Pleural Ultrasound for Clinicians

A text and E-book

Edited by Claire L Tobin and Y C Gary Lee
Fergus Gleeson, David Feller-Kopman, and Najib Rahman

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Contents

Preface

ULTRASOUND is an exciting imaging modality that allows portability, flexibility, and real-time dynamic imaging. Its use in thoracic medicine is expanding rapidly, particularly in the field of pleural disease. Use of pleural ultrasonography is increasingly recognized worldwide as an invaluable tool in the diagnosis and management of pleural patients at the bedside, significantly improving the efficiency and quality of patient care. Its use in guiding pleural intervention is now mandatory in many countries.

Proficiency in pleural ultrasound is a training requirement for respiratory specialists in a growing number of countries. Adequate training is the key to its successful application and use in clinical practice. This book is the first of its kind to fill the training needs for chest physicians and other non-radiologists, of all levels of experience, by providing essential knowledge on all aspects of pleural ultrasound in this new era. Understanding the basic principles of ultrasonography, its limitations, and commonly encountered artifacts is a crucial first step, as there is greater potential than with other forms of imaging for misinterpretation. Its skillful use can then be acquired at the bedside, with a designated mentor, through regular practice.

This book is written by chest physicians, with expert advice from internationally acclaimed thoracic radiologists. The authors are all enthusiastic teachers with many years of experience in running pleural ultrasound courses around the world. Their insight into the training needs of non-radiologists make this book unique.

This concise text is prepared with a clear clinical focus, to guide use of pleural ultrasound and enhance patient care. It delivers an extensive number of high-quality, original, real-time ultrasound images and teaching videos, carefully selected from the wide collections of the authors. We feel this provides the best learning media for readers to build an essential platform in acquiring the necessary skills in pleural ultrasound. Please refer to the E-book to view the ultrasound clips and teaching videos where you see a U or V symbol and where indicated in the caption. URLs also guide you to the ultrasound images and teaching videos should you prefer to access them this way. We feel this provides the best learning media for readers to build an essential platform in acquiring the necessary skills in pleural ultrasound. Each chapter includes tips for clinical practice and is supplemented by multiple-choice self-assessment questions. The book also covers applications beyond the pleura, ultrasound-guided procedures, training requirements, and equipment information.

On behalf of the authors, we hope this text will help you in the journey of discovering the benefits of pleural ultrasound.

Claire Tobin
Y.C. Gary Lee

January 2014

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CHAPTER ONE

Clinical Indications for Pleural Ultrasound

Sze K. Tan and Y.C. Gary Lee

INTRODUCTION

Pleural disease is commonly encountered in clinical practice. An estimated 3000 people per million population each year develop a pleural effusion.[1] The United States alone sees an estimated 1.5 million cases of pleural effusions annually.[2]

Clinical workup of a pleural effusion inevitably involves radiologic imaging techniques that may include chest radiography, ultrasonograpy, computed tomography, and magnetic resonance imaging or positron emission tomography. Sampling of the pleural fluid or tissue is often required in the management of pleural effusions. A safe and cost-effective approach is therefore essential in the diagnostic workup of these patients.

ADVANTAGES OF PLEURAL ULTRASOUND OVER CLINICAL ASSESSMENT AND CHEST RADIOGRAPHY

The growing availability of relatively inexpensive and portable ultrasound machines has greatly enhanced the diagnostic capabilities of clinicians in the assessment of pleural diseases. Pleural ultrasound offers significant advantages in the detection of pleural effusion, estimating the size and nature of the effusion, and identifying loculations and relations with other vital structures.

Ultrasonography provides prompt, accurate, radiation-free, real-time point-of-care imaging. Pleural ultrasound performs better than chest radiographs and is comparable to computed tomography (CT) scans in the assessment of pleural diseases in ambulatory and critically ill patients.[3,4] The portable nature of modern ultrasound machines allows easy bedside examinations and contributes to its growing popularity.

A rapidly growing number of centers employ ultrasonography before all pleural procedures to enhance procedural safety. The critical role of pleural ultrasound in improving the accuracy and safety of pleural puncture sites has been well established in multiple reports.[5–9] Diacon et al. have shown that even in "expert hands" the determination of the presence of pleural effusion based on physical examination and chest x-ray (CXR) was inaccurate, with an alarming 15% error rate. Without the use of ultrasound, 10% of patients will suffer accidental organ puncture to the lung, spleen, or liver during attempted thoracentesis[6] (Figures 1.1–1.3). Hirsch *et al.* reported that ultrasound-guided thoracentesis was successful in 87% of patients who had failed an attempted aspiration guided by physical examination and chest radiography.[5] These findings herald a need for change to the mandatory use of ultrasonography in localizing a safe and accurate site for thoracentesis.

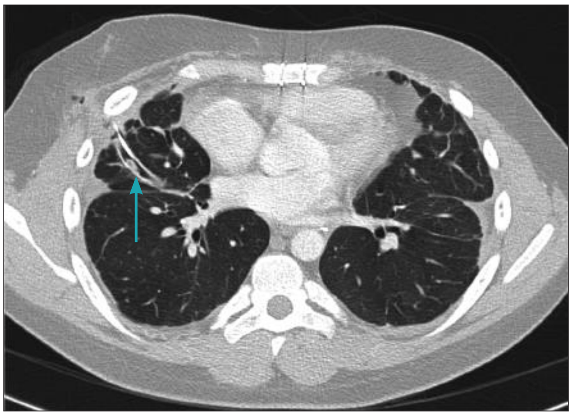

Figure 1.1 Chest drain (arrow) inserted into the right lung. Unfortunately, this patient had received a lung transplant.

