Thoracic ultrasound for beginners: utility and training issues for clinicians

Bedside thoracic ultrasound is gaining popularity among non-radiologists, because of its advantages in the diagnosis and management of pleural disease. However, it has significant potential pitfalls and formal training is essential to avoid harm. This review gives an overview of the utility of ultrasound and discusses training.

Non-radiologists from a variety of specialities have been increasingly using ultrasound in recent years to aid diagnosis and improve the safety and success of procedures. The bedside use of ultrasound in acute patient management has been enabled by technological advances improving the quality and decreasing the cost of portable ultrasound machines. One application of ultrasound that has become popular is thoracic ultrasound, particularly to aid pleural disease management and avoid complications associated with injudicious pleural procedure site selection.

Two publications have prominently advocated the utility of thoracic ultrasound – a UK National Patient Safety Agency (2008) rapid response report and the British Thoracic Society pleural disease guidelines (Davies et al, 2010; Havelock et al, 2010; Hooper et al, 2010; Roberts et al, 2010). The 2008 National Patient Safety Agency report examined 15 cases of morbidity and 12 of mortality associated with (predominantly Seldinger) chest drain insertion. A significant root cause of harm was found to be inadequate radiological guidance, leading to poor site selection and subsequent organ perforation. Such harm could be avoided by using real-time imaging. The British Thoracic Society pleural disease guidelines echoed the National Patient Safety Agency report, and strongly recommended the use of thoracic ultrasound before all procedures involving pleural fluid. These publications have essentially mandated the acquisition of thoracic ultrasound skills by physicians performing pleural procedures, particularly respiratory medicine trainees.

Utility of ultrasound

Thoracic ultrasound uniquely allows bedside real-time radiation-free imaging of the pleural space. While a primary use of thoracic ultrasound is in detection and characterization of pleural fluid, it also has many uses for other thoracic pathology (*Table 1*).

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Table 1. Utility of thoracic ultrasound

Pathology	Utility of thoracic ultrasound	Limitations
Pleural fluid	Detection, characterization and quantification; guided thoracentesis or chest tube insertion	Body habitus and rib acoustic shadows may cause imaging difficulties
Pneumothorax	Ruling out pneumothoraces, particularly post procedural	Unable to assess pneumothorax size. Several diseases (including chronic obstructive pulmonary disease) can cause false positives
Pleural thickening and nodularity	Detection, guided core biopsy	Sometimes difficult to distinguish thickening from small pleural effusion
Diaphragm	Detection of diaphragmatic nodularity or thickening; detection of elevated diaphragm or diaphragmatic paralysis	Aerated lung can limit diaphragmatic visualization
Lung	Detection of consolidation, atelectasisand peripheral lung lesions; guided biopsy	Inability to detect central lesions not abutting visceral pleura
Heart	Detection of pericardial fluid and cardiomegaly	
Rib	Detection and biopsy of rib metastases	Metastases only detectable when rib cortex is disrupted
Liver	Detection of metastases	
Cervical and supraclavicular lymph nodes	Detection and guided aspiration or biopsy	

Normal appearances

Recognizing the normal thoracic appearances is essential in acquiring thoracic ultrasound competency. This is particularly important as there are often only subtle distinguishing features between aerated lung, pleural effusion and pneumothorax.

A bright (echogenic) 'pleural stripe' represents the normal visceral and parietal pleural layers. Aerated lung is associated with the following features (*Figure 1a*):

