BJR, 2026, **99**, 195–205
https://doi.org/10.1093/bjr/tqaf288
Advance access publication: 2 December 2025
Review

Ultrasound of lung parenchyma—current state and future

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Abstract

The evidence base supporting the use of thoracic ultrasound to assess the lung parenchyma has expanded and consolidated itself significantly within the last decade. Thoracic ultrasound for lung parenchyma assessment is now finding its way into statements and clinical practice guidelines for several conditions in various settings. Since assessment of patients with possible chest disease is a very common clinical scenario, knowledge of the various types of chest imaging is essential for any physician. The most common indication for thoracic ultrasound for lung parenchymal assessment is for screening and diagnostic purposes. Several new studies have, however, demonstrated a possible large potential for using thoracic lung ultrasound to monitor lung diseases. The recent COVID-19 pandemic has increased the scope of lung parenchymal ultrasound, from diagnosis to monitoring of the disease. Deep learning of contrast-enhanced thoracic ultrasound to aid diagnosis is a new developing area. Despite increasing use of thoracic ultrasound in respiratory medicine, a consensus on assessment of competencies, and education is lacking. The aim of this review is to provide the reader with a focus overview of the current use and diagnostic limitation of thoracic ultrasound for assessment of the lung parenchyma, and future development.

Keywords: lung; thoracic; ultrasound; parenchyma.

Introduction

Thoracic ultrasound (TUS) has been widely implemented in the assessment of pleural diseases, and its use is well-integrated into international guidelines.[1-5] The use of TUS as a bedside tool to diagnose and monitor pathologic conditions in the lung parenchyma have, however, received less attention despite its advantages as radiation free and a bedside modality.

Over the past decade, a growing body of evidence has demonstrated that TUS can provide clinical relevant information on a wide range of parenchymal lung diseases.[1,6-8] The clinical implementation of TUS for lung assessment was further facilitated and consolidated by the COVID-19 pandemic, during which TUS became an important bedside tool for assessment of possible COVID-19.[9] Within the last years, TUS for lung parenchyma assessment has also begun to feature in statements and clinical practice guidelines for several conditions in various settings.[1,9-11]

Since assessment of patient with possible chest disease is a very common clinical scenario, knowledge of the role TUS in assessment of lung parenchyma and its limitations is essential for respiratory physician. The aim of this review is to provide the reader with a general overview of the current use of TUS for assessment of the lung parenchyma, as well as in which areas its role may expand even further in the future.

Indications for using TUS to assess the lung parenchyma

The most common indication for TUS in lung parenchymal assessment is screening and diagnosis. However, several new studies have demonstrated a possible large potential for using TUS to monitor lung diseases.[12-18] The use of TUS to guide invasive procedures such as transthoracic ultrasound-guided lung biopsy, is well-established. Its use is typically limited to specialized centres, and is therefore not part of this review.[19,20] Examples of general TUS "lung" indications are given in Table 1.[1,6] It is important to note that these indications often overlap with TUS assessment of related structures such as the chest wall, parietal pleura, pleural cavities, and

Received: 28 March 2025; **Revised:** 14 October 2025; **Accepted:** 14 November 2025

Table 1. Overview of general TUS indications for assessment of the lung parenchyma.

Diagnostic TUS	TUS-guided procedures
• Assessment of visceral pleura (eg, appearance, movement, and presence of B-lines) • Assessment of lung consolidation in contact with the visceral pleura • Assessment of the presence of intercostal arteries prior to intervention • Reassessment and monitoring of treatment response	• US guided lung biopsy (eg, core biopsy, needle aspiration biopsy) • US guided lung drain insertion (eg, for lung abscess) • US guided trocar insertion for thoracoscopic procedures • US guided ventilatory strategy (prone positioning, positive end-expiratory pressure (PEEP) titration)

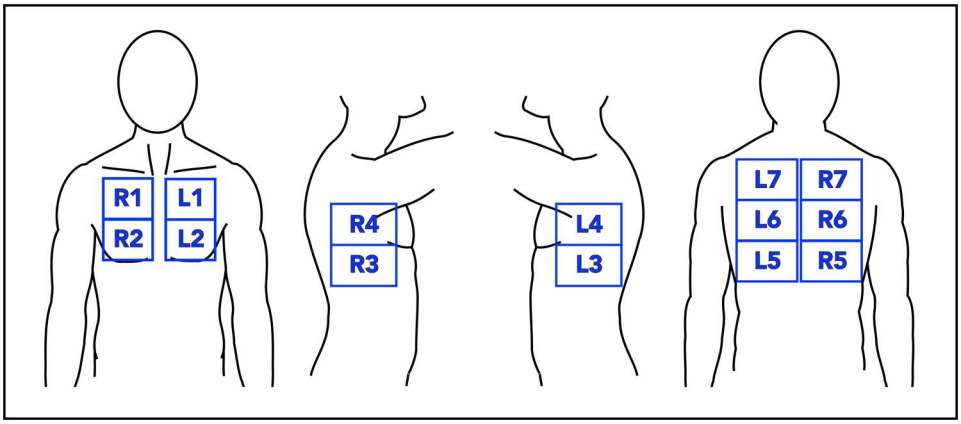

Figure 1. A 14-zone TUS scanning protocol, in which each hemithorax is divided into 2 anterior, 2 lateral, and 3 posterior zones. The protocol has been validated in various clinical scenarios and settings. Adapted from Laursen et al.[25]

diaphragm. The interested reader can find additional information on these aspects and the use of TUS-guided procedures elsewhere.[1,3,6,20-23]

TUS practical aspects when assessing the lung parenchyma

Assessment principles and scanning protocols

TUS may be performed as part of a focused assessment to answer simple dichotomic clinical questions (eg, is lung consolidation present?—yes/no) or as part of a comprehensive diagnostic assessment.[24] Many TUS scanning protocols divide the chest into a set of predefined "scanning zones" often paired with a standardized list of what is to be assessed in each. The number of zones and areas assessed differs from studies, settings, and indications.[1,24,25] Studies have indicated that choice of scanning may affect diagnostic accuracy.[26] Therefore the TUS operator needs to know which specific protocol is optimal for the given clinical setting and patient.[24] An example of a TUS scanning protocol is the 14-zone scanning protocol which has been validated for a wide range of settings and conditions (Figure 1).[1,24,25,27]

Equipment and presets

Basic TUS lung parenchyma assessment can be performed using the most standard stationary or cart-based ultrasound scanners. A low-frequency curvilinear probe (2-6 MHz) is optimal for the initial assessment as it allows assessment of both superficial structures in the lung (eg, visceral pleura) and more deeply located structures in case of pathology (eg, large lung consolidation). A high-frequency linear probe (7-12 MHz) is used for detailed assessment of the visceral pleura or subpleural pathology.[24,28,29]

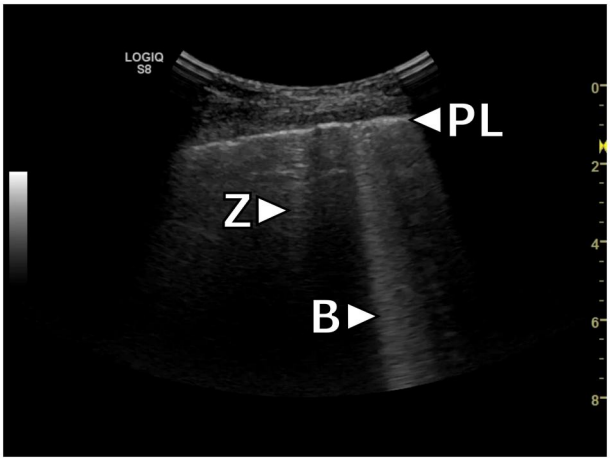

Figure 2. A B-line (B) can be seen as a hyperechoic, laser-like, vertical, reverberation artefact originating from the pleural line (PL). B-lines continue from the pleural line to the bottom edge of the screen and do not fade in intensity. This opposed to other more "faint" vertical artefacts which also originate from the pleura line. One of these are also present in the image, but noticeably it quickly fades in intensity (Z).