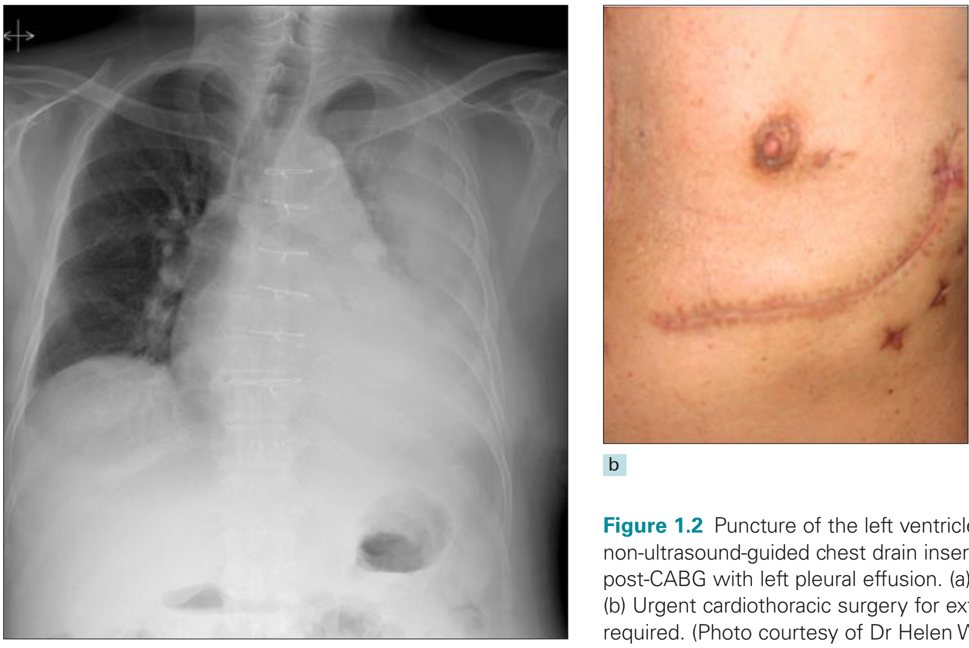

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Figure 1.2 Puncture of the left ventricle (LV) during non-ultrasound-guided chest drain insertion in a patient post-CABG with left pleural effusion. (a) CXR preprocedure. (b) Urgent cardiothoracic surgery for extensive LV repair was required. (Photo courtesy of Dr Helen Ward.)

Clinical signs of a pleural effusion may be mimicked by other pulmonary conditions, such as consolidation, collapse, and an elevated hemidiaphragm. Signs of an underlying pleural effusion cannot be differentiated from those of an underlying liver or spleen. A preprocedural ultrasound in these cases is therefore necessary to distinguish between these conditions and to select an appropriate site for thoracentesis.[10]

Chest radiographs are not as sensitive as ultrasound in detecting pleural fluid and may appear normal in such cases. As much as 500 ml of pleural fluid may be present without blunting of the lateral costophrenic angle,[11] and large effusions may be missed on a supine radiograph, as the pleural fluid layers posteriorly.[12] A loculated pleural effusion, on the other hand, may occasionally be mistaken for a solid tumor on chest radiograph. Ultrasound can separate fluid from both consolidation and atelectasis. Pleural ultrasound thus improves the yield and safety of thoracentesis in effusions, particularly in small or complex collections.[6,7,13]

PLEURAL ULTRASONOGRAPHY BY CHEST PHYSICIANS

Diagnostic competencies

Physicians given appropriate training can perform pleural ultrasound to a standard comparable with thoracic specialist radiologists. In a UK study,[14] physician-delivered thoracic ultrasound was accurate and had a high level of agreement (99.6% for detection of pleural fluid and 89.3% for assessing technical feasibility of pleural fluid for aspiration) with specialist thoracic radiologists.

Procedural competencies

The benefits of preprocedural pleural ultrasound are equally applicable whether the ultrasound examination was performed by radiologists or chest physicians.[8,9] In a prospective study of 941 thoracenteses by interventional radiologists under ultrasound guidance in a tertiary referral hospital, the incidence of postprocedural pneumothorax was 2.5%, with only 0.8% requiring tube thoracostomies. These figures compare favorably with the incidence of complications previously reported in the literature for thoracenteses without direct imaging guidance.[8] Similarly, a study of pulmonologists in Mayo Clinic[9] showed that a