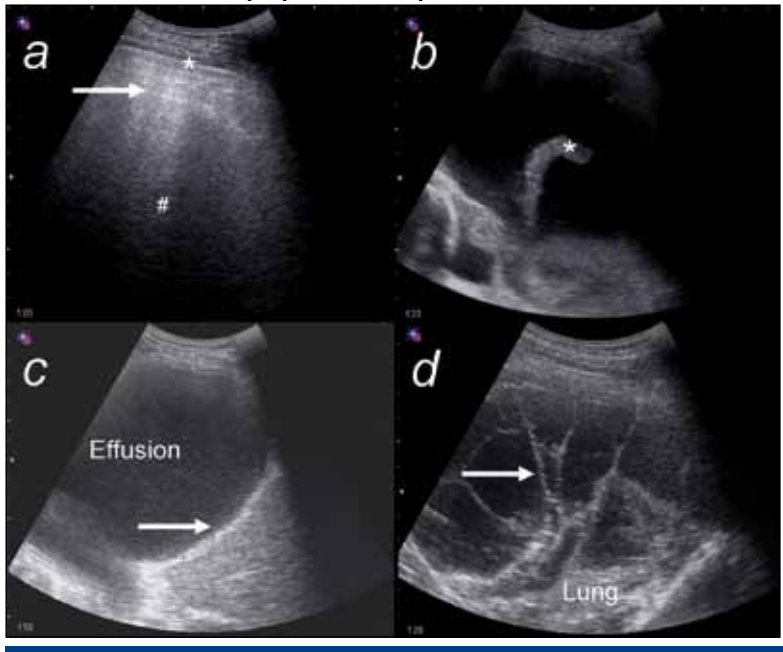
1. Pleural sliding or gliding – the interface between the visceral and parietal pleura produces a shimmering movement of the pleural stripe during ventilation
2. Vertical 'comet tail' artefacts – these are echogenic bands extending from the pleura into the deeper parts of the image, and are artefacts created by highly reflective structures found at the pleural surface
3. Horizontal reverberation artefacts – these are multiple artefactual echogenic bands parallel and deep to the pleural stripe
4. Absent distal detail – ultrasound is unable to pass through aerated lung and therefore anatomically recognizable structures are not seen deep to the pleural stripe.

Table 2. Sonographic appearances of pleural fluid

Sonographic appearance	Significance
Anechoic (dark echo-poor pleural fluid without internal structure) (*Figure 1b*)	Transudative or exudative effusion
Echogenic (numerous, often swirling, internal echoes within pleural fluid) (*Figure 1c*)	Exudative effusion. Heavily echogenic fluid is suggestive of blood or pus
Septated (visible lines within pleural fluid) (*Figure 1d*)	Exudative effusion. Septations may make drain insertion more problematic; effusions may drain poorly (although not necessarily). Fluid within a septation may contain very bright echoes, suggestive of intrapleural air (often in the context of a gas-forming empyema)

From Hirsch et al (1981); Yang et al (1992)

Figure 1. a. Normal appearances of aerated lung. * = pleural stripe, arrow = horizontal reverberation artefact, # = vertical 'comet tail'. b. Large anechoic pleural effusion surrounding atelectatic lung (*). c. Large echogenic pleural effusion causing diaphragmatic inversion (arrow). d. Heavily septated (arrow) pleural effusion.



Pleural fluid

Thoracic ultrasound is particularly suited for pleural fluid detection, and has a higher sensitivity than chest X-ray (Lipscomb et al, 1981; Eibenberger et al, 1994). The sonographic appearances of pleural fluid can help characterize pleural fluid (*Table 2*) and guide intervention. Pleural fluid is found deep to the parietal pleura, usually as a relatively dark (echo poor or hypoechoic) region which may be featureless or have bright internal echoes caused by septations, intrapleural air or proteinaceous exudative effusions. Thoracic ultrasound enables accurate pleural fluid localization and allows clinicians to determine the effusion depth. Complete hemithorax opacification ('white out') on chest X-ray, in which the differentiation between pleural fluid and collapsed or consolidated lung may be otherwise difficult, is readily evaluated by thoracic ultrasound (Yu et al, 1993) and can prevent injudicious chest tube insertion into consolidated or collapsed lung.

Several complex pleural fluid volume quantification strategies have been proposed using thoracic ultrasound (*Table 3*), predominantly for supine patients on intensive care. A more pragmatic approach is to clas-

Table 3. Proposed methods for estimating pleural fluid volume

Reference	Method	Position
Roch et al (2005)	Distance between posterior chest wall and lung > 50 mm predicts > 500 ml pleural fluid volume	Measured in supine intensive therapy unit patients at posterior axillary line at base of hemithorax using longitudinal section
Vignon et al (2005)	Distance between posterior chest wall and lung >45 mm (right) or >50 mm (left) predicts ≥800 ml volume	Measured in supine intensive therapy unit patients at posterior axillary line at base of hemithorax using transverse section
Balik et al (2006)	Volume (ml) = 20 x [maximal pleural separation at lung base (mm)]	Measured in supine intensive therapy unit patients at posterior axillary line at base of hemithorax using tranverse section
Remerand et al (2010)	Volume (ml) = effusion length (cm) x effusion cross-sectional area (cm^2)	Measured half-way between the apical and caudal limits of the effusion in paravertebral region

