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REVIEW ARTICLES

# Is thoracic ultrasound a viable alternative to conventional imaging in the critical care setting?

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## Editor's key points

- There is growing enthusiasm for using ultrasound in critical care.
- This review provides evidence for the usefulness of thoracic ultrasound in critical care.
- In expert hands, ultrasound is accurate in diagnosing pleural effusions, consolidation, and pneumothorax.
- Further research is required to explore its usefulness in diagnosing other chest conditions.

**Summary.** Thoracic imaging is regularly performed on the majority of critical care patients. Conventionally, this uses a combination of plain radiography and computed tomography. There is growing enthusiasm for the use of ultrasound to replace much of this radiology and provide more immediate, point-of-care imaging with reduction in patient transfers, ionizing radiation exposure and cost. This article explores the diagnostic performance of thoracic ultrasound in the imaging of pleural effusion, consolidation, extra-vascular lung water (EVLW), and pneumothorax. Current evidence suggests that, in expert hands, thoracic ultrasonography has similar diagnostic accuracy to computed tomography in pleural effusion, consolidation and pneumothorax. The technique also has potential to identify the cause of increased EVLW and accurately quantify pleural effusions. More large-scale studies are required in these areas however. Ultrasonography outperforms bedside chest radiography in all cases.

**Keywords:** equipment, thoracic ultrasound; imaging; intensive care; lung; pulmonary oedema

Imaging of the chest is performed on the majority of critical care patients. It relies heavily on portable plain chest X-ray (CXR) (which has problems with the technical quality of images obtainable in this setting) and, to a lesser extent, computed tomography (CT).[1–5] Both rely on ionizing radiation and the time and resources of another department.

Ultrasound is already in common use within critical care, typically to guide central venous access.[6–8] Other applications such as echocardiography and abdominal scanning in trauma are also finding their way into everyday practice.[9–17] Advocates of thoracic ultrasound suggest that the majority of important pathology can be detected with relative ease, speed, and greater reliability when compared with plain radiography. It also spares ionizing radiation exposure and, in the case of CT, potentially hazardous transfer of the patient to the radiology suite.[18 19] There is also the potential for a considerable cost saving.[1 20] Despite these factors, thoracic ultrasound is not currently in widespread use within the critical care setting except in the detection of pleural effusion.[21]

As air-filled tissues such as the lung do not return ultrasound signals well, expert radiological opinion has dismissed this as a useful application of the technology.[22] However, interpretation of various indirect ultrasound artifacts generated by aerated tissue is being suggested as a means by which to image the intrathoracic contents. The aim of this review is to explore the diagnostic performance of using these artifacts to characterize key intrathoracic pathology in the critical care population and, by extension, determine if it can replace conventional imaging.

## Literature review methodology

The Medline and EMBASE databases were searched seeking relevant articles in human subjects, written in the English language and published between 1995 and February 2012. Search terms included thoracic, chest, lung, ultrasound or ultrasonography, and critical or intensive care and those specific to particular pathologies, e.g. pneumothorax. The Cochrane Database of Systematic Reviews and International Standard Randomized Controlled Trial Number Register were also searched.

This initial search strategy revealed 825 articles. By review of titles and abstracts, duplicates, and non-relevant studies were removed leaving an initial 88 articles of potential relevance. These included 51 observational studies and 37 reviews, editorials and commentaries. These were refined by review of complete articles. Further relevant work was identified from the reference lists of the principal articles. There were no randomized controlled trials or relevant Cochrane reviews. Due to the relative paucity of evidence, a number of conference abstracts found in the primary search were, with caution, retained in the final literature pool.

## Review

Focusing on common diagnoses which require repeated imaging to diagnose and monitor treatment allows the greatest reduction in CXR/CT to be realized from a switch to ultrasonography. This strategy should also maximize reliability of the examination by allowing critical care ultrasonography (CCUS) practitioners to focus their practice on a few common pathologies. Those suggested to fit these criteria are as follows:[23]

- Pleural effusion,
- Consolidation,
- Pulmonary oedema/extravascular lung water, and
- Pneumothorax.

In all the studies discussed, the ultrasonography was performed by physicians who were described explicitly or implicitly as having training and experience in the skill. However, a lack of an agreed credentialing system makes direct comparisons of operator skill between studies difficult.