Most ultrasound scanners have specific presets that can be used for TUS, and increasingly with dedicated lung "sub-presets" for the assessment of artefacts (eg, B-lines (Figure 2)) or lung consolidations. If no such presets are available, the abdominal preset (low-frequency transducer) and musculoskeletal presets (high-frequency transducer) can generally be used. When using standard presets, the operator should, however, be able to adjust image optimization that might diminish the visibility of artefacts when assessing for the presence of these.[24]

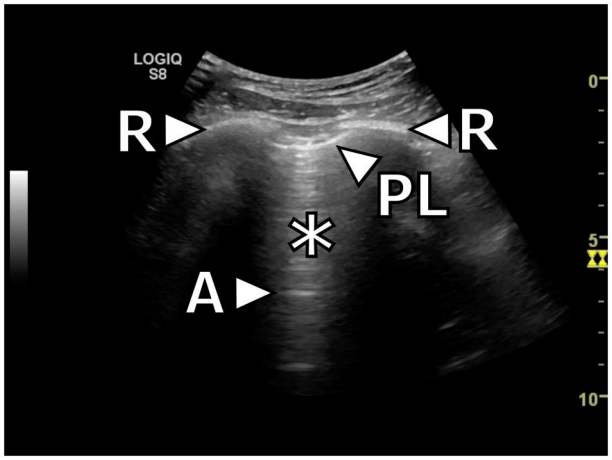

Figure 3. TUS normal sonomorphology of the lung. The hyperechoic horizontal line just below the 2 ribs (R) represent the parietal and visceral pleura (PL). The area below (*) the pleural line (PL) does not represent the lung tissue, but is instead represent artefacts, such as the A-line (A).

Patient positioning

The anterior and lateral zones of the chest can be examined with the patient in either the sitting, supine or lateral decubitus position, whereas the posterior zones is best scanned with the patient is seated.[24] In this position, they can be asked to place their hands across their shoulders. This moves the scapulae laterally, allowing better assessment of the upper zones. In addition, if the patient is lying on their side, any pleural effusion will shift posteriorly, making it more difficult to assess and plan an intervention, particularly in cases of small effusions. Many critically ill patients can only be assessed in the supine. Dedicated scanning protocols for assessing critically ill, supine, patients have been developed and validated for this setting.[14]

Normal lung sonomorphology

When placing the ultrasound transducer just above an intercostal space the so-called "pleural line" can be visualized just below and between the 2 ribs. It is seen as a hyperechoic horizontal line representing both visceral and parietal pleura[1,24,30] (Figure 3). The movement of the visceral pleura during breathing is visualized as a horizontal movement of the pleural line in synchrony with the patients breathing. This movement has been termed "lung sliding".[30,31] The normal aerated lung tissue cannot be directly visualized using TUS. Hence the area below the pleural line does not represent lung tissue. Ultrasound waves being reflected back and forth between the transducer and the pleura line generate the so-called A-lines (Figure 3).[1,24,30]

Clinical integration: limitations and strengths

Due to the air-filled nature of the lungs, ultrasound assessment of the lung parenchyma has its limitations. Recognition of possible lung pathology will typically rely on the recognition of:

- Indirect signs of possible lung pathology in the form of presence of artefacts (B-lines) or pleura line abnormalities
- Direct signs of lung pathology in the form of visible subpleural lung abnormalities

Diseases in which the density of the subpleural lung tissue is not increased (eg, chronic obstructive lung disease, emphysema, cystic lung disease) or the solid/non-aerated tissue (eg, central lung cancer) is not in contact with the visceral pleura cannot be visualized using TUS.[1,32,33] Despite these limitations, TUS generally have excellent diagnostic capabilities for assessing lung diseases causing: (1) diffusely increased lung density (eg, pulmonary oedema, interstitial lung disease, viral pneumonia) or (2) areas of solid tissue with absence of air in the lungs (eg, pneumonia, pulmonary embolism [PE], atelectasis).[9,15,17,27,34-38]

TUS diagnostic accuracy and sonomorphology in specific conditions

Community acquired pneumonia

The use of TUS in the evaluation of pneumonia is rapidly growing with increasing efficiency and accuracy compared to other diagnostic tests.[36] In a multicentre prospective study on 226 patients, TUS demonstrated a sensitivity of 93.4% and a specificity of 97.7% with respect to the diagnosis of pneumonia.[39] This has been echoed in by Desai et al[40] in a recent systematic review and meta-analysis of 29 studies with a combined sample size of 6702 participants, pooled sensitivity was 92% (95% CI: 91%-93%), specificity was 94% (95% CI, 94%-95%). Furthermore, in a systematic review and meta-analysis of 2040 patients from 16 studies, Sistani and Parooie[41] compared the diagnostic performance of chest X-ray and TUS. The overall pooled sensitivity for TUS and chest X-ray, in diagnosing pneumonia was 96% and 65%, respectively. The pooled specificity for TUS and chest X-ray was 85% and 81%, respectively. The use of TUS for diagnosing community acquired pneumonia, are now being incorporated into clinical practice guidelines as an alternative to chest X-ray.[42]

Sonographically, lung consolidation is the most common and diagnostic finding in bacterial pneumonia.[40] The sonographic characteristic of the consolidation appears as a subpleural echo-poor region or one with tissue-like echotexture (Figure 4).[1,30] The presence of air bronchograms, which sonographically appear as hyperechoic or linear punctate spots within the lung consolidation, is a typical feature to be observed in pneumonic consolidations (Figure 4).[43] The occurrence of air bronchograms is prevalent in over 90% of pneumonia cases.[39] It is important to emphasize that TUS has been shown to demonstrate a concurrent pleural effusion in 55% of pneumonia cases, a figure that is substantially higher than the 25% observed through conventional chest X-ray.[39] This is of clinical importance since routine use of TUS in patients admitted with acute respiratory symptoms results in earlier supplementary thoracocentesis and thus potentially allow earlier identification and treatment of concomitant pleural infection.[25,27]

Viral pneumonia

TUS findings in viral pneumonia are characterized by the presence of minor subpleural consolidations measuring less than 5 mm in diameter (Figure 5). These consolidations are typically accompanied by multiple and diffuse B-line artefacts.[44] Abnormalities most frequently occur within lower lung fields, specifically, over the posterior and lateral chest surface.[44,45]

In the Coronavirus Disease-2019 (COVID-19) era, TUS gained increased attention in the diagnosis and follow-up of patients.[46,47] The presence of certain typical sonographic

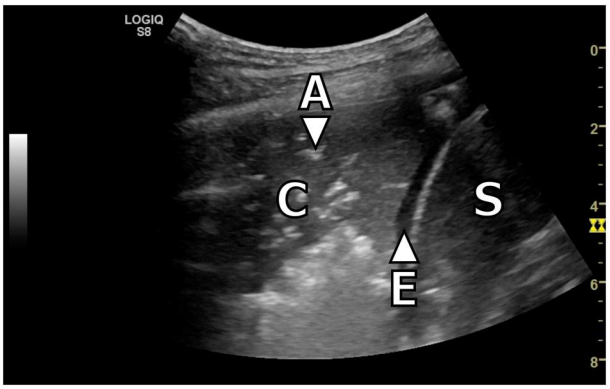

Figure 4. Visible lung consolidation (C) in a patient with community acquired pneumonia. The lung consolidated lung tissue resemble that of the adjacent spleen (S) below the diaphragm. Air bronchograms (A) can be seen as hyperechoic dots and linear structures within the consolidation. A small, simple, adjoining pleural effusion (E) is also present.

features has been identified in cases of COVID-19. These include irregular thickening of the pleural line; the presence of heterogenous B-lines, which may present as focal, multifocal or confluent; and consolidation of a variety of types.[47-49] Gil-Rodriguez et al[45] conducted a systematic review including 66 articles, with a pooled population of 4687 patients. The most common sonographic findings were at least 3 B-lines, confluent B-lines, subpleural consolidation, and uncommonly, a unilateral or bilateral pleural effusion.

Importantly, the TUS score was used as a predictor of outcomes in intensive care and emergency department settings; a higher score was associated with a higher risk of developing undesirable outcomes (death, Intensive care unit [ICU] admission, or need for mechanical ventilation).[45] In the most recent Cochrane Database Systematic Review on thoracic imaging tests for the diagnosis of COVID-19, the pooled sensitivity and specificity of TUS for diagnosing COVID-19 was 88.9% (95% confidence interval [CI], 84.9%-92.0%), and 72.2% (95% CI, 58.8%-82.5%), respectively. These results were based on 15 studies, including a total of 2410 participants. The sensitivity was found to be comparable with computed tomography (CT) of the chest and superior to chest X-ray. All 3 modalities were found to have comparable and only moderate specificity for COVID-19. Hence, in the context of suspected COVID-19, TUS and CT have more utility for ruling out COVID-19 than for differentiating COVID-19 from other causes of respiratory illness.[9]

Acute respiratory distress syndrome

Berlin's definition of acute respiratory distress syndrome (ARDS) consists of clinical criteria and requires the presence of bilateral opacities on chest imaging (to assess the extent of pulmonary infiltrates).[50] The Kigali modification of the Berlin definition, utilizes bilateral TUS abnormalities, to enhance the diagnosis of ARDS in low-income countries with insufficient resources.[51] This approach was further adapted in the ICU in a high-resource setting and showed reasonable diagnostic accuracy compared with the Berlin definition.[52] As a result, the new global definition of ARDS published in 2024 by Matthay et al[53] now include TUS among the chest imaging modalities in the definition.