sify a small pleural effusion as an effusion found only at one intercostal space, a moderate pleural effusion as occupying less than half the hemithorax and a large pleural effusion as being more sizeable. Large effusions may cause diaphragmatic inversion, associated with significant dyspnoea (*Figure 1c*) – aspiration of as little as 500 ml of pleural fluid often corrects this inversion and returns the diaphragm to its normal dome configuration, and may lead to significant symptomatic improvement.

Given the increased risk of parenchymal puncture, clinicians should avoid sampling pleural effusions which are <1 cm depth on ultrasound, unless they have significant experience in real-time needle guidance using ultrasound. There may be a role in sampling small effusions in the context of possible malignancy, for cytological analysis. Conversely, anechoic parapneumonic effusions <1 cm rarely require sampling or drainage.

Diaphragm and visceral and parietal pleurae

Thoracic ultrasound examination of the diaphragm, visceral and parietal pleural surfaces can detect pleural thickening or nodularity (*Figure 2a*). Parietal pleural thickening is usually hypoechoic (echo-poor) or anechoic (black), and may be difficult to distinguish from pleural fluid. Colour Doppler may help differentiate the two; pleural fluid may give a wave-like colour Doppler signal induced by respiratory or cardiac motion of the pleural fluid whereas pleural thickening provides very little signal (Wu et al, 1994, 1995).

The diaphragm is poorly visualized in the absence of pleural fluid (as a result of aerated lung in the costophrenic angle preventing ultrasound penetration). When seen, the diaphragm has five alternating hypo- and hyper-echoic (dark and bright) stripes; disruption of this pattern suggests pathology (*Figure 3*).

Qureshi et al (2009) examined thoracic ultrasound features with a high specificity for malignancy (95–100%) which, when taken together, gave an overall sensitivity of 79%. The following features were found to have high specificity:

1. Parietal pleural thickening >1 cm
2. Nodular pleural thickening
3. Visceral pleural thickening
4. Diaphragmatic thickening >7 mm
5. Disruption of five diaphragmatic layers
6. Diaphragmatic nodules.

Detection of pleural nodularity is highly suggestive of malignancy, and should mandate comprehensive patient evaluation even if pleural fluid evaluation reveals a transudate or cytological examination does not find malignant cells.

Thoracic ultrasound also enable real-time assessment of the dynamic diaphragmatic movement, which is particularly useful in assessing for diaphragmatic paralysis.

Pneumothorax

Separation of the parietal and visceral pleurae in pneumothorax causes disappearance of pleural sliding and vertical comet tail artefacts (Wernecke et al, 1987; Targhetta et al, 1993; Lichtenstein and Menu, 1995; Goodman et al, 1999). In contrast, there is often an accentuation of the horizontal reverberation artefacts.

Figure 2. a. Echogenic pleural effusion (*) with malignant diaphragmatic nodule (arrow). b. Consolidated lung abutting diaphragm and liver with tiny anechoic pleural effusion (*). c. Multiple liver metastases (arrow). d. Magnified view of fine needle aspiration of malignant cervical lymphadenopathy with needle visible within lymph node (arrow) and nearby carotid artery (*).

