

The Use of Lung Ultrasound in Acute Medicine

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Introduction

POCUS (Point of Care Ultrasound) refers to ultrasound performed by clinicians as part of their initial patient evaluation, often with the aim of answering a specific question as opposed to being a comprehensive assessment. Such ultrasound is non-invasive, involves no radiation and can be rapidly performed at the bedside. It is also widely practiced in emergency and intensive care medicine leading to earlier and more accurate diagnoses for a wide range of presentations such as shock, renal failure and dyspnoea.¹ POCUS has evolved from cardiological or radiological studies, reduced in complexity and scoped for clinician use. Lung ultrasound (LUS) has been largely developed by acute care clinicians and is a more recent addition to POCUS. Procedural LUS is widely recommended to improve the safety profile of pleural catheter placement (referring to BTS guidelines) but in the UK diagnostic LUS is not widely practiced despite good evidence and guideline support for its use.⁴ In this article we briefly review and describe the role of diagnostic LUS as applied to acute medicine. Potential advantages of LUS include a decreased time to diagnosis, improved diagnostic accuracy, a reduction in radiation exposure and unnecessary expensive tests. Studies have shown that at least one diagnosis was missed in around a fifth of patients with acute respiratory symptoms, resulting in increased length of stay and mortality in a third of patients.⁵⁻⁷

Transducer (probe) Choice

Higher frequency transducers (5 – 10 MHz) offer higher resolution but limited penetration (typically

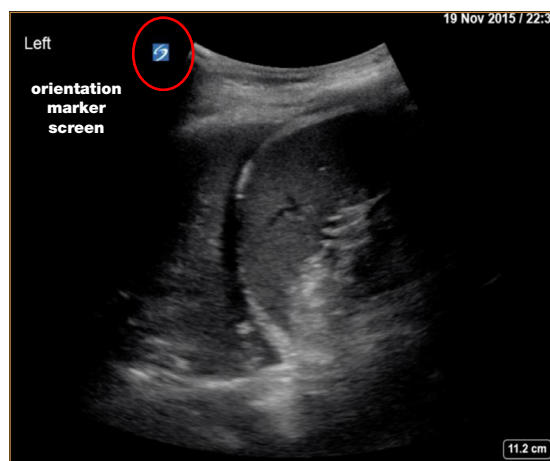
2-7 cm) while lower frequency probes (2 – 5 MHz), most often phased array echocardiography, microconvex or larger curvilinear probes, offer better penetration (5 – 20) cm from the footprint. Either can be used for imaging lung tissue, depending on the area of interest. Smaller footprint probes allow the intercostal space to be accessed easily. For detailed imaging of the (superficial) pleura in smaller adults the linear transducer is preferred. Many machines offer dedicated lung presets for a particular probe. Artefacts are helpful in LUS, hence, such presets deactivate many features that normally are employed to reduce these – important for optimal lung images.

Orientation

The transducer has a marker (dot or groove) at one end which serves to ensure the correct orientation and is directed either cephalad or to the right-hand side of the patient being scanned. The dot corresponds to a marker (usually a coloured dot, logo or indentation) which is conventionally to the left of the display screen as faced by the operator (Figure 1). The transducer is usually orientated longitudinally on the chest (sagittal or coronal) as this uses the ribs and pleural line as landmarks – which has been described as the “bat sign”. In this appearance, the white (echogenic) pleural line is identified around 5 mm below the inferior rib border (Figure 2). The ribs form acoustic shadows on either side due to the reflection of sound back to the probe. When evaluating the pleural line with a high frequency transducer, the depth is often adjusted to allow the pleural line to be shown halfway down the image. When using a low frequency transducer, the depth is



Figure 1. Marker convention



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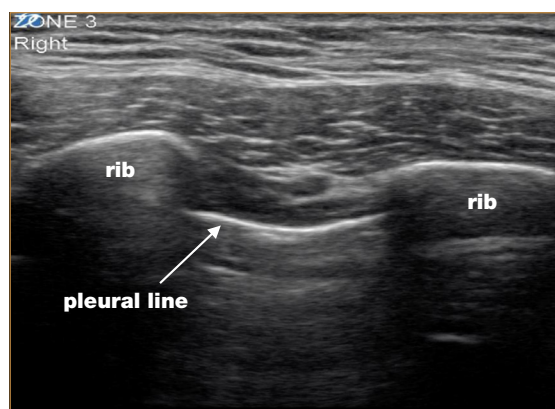


Figure 2. Normal appearance of ribs and pleural line (high frequency transducer)

usually set deeper (up to 13cm) so the pleural line is shown in the upper half of the screen.

