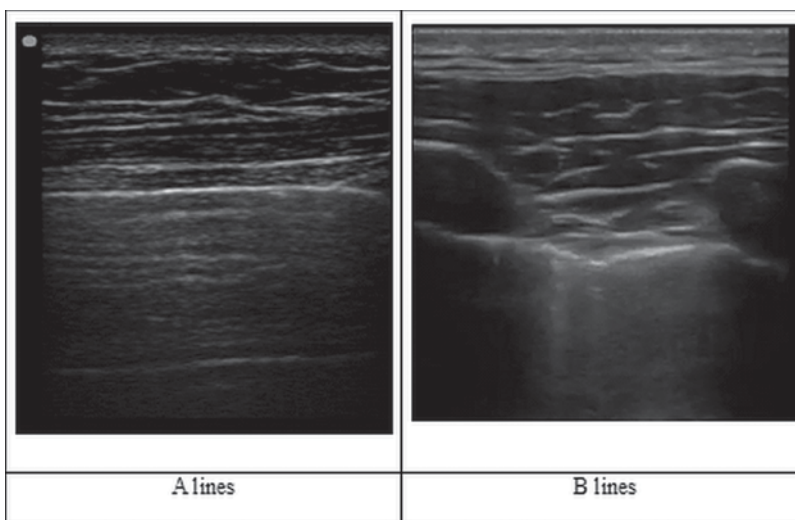


Fig. 2.3 Sonographic A and B-lines

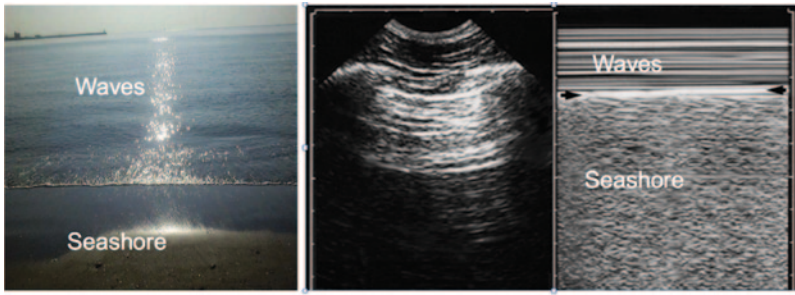


Fig. 2.4 “Seashore” sign

absence of lung sliding, presence of A-lines with or without presence of “lung point.”

The usual finding of lung sliding under the parietal pleura disappears as the lung collapses and air builds up between parietal and visceral pleural. The air between parietal and visceral pleura reflects ultrasonic waves, thereby obliterating the B-line. However, the A-line created at the interface of parietal pleura remain intact. On an M-mode imaging, the “seashore” sign created by normal lung parenchyma is replaced by a “barcode” or a “stratosphere” sign (Fig. 2.5).

In patients with mild to moderate pneumothorax, the area of lung that is still in contact with the pleura creates a “lung point”. It is point of transition between absence and reappearance of the

lung sliding and the B-line. Lung point is a dynamic sign. Similar observation can be made on an M-mode image as disappearance of “barcode” and appearance of “seashore” sign. The finding of a lung point is highly indicative a pneumothorax. However, lung point is absent if lung is completely collapsed under a massive pneumothorax (Fig. 2.6a, b and Video 2.2).

Absence of the so-called “bat sign” can also be used to look for pneumothorax [6, 7]. This is a normal pattern that can usually be easily seen and represents normal chest anatomy. The reason that it is called the bat sign is due to the likeness of a bat flying with its wings up, towards the viewer (Fig. 2.7). The anatomy that it represents is an upper and lower rib, with a pleural line, with the