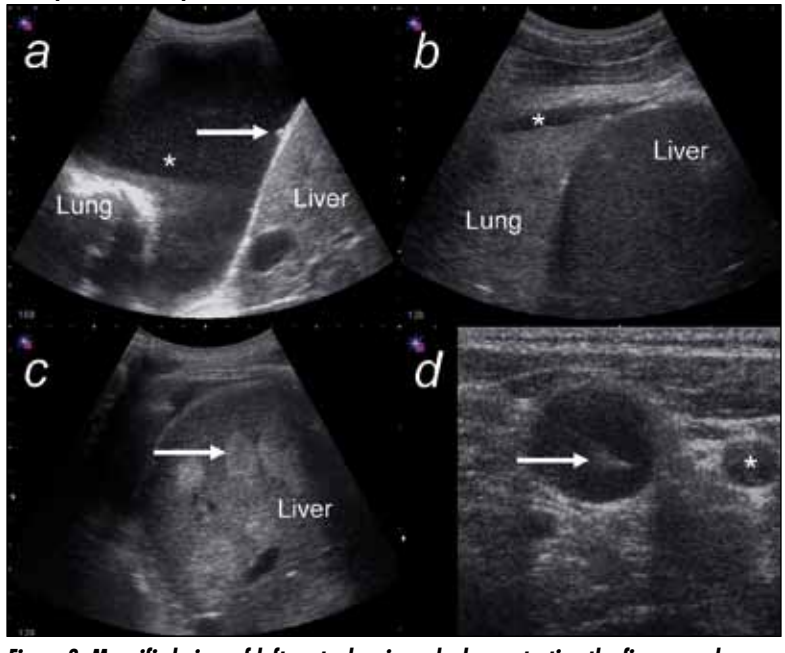
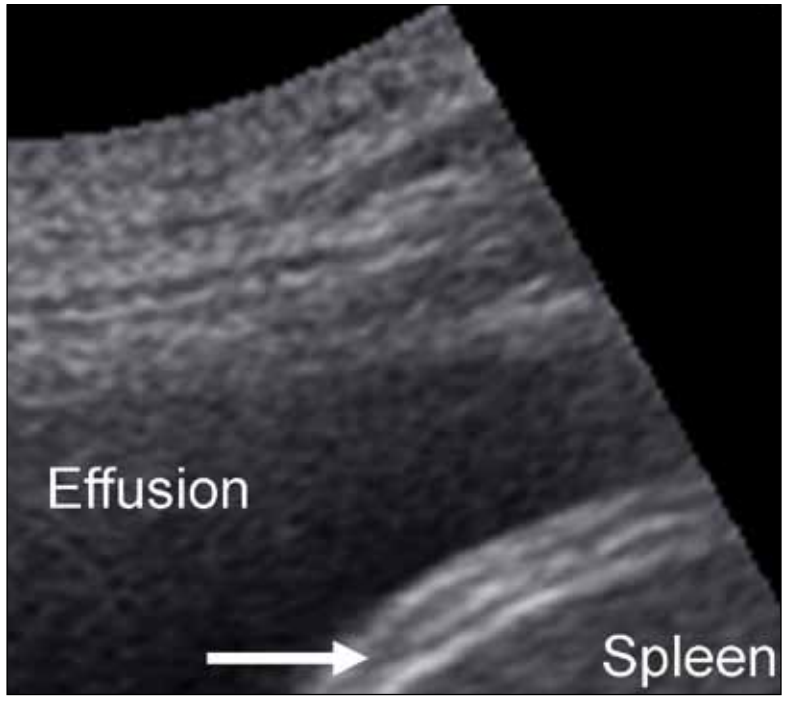


Figure 3. Magnified view of left costophrenic angle demonstrating the five normal diaphragmatic layers (arrow).



Thoracic ultrasound is unable to quantify the size of a pneumothorax; a chest X-ray is essential to confirm the ultrasound findings and to assess the pneumothorax size.

Several conditions mimic pneumothorax at ultrasound – bullous lung disease (e.g. chronic obstructive pulmonary disease; Slater et al, 2006) and previous pleurodesis (e.g. secondary to previous inflammatory pleural insults) often cause absence of the pleural sliding sign. Significant thoracic ultrasound experience is required when evaluating the possibility of pneumothorax in patients with chronic obstructive pulmonary disease. However, when present, pleural sliding and comet tails have a 100% negative predictive value for pneumothorax (Lichtenstein et al, 1999). Thoracic ultrasound is therefore best regarded as a good rule-out test for pneumothorax, and can be particularly useful post procedure (Reissig and Kroegel, 2005).

Pulmonary abnormalities

Peripheral lung abnormalities abutting the visceral pleura are visible at thoracic ultrasound, including atelectasis, consolidation, tumours and abscesses. Central abnormalities are not visible if there is aerated lung adjacent to the visceral pleura.

'Compressive' atelectasis is common with moderate or large pleural effusions. The atelectatic lung adopts a concave 'hockey stick' appearance with significant volume loss (*Figure 1b*).