### Pleural effusion

This is the typical indication for thoracic ultrasonography and has the potential ability to identify, as well as characterize, quantify, and guide the drainage of fluid.[24 25] Studies have focused either on the ability to detect effusions or the ability to quantify the fluid volume.

Several well-conducted studies have compared the ability of CCUS to detect effusions against that of CXR, using CT as a reference standard.[1 26 27] All demonstrated high sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy (DA) for CCUS whereas CXR was notably weaker, particularly in terms of sensitivity, NPV and DA (Table 1). Chest auscultation alone seems slightly superior to CXR.[1] Overall, this body of evidence suffers from a degree of heterogeneity as some restricted patient selection to those with a pre-existing diagnosis of ARDS or thoracic trauma.[1 27]

Further studies have investigated attempts to determine effusion volume and the need for insertion of a drain, evaluating performance against actual drained volume (Table 2). One involved volumetric modelling by scanning and measurement of the effusion in several planes.[28] This method compared well with similar models constructed with CT scans but from a practical point of view is complex.

Other investigators have used a more simple approach determining the value of a single measurement which would predict an effusion of a certain volume.[29–32] This has the potential to guide clinical decision making as to whether to insert a drain or not. One group using such a method also demonstrated the clinical effectiveness of this cut-off; Roch and colleagues[29] investigated the depth of effusion beneath the lung base as a means to predict a drained volume greater than or less than 500 ml and demonstrated a moderate correlation ($r$=0.5, $P$<0.01) between volume drained and improvement in $Pa_{O_2} : F_{I_{O_2}}$ ratio over the following 12 h for those patients with >500 ml drained. In this particular study however, only 20 of the 44 patients included had effusions >500 ml on which the principal study conclusions were founded.

Of note, asymmetry in CCUS performance with left-sided estimation consistently performing slightly worse has been noted in these studies.[30 31] The authors[31] suggest the presence of the heart in the left chest accounts for this and the greater interobserver variability seen in measurements of the left hemithorax. Meanwhile, differing levels of PEEP appear to have no significant effect on these models although, to date, this has only been determined through *post hoc* analysis. Parallel analysis of CXR performance produced disappointing results with moderate sensitivity and poor specificity.[31]

In summary, CCUS can reliably identify simple effusions and should be the method of choice over CXR. There is also compelling evidence that accurate and clinically useful estimations of effusion volume may also be derived by CCUS. Further studies of one single, simple method of volume estimation would add valuable homogeneity to the evidence.

**Table 1** Pleural effusion, qualitative studies. Drained Vol, drained volume; NPV, negative predictive value; PPV, positive predictive value; DA, diagnostic accuracy. *n/N* =number affected/number in study; **n/N* in terms of lung regions or hemithoraces rather than patients

| Paper | Reference test | Modality/comparison | *n/N* | Sensitivity | Specificity | PPV | NPV | DA |
|---|---|---|---|---|---|---|---|---|
| Xirouchaki[26] | CT | CCUS | 63/84* | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | | CXR | | 65.1 | 81.0 | 91.1 | 43.6 | 69.0 |
| Rocco[27] | CT | CCUS—post-drain | 38/180* | 92.0 | 95.0 | – | – | 94.0 |
| | | CCUS—48 h post-drain | 33/180* | 94.0 | 99.0 | – | – | 98.0 |
| | | CXR—post-drain | | 23.0 | 94.0 | – | – | 81.0 |
| | | CXR—48 h post-drain | | 42.0 | 97.0 | – | – | 87.0 |
| Vignon[30] | Drained Vol >800 ml | CCUS-right | 49/97 | 94.0 | 76.0 | – | – | – |
| | | CCUS-left | | 100.0 | 67.0 | – | – | – |
| | | CXR | | 75.6 | 50.9 | 67.8 | 60.4 | 90.7 |
| Roch[29] | Drained Vol >500 ml | CCUS | 20/44 | 83.0 | 90.0 | 91.0 | 82.0 | 86.0 |
| Lichtenstein[1] | CT | CCUS | 100/384* | 92.0 | 93.0 | – | – | 93.0 |
| | | CXR | | 39.0 | 85.0 | – | – | 47.0 |
| | | Auscultation | | 42.0 | 90.0 | – | – | 61.0 |