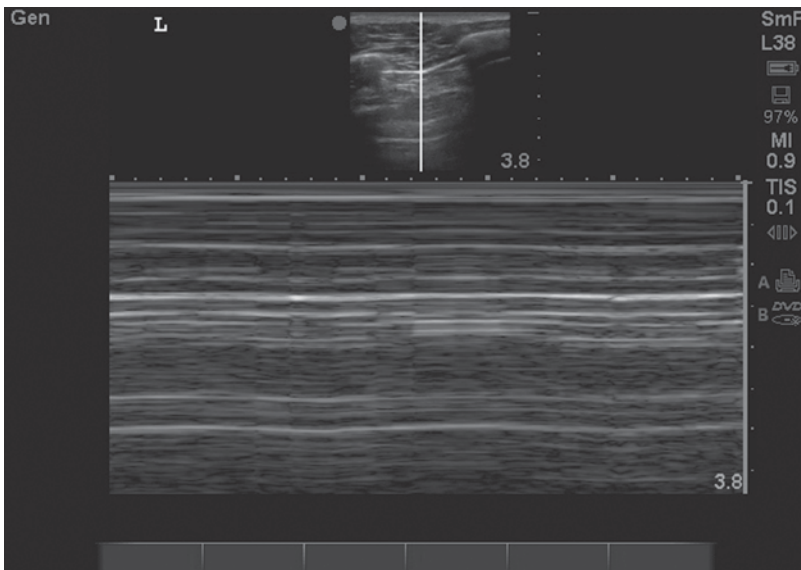


Fig. 2.5 Bar code/stratosphere sign



Fig. 2.6 “Lung point” sign

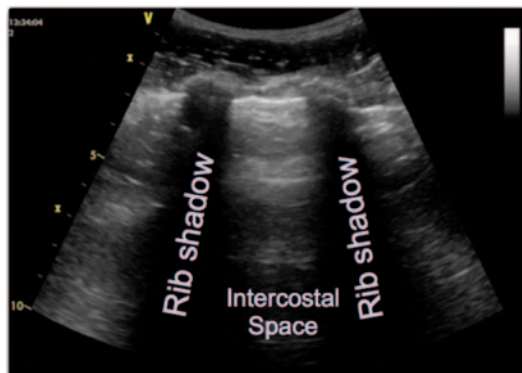


Fig. 2.7 “Bat” sign

echoes thrown off by the ribs forming the bat’s wings and the body being made up of the hyper-echoic pleural line. In a patient with a pneumothorax, this normal sign is no longer visible.

Thus, it can be seen with these constellations of signs using different scanning modes, it should be possible to accurately determine the presence or absence of a pneumothorax in most patients at the bedside, without waiting for a formal chest radiograph. The question is whether US is accurate enough to make clinical decisions without the use of radiography and we will examine this in the next section.

Evidence Base for Ultrasound for Pneumothorax

Use of US for detection of pneumothorax is extensively validated. Presence of lung sliding in an area spanning over three intercostal spaces has shown to have a negative predictive value of 100% by Lichtenstein et al. [8]. Another prospective study for presence of pneumothorax by the same group in 73 ICU patients revealed that presence of A-lines (horizontal artifacts) had

a sensitivity and a negative predictive value of 100% and a specificity of 60% for the diagnosis of pneumothorax [9]. When presence of A-line and absent lung sliding are combined, it had a sensitivity and a negative predictive value of 100% and a specificity of 96.5% [9]. Presence of lung point allows for positive diagnosis of pneumothorax. In a prospective study, lung point was present in 44 out of 66 cases of pneumothorax and in no case in control group with an overall sensitivity of 66% and specificity of 100% [10]. Absence of lung point, however, does not exclude pneumothorax.

Focusing the scan over high-yield areas can mitigate a common concern over the amount of time taken to achieve an effective scan of chest. A rapid scanning method of obtaining images from the second intercostal space on the mid clavicular line, the fourth intercostal space on anterior axillary line, the sixth intercostal space on the mid axillary line, and the eighth intercostal space on the posterior axillary line has shown a sensitivity of 98.1% and specificity of 99.2% in the diagnosis of pneumothorax with US compared to 75% sensitivity and 100% specificity of a supine chest x-ray [11].

Advantages of ultrasonographic detection of pneumothorax are numerous including immediate positive or negative diagnosis at the bedside in emergency situations, decrease in irradiation and cost. Ultrasound can be used in a number of non-trauma clinical settings; for example, it can be used to assess for the presence of pneumothorax following an invasive procedure [12, 13]. It is clear, however, that although the sensitivity and specificity of this modality can be high, there will be circumstances where chest radiography is still necessary, e.g., pre-existing lung disease, subcutaneous emphysema, extremes of body habitus, etc.