Structured approach to obtaining windows

Unlike echocardiography and eFAST (extended focused assessment with sonography for trauma) there are no internationally agreed windows to image the lung. However, most research protocols use two anterior, two lateral and one to two posterior windows (Figure 3).⁸ The more intercostal spaces imaged the more likely the operator is to identify pathology but at the expense of more time.

A structured approach to interpreting the images acquired was described by Lichtenstein in 2008 (the BLUE protocol).⁹ This was originally developed in an ICU population but has also been validated in the emergency department setting in an observational cohort study of 383 patients. Sensitivity/specificity was 87.6%/96.2% for AHF (acute heart failure), 85.6%/99% for pneumonia, 98.2%/67.3% for asthma, 46.2/100% for pulmonary embolism and 71.4/100% for pneumothorax.¹⁰

Normal thoracic appearances

When scanning a normal chest, ultrasound does not penetrate into the lung parenchyma as it is all reflected at the pleural interface – which appears as a bright white (echogenic) line on the image. Hence, as no ultrasound travels beyond the pleural line, any appearances below this interface on the image are a result of artefacts. This is because the normal lung has a large amount of air spaces which cause gross reflection at interfaces with normal soft tissue, e.g. the pleural line. Only in pathological states will ultrasound penetrate into the lung parenchyma due to the displacement of air with fluid or tissue. Therefore LUS relies heavily on artefacts for defining normal and pathological images, as opposed to other POCUS assessments where artefacts are

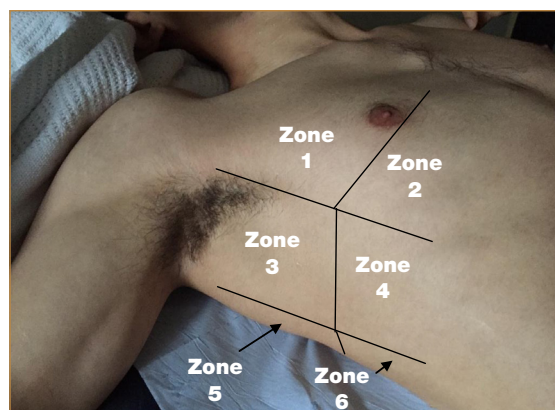


Figure 3. Typical locations for chest scanning

rarely useful. This can result in image interpretation being challenging for learners. Similar to soft tissue/air interfaces, soft tissue/bone also causes large reflections, hence ribs appear as an echogenic line with a shadow underneath.

The parietal pleura is fixed to the inner aspect of the thoracic cavity and the visceral pleura overlies the lung parenchyma. In normal states the visceral pleura slides against the fixed parietal pleura during the respiration cycle, termed lung sliding. Also, the space between the pleura is devoid of air and contains a small amount of fluid. Lung sliding gives the appearance of “shimmering” or “crawling ants” along the pleural line. Abnormal fluid in the pleural space (such as pleural effusions and blood) transmit ultrasound waves with minimal reflection thus appearing black (hypoechoic).