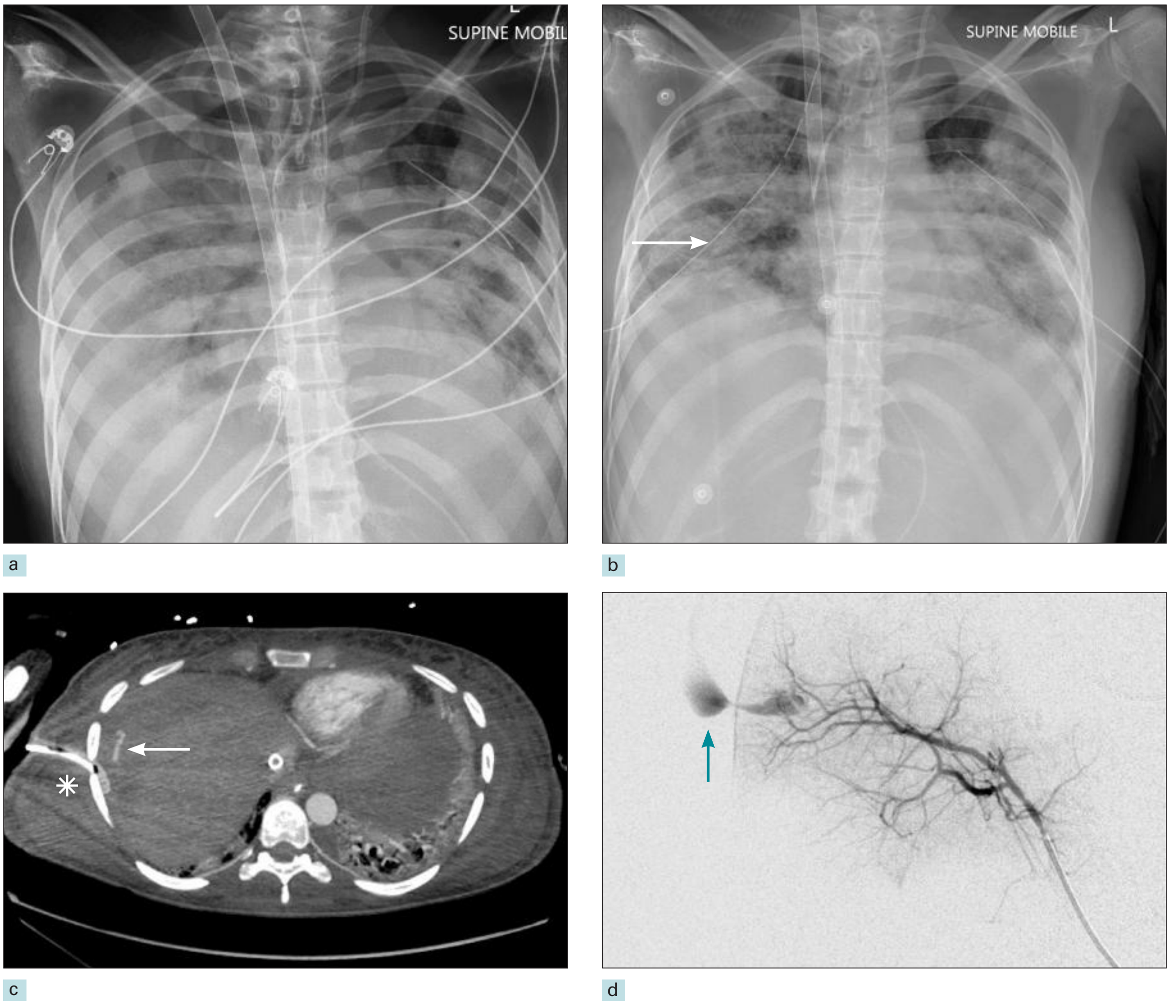


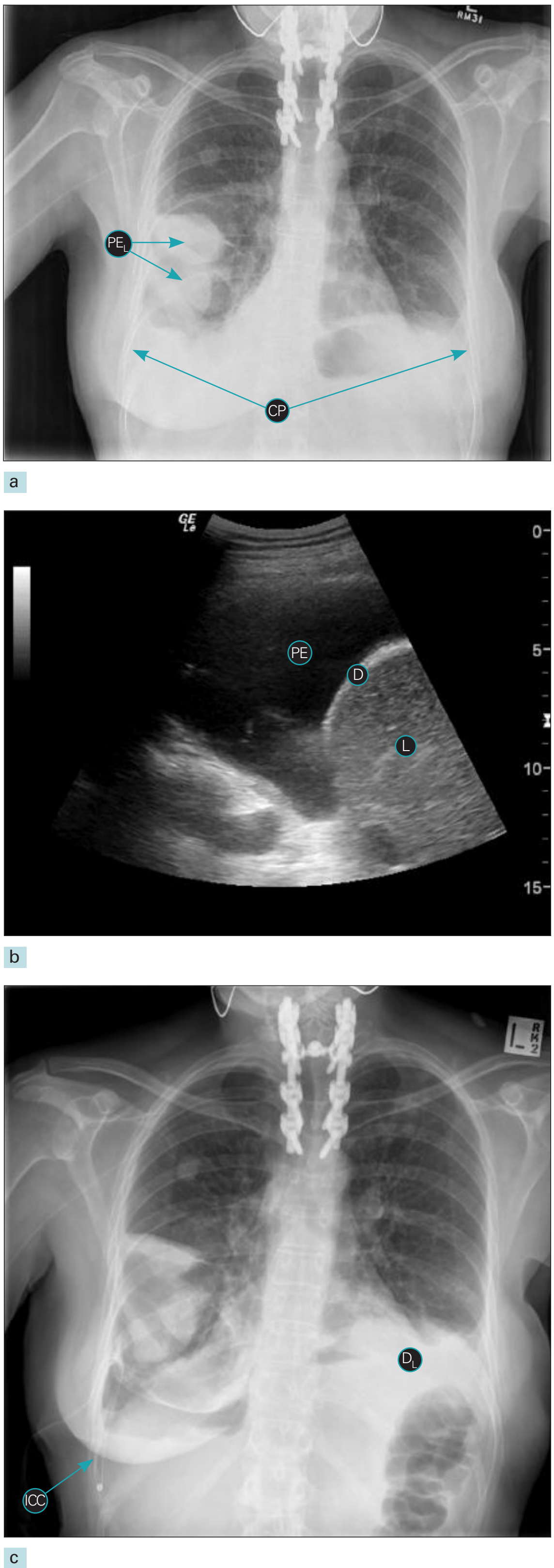
Figure 1.3 Hemoperitoneum caused by chest drain insertion. (a) CXR prior to right-sided chest drain insertion in a patient with bilateral pneumonia and pleural effusions. (b) CXR post-drain insertion (arrow). (c) CT angiogram illustrating entry site of chest drain (asterisk) and active bleeding (arrow) from trauma to the adjacent liver during insertion. (d) Arterial extravasation of contrast pre-embolization (arrow).