Consolidated lung can mimic liver or spleen, and requires careful interpretation (*Figure 2b*). The lung parenchyma is seen to have branching anechoic (black) pulmonary vessels (with a demonstrable colour Doppler signal), often with hyperechoic (echo-rich) speckles caused by air within bronchi (sonographic air bronchograms).

Other abnormalities

Detection of many other abnormalities is possible using thoracic ultrasound, including liver metastases (*Figure 2c*), pericardial effusions, rib metastases (visible when the cortex has been disrupted), and cervical and supraclavicular nodal enlargement (*Figure 2d*) (Kumaran et al, 2005). Opportunistic detection of these unexpected abnormalities during thoracic ultrasound may expedite further imaging (such as computed tomography or echocardiography) or enable minimally invasive bedside diagnostic strategies (e.g. lymph node or rib metastasis fine needle aspirate).

Intervention

In addition to its diagnostic role, thoracic ultrasound has a role in guiding pleural interventions, such as thoracentesis and chest tube insertion, in two ways:

1. Site marking – in which a site for pleural intervention is marked using thoracic ultrasound immediately before an intervention ('X' marks the spot). Patients should not be moved between site marking and intervention, as this may cause movement of lax cutaneous tissues or cause redistribution of pleural fluid (Raptopoulos et al, 1991)
2. Real-time guided intervention – in which a sterile sheath and sterile ultrasound gel are used to visualize the needle into the pleural space. This requires more technical skill but enables sampling of small or loculated effusions.

Thoracic ultrasound performs better than clinical examination and chest X-ray review in localizing pleural fluid and enabling successful thoracentesis (Kohan et al, 1986; O'Moore et al, 1987; Weingardt et al, 1994). A study by Diacon et al (2003) found that thoracic ultrasound was significantly more accurate than clinical examination in finding a safe thoracentesis site; without thoracic ultrasound, physicians were unable to propose a site in 18% of cases where sonography was successful. Furthermore, 10% of sites proposed by clinical examination would have risked organ puncture (lung, liver or spleen) (Diacon et al, 2003).

When thoracic ultrasound was combined with institutional policies restricting thoracentesis to those physicians regularly undertaking the procedure, investigators at the Mayo clinic demonstrated an eight-fold reduction in the risk of pleural aspiration-associated pneumothoraces (Duncan et al, 2009). Other observational studies have also suggested a lower complication rate of pleural aspiration performed with thoracic ultrasound guidance (Raptopoulos et al, 1991; Barnes et al, 2005).

Thoracic ultrasound is often used before medical thoracoscopy to identify a suitable port insertion site, and to identify features that may suggest a difficult procedure, such as septations (which may impede thoracoscopic view) or absent pleural sliding (suggesting pleural adhesions and difficulties in collapsing the lung before thoracoscopy).

Image-guided cutting needle biopsies of pleural thickening or nodularity may be taken under real-time ultrasound guidance. In the hands of respiratory physicians, thoracic ultrasound-directed biopsies of pleural and peripheral lung lesions ≥2 cm have been shown to be safe and to have a high diagnostic sensitivity (>85%) (Diacon et al, 2004). The use of unguided 'blind' (Abrams) pleural biopsies for the diagnosis of malignancy is discouraged, being inferior to image-guided (Maskell et al, 2003) or thoracoscopic biopsies.

Ultrasound allows localization and bedside biopsy of sites of metastatic disease, such as fine needle aspiration of cervical and supraclavicular lymphadenopathy (*Figure 2d*) or rib metastases. Neck sonography and fine needle aspiration of malignant-appearing lymph nodes has a diagnostic sensitivity of >70%, when evaluating for metastatic lung cancer (Kumaran et al, 2005). There may be a role for integrating neck sonography within the framework of a lung cancer clinic as a 'one-stop' clinic attendance allowing rapid evaluation (with or without biopsy) of lymphadenopathy.

Training issues

The relative ease in identifying a large uncomplicated pleural effusion may unfortunately encourage clinicians

to perform thoracic ultrasound without adequate training. A formal training programme is essential to avoid misinterpretation of images, particularly as pleural interventions are often determined by sonographic interpretation. After adequate training, physicians have been shown to have a complication rate of about 0.5%, comparable with radiologists (Rahman et al, 2010).

