EUROPEAN RESPIRATORY *journal*

FLAGSHIP SCIENTIFIC JOURNAL OF ERS

Early View

Task force report

# European Respiratory Society Statement on Thoracic Ultrasound

Christian B. Laursen, Amelia Clive, Rob Hallifax, Pia Iben Pietersen, Rachelle Asciak, Jesper Rømhild Davidsen, Rahul Bhatnagar, Eihab O Bedawi, Niels Jacobsen, Courtney Coleman, Anthony Edey, Gabriele Via, Giovanni Volpicelli, Gilbert Massard, Francesco Raimondi, Matthew Evison, Lars Konge, Jouke Annema, Najib M Rahman, Nick Maskell

Please cite this article as: Laursen CB, Clive A, Hallifax R, *et al*. European Respiratory Society Statement on Thoracic Ultrasound. *Eur Respir J* 2020; in press (https://doi.org/10.1183/13993003.01519-2020).

**European Respiratory Society Statement on Thoracic Ultrasound**

**Authors:**

*Christian B. Laursen*

Department of Respiratory Medicine, Odense University Hospital, Odense, Denmark

Department of Clinical Research, Faculty of Health Sciences, University of Southern Denmark, Odense, Denmark

*Amelia Clive*

Academic Respiratory Unit, University of Bristol, Bristol, United Kingdom
Southmead Hospital, North Bristol NHS Trust, Bristol, United Kingdom

*Rob Hallifax*

Oxford Centre for Respiratory Medicine, Churchill Hospital, Oxford University Hospitals NHS Foundation Trust, Oxford, United Kingdom

Oxford Respiratory Trials Unit, Nuffield Department of Medicine, University of Oxford, Oxford, United Kingdom

*Pia Iben Pietersen*

Department of Respiratory Medicine, Odense University Hospital, Odense, Denmark

Regional Center for Technical Simulation, Odense University Hospital, Odense, Denmark

Department of Clinical Research, Faculty of Health Sciences, University of Southern Denmark, Odense, Denmark

*Rachelle Asciak*

Oxford Centre for Respiratory Medicine, Churchill Hospital, Oxford University Hospitals NHS Foundation Trust, Oxford, United Kingdom

Oxford Respiratory Trials Unit, Nuffield Department of Medicine, University of Oxford, Oxford, United Kingdom

*Jesper Rømhild Davidsen*

Department of Respiratory Medicine, Odense University Hospital, Odense, Denmark

South Danish Center for Interstitial Lung Diseases (SCILS), Odense University Hospital, Odense, Denmark

Department of Clinical Research, Faculty of Health Sciences, University of Southern Denmark, Odense, Denmark

*Rahul Bhatnagar*

Academic Respiratory Unit, University of Bristol, Bristol, United Kingdom
Southmead Hospital, North Bristol NHS Trust, Bristol, United Kingdom

*Eihab O Bedawi*

Oxford Centre for Respiratory Medicine, Churchill Hospital, Oxford University Hospitals NHS Foundation Trust, Oxford, United Kingdom

Oxford Respiratory Trials Unit, Nuffield Department of Medicine, University of Oxford, Oxford, United Kingdom

*Niels Jacobsen*

Department of Respiratory Medicine, Odense University Hospital, Odense, Denmark

Regional Center for Technical Simulation, Odense University Hospital, Odense, Denmark

Department of Clinical Research, Faculty of Health Sciences, University of Southern Denmark, Odense, Denmark

*Courtney Coleman*

European Lung Foundation, Sheffield, United Kingdom

*Anthony Edey*

Department of Radiology, Southmead Hospital, North Bristol NHS Trust, Bristol, United Kingdom

*Gabriele Via*

Cardiac Anesthesia and Intensive Care, Cardiocentro Ticino, Lugano, Switzerland

*Giovanni Volpicelli*

Department of Emergency Medicine, Ospedale San Luigi Gonzaga, Torino, Italy.

*Gilbert Massard*

Faculty of Science, Technology and Medicine, University of Luxembourg, Grand-Duchy of Luxembourg

*Francesco Raimondi*

Division of Neonatology, Section of Pediatrics, Department of Translational Medical Sciences, Università "Federico II" di Napoli, Naples, Italy

*Matthew Evison*

Wythenshawe Hospital, Manchester University NHS Foundation Trust, Manchester, United Kingdom

*Lars Konge*

Copenhagen Academy for Medical Education and Simulation, The Capital Region of Denmark, Centre for HR, University of Copenhagen, Copenhagen, Denmark,

*Jouke Annema*

Department of Respiratory Medicine, Amsterdam UMC, University of Amsterdam, Amsterdam, The Netherlands.

