

Thoracic Ultrasound in Pleural Effusion

A Bedside Practical Approach Introduction

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Pleural effusion is a common clinical problem, and bedside imaging plays a central role in its timely evaluation and management. In our prior companion articles, we outlined the clinical approach to pleural disease and the role of pleural fluid analysis. In this article, we describe how thoracic ultrasound (TUS) is incorporated into routine pleural practice. The value of TUS extends well beyond procedural guidance. TUS is routinely used to characterize pleural effusion, identify pleural and parenchymal abnormalities, refine the differential diagnosis, and guide appropriate pleural procedures. We present a practical approach to image acquisition, interpretation, and clinical decision-making at the bedside. We also review common pitfalls, limitations, and safety considerations that are important to everyday practice. Our goal is to provide clinicians with a structured approach for using TUS in the assessment and management of pleural effusions.

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Pleural effusion is a common clinical problem with numerous causes, and determining the etiology is important for optimal management.¹⁻³ In our previous companion articles, we discussed the clinical approach to pleural effusions and the role of pleural fluid analysis in determining the cause of a pleural effusion.^{3,4} Thoracic ultrasound (TUS) is also an integral component of the diagnostic evaluation. The British Thoracic Society⁵ recommends performing TUS before all pleural

interventions. However, its clinical value extends well beyond procedural guidance. When performed at the bedside during initial assessment, TUS provides immediate information about fluid characteristics, septations, pleural abnormalities, and diaphragm movement and shape that directly inform differential diagnosis and management strategies. The manuscript may occasionally imply that TUS alone can guide immediate management decisions. In clinical practice, however, sonographic

ABBREVIATIONS: IET = intrapleural enzyme treatment; TUS = thoracic ultrasound

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findings should be integrated with clinical, laboratory, and radiologic data rather than interpreted in isolation.

There is significant variation in the clinical practice regarding the application of TUS. There is a need for the standardization of TUS practices and for systematic training, with ongoing evaluation of competency and institutional safety practices. In this article, we present a practical and structured bedside approach to integrating TUS into the evaluation of pleural effusion, emphasizing image acquisition, sonographic interpretation, procedural planning, and ultrasound-guided clinical decision-making.

Technical Aspects

Equipment Selection and Key Settings

We commonly use a phased array (1-5 MHz) transducer for the initial assessment (e-Fig 1, Video 1).⁶ The phased array probe has a smaller footprint, enabling operators to scan within an intercostal space. The curvilinear probe is then used in our practice to guide real-time pleural intervention because it provides a larger footprint. A high-frequency linear transducer probe provides higher resolution but limited penetration.⁶ We generally reserve high-frequency linear transducers (3-12 MHz) for near-field assessment, including evaluation of intercostal vessels before a pleural procedure, measurement of parietal pleural thickness, biopsies of chest wall lesions, and assessment of chest wall invasion by malignancy or infection.

The pleural space should be assessed with an abdominal preset at a depth of approximately 16 cm to visualize the diaphragm and liver or spleen (Video 1). The depth should be adjusted in real time to visualize the underlying pleural space and lung. Greater depth may be required in patients with obesity, whereas shallower settings can better characterize small effusions and detect pleural thickening or nodularity. We recommend adjusting gain using the liver or spleen as an acoustic window to clearly visualize the diaphragm. Misidentification of the spleen, liver, or distended stomach as a pleural effusion because of undergaining can lead to serious complications, such as inadvertent splenic or gastric puncture during pleural intervention (Video 2).

Patient Positioning and Scanning Approaches

Appropriate positioning is essential for accurate assessment and procedural safety. In patients who are ambulatory or able to tolerate positioning, we scan in the seated, forward-leaning position, whereas patients who

are critically ill or immobile are scanned in the semirecumbent position. We place the transducer in a sagittal plane with the indicator directed cephalad (Video 1). On the abdominal preset, this orientation will show structures above the diaphragm, including pleural effusion and lung, on the left side of the screen and subdiaphragmatic structures, including the liver, spleen, and kidney, on the right (Fig 1A). Consistent use of this orientation is essential for accurate interpretation. The transducer is placed perpendicular to the chest wall and moved caudally from the axilla along the posterior axillary line until the diaphragm is visualized with the liver or spleen caudally. Multiple scan lines should be examined from the anterior to the posterior chest wall to systematically assess for pleural and chest wall abnormalities. Note here that free-flowing pleural effusion is visualized in the most dependent part of the chest. The ribs may obscure visualization of a pleural abnormality; angling the transducer to look above or below the rib can overcome this limitation. Once the pleural abnormality is identified, operators should also scan in the transverse plane by rotating the probe by 90° to image the pleural space between 2 ribs once the echocardiographic window is established between the ribs. Lung ultrasound should also be performed to evaluate for atelectasis, consolidation, or mass to help determine the cause of the effusion.³