**Table 2** Pleural effusion, quantitative studies. Drained Vol, drained volume of effusion; CT Vol, CT-estimated volume of effusion; NPV, negative predictive value; PPV, positive predictive value; DA, diagnostic accuracy. *n/N*=number affected/number in study; **n/N* in terms of lung regions or hemithoraces rather than patients

| Paper | Reference test | Modality/comparison | *n/N* | AUC | *R* | $r^2$ |
|---|---|---|---|---|---|---|
| Vignon[30] | Drained Vol (Model group) | CCUS-right | 49/97 | 0.99 | 0.88 | – |
| | | CCUS-left | | 0.70 (*P*=0.003) | 0.72 | – |
| | Drained Vol (validation group) | CCUS-right | 25/19 | – | – | 0.78 |
| | | CCUS-left | | – | – | 0.51 (*P*<0.0001) |
| Balik[31] | Drained Vol | CCUS | 81/81 | – | 0.72 | 0.52 |
| | | CCUS-right | 44 | – | 0.71 | – |
| | | CCUS-left | 37 | – | 0.74 (*P*=0.46) | – |
| Remerand[28] | Drained Vol | CCUS | 102/102* | – | 0.84 | – |
| | CT Vol | CCUS | 43 | – | 0.90 | – |
| | Drained Vol | CT vol | 43 | – | 0.96 | – |
| | CT Vol | CCUS-right | 54 | – | 0.85 | – |
| | | CCUS-left | 48 | – | 0.94 (*P*<0.001) | – |
| | Drained Vol | CCUS-right | 54 | – | 0.82 | – |
| | | CCUS-left | 48 | – | 0.88 (*P*<0.001) | – |
| Roch[29] | Drained Vol | CCUS | 20/44 | – | 0.68 | – |

## Consolidation and atelectasis

Ultrasonography of the lungs and pleura relies on observing several characteristic image artifacts arising due to the ratio of fluid and air along the ultrasound beam and any boundaries between regions of one air/fluid ratio and another.[22] Pneumothorax lies at one extreme and pleural effusion the other. Between these two exists a continuum of ratios characterizing different pathologies.

While alveolar oedema, interstitial oedema, and consolidation may sometimes be difficult to distinguish on CXR, it is possible to delineate them by ultrasonography. CCUS exploits the pathophysiological differences between these processes to separate and identify them.[33] Septal oedema is driven by a transudative process resulting from elevated hydrostatic pressure. Normal pleural movement ('lung sliding' on CCUS—cyclical to-and-fro movement at the pleural interface) is preserved with no inflammatory process to form pleural adhesions and signs of interlobar oedema are found in non-dependent lung regions (hydrostatic pressure overcoming gravity). In contrast, pneumonia is an exudative process resulting often in a loss of lung sliding and interlobular oedema in any affected lung region with less uniformity.

The evidence in this field is largely from Lichtenstein and colleagues[20] and in some respects, a lack of reproduction of this work by other groups is a notable deficiency in the current literature. This group has investigated a range of ultrasound features indicative of consolidation including the 'lung pulse' as an indicator of proximal bronchial obstruction (M-mode illustrating a lack of lung motion other than transmitted cardiac pulsation through consolidated lung), 'lung hepatization' (a description of consolidated lung resembling the echo-density of the liver) (Fig. 1) and the lung shred sign (a distinct margin between normal and consolidated lung).[34] All these features demonstrated comparable diagnostic performance to CT with considerable time savings involved. However, as alluded to, there is only one other group which has repeated this work (using hepatization and the lung shred sign) but, encouragingly, it demonstrated comparable results.[26] Very posterior regions of consolidation or those deep within the lung parenchyma produced some false-negatives when using lung hepatization but sensitivity was still only slightly reduced.

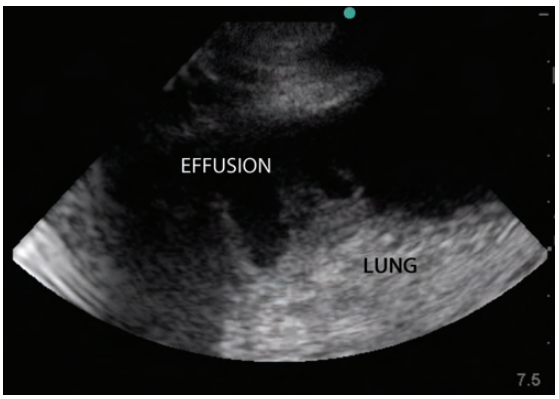


**Fig 1** Pleural effusion with consolidated lung beneath. The lung is visible as soft tissue, similar to that of liver demonstrating 'hepatization'. Bright, punctiform areas within this denote air bronchograms.