Most images are obtained using B (brightness) mode, with the aim of producing a two-dimensional representation of the anatomy under the transducer. M-mode produces an image based on ultrasound information from a cursor line against time – this cursor line appears on the B-mode image when M-mode is initially activated and its position can be manipulated. Normal

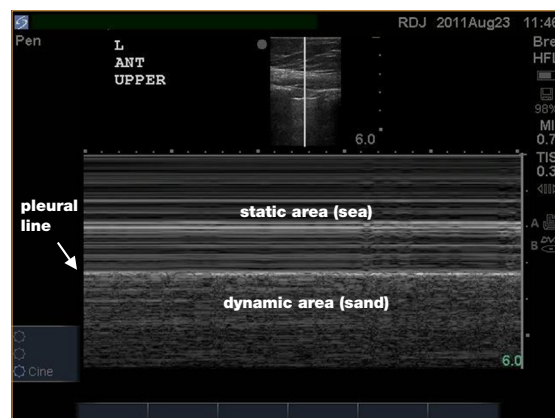


Figure 4. M-mode appearance (normal) - seashore sign

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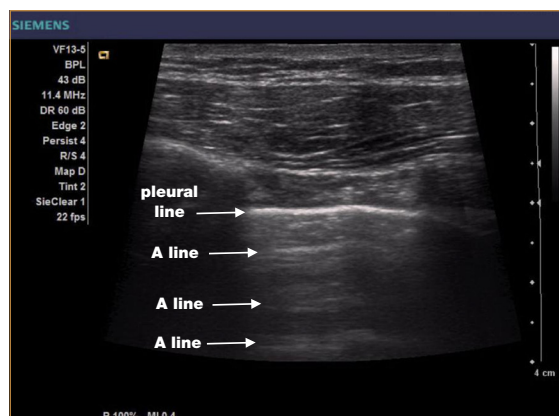


Figure 5. A-lines (normal and pneumothorax)



Figure 6. B-lines

appearances demonstrate a static appearance above the pleural line (reflecting the static nature of the superficial structures) and a dynamic appearance below the pleural line (a result of artefacts, Figure 4). In a pneumothorax (or cases where there is no pleural sliding) the M-mode appearance below the pleural line becomes more similar to above the pleural line.

Key artefacts used in LUS

A-lines

A lines are reverberation artefacts produced by reflections between the transducer footprint and other highly echogenic lines, such as the pleural line and intervening fascial planes. They appear as echogenic parallel white lines, which decrease in intensity with increasing depth (Figure 5). These are present in normal lung and in pneumothoraces as they indicate air is present below the pleura.¹¹ They are a frequently seen normal finding.

B lines

These are long, vertical hyperechoic (white) lines arising from the pleural line and move with pleural sliding as seen during normal respiration (Figure 6). They travel the full depth of the screen. B lines are thought to result from the excitation of ultrasound within air bubbles surrounded by fluid.¹² They do not fade and often increase in width with increasing distance from the pleura. They may be physiological in the lower posterior lung field due to the normal ventilation/perfusion mismatch (i.e. more perialveolar fluid in the bases) in around one quarter of normal lungs. B lines also occur pathologically when increased fluid occupies the interlobular or perialveolar space, e.g. fluid in the lung parenchyma, as found in cardiac or non-cardiac pulmonary oedema, lung contusions, fibrosis and infection. The B lines in pulmonary oedema may

be considered similarly to the Kerley B lines on the chest radiograph. Three or more seen within an intercostal space are pathological and termed B line pattern – they have also been termed lung rockets or comets tails. However, B-lines are not actually comet tail artefacts but ring-down artefacts – the former fades with depth. Ring down artefacts are often seen in other ultrasound examinations, especially when looking at areas where gas and fluid exist, e.g. gastrointestinal tract.

The term ‘interstitial syndrome’ is often used to describe pathological B lines patterns. The appearance of B lines in acute heart failure (AHF), acute respiratory distress syndrome (ARDS), pulmonary fibrosis and early pneumonia may appear similar. However, in AHF the B pattern is widespread with no spared areas whereas in ARDS and pneumonia there will be a more patchy distribution. In pneumonia, there is also reduced lung sliding due to sticky exudate and occasionally patchy subpleural thickening and subpleural fluid. In pulmonary fibrosis the B pattern may be more prominent in upper lobes and associated with thickened pleura.¹³ Adding LUS features of the B-lines to clinical assessment and blood tests all assist in reaching the right diagnosis. Severe oedema results in more B lines which become closer together and can show a confluent pattern in which the lines all fuse together – called the ‘white lung’.^{14, 15}

Other lines

True comet tail artefacts are small vertical lines (1–3 cm deep) that arise from the pleural line and fade away – they move with pleural sliding; Z-lines are similar but do not move with sliding. They are formed due to micro reverberation and are found in normal subjects with no associated pathological meaning. E lines are also a vertical micro reverberation artefact, but appear superficial to the pleura in the subcutaneous tissues and are due to surgical emphysema.