Description of Pleural Effusion

Identification of a Pleural Effusion

Pleural effusion is commonly identified as an anechoic or hypoechoic fluid-filled space, relative to the spleen or liver, bounded caudally by the diaphragm, cephalad by an atelectatic lung, and superficially by the chest wall (Fig 1B). In a healthy individual, the thoracic spine is not visible because aerated lungs prevent transmission of ultrasonic waves (Fig 1A). A pleural effusion provides an acoustic window that permits visualization of the thoracic spine, termed the spine sign (Fig 1B).⁷ In recumbent patients, pleural effusion may also be identified by the quad sign, in which the pleural space is bounded by 2 ribs and the parietal and visceral pleura (Fig 1C).⁸ Although pleural effusion is often recognized by its direct sonographic appearance, several other findings can help identify small or less conspicuous effusions. The curtain sign is a dynamic, shifting air artifact produced by the normal caudal movement of the lung obscuring the diaphragm and underlying organs, including the liver or spleen (Fig 1A, Video 1). When present, it is a sign of normality and suggests the

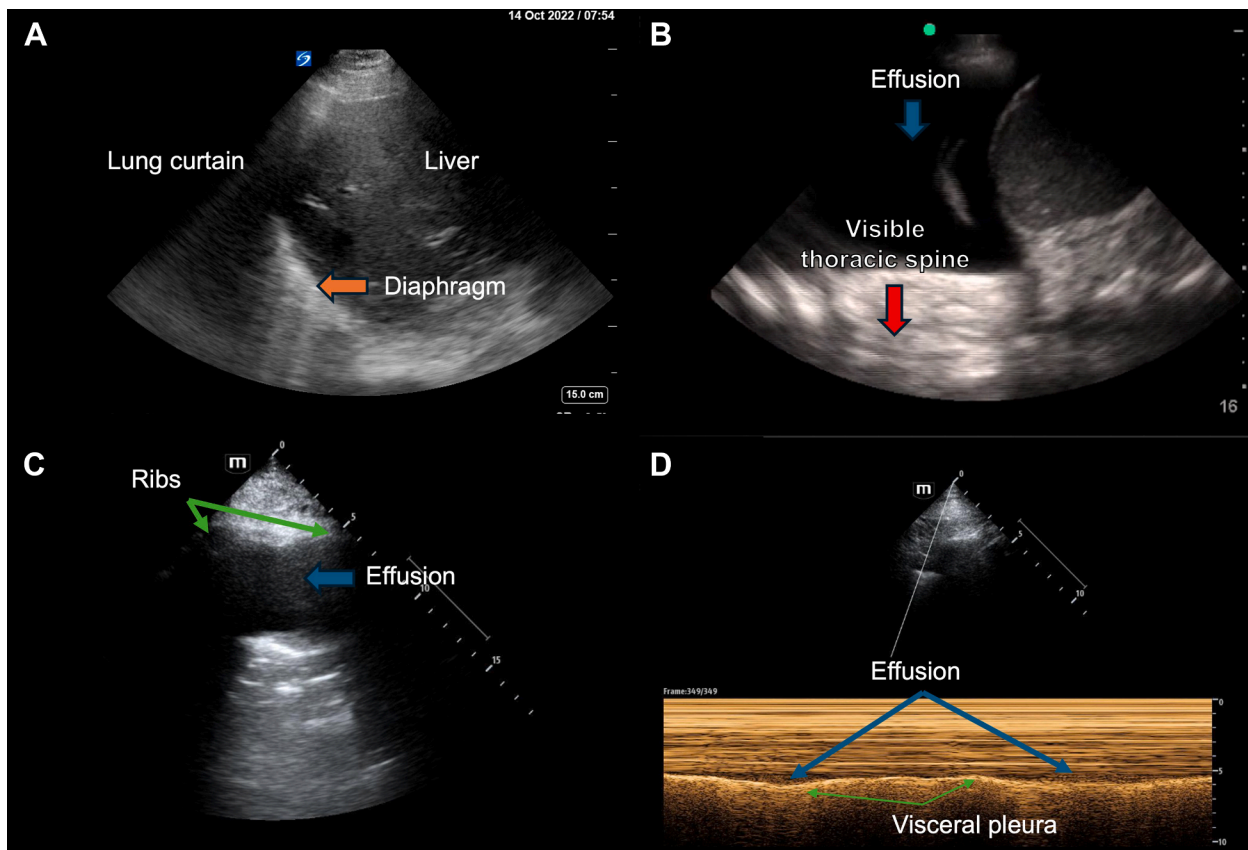


Figure 1 – A-D, Thoracic ultrasound demonstrating (A) an air-filled artifact obscuring part of the liver and diaphragm (curtain sign), (B) a large anechoic pleural effusion with visible thoracic spine (red arrow), (C) a pleural effusion between the parietal and visceral pleura bound by adjacent rib shadows (quad sign), and (D) undulating movement of the visceral pleura toward the parietal pleura during inspiration (sinusoid sign).

absence of a small pleural effusion, consolidation, or atelectasis.⁸ The sinusoid sign is observed on M-mode as an undulating motion of the visceral pleura toward and away from the chest wall, suggesting the presence of a small pleural effusion because of the separation of the visceral and parietal pleura (Fig 1D).⁸