Table 2.2 Tips for maximizing success when performing ultrasound for pneumothorax

Proper patient positioning if clinically feasible:
a. For pneumothorax: Upright as much as possible and scan apical area
b. Support patient appropriately with pillows and/or blankets
c. Adjust height and position of bed and ultrasound machine to optimize operator ergonomics
Appropriate probe selection:
d. A low-frequency (2–5 MHz) curvilinear probe for rapid scanning and enhancing area seen under the probe
e. High-frequency, high-resolution probe to better define the pathology once identified
f. Adjust depth and focus to maximize area of interest
g. Use both B and M modes to confirm presence of air
h. Color Doppler to identify blood vessels in the needle path before accessing thoracic cavity
Identify surface landmarks:
i. For rapid scanning for pneumothorax- second intercostal space (ICS) in mid-clavicular line, fourth ICS in anterior axillary line and sixth ICS in mid-axillary line, while patient is in upright or semi-upright in position

Another possible advantageous area for the use of US is in the assessment for the presence of pneumothorax following removal of chest tubes. In a study of 50 cardiothoracic surgery patients with chest tubes surgically placed at the time of operation, Saucier and colleagues found that there was 100% agreement between US and chest radiography following removal of the chest tubes [14]. Similarly, in a study of trauma patients with tube thoracostomy, they noted that use of US in the 4th or 5th intercostal space was highly predictive (100%) of the presence of post-removal pneumothorax [15]. They also noted that the 4th or 5th intercostal space performed better than the 2nd or 3rd intercostal space, and all of these ultrasounds were surgeon-performed.

Clearly, if we were to more liberally adopt the use of US for the detection of pneumothorax we could make both significant cost savings as well as reduce the radiation exposure to our patients, both central tenets of the “Choosing Wisely” campaign [16].

See Table 2.2 for tips on maximizing success when performing ultrasound for pneumothorax.

Ultrasound for Pleural Effusion/ Hemothorax in the ICU

Intensive care unit patients commonly develop intra-thoracic fluid during the course of their admission. Medical ICU (MICU) patients typically develop transudative or exudative effusions and empyema, while surgical or trauma patients overwhelmingly develop hemothorax [17].

In a prospective study of medical ICU (MICU) patients, over 60% were found to have radiographic evidence of effusions at some point during their hospitalization. The most common causes included heart failure, atelectasis and parapneumonic processes [18]. Patients who have undergone thoracic or abdominal surgery, as well as those who have sustained thoracic trauma, will frequently accumulate intra-thoracic fluid collections—effusions and, more commonly in trauma patients, hemothorax. Approximately 60% of poly-trauma patients sustain thoracic trauma and up to 18% of these patients will require tube thoracostomy for hemothorax during their initial admission [19].

As the availability of small, mobile sonographic units increased during the 1990s, it became much more possible for physicians (non-radiologists) to perform bedside diagnostic procedures and image-guided treatments for effusions and hemothorax. There are of course many advantages of diagnosing and treating intra-thoracic fluid collections via US at the bedside. Compared to CT or x-ray technology, US is inexpensive and avoids ionizing radiation exposure. The performance of bedside US precludes the need to transport critically ill patients. The quality and sensitivity of US imaging is preserved, in contrast to portable x-ray films where up to 30% of all studies are considered suboptimal [20].

Most of the early studies on diagnosing intra-thoracic fluid collections using portable US originated in the emergency medicine and trauma literature. The first description of the use of US to diagnose effusion was in 1967 [21]. In

1993 Rothlin et al. demonstrated the ease with which US can be used to diagnose CT-confirmed pleural effusion [22]. Shortly thereafter, Ma et al. demonstrated 96 % specificity, 100 % sensitivity and 99 % accuracy for identifying free pleural fluid with portable US as an extension of initial, abdominal examination [23]. Recent studies have demonstrated the superiority of US compared to chest radiograph in detecting lung pathology. In 2011, Xirouchaki et al. demonstrated a higher sensitivity, specificity and diagnostic accuracy for US examination of intrathoracic fluid, compared to chest radiograph in a heterogeneous MICU/SICU patient population [24].

Ultrasound has also been proven effective in determining the etiology of effusions, based on the internal fluid echogenicity and associated changes in pleura and adjacent lung parenchyma [17]. Transudates, most frequently seen in patients with congestive heart failure, cirrhosis, or nephrotic syndrome, are always anechoic. They do not demonstrate any internal septations or echogenic signal. Exudates, on the other hand, can be either echoic or anechoic. Parapneumonic effusions and empyema are two exudative processes that can easily be confused for solid masses because they possess such complex internal septation architecture and echodensity due to fibrin deposition and cellular debris. Blood is usually seen as a heterogeneous hypoechoic collection that may or may not contain internal septations. As a retained hemothorax matures, however, it becomes thick-walled and very echogenic [17].