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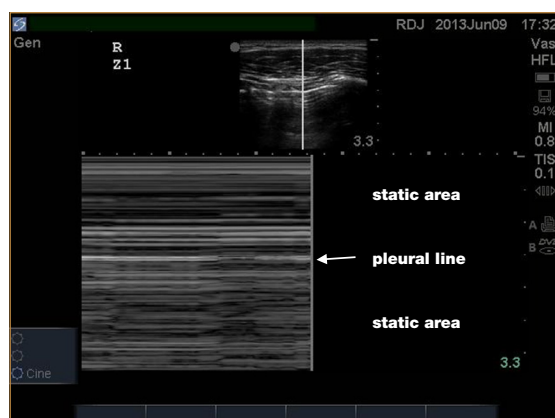


Figure 7. M-mode appearance (pneumothorax)

LUS in chest pathology

Pneumothorax

LUS has a higher sensitivity for detection of pneumothorax compared to Chest X-ray (CXR) against the reference standard of computed tomography. Unlike radiographs it is not altered by the patient being erect or supine at the time of imaging the chest and may be obtained in a shorter time. It is, particularly in the elderly, a rule out as opposed to rule in test due to high sensitivity. Early assessment for the presence of a pneumothorax is useful in many situations, such as ensuring patients are able to receive non-invasive ventilation. If lung sliding is observed, then pneumothorax is excluded at the point of interrogation. The probability of finding a small pneumothorax increases with the number of intercostal spaces investigated with the probe. Absence of lung sliding was reported as having a 100% negative predictive value and a 95% sensitivity in an intensive care setting.¹⁶ However, specificity is only 70 – 90% as anything which prevents lung movement may give similar appearances to pneumothorax with absent pleural sliding: breath holding, small tidal volumes, bullae, respiratory arrest, pleurodesis, unilateral intubation, or local fibrosis may all mimic pneumothorax. Consequently, specificity can be expected to be poorer in the elderly and those with chronic lung disease than younger, fitter patients. The “stratosphere sign” represents the stratified appearance seen above and below the pleura on M mode. In pneumothoraces, only the parietal pleura will be identified as the visceral pleura is not sliding against it, which gives the appearance of the pleural line being motionless.¹⁷ This results in pronounced A-lines being seen below the pleural line – a series of horizontal straight lines due to reflected sound from reverberation artefacts (Figure 7).

Pneumothorax is also ruled out if a lung pulse is seen. This is due to transmission of cardiac activity

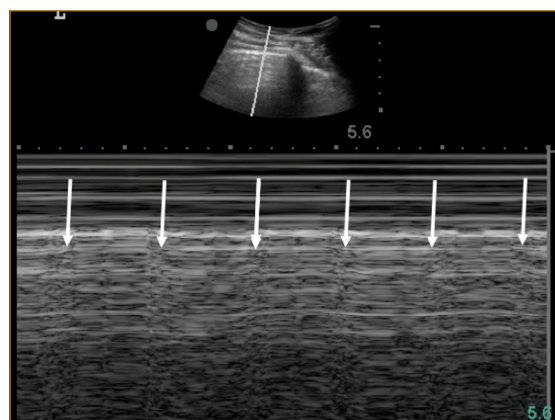


Figure 8. M-mode appearance (lung pulse)

through motionless/almost motionless lung to the pleura and can appear as vertical peaks on M mode (Figure 8). The lung pulse requires cardiac pulsation to be transmitted through lung parenchyma to the pleural line and so a pneumothorax cannot be present.