Characterization of a Pleural Effusion

Once a pleural effusion is identified, we assess sonographic features that inform diagnosis and guide management. Several quantitative methods for estimating effusion volume have been described; they are not widely used in clinical practice.⁹⁻¹¹ The effect of the effusion on diaphragmatic shape and motion is more informative. A moderate-to-large effusion may cause diaphragmatic flattening or eversion and paradoxical motion, defined as cephalad movement of the diaphragm during inspiration rather than its normal caudal descent (Video 3).^{12,13} These abnormalities strongly predict relief of dyspnea after therapeutic thoracentesis.^{14,15}

We next classify the effusion's internal echogenicity as anechoic or echogenic. An anechoic effusion

contains no visible internal echoes (Fig 2A, Video 4A). Echogenic effusions are further categorized as septated, with linear echogenic strands between the visceral and parietal pleura (Fig 2B, Video 4B); complex homogeneous, with uniformly distributed internal echoes (Fig 2C, Video 4C); or complex nonseptated, with heterogeneous internal echoes but no septations (Fig 2D, Video 4D).¹⁶ Echogenic effusions are more likely to be exudative, whereas anechoic effusions may be either transudative or exudative.¹⁷ Therefore, an anechoic effusion alone does not obviate the need for pleural fluid sampling unless bilateral anechoic effusions are present in a patient with an obvious transudative cause, such as heart failure or renal failure.^{16,17} The presence of septations or a loculated pleural effusion raises concern for complex pleural fluid etiologies, including malignancy, infection, hemothorax, and other causes. TUS is more specific than CT scan for detecting septations, which helps to differentiate simple from complicated parapneumonic effusions.^{8,18}

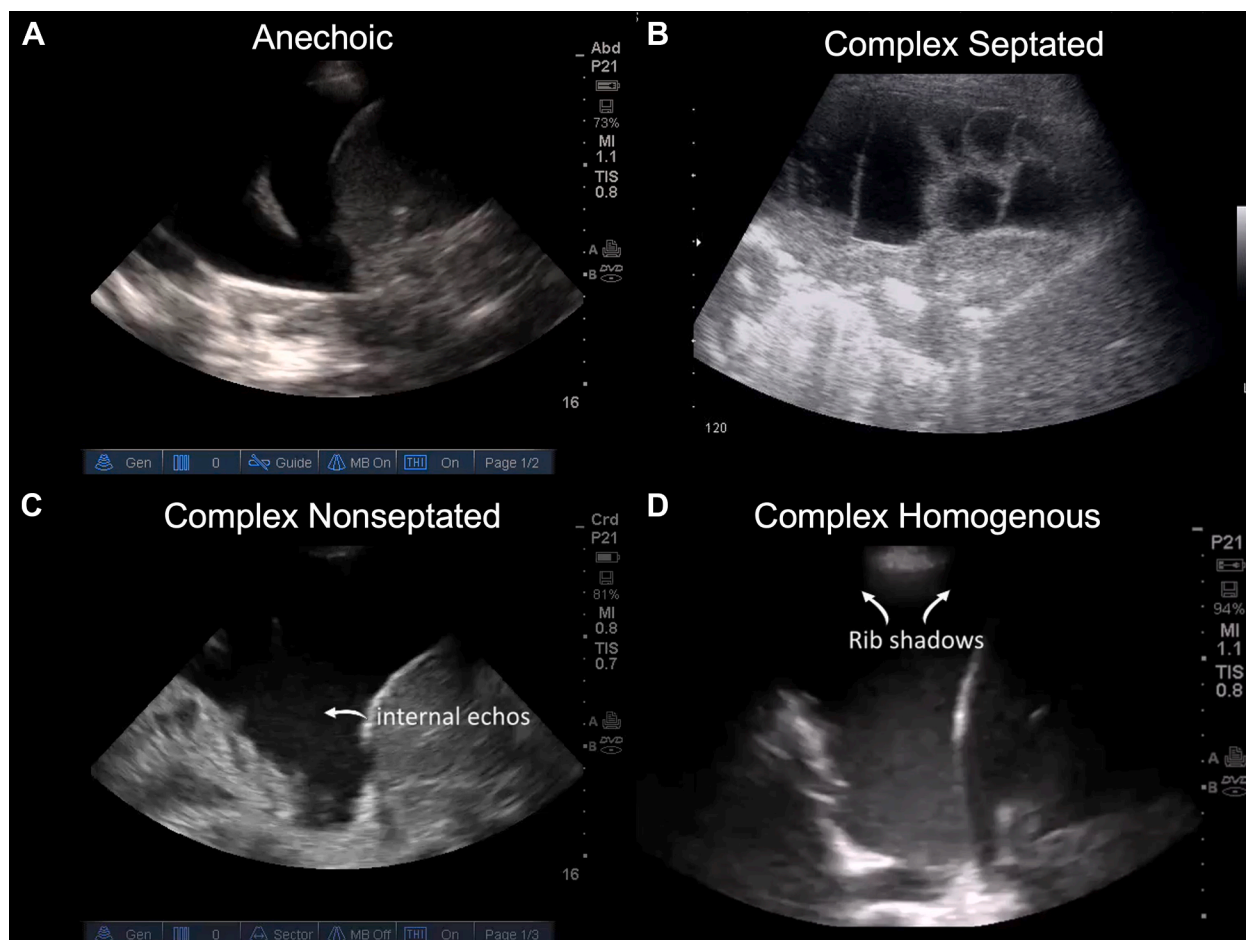


Figure 2 – A-D, Thoracic ultrasound showing classification of pleural effusions: (A) anechoic (effusion with absent visible internal echoes), (B) septated (effusion with presence of linear echogenic strands between the visceral and parietal pleura), (C) complex homogenous (effusion with uniformly distributed internal echoes), and (D) complex nonseptated (effusion with presence of heterogeneous internal echoes without septations).

