

Thoracentesis and Thoracic Ultrasound: State of the Art in 2013

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KEYWORDS

• Thoracentesis • Thoracic ultrasound • Pleural effusion

KEY POINTS

- Thoracentesis is an invaluable tool for assessing pleural disease.
- The use of ultrasonography by trained professionals has enhanced this procedure's safety and feasibility.
- Routine ultrasonography enhances preprocedural, intra-procedural, and postprocedural assessment of the pleural space.
- As equipment becomes more available and portable, its use is anticipated to grow and possibly become the standard of care.

DIAGNOSTIC AND THERAPEUTIC THORACENTESIS

The clinical or radiological recognition of a pleural effusion suggests an abnormal pathophysiological state resulting in an imbalance between absorption and production of fluid in the pleural space.¹⁻⁷ Thoracentesis is often divided into 2 categories, namely, diagnostic aspiration and therapeutic removal. Diagnostic thoracentesis is performed to obtain a small volume of fluid (50–100 mL) for the purpose of analysis, which is accomplished with a single percutaneous needle aspiration.

A therapeutic thoracentesis is performed to relieve symptoms, such as dyspnea, to relieve hemodynamic compromise or to evacuate the pleural space of infection.⁸ The therapeutic thoracentesis is normally accomplished using a temporary catheter that is removed at the end of volume removal. These categorizations are often blurred because an initial aspiration may be done to provide both analysis and relief of symptoms. It would be reasonable to consider maximal removal

of pleural effusion if an aspiration is already occurring. With this mindset, a diagnostic thoracentesis would only be performed if a therapeutic aspiration were not safe, feasible, or under other unusual circumstances.

Indications and Complications

There are no absolute contraindications to performing a diagnostic thoracentesis. Risks and benefits should be carefully considered when performing thoracentesis in patients with relative contraindications, such as a bleeding diathesis or those on anticoagulation therapy. It is debated if commonly measured parameters, including prothrombin time and activated partial thromboplastin time, alone predict the risk of bleeding complications, although thrombocytopenia along with renal dysfunction (serum creatinine >6 mg/dL) likely portends higher risks.^{9,10} Some investigators have suggested the use of a structured questionnaire to generate a bleeding score for predicting complications before invasive procedures.¹¹ Furthermore, it is

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unclear if concurrent therapy with clopidogrel or similar classes of drugs alters the risk of bleeding complications. Thromboelastography has been shown to be a better assay for detecting mild coagulation abnormalities associated with an increased risk of bleeding in a select group of patients undergoing renal biopsies, although its utility in thoracentesis has not been studied.¹² Other tests measuring platelet function have been used for patients undergoing coronary artery bypass graft but have not been investigated in patients on clopidogrel undergoing thoracentesis.¹³

Infectious complications related to thoracentesis are rare. In a study addressing this specifically, Cervini and colleagues¹⁴ reported no infections despite a large number of thoracenteses performed. However, one must be cognizant of placing a needle or catheter through infected subcutaneous tissue or skin into the sterile pleural space.

Pneumothorax is a potential serious complication associated with thoracentesis and may contribute to morbidity.^{4,15} The rates of pneumothorax while using ultrasound (US) have ranged from 1.3% to 6.7%.^{15–17} The incidence of pneumothorax without the use of US has been reported with rates varying between 4% and 30%.^{3,18,19} A pneumothorax related to thoracentesis may occur in 3 different scenarios: (1) atmospheric air introduction with the catheter removal or aspiration of fluid; (2) needle injury to the visceral pleura, permitting air to enter from the alveoli; and (3) rapid decrease in pleural pressure from aspiration resulting in visceral pleura rupture.^{2,20}

Because of the concern for pneumothorax, there were previously concerns about the safety of thoracentesis in patients on mechanical ventilation. However, studies have demonstrated that the risk of complication is no higher in patients requiring ventilation than in nonmechanically ventilated patients. In one of the largest series of thoracentesis using US on mechanically ventilated patients, only 3 out of 232 (1.3%) had a pneumothorax, none had tension physiology, and only 1 (0.004%) required chest tube placement.²¹ In this study, medical residents under attending supervision performed all needle insertions. Other investigators have cited the theoretical risk of a bronchopleural fistula (BPF) after a pneumothorax.²⁰ The use of small-gauge needles and US make BPF a very uncommon complication from diagnostic thoracentesis.