Lichtenstein and colleagues[33] also produced one notable study describing a protocol for applying CCUS in the differential diagnosis of acute dyspnoea—the BLUE (Bedside Lung Ultrasound in Emergency) protocol. This investigated the performance of four combinations of CCUS features against standard clinical and radiographic diagnoses and to some extent combines some of the features described in their other work. Individually, the sensitivity of each profile was low and highly variable but with a high specificity (Table 3). In combination however, the sensitivity improved significantly

**Table 3** Alveolar consolidation studies. FOB, fibre-optic bronchoscopy; BAL, bronchial-alveolar lavage; NPV, negative predictive value; PPV, positive predictive value; DA, diagnostic accuracy. A profile, A-lines and normal lung-sliding; B′ profile, B-lines with absent lung sliding; A/B profile, predominant A-lines one side with B-lines on the other side; C profile, anterior alveolar consolidations; PLAPS, posterior and/or lateral and/or pleural syndrome point. *n*/*N*=number affected/number in study; **n*/*N* in terms of lung regions or hemithoraces rather than patients

| Paper | Reference test | Modality/ comparison | *n*/*N* | Sensitivity | Specificity | PPV | NPV | DA | Notes |
|---|---|---|---|---|---|---|---|---|---|
| Xirouchaki[26] | CT | CCUS | 66/84* | 100.0 | 77.8 | 94.3 | 100.0 | 95.2 | |
| | | CXR | | 37.9 | 88.9 | 92.6 | 28.1 | 48.8 | |
| Lichtenstein[33] | CT | CCUS | 65/118* | 90.8 | 98.1 | 98.3 | 89.5 | 94.0 | |
| Lichtenstein[20] | CXR | CCUS | 15/60 | 93.3 | 100.0 | 93.3 | 100.0 | 98.3 | |
| Lichtenstein[34] | Clinical diagnosis and CXR/CT | CCUS | 83/260 | 10.8 | 100.0 | 100.0 | 70.5 | 66.4 | B′ profile |
| | | | | 14.5 | 100.0 | 100.0 | 71.5 | 67.5 | A/B profile |
| | | | | 21.5 | 98.9 | 90.0 | 72.9 | 68.9 | C profile |
| | | | | 42.2 | 96.0 | 83.3 | 78.0 | 73.2 | A plus PLAPS |
| | | | | 89.2 | 94.4 | 88.1 | 94.9 | 86.1 | A plus PLAP/B′/(A/B)/C |
| Lichtenstein[1] | CT | CCUS | 119/384* | 93.0 | 100.0 | – | – | 97.0 | |
| | | CXR | | 68.0 | 95.0 | – | – | 75.0 | |
| | | Auscultation | | 8.0 | 100.0 | – | – | 36.0 | |

and this became a very accurate assessment. The difficulty with this methodology lies in the complexity of the ultrasonography and to work as a pragmatic modality, further work should focus on proving the performance of a simple sign such as hepatization.

In summary, lung CCUS out-performs CXR in accurate detection of consolidation and may have a role in determination of the aetiology. Small posterior consolidations or those not contacting the pleural surface may however be missed. Work from other groups, particularly around simple CCUS signs are required to reinforce the evidence base.

## Extra-vascular lung water

Infiltration of the pulmonary-alveolar-interstitial space has two distinct and important causes—inflammatory processes including ARDS which induce capillary leak and hydrostatic oedematous processes including acute cardiogenic pulmonary oedema.[35] Differentiation of these on CT is well described but accuracy of CXR is unclear as this modality has poor ability to delineate the cause or location of excess EVLW.[19] Understanding of the pathological distribution of the ARDS process throughout the lungs, gained from CT studies, has helped here by determining it to be a non-uniform process.[36] Meanwhile the Berlin definition of ARDS allows for the fact that it may, to a degree, coexist with cardiogenic oedema; the definition requiring pulmonary oedema 'not fully explained' by cardiac causes, or systemic fluid overload.[37] Therefore, there is perhaps an emerging role for CCUS to assist in the diagnosis of ARDS. The typical sign used in this context is the B-line or ULC (Ultrasound Lung Comet), both synonymous for divergent, white, ray-like projections from the pleural line (bright echo of parietal pleura) to the very bottom edge of the CCUS image (Fig. 2). They represent a reverberation artifact through oedematous interlobular septa within the lung.[38] To be present, the parietal and visceral pleura must be well applied and so their presence is also useful in exclusion of pneumothorax.