Studies suggest that the use of US for thoracentesis can be an effective method of delivering care, with an acceptably low rate of complications. Two early initial papers showed good success rates with relatively large volumes removed (mean volumes of 442 and 823 mL, respectively) with low rates of post-procedure pneumothorax—2.8 to 4.2 %, with both studies recommending AGAINST routine chest radiographs post-procedure [25, 26]. Interestingly, although one of these initial reports did not suggest that the volume of fluid removed was a risk for pneumothorax, subsequent work by other authors showed a three-fold increase in the risk of pneumothorax

if the volume drained was over 1.8 L, rising to a six-fold increase over 2.8 L [27]. Some authors have recommended the use of pleural manometry to reduce the risks associated with thoracentesis, including pneumothorax and reexpansion pulmonary edema [28].

Further studies looking at purely critically ill patients have corroborated these initial reports. Patients undergoing mechanical ventilation seem to be at no higher risk of developing pneumothoraces following US-guided drainage procedures with a very low rate of 1.3 % [29]. Of note, in this study the gold standard was to perform chest radiography and they noted that morbid obesity and chest wall edema causing a chest wall thickness of more than 15 cm were predictive of failure of the procedure.

In a different approach Tu and colleagues used US-guided thoracentesis for diagnosis in a group of febrile mechanically ventilated patients [30]. They were successful in diagnosing infectious exudates in 62 % of their patients, with a low complication rate of only 2 %, which, however, were two hemothoraces. They had no pneumothorax or reexpansion pulmonary edema in this group.

The position of the patient does not seem to be a limiting factor, either. In a recent study, the authors examined the use of US to gain access to the thoracic cavity with the patients in either the supine or semi-recumbent position [31]. They measured the time required for needle insertion, which was a very respectable 185 s on average, with again a low rate of pneumothorax of 1.4 %.

As we have moved towards more minimally invasive therapies for various diseases, this trend has also spread into the size of chest tubes placed for fluid drainage, which is responsible in some small part for the increasing interest in US guidance as typically the position of the tube is more critical when it is of small caliber as opposed to the traditional 36- or 40-Fr “standard” chest tube placed in the 5th intercostal space in the midclavicular line. In a study examining 10- to 16-Fr chest tubes, the authors quoted a success rate for US-guided tube placement, with a low complication rate of 3 %. With the continuing adoption of small bore catheters, it is likely that US will

become increasingly used in pulmonary disease, particularly as it is clear that pre-procedure imaging can be used to predict which patients are most likely to fail with this type of drainage [32].

As the above descriptions show, US can be a highly effective and efficacious tool in the hand of the intensive care physician, and the ease of training makes it a simple and valuable adjunctive skill for the practitioner. In the next section, we will discuss some of the “nuts-and-bolts” of performing bedside procedures.

Performing Thoracic Ultrasound Examination for Hemothorax/Effusion

Positioning

Ideally, US examination for intrathoracic fluid should be conducted with the patient in a seated position. In the ICU, patient mobility is limited as a result of indwelling venous and arterial lines, the need for mechanical ventilation and patient disease, such as spinal injury, preventing the patient from sitting upright. Critically ill patients who cannot be placed in the seated position should therefore be positioned in a head-up or reverse-Trendelenburg fashion because simple fluid collections will settle at the lung bases, improving the sensitivity of US examination; even a small volume of fluid will be more evident sonographically if the patient is in a seated or head-up position. The examining physician should stand facing the patient, with the US unit positioned in such a way that the screen is visible to the examining physician without excessive rotation of the examiner’s neck or turning away from the examinee. The patient’s arm can be abducted in order to improve access to the lateral chest wall. An assistant is highly suggested to help support and turn the patient, in order to examine the posterior chest wall.

Probe Orientation and Direction

Evaluation for effusion should be performed with a 3 to 5 MHz phased-array probe oriented in the

sagittal plane (i.e., parallel to the long axis of the body). The probe indicator should be oriented towards the patient’s head. This will orient cephalad structures to the left side of the US display.