Other reported complications include splenic laceration, abdominal hemorrhage, intrathoracic hemorrhage, sheared off catheter, tumor seeding of the needle tract, hemothorax, pneumohemothorax, anxiety, and site pain.^{3,18,22–26}

Therapeutic thoracentesis has the additional complications of reexpansion pulmonary edema, hypovolemia, and hypoxemia.^{27,28} It is thought that these complications are caused by large volumes of pleural fluid being removed in a single setting. Reexpansion pulmonary edema after thoracentesis represents a potentially life-threatening complication with a mortality rate as high as 20%.²⁹ Fortunately, the occurrence of reexpansion pulmonary edema is rare (0.2%–0.5%).^{30,31} Some experts have recommend maximal removal of 1.0 to 1.5 L to avoid this complication³²; however, the more pertinent factor may be avoiding a decrease in end-expiratory pleural pressure less than -20 cm H₂O. By using manometry, larger volumes have been removed safely while avoiding a more negative pleural pressure.^{30,33,34} Also, symptoms of chest discomfort have been associated with a decrease pleural pressure less than -20 cm H₂O, and an inverse relationship was found with coughing during volume removal.³⁵

Anatomic Considerations

Intercostal spaces (ICS) are an important access portal for entering the pleural space for thoracentesis and chest tube insertion. US-assisted thoracentesis requires familiarization of the traditional anatomic landmarks (ie, course of neurovascular bundle at the inferior aspect of rib in the subcostal groove) but also variability in the course of the intercostal artery (ICA), especially in elderly patients (**Fig. 1**).^{36–38} The collateral ICA that usually runs on the superior border of inferior rib can be lacerated during thoracic procedures with the needle or during catheter insertion.³⁹ Two different studies have demonstrated that the ICA



Fig. 1. Tortuous course of intercostal artery in an elderly individual (*bold arrows*).

is more exposed in the center of the interspace in positions more posteriorly. Furthermore, studies have demonstrated that the ICA may be 20% of the way down into the ICS even as far laterally as the midaxillary line.^{38,40} Therefore, unless fluid is loculated posteriorly, this approach should be reconsidered.^{38,41} The British Thoracic Society's guidelines recommend the insertion of the needle in the triangle of safety (anterior border of latissimus dorsi, the lateral border of pectoralis major, and a horizontal line lateral at the level of the nipple) to avoid the ICA. However, an approach 9 to 10 cm lateral to the spine in the posterior axillary line is equally acceptable, especially in patients sitting upright.³²

Procedural Technique

Adequate positioning of patients is important to safely perform thoracentesis. Patients may be more comfortable while sitting on the edge of the bed with their arms and head resting on one or more pillows on a table and footstool supporting the feet. For patients unable to sit, a needle puncture may be attempted in the midaxillary line with the head of the bed maximally elevated and the arm positioned above the shoulders. Alternatively, the procedure can be performed with patients in the lateral decubitus position with the effusion side nondependent. This position may be an optimal position for patients unable to follow instructions or who are too ill to support sitting upright.