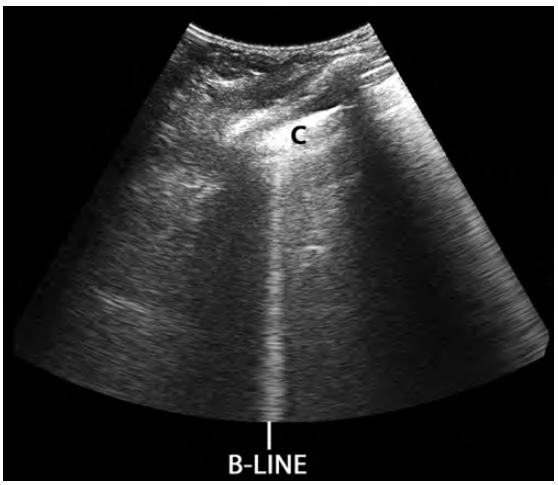


**Fig 2** B-line or ultrasound lung comet projecting down from the pleura and a small area of sub-pleural consolidation (C).

Studies have demonstrated a link between B-lines and surrogate markers of pulmonary oedema including alveolar-interstitial syndrome (AIS),[1 26] pulmonary artery wedge pressure (PAWP)[39 40] and EVLW[39 41] (Table 4). CCUS has also been shown to perform well in diagnosing cardiogenic pulmonary oedema when compared with echocardiography and functional cardiac testing.[33] There is however, no focus on any one of these modality comparisons across more than one or two studies resulting in a significantly heterogeneous evidence base. Furthermore, some of these studies are indirectly conflicting; CCUS has been shown in some studies to be comparable or superior to CXR in the diagnosis of alveolar interstitial syndrome.[1 26] Elsewhere however, AIS itself has

**Table 4** EVLW studies. EVLW, extra-vascular lung water; PAWP, pulmonary artery wedge pressure; CPCA, continuous pulse contour analysis; AIS, alveolar interstitial syndrome; NPV, negative predictive value; PPV, positive predictive value; DA, diagnostic accuracy. *n*/*N*=number affected/number in study; **n*/*N* in terms of lung regions or hemithoraces rather than patients

| Paper | Reference test | Modality/ comparison | *n*/*N* | Sensitivity | Specificity | PPV | NPV | DA | *r* |
|---|---|---|---|---|---|---|---|---|---|
| Lichtenstein[33] | Echo, functional cardiac tests & standard clinical examination | CCUS | 64/260 | 96.9 | 95.4 | 93.7 | 98.9 | 88.9 | – |
| Xirouchaki[26] | CT | CCUS | 54/84* | 94.4 | 93.3 | 96.2 | 90.3 | 94.0 | – |
| | | CXR | | 46.3 | 80.0 | 80.6 | 45.3 | 58.3 | – |
| Copetti[35] | Pulmonary oedema group (echo, CXR diagnosis) | AIS | 18/58 | 100.0 | 0.0 | – | – | – | – |
| | | Pleural abnormality | | 100.0 | 45.0 | – | – | – | – |
| | | Altered sliding | | 100.0 | 100.0 | – | – | – | – |
| | | Spared areas | | 100.0 | 100.0 | – | – | – | – |
| | | Consolidations | | 83.3 | 100.0 | – | – | – | – |
| | | Effusion | | 66.6 | 5.0 | – | – | – | – |
| | | Lung pulse | | 50.0 | 100.0 | – | – | – | – |
| | ARDS group (1994 definition) | AIS | 40/58 | 100.0 | 0.0 | – | – | – | – |
| | | Pleural abnormality | | 25.0 | 0.0 | – | – | – | – |
| | | Altered sliding | | 0.0 | 0.0 | – | – | – | – |
| | | Spared areas | | 0.0 | 0.0 | – | – | – | – |
| | | Consolidations | | 0.0 | 0.0 | – | – | – | – |
| | | Effusion | | 95.0 | 33.3 | – | – | – | – |
| | | Lung pulse | | 0.0 | 50.0 | – | – | – | – |
| Agricola[39] | EVLW | CCUS | 20/20 | 90.0 | 86.0 | – | – | – | 0.42 ($P$=0.001) |
| | PAWP | | | – | – | – | – | – | 0.48 ($P$<0.0001) |
| | CXR | | | – | – | – | – | – | 0.60 ($P$<0.0001) |
| Jambrik[41] | CPCA | CCUS | 13/13 | – | – | – | – | – | 0.67 ($P$=0.01) |
| Lichtenstein[40] | PAWP<13 | CCUS—A profile | 102/102 | 90.0 | 67.0 | 91.0 | 65.0 | – | – |
| | PAWP<18 | CCUS—A profile | | 93.0 | 50.0 | 97.0 | 24.0 | – | – |
| Lichtenstein[42] | CXR diffuse AIS | CCUS | 121/250 | 93.4 | 93.0 | – | – | – | – |
| | CXR local AIS | | | 79.3 | 65.5 | – | – | – | – |
| | CXR all AIS | | | 92.6 | 65.1 | 71.3 | 90.3 | 78.4 | – |
| Lichtenstein[1] | CT | CCUS | 184/384* | 98.0 | 88.0 | – | – | 95.0 | – |
| | | CXR | | 60.0 | 100.0 | – | – | 72.0 | – |
| | | Auscultation | | 34.0 | 90.0 | – | – | 55.0 | – |