comprehensive teaching program and compulsory use of ultrasound before thoracentesis significantly reduced the incidence of post-procedural pneumothorax from 8.6% to 1.1%. The need for tube thoracostomy drainage of pneumothorax dropped from 6% to 0%. This occurred despite an increase in the number of thoracenteses performed by the physicians. This holds true even in the intensive care unit, where the pneumothorax rate after ultrasound-guided thoracentesis in patients receiving mechanical ventilation was 1.2%.[9] Therefore, appropriately trained physicians can achieve comparable results to those of radiologists.

Recommendations

Competency in ultrasonography depends on training, and various training guidelines are now available. Many professional medical bodies have also issued statements regarding the role of ultrasonography by clinicians in the management of pleural diseases.

The British Thoracic Society pleural disease guidelines in 2010 strongly recommended the use of thoracic ultrasound guidance for all pleural procedures.[15] This is especially important when aspirating small or loculated pleural effusions, where there is near or complete opacity of the hemithorax, but without contralateral mediastinal shift, or after an unsuccessful attempt of



aspiration without imaging guidance. It has been proposed that at least level 1 competency according to the Royal College of Radiologist guidelines (www.rcr.ac.uk/docs/radiology/pdf/ultrasound.pdf) is required to safely and effectively perform thoracic ultrasound independently.

The Australasian Society for Ultrasound in Medicine similarly supports the use of ultrasonography by medical specialists, other than radiologists or sonographers, who have undergone appropriate training and credentialing.[16] Various levels of credentialing have been cited (see www.asum.com.au) and serve as a guide to the level of competency expected of clinicians utilizing ultrasound in clinical practice. The Critical Care Network of the American College of Chest Physicians, together with La Société de Réanimation de Langue Française, has defined in its consensus statement the specific skill sets required of intensivists and chest physicians involved with pleural ultrasonography. Also included are other aspects of critical care ultrasonography.[17] Specific training requirements stipulated by the above medical bodies are detailed in Chapter 11.

DIAGNOSTIC APPLICATIONS OF PLEURAL ULTRASOUND

Detection of pleural fluid

Pleural ultrasound is a sensitive modality for detecting pleural effusions, with a diagnostic accuracy of more than 90%,[3,4,14] and is significantly superior to chest radiography[3,4,18] (Figures 1.4 and 1.5). Pleural fluid is easily visualized by its characteristic appearance on ultrasound.[19,20] Typically, it is seen as an echo-free or dark zone that changes its shape with respiratory movements or contains movable echo densities. Ultrasound can confirm the presence of pleural fluid, especially in small or loculated pleural effusions, and distinguish it from pleural thickening[21] (see also Chapter 5).

Figure 1.4 A patient with an elevated left hemidiaphragm, where the presence and extent of a right pleural effusion may be underestimated on a routine chest radiograph. (a) CXR showing multiple right pleural fluid loculations (PE_L) and bilateral blunting of costophrenic angles (CP). (b) Ultrasound demonstrating the moderate pleural effusion (PE) as well as liver (L) and diaphragm (D). (c) CXR post-insertion of a right intercostal catheter (ICC). The elevated left hemi-diaphragm (D_L) may lead one to underestimate the extent of the right effusion on the initial CXR.