The only way to definitively diagnose pneumothorax with LUS is to observe the lung point, which is the point at which the visceral and parietal pleura separate so demonstrating both pleural sliding and its absence in the same screen; it moves with respiration (Figure 9).^{17, 18} Lung points have a sensitivity of 66% because in large pneumothoraces there is very little contact between visceral and parietal pleura but are highly specific for pneumothorax.¹⁷

As A lines originate from the parietal pleura they are prominent in pneumothoraces. B lines originate from gas and fluid in the peripheral lung parenchyma, adjacent to the visceral pleura, and are therefore not seen in pneumothoraces.¹⁹

Pneumonia

Chest radiograph (CXR) is the first line recommended investigation for suspected pneumonia. However, there are limitations to CXR, varying interpretation



Figure 9. Lung point (M-mode)

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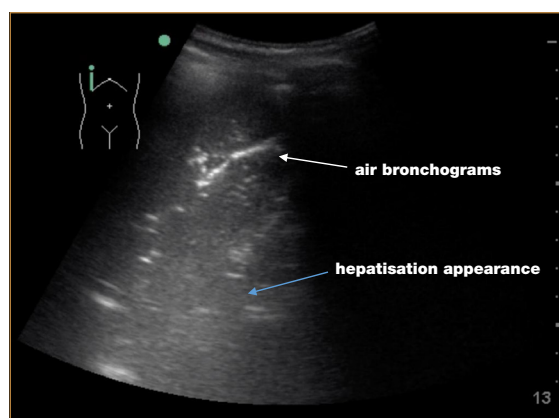


Figure 10. Air bronchograms and hepatisation

due to inter-observer variability and patient/environment related factors leading to suboptimal images. A recent study of 105 patients, 68 with pneumonia, reported a sensitivity of /specificity of 99%/65% for LUS and 77%/60% for CXR.²⁰ LUS can only detect peripheral consolidation that abuts the pleural interface.²¹ Ticinesi et al, showed that LUS was superior in detecting pneumonia compared to CXR in patients admitted to an acute geriatric ward.²² A 2016 systematic review and meta-analysis including 16 studies and 2359 patients reported LUS to have a sensitivity of 80-90% and specificity of 70-90% with an area under the curve (AUC) of 0.93 on a Receiver Operating Characteristic (ROC) plot.²³ Reference standards varied but most commonly were discharge diagnosis as opposed to computed tomography, which would be the gold standard for identifying consolidation.

There are a range of different sonographic features suggesting pneumonia: from focal (asymmetrical) B lines over the infected area (see above), pleural thickening with small subpleural fluid to consolidated lung and associated pleural effusions. Consolidated and collapsed lung (atelectasis) are non-aerated, with ultrasound appearances similar to those of solid organs, such as liver, hence the term 'hepatisation' is used and this is most frequently noted at the bases of the lungs. The border of normal lung to consolidated areas is irregular and termed the 'shred sign' – relevant in subpleural as opposed to translobar types.

In consolidation, there is usually patency of the larger airways which allow the movement of air during the respiratory cycle. Air within hepatised lung appears as echogenic (white) branching tree like structures (Figure 10). If they increase in size or move with respiration, they are termed dynamic air bronchograms and are considered pathognomonic for pneumonia. If such air bronchograms do not appear to change size or move with respiration they are termed static air bronchograms – these

are observed in both pneumonia and in atelectasis. In atelectasis, and to some degree pneumonia, airways into the hepatised lung are not patent due to blockage (e.g. mucus plug), hence the lack of change in the appearance of the air bronchogram with the respiratory cycle.

It is difficult to differentiate between consolidation as a consequence of infarction as opposed to infection but the former usually involves a smoother pleura as different from the 'shred' sign with a thickened irregular pleura.

Lung abscesses appear as fluid or fluid/air filled collections within consolidated tissue.

Interstitial syndrome

This describes the pattern of pathological B lines (defined as ≥ 3 in any field) and may be caused by AHF, ARDS, lung fibrosis or interstitial pneumonia/pneumonitis. The key LUS finding for the diagnosis of AHF is the presence of bilateral B lines. In severe cases, most windows, including upper zones, will be affected and the number of B-lines within an intercostal space will be increased; this may result in a 'white lung' appearance. With successful treatment, a reduction on the number of B-lines is expected, hence, LUS can guide therapy and be used in a serial manner. A lines are not seen when B-lines are predominant.