*Najib M Rahman**

Oxford Centre for Respiratory Medicine, Churchill Hospital, Oxford University Hospitals NHS Foundation Trust, Oxford, United Kingdom

Laboratory of Pleural and Lung Cancer Translational Research, Nuffield Department of Medicine, University of Oxford, Oxford, United Kingdom

Oxford Respiratory Trials Unit, Nuffield Department of Medicine, University of Oxford, Oxford, United Kingdom

National Institute for Health Research, Oxford Biomedical Research Centre, University of Oxford, Oxford, United Kingdom

*Nick Maskell**

Academic Respiratory Unit, University of Bristol, Bristol, United Kingdom
Southmead Hospital, North Bristol NHS Trust, Bristol, United Kingdom

*Joined last authors

**Abstract**

Thoracic ultrasound is increasingly considered to be an essential tool for the pulmonologist. It is used in diverse clinical scenarios, including as an adjunct to clinical decision making for diagnosis, a real-time guide to procedures, and a predictor or measurement of treatment response. The aim of this European Respiratory Society task force was to produce a statement on thoracic ultrasound for pulmonologists using thoracic ultrasound within the field of respiratory medicine. The multidisciplinary panel performed a review of the literature, addressing major areas of thoracic ultrasound practice and application. The selected major areas include equipment and technique, assessment of the chest wall, parietal pleura, pleural effusion, pneumothorax, interstitial syndrome, lung consolidation, diaphragm assessment, intervention guidance, training, and the patient perspective. Despite the growing evidence supporting the use of thoracic ultrasound, the published literature still contains a paucity of data in some important fields. Key research questions for each of the major areas were identified, which serve to facilitate future multi-centre collaborations and research to further consolidate an evidence-based use of thoracic ultrasound, for the benefit of the many patients being exposed to clinicians using thoracic ultrasound.

## Introduction

Thoracic ultrasound (TUS) is increasingly considered an essential tool for the pulmonologist [1-3]. Although this technique was for many years considered “of no use” in the lung, many decades of research have demonstrated high clinical utility in a number of areas of pulmonary disease. While the technique of TUS originated with radiologists, it is increasingly being used by pulmonologists “at the bedside”, and in this context is used with several potential aims. These include as an adjunct to clinical decision making for diagnosis, as a real-time guide to procedures, and as a predictor or measurement of treatment response [1, 2, 4-6].

This European Respiratory Society (ERS) statement has been written in light of the growing evidence behind the use of TUS across a broad range of respiratory disease areas, as a summary of the evidence to clinicians who wish to understand the current rationale and state of the art of this technique. An evidence-based approach has been used throughout, addressing major areas of TUS practice and application. These include chapters on required equipment and technique, assessment of the chest wall, parietal pleura, pleural effusion, pneumothorax, the utility of ultrasound (US) in diffuse lung parenchymal diseases, diaphragm assessment, intervention guidance, and finally suitable training in TUS.

We have highlighted areas of potential future research, as suggested by the current state of the evidence, at the end of each topic, and hope that this will lead to further definitive studies which will further improve our diagnostic and treatment armamentarium and benefit our patients.

## Methods

The task force was comprised of clinicians with internationally recognised expertise in TUS. In order to reflect the multidisciplinary use of TUS, the expert group included pulmonologists and relevant experts from other specialties (e.g. radiology, emergency medicine, intensive care, thoracic surgery, paediatrics). This group was supplemented with young ERS members with TUS experience, and representatives of the European Lung Foundation (ELF). An ERS methodologist provided feedback on research strategy, evidence and statement synthesis, and oversight of the task force process.

The task force was initiated in December 2018 and comprised one face-to-face meeting, regular telephone conferences and e-mail correspondence. Initially, the task force established the overall scope and aim of the statement. It was agreed to limit the statement to the general use of TUS in the context

of the clinical use by a pulmonologist. The members then agreed on a list of core topics which was to be addressed in the final statement.

A group of task force members with a designated topic leader was assigned to each topic and was responsible for development of a search strategy, evidence synthesis, and writing of an initial topic section for the statement. MEDLINE and Scopus databases were used for the literature searches, with inclusion of additional studies identified by individual task force members. An ELF representative was assigned to the write a section on the topic “patient perspectives”. The search terms for each topic are provided in the Appendix. The topic leader identified and used relevant studies and knowledge of current clinical practice to make an initial topic draft which the topic group then reviewed until a proposed final topic section had been completed. In addition to evidence synthesis, each group was given the task of identifying major gaps in the current evidence and provide key areas for future TUS research. The findings from the literature regarding the “patient perspectives” topic were shared with patients who had experience of TUS to identify additional perspectives.