Depending on the patient’s pathology, it may be necessary to perform a partial or complete examination of the thorax—as mentioned, simple effusions and hemothoraces will settle by gravity in the posterior and inferior costophrenic angles, while loculated pleural effusions can be located anywhere in the chest. To begin a complete sonographic examination of the chest for fluid, the probe is initially placed between ribs in the mid-axillary line (Fig. 2.8) When the structures of the chest wall are visualized, including the subcutaneous soft tissue, intercostal muscle, pleural line and underlying lung tissue, probe depth and gain are optimized. By angling the probe cephalad or caudad, one can visualize the pleura and lung underlying adjacent sonographically opaque ribs. When that first interspace has been satisfactorily visualized, the probe is moved either upward or downward to an adjacent rib-space. In this fashion, moving up and down the long-axis of the chest, a vertical scan-line can be created allowing the examiner to compose a two-dimensional model in her own mind. When this vertical scan line has been completed, the probe can be moved to a second scan line, anteriorly or posteriorly along the patient’s chest wall. If, by the patient’s history, a hemothorax or simple effusion is suspected, subsequent examination can be directed to the posterior costophrenic



Fig. 2.8 Probe position for hemothorax/effusion detection

angle. Or, by moving methodically across the anterior and posterior chest in regularly spaced vertical scan lines, the entirety of the chest can be examined. In the last several years, protocols have been developed to streamline the need for completing a complete chest examination, expediting diagnosis by examining the chest at a set number of standardized locations [33, 34]. These protocols have not been validated for the diagnosis of effusion or hemothorax—a complete examination guided by knowledge of the patient's pathology and common sense is still recommended.

Landmarks and Characteristic Findings on Examination

The normal anatomy of the chest guides the comprehensive US examination for fluid. At the beginning of the examination, the soft tissues of the chest wall, ribs and pleura should be examined. The ribs themselves pose a barrier to examination due to their sonographic opacity, though this issue is easily dealt with by angling the probe around the rib. Pathology of the chest wall, such as soft tissue edema or costal fractures/hematoma, and anatomic variability, such as excessive adipose or muscle tissue, can also pose as an obstacle to obtaining accurate sonographic images.

Normal anatomy should be examined and used for orientation. The pleura should appear as a bright, echogenic line approximately 5 mm deep to the cortex of the rib (Fig. 2.9). In the presence of pathology, the pleura may be thickened or demonstrate nodules. A thickness greater than 3 mm is considered abnormal and is usually associated with an exudative effusion elsewhere in the thorax. When examining regions of the thorax that do not overly a fluid collection, normal pleural sliding and A-lines should be seen.

Arguably the most important landmarks of the chest, and the site where some authors suggest the effusion exam should start, are the hemidiaphragms with adjacent solid organs, the liver and spleen. The liver and spleen can be used as

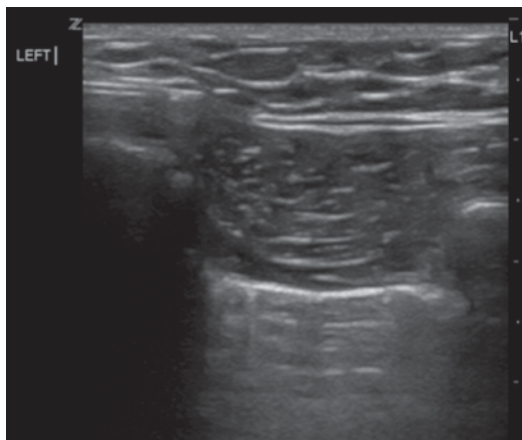


Fig. 2.9 Normal pleural anatomy

acoustic windows to the chest—by directing the probe cephalad through these organs, the hemidiaphragms should be visualized. Directing the probe upward through solid organs is also a good way to visualize fluid overlying the diaphragm. Furthermore, as the most inferior structures of the chest, they should be visualized during thoracentesis or the placement of a thoracostomy tube, in order to avoid inadvertently traversing the diaphragm and/or entering the peritoneum.