Associated Sonographic Signs

A pleural effusion provides an acoustic window that facilitates the detection of pleural nodules that might otherwise be difficult to visualize. We carefully inspect the diaphragmatic pleura for nodularity because nodularity combined with pleural thickening is strongly suggestive of malignancy (Figs 3A, 3B).¹⁹ Parietal pleural thickening can be assessed with a curvilinear probe at a shallow depth or with a linear probe when higher resolution is needed. Normal pleural surfaces are smooth, hyperechoic, and mobile with respiration, with a thickness of 0.2 to 0.3 mm.²⁰ Thickened pleura appears irregular and hyperechoic and is often associated with absent lung sliding (Fig 3B). Pleural thickening > 1 cm is suggestive of primary pleural malignancy such as malignant mesothelioma or pleural metastasis (eg, lung cancer), chronic infection including TB or chronic empyema, old hemothorax, chronic radiation pleuritis, trapped lung or inflammation,

connective tissue related, IgG4 disease, and benign asbestos pleural effusion.^{2,19,21,22} Of note, in asbestos-endemic regions, sonographic morphology alone may not reliably distinguish malignant pleural disease from benign asbestos-related pleural abnormalities.^{21,23}

The hematocrit sign appears as a distinct fluid-fluid level, with a dependent hyperechoic layer of settled red blood cells beneath an anechoic to hypoechoic plasma layer, and suggests hemothorax (Fig 3).²⁴ Of note, the hematocrit sign is not exclusive to hemothorax, and it can be seen in exudate. Inadequate gain adjustment or use of the cardiac preset can create artifacts which may mimic the hematocrit sign. Occasionally, hyperechoic gas bubbles are seen floating cephalad within the pleural space, termed the suspended microbubbles sign, which suggests an alveolar-pleural or bronchopleural fistula in the setting of pleural infection, gas-forming pleural infections, or esophageal perforation (Fig 3D).²⁵