Thoracentesis is performed under aseptic precautions. Once the site is properly marked using US, attention is then directed to local anesthesia. Given that the parietal pleura, rib periosteum, and epidermal nerve endings are the most sensitive area for pain during thoracentesis, lidocaine should be applied to these areas. The finder needle is used to penetrate the skin and subcutaneous tissue while continuously aspirating until fluid is aspirated. If the needle contacts a rib, an anesthetic may be injected and the needle repositioned superior to the rib. After fluid is obtained, the finder needle may be retracted until aspiration stops. This location is close to the parietal pleural and can then be anesthetized generously, after which the seeker needle is withdrawn. A catheter over a placement needle is then advanced, following the same track into the pleural space with continued manual aspiration. A small stab incision may be necessary to prevent kinking of the catheter as it enters the subcutaneous tissue. The catheter is advanced while the needle is kept still with the elbow holding the aspiration syringe relatively fixed to the body. On fluid retrieval, the catheter is advanced into the pleural

space and the needle removed. The catheter is then attached to a drainage system. The use of a vacuum bottle drainage system has been associated with a higher risk for pneumothorax, and manual aspiration is preferred.⁴² There may be several variations of this technique depending on operator experience and the type of commercial catheter used.

Specimen Handling

Diagnostic thoracentesis requires approximately 50 mL of pleural fluid. Common tests performed on pleural fluid include cell count with differential, pH, total protein, lactate dehydrogenase, glucose, gram stain and culture, and cytology. Additional tests (**Table 1**) include pleural fluid hematocrit, albumin, brain natriuretic peptide, adenosine deaminase, triglycerides, cholesterol, amylase, and mycobacterial or fungal cultures, depending on the clinical scenario. For cell count and differential, the fluid should be placed in EDTA-treated tubes if the syringe was not initially heparinized because fluid collected in tubes without anticoagulants can give inaccurate numbers.⁴³ Fluid pH should be measured with a blood gas machine whenever a parapneumonic effusion or malignancy is suspected.⁴⁴ Collection of pleural fluid for the measurement of pH warrants careful attention because admixture of air, lidocaine, or heparin with pleural fluid alters the measured pH.^{45,46} If analyzed expeditiously, it is not necessary to place samples on ice because the pH of a sample at room temperature does not change significantly during the first hour following thoracentesis.⁴⁷

In addition to the previously mentioned tests, fluid may be sent separately for cytologic preparation. One should consult with their institutional

Table 1
Additional tests on pleural fluid

Tests	Clinical Scenario
Hematocrit	Hemothorax
Albumin	Gradient helpful in differentiating transudate vs exudate
BNP level	CHF
Adenosine deaminase	Tuberculosis
Triglyceride	Chylothorax
Cholesterol	Pseudochylothorax, rheumatoid arthritis, chronic pleuritis

Abbreviations: BNP, brain natriuretic peptide; CHF, congestive heart failure.

pathologists to determine the optimal means of delivering fluid for analysis; but typically fluid may be analyzed by thin preparations, cytospin, cell blocks, and other techniques. It is generally recommended that both cell blocks and smears be used in evaluating all fluids submitted to the cytology laboratory.^{48–51} In addition to processing the sample, other factors, such as type of tumor, associated other diagnosis (heart failure, pulmonary emboli, pneumonia, lymphatic obstruction, or hypoproteinemia), and tumor burden, among others, may alter the diagnostic yield.⁵² For the purposes of evaluating a malignant pleural effusion, only 50 to 60 mL of fluid is required because larger volumes do not significantly increase the yield of pleural fluid cytology.^{53,54} On the other hand, analyzing less volume seems to reduce the diagnostic yield for pleural malignancy.⁵⁵

Role of Follow-up Imaging

A routine chest radiograph after thoracentesis is not required for most asymptomatic and nonventilated patients.^{56,57} This point was best illustrated by a prospective study whereby, of the 488 asymptomatic patients, only one patient was found to have pneumothorax on a post-thoracentesis radiograph.⁵⁸ If, however, the primary purpose for a postprocedural radiograph is to assess lung expansion and assess for potential lung entrapment, trapped lung, and future therapeutic decision making, then obtaining a plain radiograph in asymptomatic patients is reasonable. Alternatives to a postprocedural radiograph may include the use of US to detect complications and to determine the presence of remaining fluid. On the other hand, a manometer attached to the thoracentesis catheter can provide information regarding the expandability of the lung.