been revealed as a very non-specific sign in its own right unless combined with a number of other CCUS features such as reduced lung sliding, pleural abnormalities and sub-pleural consolidation.[33] Several studies also used CXR as an element of the reference standard whilst the literature elsewhere demonstrates the fallibility of this modality.[35 39 42]

A predominance of A-lines on CCUS has been correlated to PAWP.[40] A-lines are horizontal lines with a regular vertical spacing down the image and are the normal reverberation artifact of the pleural line on CCUS (Fig. 3). In the presence of lung sliding, they define the CCUS appearance of normal, non-oedematous lung.[22] By definition, a B-line will result in loss of all A-lines within the CCUS scan-field making these a simple, mutually-exclusive finding. A predominance of fields across the chest demonstrating A-lines was found to have a high sensitivity for PAWP<18 mm Hg. The specificity at this threshold was low but improved for a lower PAWP threshold of <13 mm Hg. However, the same group has also demonstrated that B-lines can be a normal finding in the peri-diaphragmatic regions in healthy individuals.[34 38] This clearly has implications for the specificity of this sign when taken in isolation.

By contrast, a study evaluating the B-profile (B-lines with preserved lung sliding) in the context of pulmonary oedema was considerably more promising.[33] Therefore, there seems to be a significant difference between detecting the B-profile as in this case and simply detecting B-lines (with no consideration of lung sliding).

In summary, the differentiation of pulmonary oedema from pneumonia is possible but simple diagnosis of AIS alone is not sufficient. Further work is required but it would seem there is potential for ultrasound to exclude a cardiac cause of pulmonary oedema if the B-profile is absent. The evidence in this field is particularly heterogeneous and in

some cases suffers from the use of CXR-based reference standards.

## Pneumothorax

Pneumothorax has been considered as a particularly valuable application of ultrasonography and there are compelling studies of detection of post-pleural biopsy pneumothorax outside the critical care literature.[43 44] The diagnosis on CCUS is defined by an absence of B-lines and lung sliding and the presence of A-lines. M-mode images will also reveal the 'stratosphere' sign (parallel lines due to the air gap ablating the ability to detect any movement deep to the pneumothorax) (Fig. 4) in place of the 'seashore' sign (parallel lines for unmoving chest wall tissues above a granular pattern depicting moving lung) (Fig. 5). Lung sliding can only occur when both parietal and viscera pleura are in contact. In the case of absent lung sliding, A-lines distinguish between pneumothorax and effusion (being absent in the latter). Pleural adhesions may also ablate lung sliding but in this instance, other signs of lung pathology such as consolidation or B-lines denoting oedema would be expected.