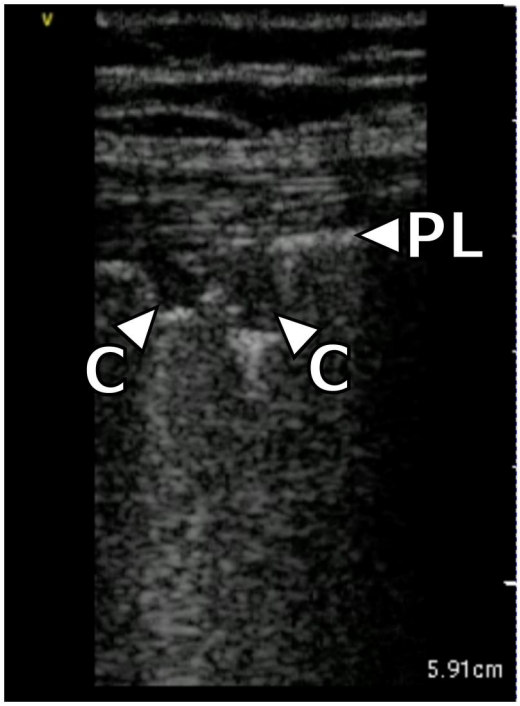

Figure 5. TUS image from a patient scanned due to suspected COVID-19 with lung involvement. Two anechoic, small, subpleural consolidations (C) are present just below the pleural line (PL). The examination was performed with a high-frequency, linear transducer, connected to a hand-held ultrasound device.

The sonographic pattern in ARDS is that of heterogenous B-lines with a non-gravity-dependent distribution that may coexist with spared areas, pleura line irregularities, and consolidations (Figure 6).[54,55] The various patterns seen in different scanning zones can be used as a means of scoring and classifying ARDS into focal and non-focal phenotypes.[56] In a recent meta-analysis, Boumans et al[57] reviewed 11 studies including 2075 patients, of whom 598 (29%) had ARDS. Nine studies reported on ARDS diagnosis, and 2 reported on focal versus non-focal ARDS subphenotypes classification. Meta-analysis showed a pooled sensitivity of 0.631 (95% CI, 0.450-0.782) and pooled specificity of 0.942 (95% CI, 0.856-0.978) of TUS for ARDS diagnosis and in addition, TUS has shown accurately differentiate between focal versus non-focal ARDS subphenotypes.

Pulmonary embolism

In the diagnosis of pulmonary embolism CT pulmonary angiogram (CTPA) remains the most widely used reference standard investigation.[58] However, there is emerging evidence of using lung parenchymal ultrasound to support pulmonary embolism diagnostic pathways. Lung consolidations are the most typical and common TUS finding in patients with PE.[35] The parenchymal changes occur secondary to embolic vascular occlusion, which can lead to either round atelectasis due to surfactant breakdown or lung parenchymal infarction with or without necrosis. These lung parenchymal changes can be identified by TUS as a subpleural consolidation.[59] The typical sonographic appearance of such a lesion is as a hypoechoic, sharply demarcated, pleural-based lesion, which can vary in size and shape (Figure 7).[35]

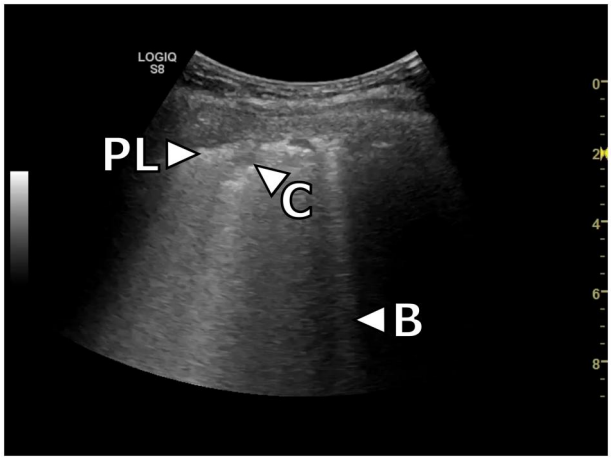

Figure 6. TUS image from the anterior chest surface in a patient with ARDS. Multiple B-lines (B) are present alongside a thickened and irregular pleural line (PL), and small subpleural consolidations (C).

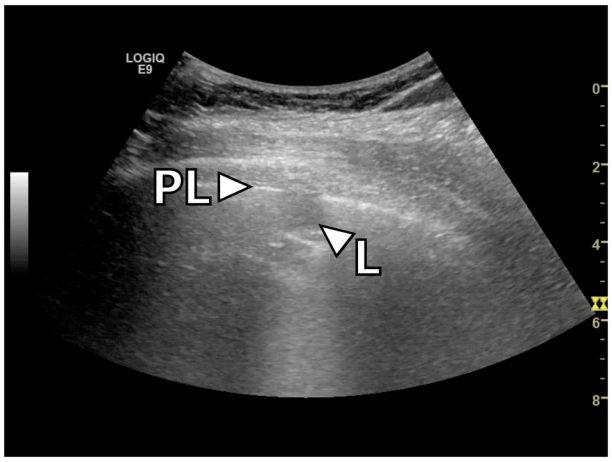

Figure 7. TUS image of a single, small, hypoechoic, sharply demarcated, pleural-based lesion (L) just below the pleural line (PL). The image if from a patient with dyspnoea and pleuritic chest pain. Subsequent CT pulmonary angiography confirmed the diagnosis of pulmonary embolism.

The diagnostic accuracy depends on which specific TUS findings are considered as being diagnostic for PE. Falster et al[35] conducted a systematic review and meta-analysis on the diagnostic accuracy of ultrasound in suspected PE. For the meta-analysis of TUS findings, 19 studies were included, in which a total of 2134 patients had been included. The most sensitive TUS finding was that of one or more hypoechoic pleural-based lesion(s), which had a sensitivity of 81.4% (95% CI, 73.2%-87.5%), and a specificity of 87.4% (95% CI, 80.9%-91.9%). It is noteworthy, that of different findings when performing TUS, echocardiography, or ultrasound assessment of the deep veins included in the meta-analysis, this TUS finding was the most sensitive of all ultrasound signs for PE. The most specific TUS finding was that of 2 or more hypoechoic pleural-based lesions, which had a sensitivity and specificity of 44.2% (95% CI, 38.0%-50.6%) and 96.5% (95% CI, 93.2%-98.5%), respectively.

More recently Falster et al[60] conducted a randomized clinical trial in which patients with suspected PE were randomly assigned to either direct diagnostic imaging (controls) or focused lung, cardiac, and deep venous ultrasound by unblinded investigators. Ultrasound could: (1) dismiss PE if no signs of PE and low clinical suspicion or an alternate diagnosis, (2) confirm PE in case of visible venous thrombus, ≥2 subpleural infarctions, McConnell's, or D-sign, or (3) refer to diagnostic imaging if neither category was fulfilled or a patient with confirmed PE by ultrasound required admission. The primary endpoint was the proportion of patients referred to diagnostic imaging. In the trial, ultrasound reduced referral for diagnostic imaging substantially by 45.2% (95% CI, 34.3%-56.6%) ($P < .0001$). During follow-up the number of patients who did not receive anticoagulation but was diagnosed with PE was, however, higher in the ultrasound group. Despite this difference was not statistically significant, further studies demonstrating an acceptable safety rate is warranted, especially if ultrasound is to be used as a rule-out-tool.