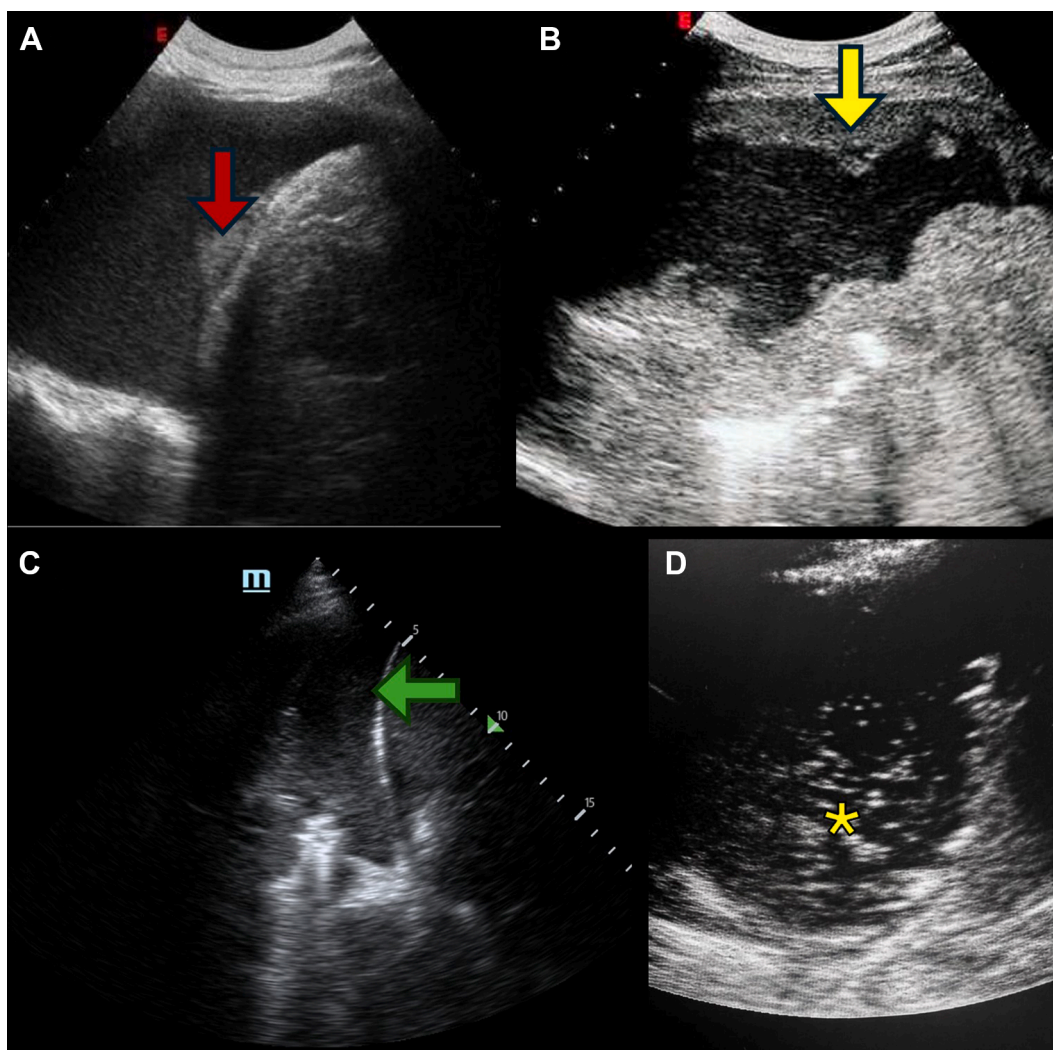


Figure 3 – A-D, Associated clinically useful pleural findings: (A) multiple nodules over the diaphragmatic pleura (red arrow), (B) parietal pleural thickening and nodularity (yellow arrow), (C) hematocrit sign with fluid-fluid level (green arrow), and (D) loculated effusion with suspended hyperechoic (yellow asterisk) microbubbles.

Complementary Assessment

Pleural ultrasonography is incomplete without lung ultrasonography. Once the pleural space has been characterized, we assess the underlying lung to determine the cause of the effusion. Underlying lung consolidation with ipsilateral effusion strongly suggests a parapneumonic effusion (Fig 4A). Consolidation should be distinguished from compressive atelectasis of the lung, which is typically seen with a large effusion as a small, compressed, floating lung that lacks dynamic air bronchograms (mobile punctate hyperechoic foci within the consolidated lung that move with respiration) (Video 5). Empyema necessitans is a severe complication of pleural infection that can be identified by TUS as extravasation of empyema through parietal pleura into the chest wall across the rib space (Fig 4B).

Interstitial syndrome with multiple smooth B-lines together with bilateral pleural effusions suggests heart failure (Fig 4C).²⁶ Presence of a lung mass is highly suggestive of malignancy (Fig 4D). Details of lung ultrasonography are described elsewhere.²⁷ Chest CT scan also has an important role in the assessment of a pleural effusion. CT scan may be more valuable than TUS for assessing certain loculated pleural effusions, particularly intrafissural loculations or collections located behind vascular structures or osseous structures.

Because pleural effusion may reflect elevated left-sided filling pressures, bedside echocardiography provides complementary information when cardiac cause is suspected. Useful findings include an E/e' ratio > 14, left atrial volume index > 34 mL/m², and E/A ratio > 2.²⁸ In a patient with bilateral anechoic effusions and