Pleural US

US has been used in the medical field for more than 50 years.⁵⁹ Nonradiology specialties are currently using US in various applications, including emergency medicine, endocrinology, cardiology, surgery, and obstetrics. It has been only within the past decade that US has gained popularity by pulmonologists. This popularity may have been facilitated by decreasing costs, increasing portability, and increasing education regarding the technology.

The basic hardware requirements include a transducer, US machine, and image storage capacity. The transducer should have a probe that will fit between the intercostal space; typically, this is the same as the abdominal probe and distinct from a vascular and other probes. The frequency of the US probe should be 3.5 to 5.0

MHz.⁶⁰ Lower-frequency US have better penetration but lower image resolution, whereas higher-frequency US provides better images but decreases visualization of deeper structures. The frequency within 3.5 to 5.0 MHz allows for a balance of depth and clarity for pleural imaging. Of course, structures such as the ribs prevent US waves from traversing the tissue and result in artifacts.

Aside from the size and portability of the US machine, as well as use of specified probes, image storage and Doppler capabilities may be considered. Image storage and labeling are essential when billing for the use of US to guide the thoracentesis. Thoracentesis uses CPT code 32421 or 32422, whereas US is an add-on code (76942–26). Although Doppler is not necessary, in select cases, it can image aberrant vessels that prohibit a selected procedural target point.⁶¹

In addition to hardware, thoracic US requires skills to perform and interpret pleural US. With appropriate training, this can be accomplished. A prospective study comparing the diagnostic accuracy of pulmonologists with radiologists in identifying pleural effusions was 99.6% correct and garnered no false positives.⁶² Other studies have supported the use of US by nonradiologists in accurately interpreting findings of hemoperitoneum and performing basic general US examinations in intensive care units.^{63,64} Recognizing the importance of US for performing thoracentesis, the current American College of Graduate Medical Education program requirements mandate pulmonary/critical care fellowship programs to provide education on US techniques to perform thoracentesis.^{65,66} In some medical schools, portable US devices are now a part of their physical examination curriculum.⁶⁷

Although US can access up to 70% of the pleural surface, there remain some areas that are limited on US visualization because of the bony thoracic cage.⁶⁸ Furthermore, because US waves do not travel through an air medium, certain conditions with bullae or extensive subcutaneous air may hamper US imaging of the pleural surface. The air barrier may also, at times, limit the visualization of the normal lung parenchyma. Another potential limitation is the variable individual operator skills and experience to obtain/interpret images correctly. The American College of Chest Physicians/Société de Réanimation de Langue Française have published guidelines for US competence in pulmonary/critical care.⁶⁹

Preprocedural and Intraprocedural US

US may be useful before, during, and after the thoracentesis (**Table 2**).

Table 2
Advantages of US-guided thoracentesis

Preprocedure	Evaluate patient at bedside immediately before procedure Evaluate quantity of pleural effusion Assess potential procedural difficulties Assess differential diagnosis based on US appearance
Intraprocedure	Assess best entry point Place needle or catheter in real time Avoid injury to other structures
Postprocedure	Evaluate for pneumothorax Evaluate extent of remaining fluid

The key advantages of US with preprocedural assessment of the pleural space include a point-of-care evaluation, assessment of potential anatomic procedural difficulties, generating differential diagnoses, and marking the best site of entry. US has shown to be more sensitive and accurate compared with lateral decubitus radiography in detecting pleural effusions.^{66,70} In a prospective study, bedside US improved the puncture site selection in up to 54% of the patients when physicians were unable to locate a puncture site by physical examination. Also, in the same study, US prevented potential accidental organ puncture in 10% of all cases.⁷¹ It is important to note that the benefit of US site selection in decreasing pneumothoraces occurs with only real-time needle puncture or immediate preprocedure marking (patient in same position/location). Notably, US marking of the effusion to perform the thoracentesis at a later time or location does not reduce iatrogenic pneumothoraces.^{66,72}

Preprocedural identification of adhesions and complex loculations may predict successful pleural space access for thoracentesis or other pleural procedures. In a retrospective study, US characteristics of empyema predicted the success of drainage with a complex or septated sonographic pattern having less success.⁷³ Furthermore, thoracic US before medical thoracoscopy improved pleural access and predicted fibrous septations.⁷⁴ **Figs. 2–4** demonstrate different US patterns seen in pleural effusions.