Training standards

The Royal College of Radiologists (2005) have produced training guidelines for clinicians wishing to acquire ultrasound competence. The minimum training requirements to safely perform thoracic ultrasound (level 1) are:

1. Attendance at a theoretical course and appropriate background reading
2. Observation of 20 thoracic ultrasound examinations
3. Performing 10 thoracic ultrasound examinations for pleural effusions
4. Performing 20 thoracic ultrasound examinations on normal patients
5. Performing five thoracenteses or chest tube placements using both site marking and real-time guidance.

Other international agencies have published ultrasound training guidelines, such as the American College of Chest Physicians (Mayo et al, 2009), the American College of Surgeons (1998) and the American College of Emergency Physicians (2008).

Several UK authorities responsible for clinician training have now made ultrasound skill acquisition mandatory – the Joint Royal College of Physicians Training Board (2010) has made level 1 thoracic ultrasound part of the training of respiratory physicians, and the College of Emergency Medicine (2010) requires all emergency medicine physicians to recognize pleural fluid as part of a multisystem 'trauma' ultrasound (focussed assessment using sonography in trauma; FAST).

Mentor

A named mentor (usually a radiology consultant) is an essential part of thoracic ultrasound training and ongoing professional development. Once a clinician has attained level 1 competency, the mentor should continue to provide a vital opinion in difficult cases, particularly during early independent practice. Level 1 practitioners should keep a record of thoracic ultrasound examinations performed, and regularly discuss their findings with their mentor (preferably using stored clips or images of thoracic ultrasound examinations).

Pitfalls

Various potential problems associated with thoracic ultrasound use should be highlighted during clinician training.

Overconfidence

Thoracic ultrasound may detect very small pleural effusions (<1 cm) that are not even apparent on chest X-ray; inexperienced clinicians may be tempted to aspirate such effusions even though the procedural risks are high and potential benefits may be limited. If a diagnostic aspiration is likely to be helpful, this should be performed by an experienced sonographer using direct real-time ultrasound guidance.

Misinterpretation

Various mimics of pleural fluid exist, including normal lung or an elevated hemidiaphragm with massive ascites or other upper abdominal pathology, such as cysts, which may mimic a septated pleural space. Identification of liver or spleen, and then diaphragm, is a crucial part of defining the inferior extent of the pleural space to avoid misinterpretation.

Posterior approach

It is relatively underappreciated that the intercostal vessels lie exposed within the intercostal space posteriorly, only becoming protected by the flange of the superior rib as they reach the angle of the rib more laterally. However, thoracic ultrasound often finds maximal pleural fluid depth posteriorly, at a site likely associated with the highest risk of intercostal laceration during intervention. Therefore, contingent on an adequate volume of pleural fluid, any intervention should be performed as far laterally as possible to minimize the risk of vascular trauma (Wrightson et al, 2009, 2010). Any thoracic ultrasound training should emphasize that the lateral 'safe triangle' (bounded by pectoralis major and latissimus dorsi) remains the ideal default location for intervention, where thoracic ultrasound allows.

Conclusions

Thoracic ultrasound provides a valuable extension to clinical examination and confers significant advantages in disease diagnosis and intervention, particularly for pleural disease. Improvements in the cost and portability of ultrasound machines have meant that its bedside use has become commonplace on respiratory and other acute

KEY POINTS

- Thoracic ultrasound enables rapid bedside imaging of the pleural space and peripheral lung abnormalities.
- Thoracic ultrasound should be used before any intervention for pleural fluid to improve patient safety and increase diagnostic yield.
- Intercostal vessels lie exposed posteriorly and any pleural intervention should take place as far laterally as possible, preferably within the 'safe triangle', provided thoracic ultrasound suggests this is appropriate.
- After formal training, clinicians using thoracic ultrasound have a similar low complication rate to radiologists.
- Without adequate training and mentorship, thoracic ultrasound image misinterpretation could cause significant harm.
- Training in thoracic ultrasound is mandatory for UK respiratory trainees; other clinicians should also consider thoracic ultrasound skill acquisition.

wards. Despite these benefits, it is essential that clinicians undertake a comprehensive training programme and are formally signed off with level 1 certification before undertaking any unsupervised thoracic ultrasound scans. This will help to avoid image misinterpretation which could threaten patient safety. **BJHM**

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