CXR and clinical examination are known to have poor sensitivity for detection of interstitial oedema. A recent meta-analysis reported LUS to have a sensitivity of 82.5% and specificity of 83.6% with a positive LR of 6 and negative LR of 0.13.²⁴ A second meta-analysis of 6 cohort studies included 1827 patients with a pooled estimate for sensitivity of 0.88 (95% CI 0.75 – 0.95) and specificity of 0.90 (95% CI 0.88 – 0.92) compared to a sensitivity of 0.73 (95% CI 0.70 – 0.76) and specificity 0.90 (CI 0.70 – 0.76) for CXR.²⁵ An Italian study found that LUS added to the accuracy of clinical assessment in diagnosing AHF while CXR and BNP did not (AUC 0.95 for clinical assessment and LUS vs 0.88 for clinical assessment alone).²⁶ This equated to a reduction in diagnostic error of 8/100 patients.

The addition of focused echo to assess for systolic or diastolic dysfunction with LUS increases the specificity for the diagnosis of pulmonary oedema. Russell and Ehrman found that a modified lung and cardiac ultrasound protocol had a 100% specificity for a diagnosis of acute decompensated heart failure.²⁷

A negative to any assessment in the acutely dyspnoeic patient is the time taken to perform the study. However, evidence would suggest that LUS can be performed in a timely manner, with a high inter-relator reliability, resulting in appropriate treatment (such as nitrates and diuresis) being

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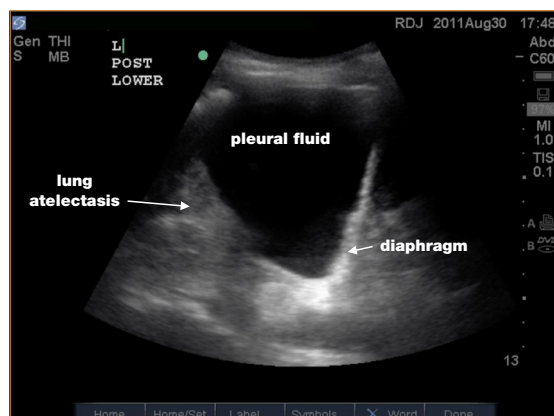


Figure 11. Pleural effusion and adjacent atelectased lung

initiated immediately instead of waiting for other investigations such as a CXR or BNP (brain natriuretic peptide).²⁸

Pleural Effusion

Pleural effusions appear as anechoic/hypoechoic (black) areas and are seen in locations where ultrasound would not normally penetrate the visceral pleura due to the high aeration of normal lung. In large effusions, adjacent lung will be experiencing atelectasis and be visible and vertebral bodies may be also be seen, known as the V or vertebral or spine sign (Figure 11). LUS is highly sensitive (> 90%) and specific (90 – 100% for pleural effusion, depending on study population), outperforming plain radiographs against the reference standard of computed tomography (sensitivity 92% compared to 39% respectively).²⁹ CXR can only visualize effusion if the volume is greater than 200ml in patients in an orthostatic position while LUS may identify effusions of 25–50 ml.^{30,31} Sensitivity is increased by the patient sitting supine so allowing fluid to collect in the dependent regions.

Small effusions may be visualised between the area bordered by rib shadows to the side and visceral/

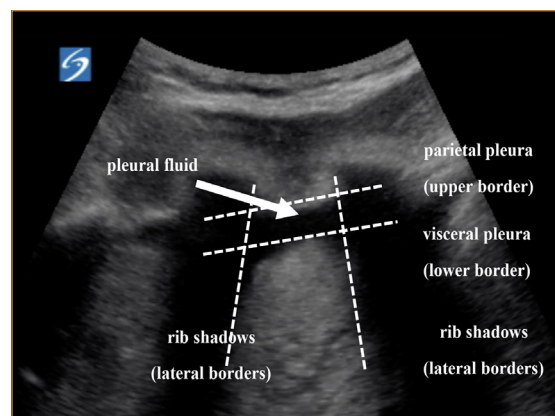


Figure 12. Quad sign

parietal pleura above and below – termed the quad sign (Figure 12). On occasions, the appearance of internal mammary vessels or pleural thickening may look like a small effusion (Figure 13), however, fluid moves dynamically during the respiratory cycle. This can be demonstrated on M mode as the lung parenchyma moves into and out of the effusion with respiration – the ‘sinusoidal sign’ (Figure 14).