Postprocedure US

There are several advantages of using US after a pleural procedure such as thoracentesis. It

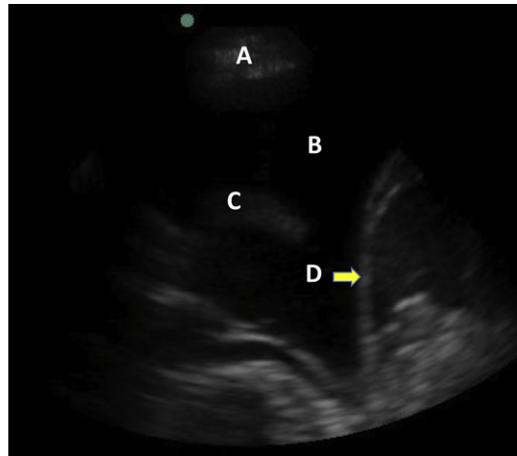


Fig. 2. Pleural fluid boundaries on US imaging. (A) Chest wall, (B) pleural effusion, (C) atelectatic lung, (D) diaphragm.

allows for an immediate evaluation of the volume and character of effusion remaining, facilitating medical decision making as to whether more needs removed. Postprocedural bedside US also allows the proceduralist to immediately manage complications, such as pneumothorax.

The first reported US findings of pneumothorax were described in 1986 on a horse.⁷⁵ Today, US has been shown to be more sensitive than chest radiograph for the detection of a pneumothorax.^{76,77} In a study comparing computed tomography (CT) with US, US detected 92% of pneumothoraces seen on CT scan.^{76,78} In another study, pleural US demonstrated superiority over chest radiographs in detecting residual pneumothorax following a drainage procedure.⁷⁹ All pneumothoraces detected on US resulted in therapeutic intervention. Using US, the lack of lung sliding and/or the absence of B lines have been described by Lichtenstein and colleagues⁸⁰ as strong indicators of pneumothorax. The presence of B lines and lung sliding rules out a pneumothorax (negative predictive value 100%).⁸¹ Less reliable signs that have been described for US detection of pneumothorax include lung point (100% specificity; estimates size of pneumothorax) and lung pulse (rules out pneumothorax).^{81,82}

US can also be used to detect pulmonary edema and may be useful to confirm suspicion of reexpansion pulmonary edema. US B lines (comet-tail artifact, lung rockets) are the US equivalent of Kerley lines on chest radiograph (97% sensitivity, 95% specificity).^{83,84} They appear as vertical narrow lines arising from the pleural line to the edge of the US screen.⁸⁵