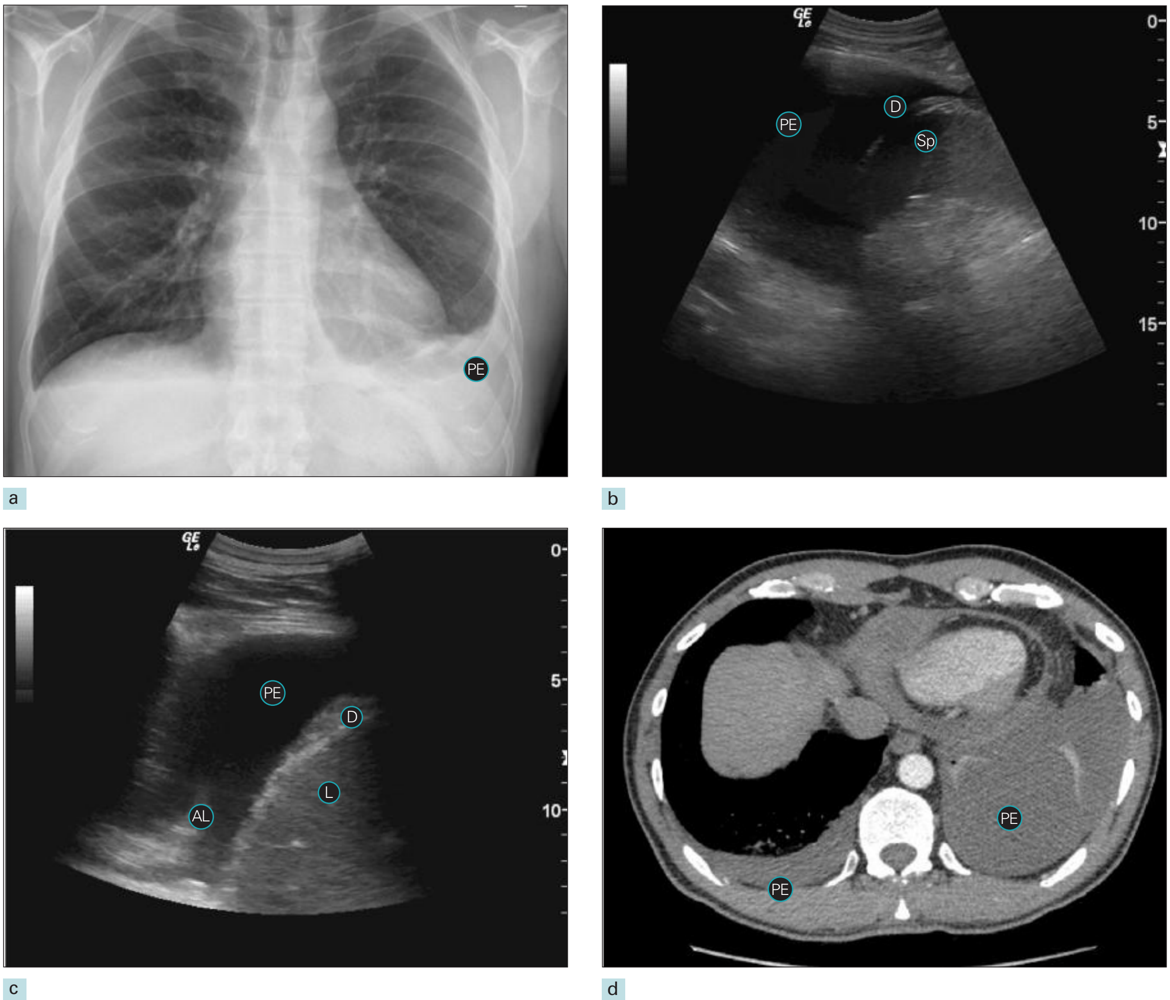


Figure 1.5 A patient with bilateral pleural effusions that are not fully appreciated on a routine chest radiograph. (a) The chest radiograph demonstrates only a left pleural effusion (PE). (b) Ultrasound of the left hemithorax confirming a moderate left pleural effusion (PE) (D = diaphragm, Sp = spleen). (c) Ultrasound also demonstrates a right pleural effusion (PE) in the same patient, not apparent on the CXR (AL = atelectatic lung, L = liver, D = diaphragm). (d) A CT thorax confirming the presence of bilateral pleural effusions (PE).

Quantification of pleural fluid

Pleural ultrasound gives a better estimate of the volume of pleural fluid than a chest radiograph.[18] This was especially evident when the sonographic estimation of pleural fluid volume in a supine patient was compared with a lateral decubitus chest radiograph.[18] There are various methods of estimating the volume of pleural fluid with ultrasound; both qualitative[14,22,23] and quantitative[24–27] means have been described. Estimating the fluid volume may aid in determining the safety and need for thoracentesis,[25,26] and assessing the depth of pleural fluid from the chest wall will guide the degree of penetration required for safe thoracentesis.

Nature of pleural fluid

The sonographic findings of the pleural fluid often help to determine the nature of the pleural effusion. Four basic patterns of internal echogenicity of pleural fluid have been described: anechoic, complex nonseptated, complex septated, and homogeneously echogenic[28] (see Chapter 5). The relationship between these patterns and their nature, i.e., whether it is a transudative or an exudative effusion, has been well described in various studies.[5,10,28,29] Other associated features seen on ultrasound, such as thickened pleura, lung parenchymal lesions, pleural and diaphragmatic nodules, and diaphragmatic thickening, are also helpful in providing further insight into the nature of the pleural effusion.[28,29]

Pleural loculations and adhesions

Pleural ultrasound allows better characterization of pleural fluid collections, with fibrin strands, septations, and loculations more readily detected on ultrasonography than on CT scans[6,30] (Figure 1.6).

The patterns of echogenicity and presence of septation or loculation may influence the subsequent approach to management. In the study by Tu et al.,[31] the presence of septations and the increasing echogenicity of the pleural fluid suggested a higher likelihood of empyema, and hence the need for diagnostic thoracentesis and probable chest tube insertion.

The efficacy of image-guided percutaneous drainage of thoracic empyema can also be predicted by the preprocedural sonographic patterns. The chances of success were better with either an anechoic or complex nonseptated rather than a complex septated empyema.[32] This has led some authors to suggest that patients with empyema should receive a thoracic ultrasound early and be stratified according to the sonographic appearance. Depending on the severity of septations on ultrasound, mechanical adhesiolysis via thoracoscopy or thoracotomy may be required early on for optimal treatment.[33] This approach has yet to be formally tested but highlights the potential contribution of ultrasonography to conventional diagnostic or management algorithms.