Malignancy

In lung cancer, guidelines advocate staging CT and positron emission tomography (PET) scans for the diagnosis, staging and follow-up of treatment response of lung cancer.[61] Nevertheless, these modalities have some limitations in the identification of chest wall invasion, which is present in up to 45% of all T3 lung cancers and 5% of all primary lung cancers.[62] Several studies have documented TUS being superior to CT in the assessment and diagnosis of possible chest wall invasion in malignancy.[63-65] Therefore, it is suggested that for appropriate staging, TUS should be used as an adjunct tool to further characterize the tumour, guide tissue sampling, and determine presence of invasive growth s.[1,66]

Sonographically, malignant lung lesions appear in variable sizes, shapes, echogenicity, and with well-defined as well as more diffusely demarcated margins (Figure 8). Hence apart from obvious signs of malignancy (eg, visible invasive growth), conventional B-mode findings are generally unspecific for malignancy (Figure 9).[1,67] A mobile lesion with the presence of lung sliding rules out invasive growth into the parietal pleura and chest wall, whereas absence of lung sliding can indicate possible invasive growth.[63-65]

Interstitial lung disease

Interstitial lung diseases (ILD) constitute a heterogeneous disease entity that encompasses idiopathic, granulomatous, exposure- and drug-related ILD, but also connective tissue disease (CTD)-related subtypes.[68] High-resolution CT (HRCT) together with multidisciplinary discussions are considered the diagnostic gold standard and required for classification of ILD; however, at risk of exposure to radiation and increasing health costs. Therefore, TUS has been investigated as an alternative tool to diagnose ILD,[1,69] but its utility is mostly investigated in order to detect ILD based on the number of B-lines in patients with CTD-ILD.[38,70-74] A recent meta-analysis of 487 patients with CTD revealed, TUS to have a sensitivity and specificity of 85.9% (95% CI, 81.2%-89.8%) and 83.9% (95% CI, 78.2%-88.6%), respectively for diagnosing CTD-ILD,[75] thus demonstrating the potential of TUS to detect possible ILD in patients with CTD. Apart from using TUS as a tool for screening and diagnosing ILD, results from disease monitoring studies are awaited in order to establish whether TUS could have a potential role in this context.[76]

In ILD, the most crucial sonographic pattern to indicate ILD is diffuse, bilateral B-lines with a heterogeneous distribution, whereas pleural irregularity with nodulation,

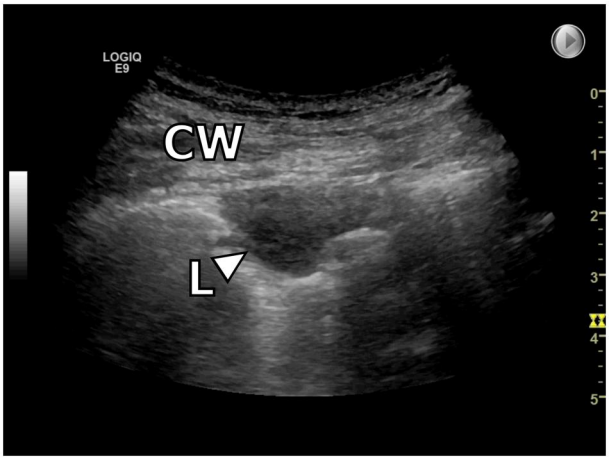

Figure 8. TUS image from a patient with a small, subpleural placed, lung cancer. The lesion (L) is hypoechoic and relatively well-demarcated. Lung sliding was absent, but no obvious invasive growth into the chest wall (CW) is present. The ultrasound pattern is unspecific. The diagnosis was established by ultrasound guided transthoracic biopsy.

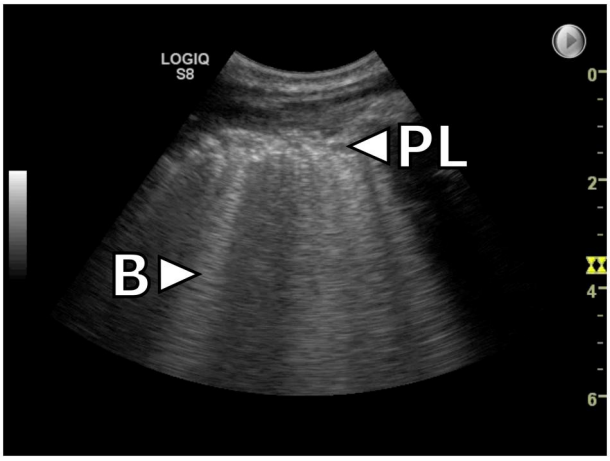

Figure 10. TUS image from a patient with idiopathic pulmonary fibrosis. The transducer has been placed corresponding to assessment of the right lower lobe (scanning zone R5). Multiple B-lines (B) are present, the pleural line (PL) is irregular, fragmented, and thickened.

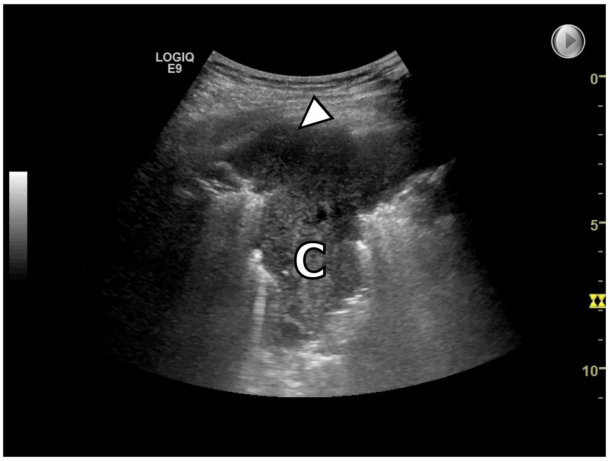

Figure 9. TUS image from a patient with a large, lung cancer (C). The lesion has an irregular shape with a homogenic, tissue organ-like echogenicity. Invasive growth of the lesion into the chest wall can be directly visualized (arrow). The finding is highly suspicious for malignancy. The diagnosis was confirmed by ultrasound-guided transthoracic biopsy.

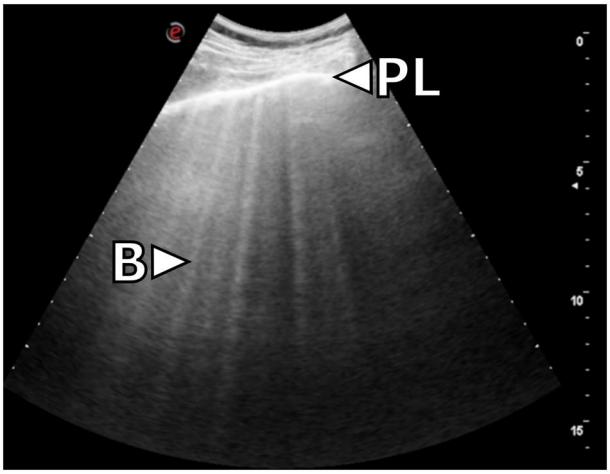

Figure 11. TUS image from a patient with cardiogenic pulmonary oedema, multiple B-lines (B) are present. The pleural line (PL) appears normal, without signs of thickening, fragmentation or irregularities.

thickening, or fragmentation indicate fibrotic phenotypes subtypes of ILD (Figure 10).[77,78] Furthermore, TUS may be useful tool to assess the extent of pulmonary fibrosis and correlate with the reduction in the static lung volume and gas transfer when there is an increase in the distance between B-lines and increasing pleural line irregularity.[69]

Cardiogenic and non-cardiogenic pulmonary oedema

The pathophysiology of acute pulmonary oedema involves the accumulation of fluid in the alveoli and pulmonary interstitial spaces. This ultimately leads to impaired gas diffusion, thereby contributing to shortness of breath.[79] TUS is considered as being superior to chest X-ray as the initial imaging modality for diagnosing pulmonary oedema.[1,11,27,30,80] A systematic review and meta-analysis undertaken by Maw et al[81] compared the diagnostic accuracy of chest X-ray and TUS for diagnosing pulmonary oedema in patients with suspected decompensated heart failure. A total of 6 comparative studies were included, representing a total of 1827 patients. Pooled estimates for TUS were 88% (95% CI, 75%-95%) for sensitivity and 90% (95% CI, 88%-92%) for specificity. Pooled estimates for chest X-ray were 73% (95% CI, 70%-76%) for sensitivity and 90% (95% CI, 75%-97%) for specificity. Similarly, in a systematic review and meta-analysis by Elgenidy et al,[82] including 33 studies with 2301 haemodialysis patients, TUS was found to be an efficient bedside tool for detecting non-cardiogenic pulmonary oedema and changes in extravascular lung water. In this context, it is noteworthy that Corcoran et al[18] could demonstrate that TUS seems to be superior to CT in detecting changes in extravascular lung water. Randomized clinical trials have additionally demonstrated a potential impact when TUS is used as a pulmonary oedema monitoring tool.[15,17] Hence one of the next steps in TUS research and clinical implementation, will most likely be as an extravascular lung water monitoring tool.