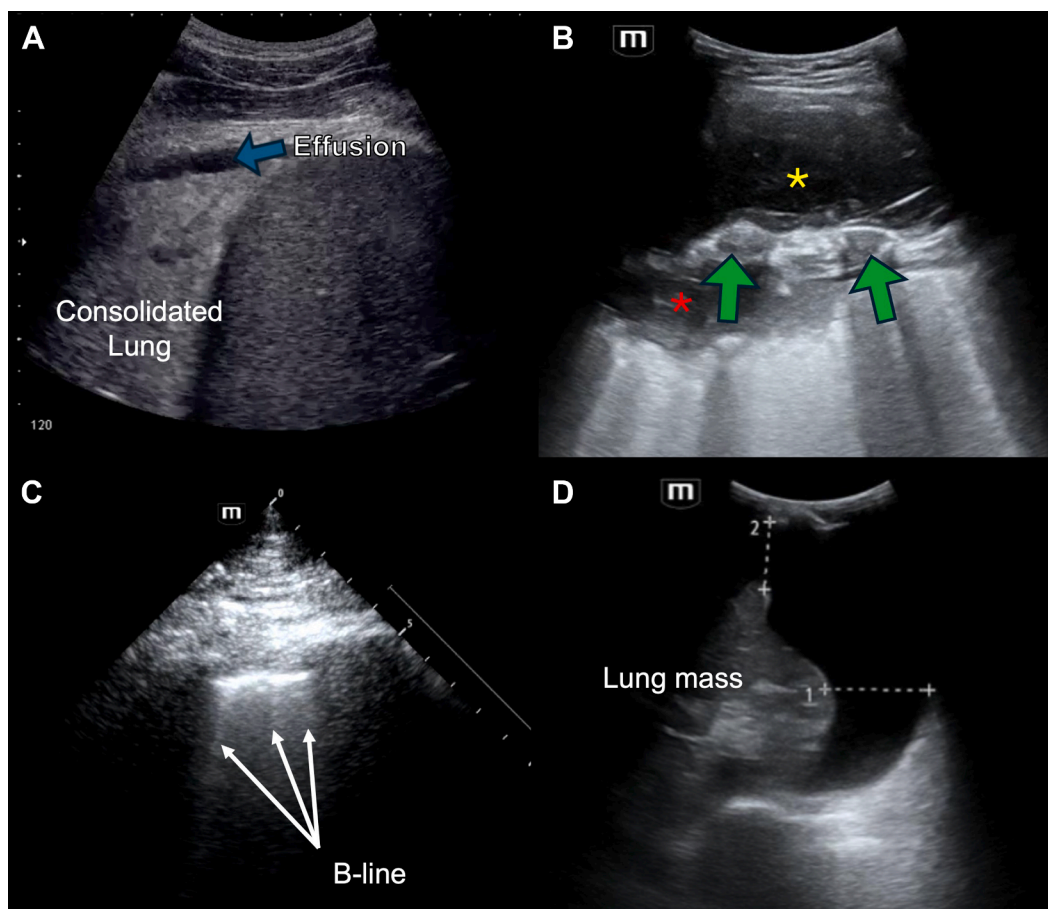


Figure 4 – A-D, Thoracic ultrasound demonstrating useful lung findings: (A) consolidated lung with a small pleural effusion, (B) empyema necessitans identified as extravasation of empyema (red asterisk) through the parietal pleura into the chest wall (yellow asterisk) across the ribs (green arrows), (C) interstitial syndrome with multiple smooth B-lines, and (D) large lung mass with anechoic effusion.

these echocardiographic findings, diagnostic thoracentesis may be deferred.

Clinical Decision-Making

To Drain or Not to Drain

When pleural effusion is identified on TUS, the first question is whether it should be drained for diagnostic or therapeutic reasons (Fig 5). Diagnostic thoracentesis can be deferred when bilateral anechoic effusions are present with an obvious transudative cause (congestive heart failure, renal failure, or hepatic failure), the effusion is too small for safe drainage (< 1-cm depth), or it is unsafe to drain the effusion (eg, an uncooperative or agitated patient) (Fig 5).^{1,4} The decision to perform therapeutic thoracentesis depends on the degree of dyspnea, the presence of an abnormal diaphragmatic shape or movement, and whether the underlying cause is amenable to alternative medical therapies. For example, a symptomatic patient with

congestive heart failure-related effusion and normal diaphragmatic shape and motion may respond to diuretics alone, without the need for therapeutic drainage. In most other clinical scenarios, diagnostic or therapeutic thoracentesis should be considered even when the pleural effusion appears anechoic on ultrasound, because anechoic effusion can be exudative or transudative (Fig 5).^{16,17}

Thoracentesis or Chest Tube

Once pleural fluid drainage is indicated, the next question is whether to proceed with thoracentesis or placement of a small-bore chest tube (Fig 5). We suggest initial small-bore chest tube placement for a septated, complex, homogeneous effusion or an effusion with a suspended microbubble or hematocrit sign, only when clinical suspicion for pleural infection or hemothorax is high (Fig 5).^{29,30} These scenarios typically require intrapleural enzyme therapy (IET) in pleural infection or close monitoring of tube output in hemothorax. If