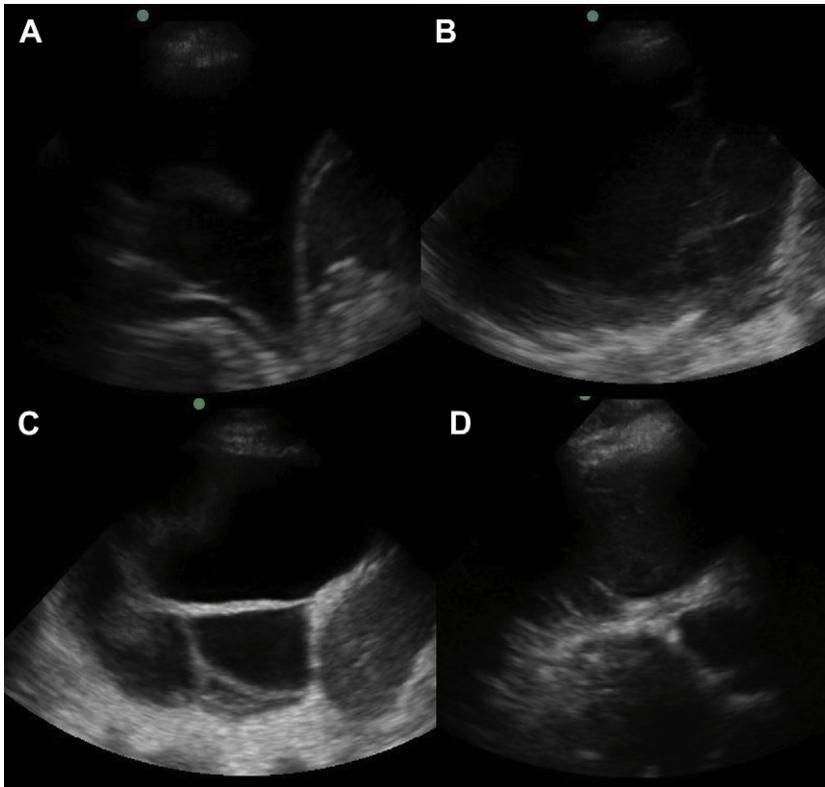


Fig. 3. US patterns of pleural effusion. (A) Anechoic, simple, (B) complex nonseptated, (C) complex septated, (D) homogenous echogenic.

Pleural Procedural Service

Specialized services in pleural procedures and disease management have recently become more popular with the expanding number of pleural procedures available to physicians and the accessibility of US.^{86,87} In addition, there is a growing number of patients presenting with pleural disease, caused by both infectious and malignant causes.^{87–91} A successful procedural unit may facilitate a rapid diagnosis and treatment

of pleural disease. In cases of pleural infections, an early diagnosis may make a significant difference in a patient's outcome. Furthermore, the development of a dedicated service provides the opportunity for research in pleural disease.⁹² Finally, a dedicated pleural procedural service provides a training environment for education. Frequent repetition with experienced senior supervision may permit learning of thoracic US and thoracentesis skills.

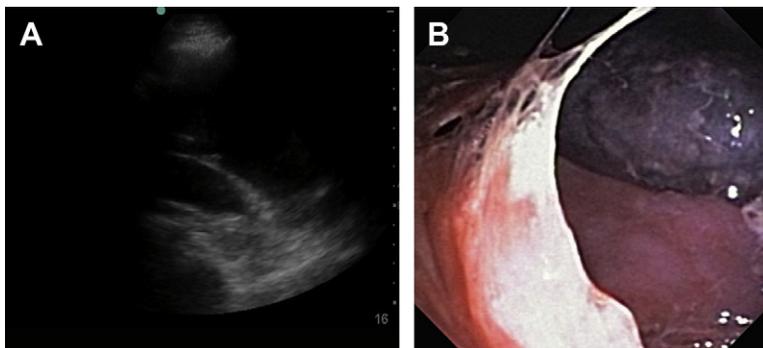


Fig. 4. Confirmation of US images and thoracoscopy. (A) US image of pleural effusion with adhesion. (B) Same adhesion band visualized on pleuroscopy.

A potential criticism to a dedicated thoracentesis procedural service is that it decreases the number of routine thoracentesis performed by other, perhaps qualified, individuals. Most pulmonologists are experienced with thoracentesis; but when additional skills are added, such as US, manometry, and complication management (tube thoracostomy), the number of qualified pulmonologists decreases. In a retrospective series examining complications before and after instituting a thoracentesis service, there was a significant and dramatic decrease in complications by using a select group of pulmonologists to perform all the thoracentesis at a single institution.⁶²

SUMMARY

Thoracentesis is an invaluable tool for assessing pleural disease. The use of US by trained professionals has enhanced this procedure's safety and feasibility. Routine US enhances the preprocedural, intra-procedural, and postprocedural assessment of the pleural space. As equipment becomes more available and portable, its use is anticipated to grow and possibly become the standard of care.

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