In cardiogenic and non-cardiogenic pulmonary oedema, the typical pattern is that of multiple B-lines in several

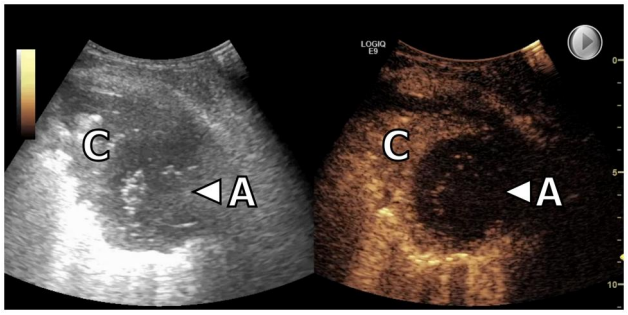

Figure 12. CEUS image from a patient with a lung abscess. When compared to the conventional 2D image (left), the CEUS image (right) allows a more accurate identification and delineation of the abscess (A) within the consolidated lung tissue (C).

scanning zones (Figure 11). As opposed to the B-line pattern seen in viral pneumonia, ARDS, and ILD, the B-lines in pulmonary oedema are the most pronounced in dependent areas of the lung and spared areas with normal findings in these areas not being common. To what an extent multiple B-lines must be present in order to fulfil TUS diagnostic criteria for pulmonary oedema varies. In many studies the proposed definition of the so-called "interstitial syndrome" has been used as diagnostic criteria.[1,27,81] The interstitial syndrome has been defined as multiple B-lines (>2) in at least 2 of the scanned anterior and lateral zones on each side.[30,83]

Advanced TUS techniques

Contrast-enhanced ultrasound

In current international contrast-enhanced ultrasound (CEUS) guidelines, the recommendations with regards to the lungs is limited to delineate lung abscesses (Figure 12) and to guide ultrasound-guided lung biopsy. The more general recommendations of using CEUS to identify needle or catheter position is also of relevance in a TUS context.[84] Several studies have documented that CEUS can improve the diagnostic yield of TUS-guided biopsies, by identifying malignant vascularization patterns and necrotic, non-viable areas within a malignant lesion.[85] Several other indications in which CEUS could have a clear clinical potential have been described, but more research is needed to establish its ideal use in current clinical practice guidelines.[85,86]

Elastography

The use of supplementary elastography to assess and monitor tissue density have been assessed and implemented in other forms of clinical ultrasound.[87] From a theoretical perspective TUS with supplementary elastography might have the same clinical utility.[88] In a recent systematic review Vargas-Ursua et al[88] identified 18 studies in which various forms of elastography (eg, strain transient elastography, point shear-wave elastography, 2D shear-wave elastography) had been studied as a supplement to TUS. The most common conditions in which the use of elastography had been assessed were subpleural consolidations, ILD, and pleural effusion. Study design and the used ultrasound methods were, however, to heterogenic to allow any meta-analysis or clear indications.[88] As such clinical implementation must await additional research.

Use of TUS for lung parenchyma assessment in specific settings

Acute respiratory failure in the emergency department

Several studies have described TUS as an integrated bedside tool for assessment of patients admitted to an emergency department with respiratory failure.[25,27,80,83,89] A common scenario in this context is the differentiation between cardiogenic pulmonary oedema and chronic obstructive pulmonary disease (COPD) exacerbation. TUS is particularly useful for this differentiation since patients with cardiogenic pulmonary oedema is expected to have diffuse, multiple B-lines bilaterally, as opposed to patients with COPD exacerbation in which diffuse, bilateral B-lines are absent.[32,89] Pivetta et al[90] studied the effect on diagnostic accuracy when TUS was integrated into clinical assessment for differentiating acute decompensated heart failure from noncardiogenic dyspnoea in the emergency department. The study prospectively enrolled 1005 patients and could demonstrate that the LUS-implemented approach had a significantly higher sensitivity (97% [95% CI, 95%-98.3%]) and specificity (97.4% [95% CI, 95.7%-98.6%]) than initial clinical work-up, chest X-ray, and natriuretic peptides. In a trial by Laursen et al,[27] patients acutely admitted with respiratory symptoms patients were randomized to usual diagnostics or an approach in which focused lung, cardiac, and deep venous ultrasound was integrated into the diagnostic pathway. The primary endpoint was the proportion of patients with a correct presumptive diagnosis 4 hours following admission. In the study, 88.0% (95% CI, 82.8%-93.1%) in the ultrasound group versus 63.7% (95% CI, 56.1%-71.3%) in the control group had correct presumptive diagnoses ($P < .0001$) 4 hours after admission. Additionally, more patients in the ultrasound group had received correct treatment 4 hours following admission (78% [95% CI, 71.3%-84.4%] vs. 56.7% [95% CI, 48.9%-64.5%], $P < .0001$). Hence, both classical diagnostic accuracy studies, as well as randomized trials have demonstrated the utility of TUS as an important diagnostic tool for acute respiratory failure in the emergency department.[1,10,11,30]

Intensive care setting

Imaging in an ICU pose a particular clinical dilemma. Transfer of the patients for imaging procedures in the radiology department is challenged by the patient being critically ill, and often with need of concomitant respiratory and circulatory support.[10,91] As such, point-of-care TUS have been particularly studied and implemented in an ICU setting.[12-14,23,30,34,56,92] The general TUS principles used for the patient with acute respiratory failure in an ED setting, also apply in an ICU setting.[92] An important difference is the choice of scanning protocol. Several of the TUS scanning protocols developed and validated in an ICU setting, therefore use scanning principles in which the protocols rely less on posterior "scanning zones."[12,14,23,92] Apart from using TUS as a diagnostic tool, studies have also assessed TUS as monitoring tool for lung aeration, ventilator associated pneumonia, and to guide mechanical ventilation and fluid management.[12-14,23,93,94] Several trials are ongoing in this field and will help further clarify the optimal use of TUS in this context.[23,93,95]

Evidence-based training and competency assessment

Health-care staff performing TUS needs to have sufficient training to establish indications, perform, interpret, and integrate the findings into the given clinical context.[1] Within recent years, several studies have provided a framework which can be used to ensure evidence-based education and competency assessment in TUS.[96-99] Generally, local or national training requirements for obtaining basic competency in TUS should be followed,[3,100] but if none exists the European Respiratory Society training program may serve as an alternative until such has been established.[101]

Conclusions and future direction

Lung parenchymal ultrasound has emerged as an effective and valuable tool for diagnosing, monitoring, and guiding intervention of certain lung parenchymal diseases. Further research, including the use of contrast-enhanced ultrasound, may expand its diagnostic utility and accuracy.

Funding

None declared.

Conflicts of interest

C.B.L.: Payment for lectures at educational events, symposia, or courses organized by AstraZeneca, Chiesi Pharma, GlaxoSmithKline, and Boehringer Ingelheim. All other authors declare that they have no conflicts of interest.