Fluid appears as a dark, relatively anechoic stripe that displaces the lung from its normal apposition to the chest wall or diaphragm (Fig. 2.10). Fluid depth should be estimated. Most US units will have a distance scale or a caliper function that will allow an estimation

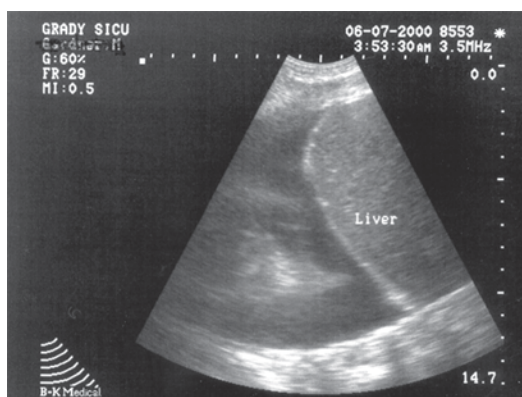


Fig. 2.10 Pleural effusion

of the depth of a fluid collection in two dimensions. If the goal of examining for the presence of intra-thoracic fluid is drainage, a site should be selected where the interpleural distance (i.e., the distance between visceral and parietal pleura) is at least 10 to 15 mm, in order to avoid injuring the lung [35].

The echogenicity of the fluid should be characterized. As mentioned previously, the character of fluid is suggestive of its etiology. Fluid collections can be homogeneously anechoic, echogenic (i.e., containing sonographically opaque particulate matter suspended in fluid) or complex (i.e., possessing internal septations). In order to determine the echogenicity of a thoracic fluid collection, it can be compared to the appearance of the gallbladder—in the absence of coexisting pathology, bile is assumed to be a simple, anechoic fluid.

Transudative processes, most frequently seen in patients with congestive heart failure, cirrhosis, or nephrotic syndrome, will always be anechoic and without internal structure or septations. Transudative fluid will appear to be of equal darkness when compared to the contents of the gallbladder.

Exudative processes can be either anechoic or echogenic and can also be complex. Some malignant exudative effusions are thin and appear anechoic. Parapneumonic effusions and empyema, on the other hand, are two exudative processes that are easily confused for solid masses because they possess such complex internal septation architecture and echodensity, due to fibrin deposition and cellular debris. Obviously the success of any thoracic drainage procedure will depend to a certain extent on the type of fluid and the characteristics mentioned above.

Although fresh blood is usually seen as a heterogeneous anechoic or hypoechoic collection, the character of the fluid will change over time as evolving blood clot generates some sonographic shadows. A hemothorax may demonstrate some echogenicity and may or may not contain internal septations. As a retained hemothorax matures, it becomes thick-walled and very echogenic [17].

The most dramatic and obvious ultrasonographic finding indicative of a thoracic fluid collection is the sight of a sliver of lung floating in a dark, relatively anechoic background. The lung can be seen pulsating with patient respirations or with the cardiac cycle (Video 2.3). The lung parenchyma will typically show signs of collapse and alveolar consolidation under these circumstances—B-line artifacts and bronchograms can be seen.

There are three signs that are diagnostic of a pleural effusion or hemothorax. First is the quad sign, which is seen in the 2D mode, in the presence of a small volume of fluid between the chest wall and lung. With the probe positioned over an intercostal space, the displaced surface of the lung forms the base of an anechoic quadrangle; the parietal pleura/chest wall are the top side and the shadows cast by adjacent ribs form the sides of this rough quadrangle (Fig. 2.11).

With the US in M-mode, it is possible to appreciate what is called the sinusoid sign. With the probe again over an intercostal space, the lung's parietal pleura can be seen to be displaced from the parietal pleura. Over the course of several of the patient's respiratory cycles, the hyperechoic visceral pleura can be seen to trace a bright sine-wave pattern as it approaches and then recedes from the chest wall (Fig. 2.12).

Finally, the V-sign was recently described as a method for diagnosing the presence of free pleural fluid [36]. This sign is elicited while examining a supine patient, using a low-frequency probe. The probe is placed low on the chest wall, at approximately the level diaphragm and aimed cephalad and towards the spine. Under normal physiologic conditions, the inflated lung would block the transmission of sound waves to the posterior thoracic structures. However, in the presence of fluid, which acts as an acoustic window, it is possible to see the contour of vertebrae at the deep aspect of the US display (Fig. 2.13).

See Table 2.3 for tips on maximizing success when performing ultrasound for hemothorax/effusion.

Ultrasonography in the ICU

Practical Applications

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