Unlike CXR, LUS can provide information on the aetiology of the effusion. Anechoic effusions are more likely to be transudates. Those containing echogenic material are more likely to be exudates or haemothoraces with components of clotted blood. In cases of subpleural consolidation, this may also appear as a hypoechoic area, however, unlike a pleural effusion, the lower border to this area is irregular – the ‘shred sign’ (Figure 15).

It is important to look for other signs that may suggest the aetiology of the effusion. For example, bilateral pleural effusions with an associated bilateral B pattern, a dilated inferior vena cava and hepatic veins suggest cardiac failure while a parapneumonic effusion is suggested by the presence of consolidation with dynamic air bronchograms and focal B lines.



Figure 13. Internal mammary vessel not to be confused with a small pleural effusion



Figure 14. Sinusoidal sign

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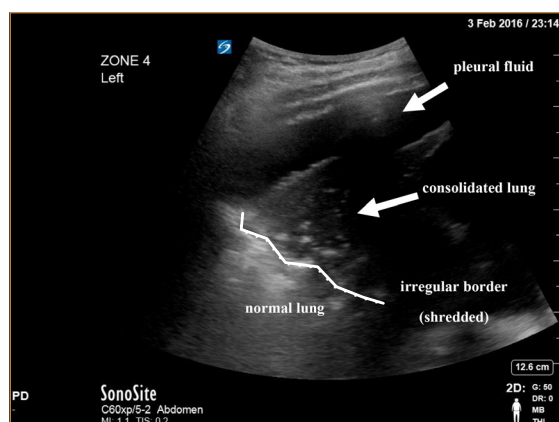


Figure 15. Shred sign

For ultrasound guided therapeutic procedures

Thoraco-centesis

LUS increases the success rate of thoracentesis from a landmark technique-based failure rate of around one third to around zero. The rate of procedure related pneumothorax is reduced from 10–20% to < 5%.^{32–34} The procedure can either be done in real time using US during needle insertion, or marking a spot using US and inserting the needle immediately after this. With the latter approach, the patient's position needs to be maintained as fluid is dependant and may change location, increasing the risk of injury. Using the former approach allows the operator to observe the movement of the diaphragm during respiration, potentially reducing the risk of iatrogenic injury. LUS ensures minimising the risk of visceral injury to nearby organs (lung, liver, heart, spleen) as well as allowing the operator to identify where most of the fluid is and the best angle for insertion. As

with central venous line insertion, US is useful for noting the correct position of the guidewire before continuing with the procedure.^{35–37}

Nakitende et al found that emergency residents, following an educational session, were able to confirm thoracostomy tube placement using US with good accuracy in a cadaveric model.³⁸ This is important, as studies have shown 2.6% of thoracostomy tubes are inserted in the subcutaneous tissue.^{39–41}

Conclusion

LUS is easy to perform and has both a diagnostic and procedural role in acute medicine. It has superior performance to CXR in diagnosing AHF, pneumonia and pleural effusions, and offers more rapid diagnosis. Its uptake needs to involve high quality teaching, mentors and an adequate governance structure. Indeed, many acute physicians currently use LUS for thoracocentesis, extension of this skill set to learn other thoracic compartment pathology is an achievable goal.

Abbreviations

AHF – acute heart failure
ARDS – adult respiratory distress syndrome
AUC – area under the curve on a Receiver Operating Characteristic (ROC) plot
BNP – B-type natriuretic peptide
CXR – Chest X ray
LUS – Lung ultrasound
POCUS – Point-of-care ultrasound
ROC – Receiver Operating Characteristic plot
US – Ultrasound

Conflicts of Interest

The authors have no conflicts of interest to declare

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