References

1. Laursen CB, Clive A, Hallifax R, et al. European respiratory society statement on thoracic ultrasound. *Eur Respir J*. 2021;57:2001519. https://doi.org/10.1183/13993003.01519-2020
2. Roberts ME, Rahman NM, Maskell NA, et al. British thoracic society guideline for pleural disease. *Thorax*. 2023;78:1143-1156. https://doi.org/10.1136/thorax-2023-220304
3. Asciak R, Bedawi EO, Bhatnagar R, et al. British thoracic society clinical statement on pleural procedures. *Thorax*. 2023;78:s43-s68. https://doi.org/10.1136/thorax-2022-219371
4. Bedawi EO, Ricciardi S, Hassan M, et al. ERS/ESTS statement on the management of pleural infection in adults. *Eur Respir J*. 2023;61:2201062. https://doi.org/10.1183/13993003.01062-2022
5. Sundaralingam A, Grabczak EM, Burra P, et al. ERS statement on benign pleural effusions in adults. *Eur Respir J*. 2024;64:2302307. https://doi.org/10.1183/13993003.02307-2023
6. European Respiratory Society. *Thoracic Ultrasound*. Vol. 79. ERS Monograph. European Respiratory Society; 2018: 265.
7. Laursen CB, Graumann O, Rahman NM. Thoracic ultrasound—new challenges, new horizons. *Ultraschall Med*. 2021;42:226-227.
8. Ovesen SH, Clausen AH, Kirkegaard H, et al. Point-of-care lung ultrasound in emergency medicine: a scoping review with an interactive database. *Chest*. 2024;166:544-560. https://doi.org/10.1016/j.chest.2024.02.053
9. Ebrahimzadeh S, Islam N, Dawit H, et al.; Cochrane COVID-19 Diagnostic Test Accuracy Group. Thoracic imaging tests for the diagnosis of COVID-19. *Cochrane Database Syst Rev*. 2022;5:CD013639. https://doi.org/10.1002/14651858.CD013639.pub5
10. Chiumello D, Sferrazza Papa GF, Artigas A, et al. ERS statement on chest imaging in acute respiratory failure. *Eur Respir J*. 2019;54:1900435. https://doi.org/10.1183/13993003.00435-2019
11. Gargani L, Girerd N, Platz E, et al.; Members of the 2020-2022 EACVI Scientific Documents Committee. Lung ultrasound in acute and chronic heart failure: a clinical consensus statement of the European association of cardiovascular imaging (EACVI). *Eur Heart J Cardiovasc Imaging*. 2023;24:1569-1582. https://doi.org/10.1093/ehjci/jead169
12. Bouhemad B, Liu ZH, Arbelot C, et al. Ultrasound assessment of antibiotic-induced pulmonary reaeration in ventilator-associated pneumonia. *Crit Care Med*. 2010;38:84-92. https://doi.org/10.1097/CCM.0b013e3181b08cdb
13. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby JJ. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. *Am J Respir Crit Care Med*. 2011;183:341-347. https://doi.org/10.1164/rccm.201003-0369OC
14. Mongodi S, Bouhemad B, Orlando A, et al. Modified lung ultrasound score for assessing and monitoring pulmonary aeration. *Ultraschall in Der Medizin*. 2017;38:530-537. https://doi.org/10.1055/s-0042-120260
15. Araiza-Garaygordobil D, Gopar-Nieto R, Martinez-Amezcua P, et al. A randomized controlled trial of lung ultrasound-guided therapy in heart failure (CLUSTER-HF study). *Am Heart J*. 2020;227:31-39. https://doi.org/10.1016/j.ahj.2020.06.003
16. Falster C, Jacobsen N, Wulff Madsen L, et al. Lung ultrasound may be a valuable aid in decision making for patients admitted with COVID-19 disease. *Eur Clin Respir J*. 2021;8:1909521. https://doi.org/10.1080/20018525.2021.1909521
17. Arvig MD, Lassen AT, Gæde PH, et al. Impact of serial cardiopulmonary point-of-care ultrasound exams in patients with acute dyspnoea: a randomised, controlled trial. *Emerg Med J*. 2023;40:700-707. https://doi.org/10.1136/emermed-2022-212694
18. Corcoran JP, Hew M, Attwood B, et al. Lung ultrasound reproducibly outperforms computed tomography in the detection of extravascular lung water in patients undergoing haemodialysis. *Diagnostics (Basel)*. 2024;14:589. https://doi.org/10.3390/diagnostics14060589
19. Li X, Kong L. Ultrasound versus computed tomography-guided transthoracic biopsy for pleural and peripheral lung lesions: a systematic review and meta-analysis. *Acta Radiol*. 2023;64:2999-3008. https://doi.org/10.1177/02841851231206349
20. Bedawi EO, Talwar A, Hassan M, et al. Intercostal vessel screening prior to pleural interventions by the respiratory physician: a prospective study of real world practice. *Eur Respir J*. 2020;55:1902245. https://doi.org/10.1183/13993003.02245-2019
21. Laursen CB, Bhatnagar R, Juul AD. A stepwise approach for performing ultrasound guided transthoracic lung biopsy. *J Vis Exp*. 2023;201. https://doi.org/10.3791/65769
22. Corcoran JP, Psallidas I, Hallifax RJ, Talwar A, Sykes A, Rahman NM. Ultrasound-guided pneumothorax induction prior to local anaesthetic thoracoscopy. *Thorax*. 2015;70:906-908. https://doi.org/10.1136/thoraxjnl-2014-206676
23. Mojoli F, Bouhemad B, Mongodi S, Lichtenstein D. Lung ultrasound for critically ill patients. *Am J Respir Crit Care Med*. 2019;199:701-714. https://doi.org/10.1164/rccm.201802-0236CI
24. Laursen CB, Davidsen JR, Gleeson F. Technique and protocols. In: Laursen CB, Rahman N, Volpicelli G, eds. *Thoracic Ultrasound (ERS Monograph)*. European Respiratory Society; 2018:14-30. Chapter 2.
25. Laursen CB, Sloth E, Lambrechtsen J, et al. Focused sonography of the heart, lungs, and deep veins identifies missed life-threatening conditions in admitted patients with acute respiratory symptoms. *Chest*. 2013;144:1868-1875. https://doi.org/10.1378/chest.13-0882
26. Volpicelli G, Cardinale L, Mussa A, Valeria C. Diagnosis of cardiogenic pulmonary edema by sonography limited to the anterior lung. *Chest*. 2009;135:883; author reply 883-884. https://doi.org/10.1378/chest.08-1313
27. Laursen CB, Sloth E, Lassen AT, et al. Point-of-care ultrasonography in patients admitted with respiratory symptoms: a single-