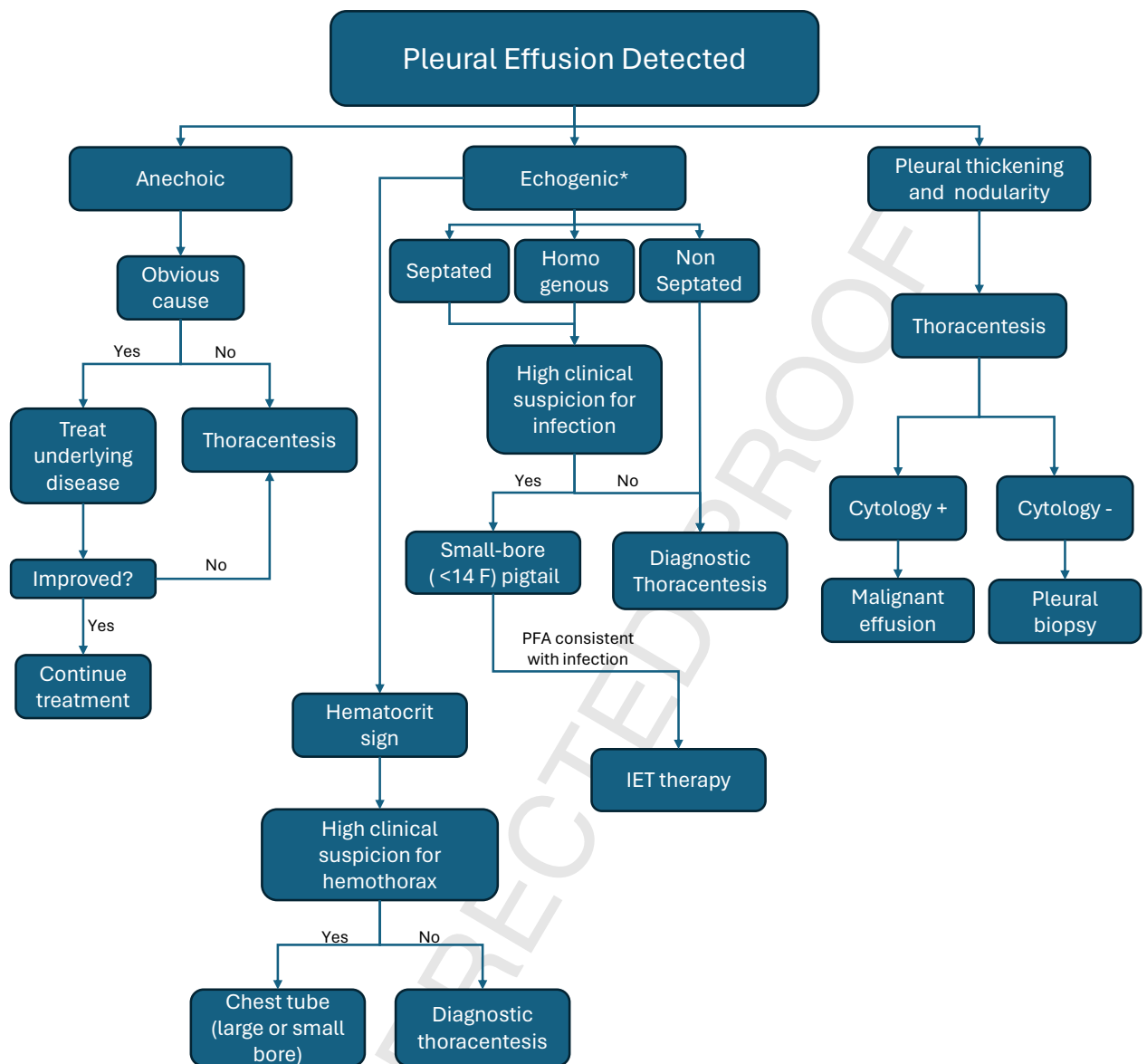


Figure 5 – Algorithm demonstrating the diagnosis and management of a pleural effusion based on thoracic ultrasound findings. *Echogenic effusion can be seen in pleural infection, malignancy, inflammation, chylothorax, pseudochylothorax hemothorax, or prior pleural procedures. IET = intrapleural enzyme therapy; PFT = pleural fluid analysis.

clinical suspicion for infection is low, diagnostic thoracentesis should be performed to establish the underlying cause (Fig 5). Of note, the presence of echogenicity is not specific to pleural infection and may also be seen with malignancy, inflammation, chylothorax, pseudochylothorax hemothorax, or prior pleural procedures. Organized pleural effusion with multiple rigid, nonmobile septations may predict failure of IET, in which case thoracic surgery may be necessary to evacuate the pleural space after a brief trial of IET (Video 6).

It is also important to differentiate empyema from a lung abscess that has not yet ruptured into the pleural space because a lung abscess is often treated with a prolonged antibiotic course rather than drainage. Inadvertent tube placement into a lung abscess risks bleeding, bronchopleural fistula, and dissemination of infection. On TUS, a lung abscess appears as a thick-walled, round, well-circumscribed fluid-filled lesion with internal echoes and suspended microbubbles.³¹ Contrast-enhanced TUS can be helpful to differentiate empyema from a lung abscess. A lung abscess will appear as a

nonenhancing area (necrosis) surrounded by enhancing inflamed lung parenchyma (e-Fig 2), whereas empyema is not surrounded by lung parenchyma.

When to Consider Pleural Biopsy

Pleural thickening and nodularity identified on TUS are highly suggestive of malignancy.¹⁹ When these findings are present and initial pleural cytology is negative, ultrasound-guided pleural biopsy should be performed to establish a tissue diagnosis (Fig 5). TUS not only identifies the optimal biopsy site by defining the area of maximal thickening or discrete nodularity but also confirms a safe needle path that avoids the intercostal vessels and underlying lung parenchyma (subsequently discussed) (Video 7).

Procedural Guidance and Safety

Safe Site Selection and Procedural Technique

The British Thoracic Society⁵ guidelines recommend TUS guidance as the standard of care for pleural procedures. TUS reduces the risk of pneumothorax, inadvertent organ puncture rate, and dry tap.³² A safe insertion site is identified when the effusion is clearly bounded by the diaphragm, lung, and chest wall, as previously described, with the patient positioned as previously outlined. We typically select a site near the midaxillary line or at least 6 cm lateral to the thoracic spine to avoid the exposed intercostal neurovascular bundle.³³ Once a safe site is identified, we use a high-frequency probe to assess for exposed intercostal vessels within the intercostal space to minimize the risk of arterial injury (Video 7). This risk is greater in older patients with tortuous arteries.³⁴ The site should be marked immediately before the procedure without repositioning the patient. For small pleural effusions or in patients with substantial chest wall abnormalities, such as scoliosis, we perform drainage under real-time ultrasound guidance. For novice operators, tracing the intercostal space with ultrasound can provide a visual guide when surface anatomy is difficult to identify by palpation.