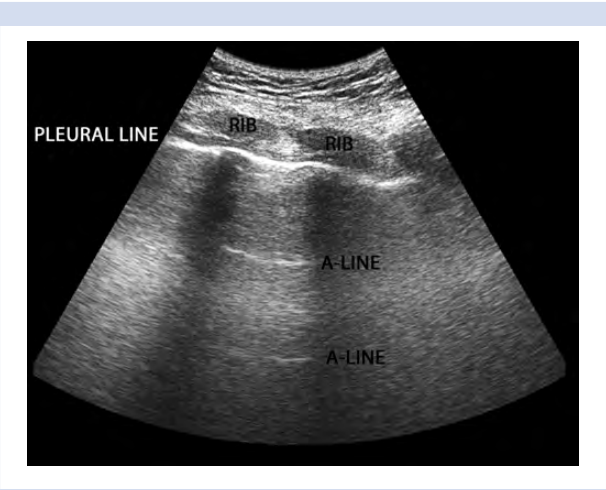


**Fig 3** Normal lung. Ribs give rise to dark, hypo-echoic rib-shadows projecting down the image.

The largest current study of pneumothoraces in critical care patients (44 pneumothoraces) excluded ventilated patients on grounds of reduction in ultrasound sensitivity for pneumothorax in such individuals—an anomaly not discussed elsewhere.[45] The particular focus was monitoring resolution or recurrence of pneumothorax but this makes it unique within the literature. The study did demonstrate the time benefits in reaching a diagnosis with ultrasound over CXR [35 min (34 min) *vs.* 71 min (56 min), $P<0.0001$].

The next largest study was conducted amongst critical care trauma victims.[46] Although only available in abstract with limited methodological information, this group demonstrated a very high sensitivity and strong correlation to CT findings ($r=0.9$). Other moderate sized studies have investigated pneumothoraces using similar methodology: blinded ultrasound operators imaging polytrauma victims who also underwent CXR and CT.[47–49] In all cases, CCUS outperformed CXR against reference CT findings (Table 5).

There are only two studies currently available which examined unselected critical care patients.[26 33] Both of these studies highlight the potential difficulty of prospectively recruiting patients with what is a relatively uncommon diagnosis—a total of 17 patients affected in 302 studied individuals. The limited data did however reflect the promising performance of CCUS noted elsewhere.

False-negatives were rare in all studies and where this did occur, the missed pneumothoraces were reported to be invariably small and clinically insignificant even in ventilated patients. False-positives (usually attributed either to pleural tethering ablating normal lung sliding or surgical emphysema) were even less common.

In summary, CCUS has the potential to replace CXR in the diagnosis and monitoring of pneumothorax. Whilst there are limited data available, there is a consensus that CCUS is at least comparable and probably superior to CXR for this diagnosis when compared with CT findings. Greatest data and methodological homogeneity exist among studies of

**Table 5** Pneumothorax studies. NPV, negative predictive value; PPV, positive predictive value; DA, diagnostic accuracy. *n/N*=number affected/number in study; **n/N* in terms of lung regions or hemithoraces rather than patients

| Paper | Reference test | Modality/comparison | *n/N* | Sensitivity | Specificity | PPV | NPV | DA |
|---|---|---|---|---|---|---|---|---|
| Fragou[46] | Radiography | CCUS | 37/100 | 99.0 | 100.0 | – | – | – |
| Galbois[45] | CT if discrepancy | CCUS | 44/44* | 100.0 | 90.9 | 97.1 | 100.0 | 97.7 |
| | | CXR | | 60.6 | 100.0 | 100.0 | 64.9 | 70.5 |
| Zhang[49] | CT or drainage | CCUS | 29/135 | 86.2 | 97.2 | 89.3 | 96.3 | 94.8 |
| | | CXR | | 27.6 | 100.0 | 100.0 | 83.5 | 84.4 |
| Soldati[48] | CT | CCUS | 25/218* | 92.0 | 99.5 | 95.8 | 98.9 | 98.6 |
| | | CXR | | 52.0 | 100.0 | 100.0 | 94.1 | 94.5 |
| Rowan[47] | CT | CCUS | 11/27 | 100.0 | 93.8 | 91.7 | 100.0 | 96.3 |
| | | CXR | | 36.4 | 100.0 | 100.0 | 69.6 | 74.1 |
| Xirouchaki[26] | CT | CCUS | 8/84* | 75.0 | 93.4 | 54.5 | 97.3 | 91.7 |
| | | CXR | | 0.0 | 98.7 | 0.0 | 90.4 | 89.3 |
| Lichtenstein[33] | CXR/CT and standard care | CCUS | 9/260 | 88.9 | 100.0 | 100.0 | 99.6 | 99.6 |