blind, randomised controlled trial. *Lancet Respir Med*. 2014;2:638-646. https://doi.org/10.1016/s2213-2600(14)70135-3
28. Koenig SJ, Narasimhan M, Mayo PH. Thoracic ultrasonography for the pulmonary specialist. *Chest*. 2011;140:1332-1341. https://doi.org/10.1378/chest.11-0348
29. Alerhand S, Graumann O, Nelson BP. Physics and basic principles. In: Laursen CB, Rahman NM, Volpicelli G, eds. *Thoracic Ultrasound (ERS Monograph)*. Sheffield: European Respiratory Society; 2018:1-13. Chapter 1.
30. Volpicelli G, Elbarbary M, Blaivas M, et al.; International Liaison Committee on Lung Ultrasound (ILC-LUS) for International Consensus Conference on Lung Ultrasound (ICC-LUS). International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med*. 2012;38:577-591. https://doi.org/10.1007/s00134-012-2513-4
31. Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung sliding. *CHEST J*. 1995;108:1345-1348. https://doi.org/10.1378/chest.108.5.1345
32. Lichtenstein D, Meziere G. A lung ultrasound sign allowing bedside distinction between pulmonary edema and COPD: the comet-tail artifact. *Intensive Care Med*. 1998;24:1331-1334.
33. Davidsen JR, Bendstrup E, Henriksen DP, Graumann O, Laursen CB. Lung ultrasound has limited diagnostic value in rare cystic lung diseases. In: *C104 Rare Interstitial Lung Disease: Lam, Cystic Lung Disease, and More*. American Thoracic Society; 2016: A6260.
34. Lichtenstein DA, Lascols N, Meziere G, Gepner A. Ultrasound diagnosis of alveolar consolidation in the critically ill. *Intensive Care Med*. 2004;30:276-281. https://doi.org/10.1007/s00134-003-2075-6
35. Falster C, Jacobsen N, Coman KE, et al. Diagnostic accuracy of focused deep venous, lung, cardiac and multiorgan ultrasound in suspected pulmonary embolism: a systematic review and meta-analysis. *Thorax*. 2022;77:679-689. https://doi.org/10.1136/thoraxjnl-2021-216838
36. Gentilotti E, De Nardo P, Cremonini E, et al. Diagnostic accuracy of point-of-care tests in acute community-acquired lower respiratory tract infections. A systematic review and meta-analysis. *Clin Microbiol Infect*. 2022;28:13-22. https://doi.org/10.1016/j.cmi.2021.09.025
37. Chiu L, Jairam MP, Chow R, et al. Meta-Analysis of point-of-care lung ultrasonography versus chest radiography in adults with symptoms of acute decompensated heart failure. *Am J Cardiol*. 2022;174:89-95. https://doi.org/10.1016/j.amjcard.2022.03.022
38. Sofiudottir BK, Harders S, Laursen CB, et al. Detection of interstitial lung disease in rheumatoid arthritis by thoracic ultrasound: a diagnostic test accuracy study. *Arthritis Care Res*. 2024;76:1294-1302. https://doi.org/10.1002/acr.25351
39. Reissig A, Copetti R, Mathis G, et al. Lung ultrasound in the diagnosis and follow-up of community-acquired pneumonia: a prospective, multicenter, diagnostic accuracy study. *Chest*. 2012;142:965-972. https://doi.org/10.1378/chest.12-0364
40. Desai D, Shah AB, Dela JRC, et al. Lung ultrasonography accuracy for diagnosis of adult pneumonia: systematic review and meta-analysis. *Adv Respir Med*. 2024;92:241-253. https://doi.org/10.3390/arm92030024
41. Sistani SS, Parooie F. Diagnostic performance of ultrasonography in patients with pneumonia: an updated comparative systematic review and meta-analysis. *J Diagn Med Sonogr*. 2021;37:371-381. https://doi.org/10.1177/8756479321992348
42. Jones BE, Ramirez JA, Oren E, et al. Diagnosis and management of community-acquired pneumonia. An official American thoracic society clinical practice guideline. *Am J Respir Crit Care Med*. 2025. https://doi.org/10.1164/rccm.202507-1692ST
43. Weinberg B, Diakoumakis EE, Kass EG, Seife B, Zvi ZB. The air bronchogram: sonographic demonstration. *AJR Am J Roentgenol*. 1986;147:593-595.
44. Testa A, Soldati G, Copetti R, Giannuzzi R, Portale G, Gentiloni-Silveri N. Early recognition of the 2009 pandemic influenza A (H1N1) pneumonia by chest ultrasound. *Crit Care (Fullerton)*. 2012;16:R30. https://doi.org/10.1186/cc11201
45. Gil-Rodriguez J, Perez de Rojas J, Aranda-Laserna P, et al. Ultrasound findings of lung ultrasonography in COVID-19: a systematic review. *Eur J Radiol*. 2022;148:110156. https://doi.org/10.1016/j.ejrad.2022.110156
46. Shaw JA, Louw EH, Koegelenberg CFN. Lung ultrasound in COVID-19: not novel, but necessary. *Respiration*. 2020;99:545-547. https://doi.org/10.1159/000509763
47. Shokoohi H, Duggan NM, Garcia-de-Casasola Sanchez G, Torres-Arrese M, Tung-Chen Y. Lung ultrasound monitoring in patients with COVID-19 on home isolation. *Am J Emerg Med*. 2020;38:2759 e5-2759-e8. https://doi.org/10.1016/j.ajem.2020.05.079
48. Poggiali E, Dacrema A, Bastoni D, et al. Can lung US help critical care clinicians in the early diagnosis of novel coronavirus (COVID-19) pneumonia? *Radiology*. 2020;295:E6. https://doi.org/10.1148/radiol.2020200847
49. Skaarup SH, Aagaard R, Ovesen SH, et al. Focused lung ultrasound to predict respiratory failure in patients with symptoms of COVID-19: a multicentre prospective cohort study. *ERJ Open Res*. 2022;8:00128-2022. https://doi.org/10.1183/23120541.00128-2022
50. Force ADT, Ranieri VM, Rubenfeld GD, et al. Acute respiratory distress syndrome: the Berlin definition. *JAMA*. 2012;307:2526-2533. https://doi.org/10.1001/jama.2012.5669
51. Riviello ED, Kiviri W, Twagirumugabe T, et al. Hospital incidence and outcomes of the acute respiratory distress syndrome using the kigali modification of the Berlin definition. *Am J Respir Crit Care Med*. 2016;193:52-59. https://doi.org/10.1164/rccm.201503-0584OC
52. Vercesi V, Pisani L, van Tongeren PSI, et al.; Lung Ultrasound Consortium. External confirmation and exploration of the kigali modification for diagnosing moderate or severe ARDS. *Intensive Care Med*. 2018;44:403-404. https://doi.org/10.1007/s00134-018-5048-5
53. Matthay MA, Arabi Y, Arroliga AC, et al. A new global definition of acute respiratory distress syndrome. *Am J Respir Crit Care Med*. 2024;209:37-47. https://doi.org/10.1164/rccm.202303-0558WS
54. Pesenti A, Musch G, Lichtenstein D, et al. Imaging in acute respiratory distress syndrome. *Intensive Care Med*. 2016;42:686-698. https://doi.org/10.1007/s00134-016-4328-1
55. Islam M, Levitus M, Eisen L, Shiloh AL, Fein D. Lung ultrasound for the diagnosis and management of acute respiratory failure. *Lung*. 2020;198:1-11. https://doi.org/10.1007/s00408-019-00309-1
56. Pierrakos C, Smit MR, Pisani L, et al. Lung ultrasound assessment of focal and non-focal lung morphology in patients with acute respiratory distress syndrome. *Front Physiol*. 2021;12:730857. https://doi.org/10.3389/fphys.2021.730857
57. Boumans MMA, Aerts W, Pisani L, Bos LDJ, Smit MR, Tuinman PR. Diagnostic accuracy of lung ultrasound in diagnosis of ARDS and identification of focal or non-focal ARDS subphenotypes: a systematic review and meta-analysis. *Crit Care (Fullerton)*. 2024;28:224. https://doi.org/10.1186/s13054-024-04985-1
58. Falster C, Hellfritzsch M, Gaist TA, et al. Comparison of international guideline recommendations for the diagnosis of pulmonary embolism. *Lancet Haematol*. 2023;10:e922-e935. https://doi.org/10.1016/S2352-3026(23)00181-3
59. Mathis G, Dirschmid K. Pulmonary infarction: sonographic appearance with pathologic correlation. *Eur J Radiol*. 1993;17:170-174.
60. Falster C, Morkenborg MD, Thrane M, et al. Utility of ultrasound in the diagnostic work-up of suspected pulmonary embolism: an open-label multicentre randomized controlled trial (the PRIME study). *Lancet Reg Health Eur*. 2024;42:100941. https://doi.org/10.1016/j.lanepe.2024.100941