Pleural ultrasound enables the detection of pleural adhesions and can provide useful information before thoracosopic procedures.[19,34] A preprocedural pleural ultrasound potentially reduces complications by guiding trocar placement and helps determine the need for open thoracotomy in patients who are planned for video-assisted thoracoscopic surgery. Similarly, pleural ultrasound before medical thoracoscopy may help to select an optimal site for pleural access and thus reduce pleural access failure rates.[35]

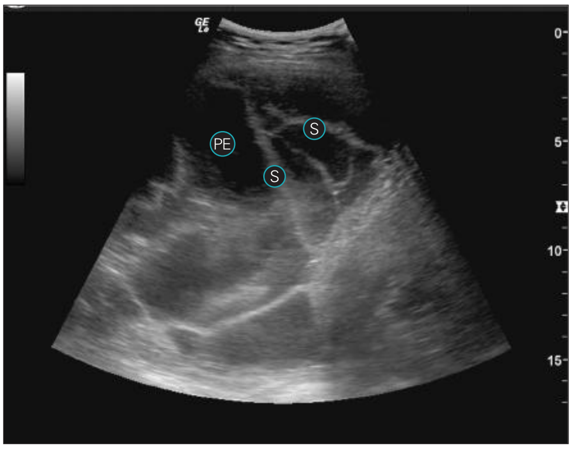
Recognizing features of malignant pleural effusions

Pleural ultrasound can provide useful clues toward the diagnosis of malignant pleural effusion.[36,37] In the study by Qureshi *et al.*, pleural ultrasound is able to distinguish malignant from benign effusions with an overall sensitivity of 79% and specificity of 100%; these figures are comparable to those of contrast-enhanced CT scanning.[36] Ultrasound can detect thickening and nodularity of the parietal, visceral, and diaphragmatic pleura, as well as demonstrate loss of the five diaphragmatic layers (see Chapter 6)—all are features that suggest a malignant pleural effusion in the absence of empyema. Pleural ultrasound is more sensitive than contrast-enhanced CT scans in demonstrating visceral pleural disease and diaphragmatic nodularity[36] (Figure 1.7).

Pleural and chest wall invasion by lung cancer may also be evaluated with thoracic ultrasound (see Chapter 10). High-frequency ultrasound can help distinguish the tumor from other soft tissues of the chest wall and pleura.[38] The information obtained helps to determine the resectability of the tumor as well as the site and extent of resection. This has important implications with regard to patient management and prognostication.

The shape and movement of the diaphragm can also be assessed.[19] Diaphragmatic palsy, e.g., from tumor infiltration of the phrenic nerve, may be diagnosed by real-time visualization on ultrasound, and can influence management.

CHAPTER 1



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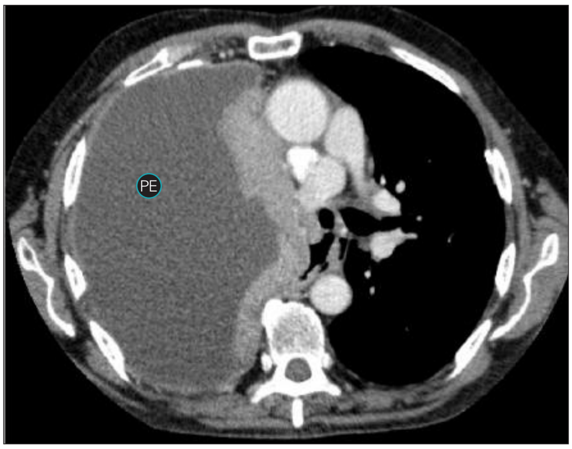

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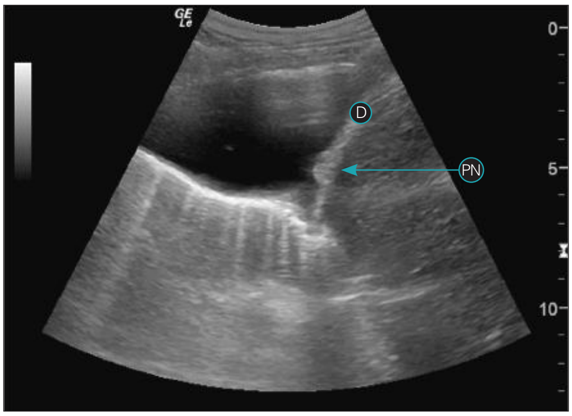
Figure 1.6 A patient with a right malignant pleural effusion. (a) Multiple septations (S) in pleural effusion (PE) are easily seen on pleural ultrasonography. (b) CT thorax of the same patient with no evidence of septations (PE = pleural effusion).

Figure 1.7 Pleural nodularity (PN) and diaphragmatic thickening (D) are easily seen on ultrasonography.



ULTRASONOGRAPHY IN PLEURAL PROCEDURES

In addition to thoracentesis, pleural ultrasound can guide other pleural interventions, such as chest drain insertions and transthoracic biopsies[19,39] (see Chapters 9 and 10). Ultrasound guidance has been used effectively in chest drain insertion to evacuate different types of pleural effusions.[32,39,40] Accuracy of tube placement and procedural safety are significantly enhanced by pleural ultrasonography. Real-time imaging can also allow the operator to monitor the adequacy of drainage during the procedure.[39]

Thoracic ultrasound has been used to guide biopsies of pleura, peripheral lung lesions, chest wall, and mediastinal lesions.[41–45] Ultrasound-guided pleural biopsy has been shown to have a higher diagnostic sensitivity for pleural tuberculosis and pleural malignancies over the traditional “blind” Abrams needle biopsies.[41] Ultrasound can help localize peripheral lung lesions and guide biopsies under real time.[42–44] Diagnostic yields of up to 77% have been obtained for subpleural lung nodules less than 2 cm in diameter.[43] Success rates up to 96% for biopsying transthoracic lesions less than 3 cm in diameter have been reported.[45]

Being able to observe accurately the course of the biopsy needle in real-time imaging also reduces the risks of lung puncture and post-procedural pneumothorax.[42–45] Similarly, large vessels may be avoided during needle biopsies.[19] Other advantages of ultrasound guidance include a shorter procedure time[42,44] and the ability to screen for pneumothorax immediately post-biopsy[19] (see Chapter 7).