Pleural biopsy should always be performed under real-time TUS guidance so that the intercostal neurovascular bundles can be avoided during needle advancement. A careful TUS examination should be performed to assess adequate depth and position before the pleural biopsy (Fig 4D). The safety advantage of TUS lies in its real-time capability, which allows the operator to compensate for respiratory motion while advancing the needle under direct visualization.³⁵

Postprocedural Assessment

We perform postprocedural TUS to assess complications, particularly bleeding and pneumothorax. Intrapleural bleeding may appear as a plume sign, where pulsatile color Doppler flow originates from the parietal pleural surface (Video 8).³⁶ Bleeding can be seen as spreading echogenic material arising from the entry site and depositing in the dependent part of the pleural effusion. Pleural effusion size can be seen increasing in real time during the event of bleeding.^{37,38} Lung sliding should be assessed in the ipsilateral lung before and after the pleural procedure, especially the apex in a sitting patient and anterior chest in a recumbent patient.^{26,39,40} New loss of lung sliding after the procedure suggests pneumothorax.

Ultrasound-Guided Pleural Management

TUS also guides subsequent pleural management. As previously discussed, we use TUS to guide IET in pleural infection. In patients with malignant pleural effusion or hemothorax, once active bleeding has ceased, the presence of septations or retained clot on TUS supports the use of intrapleural thrombolytics to facilitate pleural evacuation.⁴¹⁻⁴³

TUS also helps identify candidates for pleurodesis and predict its likelihood of success in malignant pleural effusion. Nonexpendable lung is a contraindication to pleurodesis. Expandable lung demonstrates deformation in response to cardiac impulses, termed cardiophasic variability, whereas this motion is blunted in nonexpendable lung. Cardiophasic variability is measured with a low-frequency probe using M-mode, with the interrogation line positioned perpendicular to the atelectatic lung during quiet breathing. Cardiophasic variability of < 1 mm strongly predicts nonexpendable lung.⁴⁴ Pleurodesis induces pleural inflammation that abolishes lung sliding, which can be quantified using the pleural adherence score.⁴⁵ After 24 hours after pleurodesis, lung sliding is assessed in 9 predefined thoracic regions and scored as present (1 point), questionable (2 points), and absent (3 points), for a maximum score of 27. Higher scores indicate greater pleural adherence and a higher likelihood of pleurodesis success. We remove the chest tube once the score reaches ≥ 20 . This approach has been shown in a randomized study to shorten hospital length of stay and allow earlier chest tube removal compared with traditional output-based criteria, without reducing pleurodesis success.⁴⁵

Pitfalls

Despite its utility, TUS has important limitations that operators must recognize to avoid diagnostic errors and procedural complications. Improper patient positioning is the most common error seen in clinical practice. In a supine patient, a moderate free-flowing effusion may layer posteriorly and appear small or be missed. Obesity and subcutaneous edema degrade image quality; however, a low-frequency probe and increased depth can partially compensate. Subcutaneous emphysema obscures the pleura and underlying lung pathology by reflecting the ultrasound beam superficially, and there is no reliable way to overcome this limitation.

Loculated effusions may occur anywhere in the thorax, including the interfissural, anterior chest, and interscapular regions. This requires a systematic scanning approach beyond the standard posterior and lateral windows. For interscapular loculations, asking the patient to cross both arms anteriorly in a self-hug position displaces the scapulae laterally and improves acoustic access. Significant scoliosis can impair both the visualization of effusion and the identification of a safe drainage site. In these cases, real-time ultrasound-guided drainage is preferred.

Echogenic effusions may be mistaken for soft tissue, consolidated lungs, or solid organs. Careful identification of the diaphragm as an anatomic landmark is essential for correctly distinguishing these findings. Similarly, pleural thickening may mimic a small effusion. The absence of respiratory variation and sinusoidal sign on M-mode can help differentiate pleural thickening from a true effusion.

Quality Assurance and Documentation

Documentation of TUS findings serves both clinical and billing purposes and should be tailored to the indication. A structured approach that includes laterality, qualitative size, internal characteristics, diaphragmatic shape and motion, and relevant lung and cardiac findings improves consistency and longitudinal comparisons.

Competency in pleural TUS should be developed through structured training and maintained through regular clinical use with image review. Currently, no standardized curriculum exists within pulmonary and critical care medicine fellowship training, despite widespread use and teaching of TUS in this setting.⁴⁶

Future Directions

Several emerging technologies, including contrast-enhanced TUS, have the potential to enhance the role of TUS in pleural disease evaluation and management. Contrast-enhanced TUS can be potentially useful to differentiate benign pleural disease from malignant pleural disease, differentiate lung abscess from loculated pleural effusion, and guide tissue biopsy.^{47,48} Artificial intelligence algorithms are being developed to assist with effusion detection and characterization, which may improve diagnostic consistency.⁴⁹ Additionally, integrating TUS findings into clinical prediction models for effusion etiology is an active area of investigation that may further refine the diagnostic approach and management of pleural disease.

Finally, establishing a standardized TUS curriculum should be prioritized to support consistent training and implementation in pulmonary and critical care training programs.

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Additional information: The e-Figures and Videos are available online under "Supplementary Data."

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