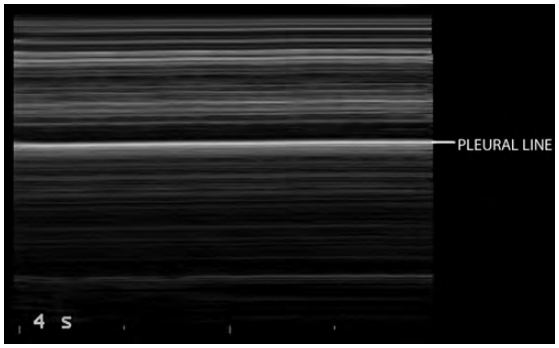


**Fig 4** Stratosphere sign. M-mode image of pneumothorax. A continuous line from left to right represents an unchanging signal (unmoving tissue) over time. This occurs below the pleural line in pneumothorax as the air gap ablates any motion signal occurring in tissue below. Named for the resemblance to jet liner vapour trails.

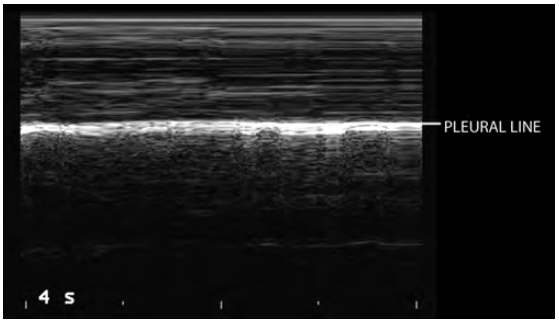


**Fig 5** Seashore sign. M-mode image of normally inflated lung. Minimal motion of chest wall tissues gives rise to parallel lines above (waves of the sea). A granular pattern below the pleural line (sand on the shore) results from constantly changing signal from moving lung.

traumatic pneumothorax. Overall however, pneumothorax literature is generally less methodologically robust and has a higher proportion of conference abstracts than data for other pathology. This is probably a result of the lower incidence of this condition.

### Training

A key difficulty in attempting to replace CXR will be in elevating every practicing critical care physician to some level of expertise in the skill. A number of expert working groups and professional bodies including The Royal College of Radiologists have produced consensus statements regarding the core competencies required for CCUS.[50–53] On the basis of these a round-table party representing several critical care societies agreed this training should be part of every critical care education programme.[54] As yet, there is little consensus on how this should be delivered, tested or accredited. Almost without exception, the studies reported earlier involved CCUS performed by enthusiastic experts in the field, proving the technology, not the ultrasonographer. There have been a number of small studies and conference abstracts which demonstrate satisfactory acquisition of the skill within anywhere from 2 h to 4 months training and between 20 and 80 supervised scans.[45 55–59] As yet there are no large, formal studies of the optimal format of training, or its ability to produce competent sonographers. So while the depth and breadth of training is reasonably well defined and agreed upon, a validated means by which to achieve it is lacking. This requires further investigation although the feasibility of conducting adequate studies is not without problem, particularly as most training in critical care medicine occurs amongst relatively small groups.

## Conclusions

Although studies are small or moderate in size they are for the most part, methodologically robust and suggest that in the hands of relative experts, CCUS performs extremely well. In the diagnostic groups discussed above, performance approaches that of CT and surpasses that of CXR in almost every respect. Traumatic pneumothorax, qualitative reporting of effusions and demonstration of consolidation seem to hold the greatest body of evidence although large and reproduced studies are lacking. Quantitative characterization of effusions as well as determination of the origin of septal oedema show promise as further applications but, of all the indications, these require the most work. Evidence that employing ultrasound diagnoses results in management and intervention which is safer and more efficacious is with one exception almost absent.[29]

Other benefits such as the potential for cost, time, and radiation savings have been discussed elsewhere in the literature.[1 20 60 61] With the correct training and accreditation process established, thoracic ultrasound will likely hold great promise, but as yet remains in its infancy.[52–54] As with many techniques in medicine, it has had to go through an experimental phase to prove the technology. The challenge now is to take a promising tool from the clinical research setting and develop it into a new skill for the practicing clinician to adopt.

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## Declaration of interest

None declared.

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