61. Rami-Porta R, Call S, Dooms C, et al. Lung cancer staging: a concise update. *Eur Respir J*. 2018;51:1800190. https://doi.org/10.1183/13993003.00190-2018
62. Filosso PL, Sandri A, Guerrera F, et al. Primary lung tumors invading the chest wall. *J Thorac Dis*. 2016;8:S855-S862. https://doi.org/10.21037/jtd.2016.05.51
63. Bandi V, Lunn W, Ernst A, Eberhardt R, Hoffmann H, Herth FJ. Ultrasound vs. CT in detecting chest wall invasion by tumor: a prospective study. *Chest*. 2008;133:881-886. https://doi.org/10.1378/chest.07-1656
64. Chira R, Chira A, Mircea PA. Intrathoracic tumors in contact with the chest wall—ultrasonographic and computed tomography comparative evaluation. *Med Ultrason*. 2012;14:115-119.
65. Sripathi S, Mahajan A. Comparative study evaluating the role of color doppler sonography and computed tomography in predicting chest wall invasion by lung tumors. *J Ultrasound Med*. 2013;32:1539-1546. https://doi.org/10.7863/ultra.32.9.1539
66. Suzuki N, Saitoh T, Kitamura S. Tumor invasion of the chest wall in lung cancer: diagnosis with US. *Radiology*. 1993;187:39-42.
67. Dietrich CF, Mathis G, Cui XW, Ignee A, Hocke M, Hirche TO. Ultrasound of the pleurae and lungs. *Ultrasound Med Biol*. 2015;41:351-365. https://doi.org/10.1016/j.ultrasmedbio.2014.10.002
68. Travis WD, Costabel U, Hansell DM, et al.; ATS/ERS Committee on Idiopathic Interstitial Pneumonias. An official American thoracic society/European respiratory society statement: update of the international multidisciplinary classification of the idiopathic interstitial pneumonias. *Am J Respir Crit Care Med*. 2013;188:733-748. https://doi.org/10.1164/rccm.201308-1483ST
69. Hasan AA, Makhlouf HA. B-lines: transthoracic chest ultrasound signs useful in assessment of interstitial lung diseases. *Ann Thorac Med*. 2014;9:99-103. https://doi.org/10.4103/1817-1737.128856
70. Tardella M, Gutierrez M, Salaffi F, et al. Ultrasound in the assessment of pulmonary fibrosis in connective tissue disorders: correlation with high-resolution computed tomography. *J Rheumatol*. 2012;39:1641-1647. https://doi.org/10.3899/jrheum.120104
71. Pinal-Fernandez I, Pallisa-Nunez E, Selva-O'Callaghan A, et al. Pleural irregularity, a new ultrasound sign for the study of interstitial lung disease in systemic sclerosis and antisynthetase syndrome. *Clin Exp Rheumatol*. 2015;33:S136-S141.
72. Gargani L, Doveri M, D'Errico L, et al. Ultrasound lung comets in systemic sclerosis: a chest sonography hallmark of pulmonary interstitial fibrosis. *Rheumatology*. 2009;48:1382-1387. https://doi.org/10.1093/rheumatology/kep263
73. Otaola M, Paulin F, Rosemffet M, et al. Lung ultrasound is a promising screening tool to rule out interstitial lung disease in patients with rheumatoid arthritis. *Respirology*. 2024;29:588-595. https://doi.org/10.1111/resp.14679
74. Otaola M, Vasarmidi E, Ottaviani S, et al. Performance of lung ultrasound as a screening tool for subclinical rheumatoid Arthritis-Associated interstitial lung disease: a multicenter study. *Chest*. 2024;167:1687-1695. https://doi.org/10.1016/j.chest.2024.11.038
75. Xie HQ, Zhang WW, Sun S, et al. A simplified lung ultrasound for the diagnosis of interstitial lung disease in connective tissue disease: a meta-analysis. *Arthritis Res Ther*. 2019;21:93. https://doi.org/10.1186/s13075-019-1888-9
76. Legue S, Marchand-Adam S, Plantier L, et al. ThOracic ultrasound in idiopathic pulmonary fibrosis evolution (TOUPIE): research protocol of a multicentric prospective study. *BMJ Open*. 2021;11:e039078. https://doi.org/10.1136/bmjopen-2020-039078
77. Moazedi-Fuerst FC, Kielhauser S, Brickmann K, et al. Sonographic assessment of interstitial lung disease in patients with rheumatoid arthritis, systemic sclerosis and systemic lupus erythematosus. *Clin Exp Rheumatol*. 2015;33:S87-S91.
78. Tardella M, Di Carlo M, Carotti M, Filippucci E, Grassi W, Salaffi F. Ultrasound B-lines in the evaluation of interstitial lung disease in patients with systemic sclerosis: cut-off point definition for the presence of significant pulmonary fibrosis. *Medicine (Baltimore)*. 2018;97:e0566. https://doi.org/10.1097/MD.0000000000010566
79. Ware LB, Matthay MA. Clinical practice. Acute pulmonary edema. *N Engl J Med*. 2005;353:2788-2796. https://doi.org/10.1056/NEJMcp052699
80. Riishede M, Lassen AT, Baatrup G, et al. Point-of-care ultrasound of the heart and lungs in patients with respiratory failure: a pragmatic randomized controlled multicenter trial. *Scand J Trauma Resusc Emerg Med*. 2021;29:60. https://doi.org/10.1186/s13049-021-00872-8
81. Maw AM, Hassanin A, Ho PM, et al. Diagnostic accuracy of point-of-care lung ultrasonography and chest radiography in adults with symptoms suggestive of acute decompensated heart failure: a systematic review and meta-analysis. *JAMA Netw Open*. 2019;2:e190703. https://doi.org/10.1001/jamanetworkopen.2019.0703
82. Elgenidy A, Amin MA, Awad AK, et al. The use of lung ultrasound in evaluation of extravascular lung water in hemodialysis patients: systematic review and meta-analysis. *Hemodial Int*. 2024;28:148-161. https://doi.org/10.1111/hdi.13141
83. Volpicelli G, Mussa A, Garofalo G, et al. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. *Am J Emerg Med*. 2006;24:689-696. https://doi.org/10.1016/j.ajem.2006.02.013
84. Sidhu PS, Cantisani V, Dietrich CF, et al. The EFSUMB guidelines and recommendations for the clinical practice of contrast-enhanced ultrasound (CEUS) in non-hepatic applications: update 2017 (long version). *Ultraschall Der Medizin*. 2018;39:e2-e44. https://doi.org/10.1055/a-0586-1107
85. Jacobsen N, Pietersen PI, Nolsoe C, Konge L, Graumann O, Laursen CB. Clinical applications of Contrast-Enhanced thoracic ultrasound (CETUS) compared to standard reference tests: a systematic review. *Ultraschall Der Medizin*. 2022;43:72-81. https://doi.org/10.1055/a-1143-3141
86. Safai Zadeh E, Gorg C, Prosch H, et al. WFUMB technological review: how to perform Contrast-Enhanced ultrasound of the lung. *Ultrasound Med Biol*. 2022;48:598-616. https://doi.org/10.1016/j.ultrasmedbio.2021.11.014
87. Sigrist RMS, Liau J, Kaffas AE, Chammas MC, Willmann JK. Ultrasound elastography: review of techniques and clinical applications. *Theranostics*. 2017;7:1303-1329. https://doi.org/10.7150/thno.18650
88. Vargas-Ursua F, Ramos-Hernandez C, Pazos-Area LA, et al. Current evidence for lung ultrasound elastography in the field of pneumology: a systematic review. *ERJ Open Res*. 2024;10:00081-2024. https://doi.org/10.1183/23120541.00081-2024
89. Volpicelli G, Cardinale L, Garofalo G, Veltri A. Usefulness of lung ultrasound in the bedside distinction between pulmonary edema and exacerbation of COPD. *Emerg Radiol*. 2008;15:145-151. https://doi.org/10.1007/s10140-008-0701-x
90. Pivetta E, Goffi A, Lupia E, et al.; SIMEU Group for Lung Ultrasound in the Emergency Department in Piedmont. Lung ultrasound-implemented diagnosis of acute decompensated heart failure in the emergency department—a SIMEU multicenter study. *Chest*. 2015;148:202-210. https://doi.org/10.1378/chest.14-2608
91. Lichtenstein D, Goldstein I, Mourgeon E, Cluzel P, Grenier P, Rouby JJ. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. *Anesthesiology*. 2004;100:9-15.
92. Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest*. 2008;134:117-125. https://doi.org/10.1378/chest.07-2800
93. Rusu D-M, Grigoraș I, Blaj M, et al. Lung ultrasound-guided fluid management versus standard care in surgical ICU patients: a randomised controlled trial. *Diagnostics (Basel)*. 2021;11:1444. https://doi.org/10.3390/diagnostics11081444
94. Via G, Storti E, Gulati G, Neri L, Mojoli F, Braschi A. Lung ultrasound in the ICU: from diagnostic instrument to respiratory monitoring tool. *Minerva Anestesiol*. 2012;78:1282-1296.
95. Blok SG, Mousa A, Brouwer MG, et al. Effect of lung ultrasound-guided fluid deresuscitation on duration of

ventilation in intensive care unit patients (CONFIDENCE): protocol for a multicentre randomised controlled trial. *Trials*. 2023;24:226. https://doi.org/10.1186/s13063-023-07171-w
96. Pietersen PI, Konge L, Madsen KR, et al. Development of and gathering validity evidence for a theoretical test in thoracic ultrasound. *Respiration*. 2019;98:221-229. https://doi.org/10.1159/000500146
97. Pietersen PI, Bhatnagar R, Andreasen F, et al. Objective structured clinical examination in basic thoracic ultrasound: a European study of validity evidence. *BMC Pulm Med*. 2023;23:15. https://doi.org/10.1186/s12890-022-02285-4
98. Rasmussen KMB, Hertz P, Laursen CB, et al. Ensuring basic competence in thoracentesis. *Respiration*. 2019;97:463-471. https://doi.org/10.1159/000495686
99. McCracken DJ, Bedawi EO, Stevenson M, Cullen KM, Stanton AE, Rahman NM. Thoracic ultrasound competence for ultrasound guided pleural procedures: the creation and validation of an assessment tool for use in the certification of basic thoracic ultrasound competence. *J Clin Ultrasound*. 2022;50:781-788. https://doi.org/10.1002/jcu.23137
100. Stanton AE, Edey A, Evison M, et al. British thoracic society training standards for thoracic ultrasound (TUS). *BMJ Open Respir Res*. 2020;7:e000552. https://doi.org/10.1136/bmjresp-2019-000552
101. Pietersen PI, Bhatnagar R, Rahman NM, et al. Evidence-based training and certification: the ERS thoracic ultrasound training programme. *Breathe (Sheff)*. 2023;19:230053. https://doi.org/10.1183/20734735.0053-2023

British Journal of Radiology, 2026, 99, 195–205
https://doi.org/10.1093/bjr/tqaf288
Review