Ultrasound-assisted cutting needle biopsy has been proven safe even when performed by chest physicians for small (<2 cm) lung lesions abutting or involving the pleura.[46] In this study by Diacon *et al.*, the sensitivity of the biopsy for neoplastic disease was 85.5% (and 100% for malignant mesothelioma). The rate of pneumothorax was 4%, of which only half required pleural drainage.

CONCLUSION

Pleural ultrasound has firmly established its place in the diagnostic workup of pleural diseases. It can accurately identify the presence of pleural fluid, pleural adhesions and loculations, and features suggestive of pleural malignancies. Valuable information of other thoracic structures, e.g., the diaphragm and the chest wall, can be gained and may guide subsequent therapy. The benefits in improving procedural safety make pleural ultrasound an indispensable tool for all pleural procedures. This benefit is independent of the specialty of the operator. Pleural ultrasound has become mandatory before all pleural procedures in a growing number of centers, and adequate training is paramount to fully realize its advantages.

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MCQ 1

Q Which of the following statements are *true* (multiple answers possible)?

- **a.** Pleural ultrasound is superior to a physical examination and chest radiograph in avoiding accidental puncture of visceral organs in pleural procedures.
- **b.** The absence of blunting of the costophrenic angles on chest radiograph reliably excludes the presence of a pleural effusion.
- **c.** A pleural ultrasound should be performed before all pleural procedures, especially if the pleural effusion is small and loculated.
- **d.** Appropriately trained physicians are able to perform pleural ultrasound at a comparable level to specialist thoracic radiologists.
- **e.** The presence of radiation from pleural ultrasonography limits its repeated use in clinical settings.

MCQ 2

Q Which one of the following regarding ultrasound-guided pleural biopsies is *false*?

- **a.** Ultrasound-guided pleural biopsies give better yields than traditional Abrams needle biopsies.
- **b.** Ultrasound-guided biopsies of visualized subpleural lung nodules give higher diagnostic yields than bronchoscopic biopsies.
- **c.** Ultrasound-guided biopsies can be considered in the assessment of peripheral thoracic lesions in patients who are not medically fit to undergo major surgical procedures.
- **d.** Ultrasound-guided biopsies should never be performed for peripheral thoracic lesions less than 3 cm, as the yield is significantly less.
- **e.** Pleural ultrasound may be used to detect post-procedural pneumothoraces.

MCQ 3

Q Pleural ultrasound allows the following:

- **a.** Detection of pleural fluid and its differentiation from solid organs.
- **b.** Better estimation of volume of pleural fluid when compared to a chest radiograph.
- **c.** Differentiation of transudative pleural fluids from exudative ones.
- **d.** Better visualization of pleural thickening and nodularity when compared to other imaging modalities.
- **e.** All of the above.

MCQ 4

Q In addition to the assessment of pleural fluid, pleural ultrasound may also be used in assessing the:

- **a.** Structural features of the diaphragm.
- **b.** Diaphragmatic movements.
- **c.** Pleural and chest wall invasion by lung cancer.
- **d.** Presence of pleural adhesions.
- **e.** All of the above.

ANSWERS

A **1.** a, c, and d are all true.

Pleural fluid may be detected on ultrasound and not visualized on CXR (see Chapter 1). Ultrasound is radiation-free.

A **2.** d See Chapter 1 for reference.

A **3.** e

A **4.** e

CHAPTER TWO

Basic Physics of Diagnostic Ultrasound and Control "Knobology"

Nagmi R. Qureshi

INTRODUCTION

This chapter provides an introduction to the basic physics of diagnostic ultrasound. A clear understanding of the principles of ultrasound is vital for appreciating the potential limitations of thoracic ultrasound and interpreting commonly encountered artifacts. The function of the main ultrasound controls will be discussed, and how these can be adjusted to optimize the ultrasound settings to ensure a diagnostic quality image is routinely obtained.

GENERATION AND TRANSMISSION OF THE ULTRASOUND WAVE

Ultrasound is a sound wave with frequencies that range from 2 to 20 MHz. These frequencies are much greater than sound waves audible to the human ear, which range from 20 Hz to 20 kHz.

Ultrasound waves are produced by piezoelectric crystal elements within a transducer. This crystal has the ability to change shape and thickness when an electrical voltage is applied across it, causing it to vibrate at a specific range of frequencies that produces a sound wave. Transducers consist of multiple elements that are usually pulsed sequentially and function as both the transmitter of sound and the receiver of the reflected echo. As each element cannot simultaneously transmit and receive an echo, another sound wave cannot be generated until the initial echo has been received. The sound waves from the ultrasound beam are transmitted as a series of longitudinal waves that vibrate back and forth, producing a wave of compression and rarefaction of the surrounding tissues. Each repetition of this back-and-forth motion produces a new wave, the length of which represents its wavelength. Unlike x-rays, a sound wave requires a medium for transmission. Because of the difference in the acoustic impedance (effectively, the fraction of the ultrasound wave transmitted or reflected) between the probe and air, a coupling medium, gel, is used to help match their impedances and enable through-transmission of the ultrasound wave (Figure 2.1—clip).

Figure 2.1 Curvilinear transducer that shows no transmission of the ultrasound wave until gel is applied to the transducer face. View E-book for ultrasound clip or watch it at http://goo.gl/ZadCSC.

The speed of transmission of ultrasound is independent of its frequency and depends on the density and compressibility of the tissue through which it is traveling. For practical purposes, all tissues except bone and air have an average velocity of 1540 m/s. Solids and liquids typically consist of tight, large particles, are less compressible, and transmit sound rapidly. Air, however, is a poor transmitter of sound due to its low density and high compressibility.[1]

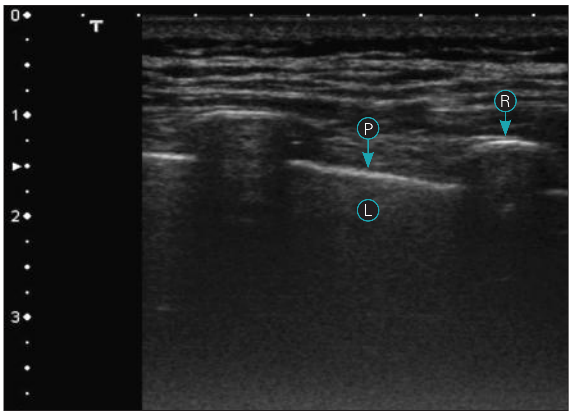


Figure 2.2 Pleural ultrasound showing echogenic reflection of the ultrasound wave from the rib (R) and pleural–lung interface. P = pleura, L = lung.

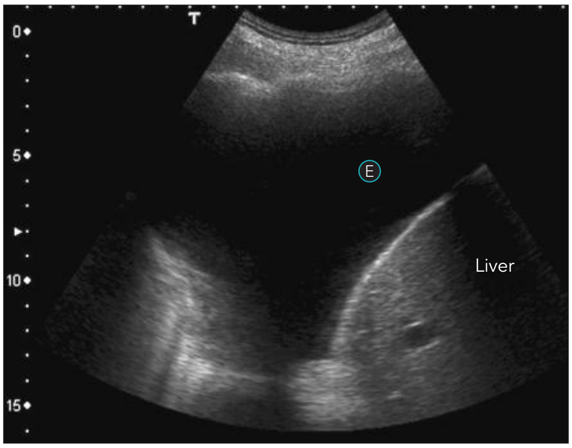
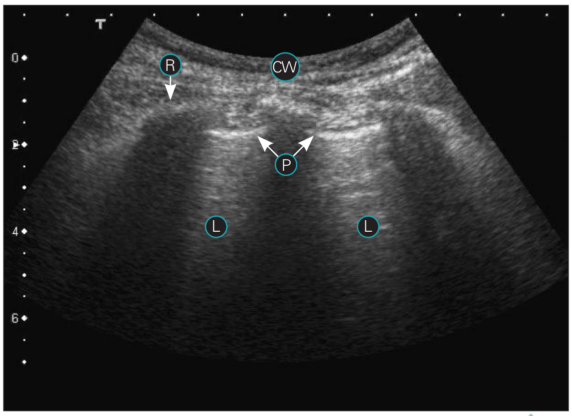


Figure 2.3 Normal appearance of a simple pleural effusion (E) that appears as an echo-poor space. This is due to limited reflection and attenuation of the ultrasound wave by fluid.



INTERACTION OF SOUND WAVES WITH MATTER

As an ultrasound wave passes through matter it interacts in several different ways and can be reflected, transmitted forward, absorbed, scattered, or refracted.

Reflection

The ultrasound image is produced from the proportion of the transmitted beam that is reflected back to the transducer. The amount reflected at an interface is primarily dependent on the difference in the acoustic impedance of the adjacent tissues. This is defined as the product of the density and velocity of sound in the material. The greater the difference in impedance at an interface, the greater the proportion of the echo that is reflected back and the stronger and brighter the echo displayed. Highly reflective interfaces cause strong echoes that are displayed as a bright spot on the screen. This is typically seen at bone and air interfaces where nearly 99% of the wave can be reflected, leaving only 1% to be transmitted forward (Figure 2.2). The opposite is seen with poorly reflective interfaces such as fluid, where there is little or no reflection, and this is displayed as an echo-poor area (Figure 2.3). In addition, the angle of the incident wave can also influence the echo. Typically the closer the transmitted wave is to the perpendicular, the stronger the echo.

Attenuation

As the wave travels forward, it continuously loses energy and intensity, with fewer echoes being reflected back at each interface. This is generally referred to as attenuation and primarily occurs due to absorption and, to a lesser extent, scatter. The degree of attenuation or the attenuation coefficient is dependent upon the density of the material and the frequency of the transducer. Typically water produces the least attenuation and provides an excellent acoustic window for scanning. Bone and lung have the highest attenuation coefficients and are poor transmitters of ultrasound (Figure 2.4—clip). Attenuation can lead to artifacts, which will be discussed later in this section.

Figure 2.4 Normal ultrasound appearance of the lung (L), pleura (P), and ribs (R). CW = chest wall. There is poor transmission of the ultrasound wave into the normally aerated lung seen below the pleural line (in between rib shadowing). View E-book for ultrasound clip or watch it at http://goo.gl/quQ9GC.