Using the proposed topic sections, the task force chairmen comprised a first draft of the statement manuscript. Task force members then provided comments and suggestions in the making of the final manuscript based on the draft. The final version of the manuscript was reviewed and approved by all task force members. The statement provides an overview of the evidence and current clinical practice for general TUS performed by pulmonologists but does not provide recommendations for clinical practice.

According to ERS policies task force members disclosed potential conflict of interests at the beginning of the task force process and prior to the publication of the statement manuscript.

## Results

### 1. Equipment and technique

*Overview of the evidence and current practice*

When compared to other forms of clinical US with an established clinical tradition or more narrow clinical indication, international consensus publications regarding the equipment and technique used for

TUS are scarce [1, 3, 7]. The first international consensus paper on point-of-care lung US provides some essential basic definitions and terminology [1]. However, when compared to recommendations on point-of-care cardiac US, a general recommendation regarding equipment and technique is not provided [8]. This reflects current clinical practice, in which choice of TUS scanning protocol, equipment and technique varies between specialties and countries. Numerous different protocols, techniques and use of different equipment have been assessed and validated in prospective diagnostic accuracy studies [6, 9-29]. Studies directly assessing or comparing different TUS equipment or techniques are fairly limited. These studies have however demonstrated that factors such as choice of US machine (e.g. high-end, hand-held), protocol, transducer and patient positioning have a potential clinical impact [30-39]. Even though studies have addressed important factors, it is not possible to derive a universal and evidence-based TUS approach for any given clinical scenario. Apart from the examination itself, the COVID-19 pandemic has increased awareness of US operators in ensuring necessary safety precautions, specifically regarding cleansing of equipment and appropriate infection control [40].

*Table 1. Recommendations for future research: Equipment and technique*

| Area of future research | Question |
|---|---|
| **Protocol** | Which specific TUS protocol is optimal for a given clinical setting or problem? |
| **US equipment and software** | What is the optimal choice of US equipment and software in a given clinical setting or problem? |
| **Inter- and intra-observer variance** | What are the inter- and intra-observer variance for the specific protocols and equipment in various clinical settings? |

*Conclusions*

Many different approaches and techniques have been described and validated. Comparative studies directly comparing different TUS approaches are limited. Given the many clinical settings and indications, a “one size fits all” TUS approach is not feasible or meaningful. There remains a need to

reach consensus on a general TUS principles and to determine the optimal approach for more specific clinical problems or settings.

**2. Chest wall and parietal pleura**

*Chest wall soft tissues*

On TUS, the intercostal muscle and fascia are visualised as echogenic layers under the subcutaneous tissue (fig. 1). TUS can be used to identify and characterise superficial chest wall lesions, although generally cross-sectional imaging modalities, such as computed tomography (CT) and magnetic resonance imaging (MRI) are more accurate [41].

*Visceral and parietal pleura*

Below the intercostal muscle, the visceral and parietal pleura are visualised as an echogenic 'pleural line' visible between and deep to the ribs (fig 1.). In healthy individuals, the pleural line slides parallel to the chest wall during respiration generating a sparkling appearance ('lung sliding') and may move in synchrony with cardiac pulsation ('lung pulse'). Lung sliding can be confirmed using M-mode, which gives a characteristic 'seashore' sign [1].

Hypoechoic parietal pleural thickening may mimic a pleural effusion on US and use of colour Doppler may help to differentiate these conditions, with fluid showing disordered colour flow unlike static, solid pleural thickening. Benign pleural tumours such as fibromas and lipoma are relatively rare, are usually round or ovoid in shape, hypoechoic and homogeneous and do not infiltrate surrounding structures (fig. 1) [42]. Asbestos-related pleural plaques have a distinctive TUS appearance and are hypoechoic, elliptical, and smoothly limited foci; if calcified, they produce prominent acoustic shadows [42].

Malignant pleural nodularity is a more common finding and can be seen as irregular, well-circumscribed, often heterogeneous lumps arising from the parietal pleura and distorting the normal contour of the visceral pleura. They may be associated with a pleural effusion or chest wall/rib invasion [43].

TUS has been evaluated in the identification of the presence and degree of chest wall invasion of intrathoracic malignancies, and in one study was shown to have a higher sensitivity than CT [44]. The absence of pleural motion next to a peripheral lung lesion may identify parietal pleural invasion thus refining radiological staging. In one study, the use of qualitative and quantitative colour Doppler

sonography was more sensitive and specific than CT for predicting chest wall invasion by lung tumours [45].

*Ribs*

The ribs are seen as superficial, curvilinear structures, which completely reflect the US wave, resulting in posterior acoustic shadowing (rib shadows) (fig. 1). If an US probe is placed along the long axis of a rib, the cortex of the bone is visible as a static, bright, echogenic line. When a cortical fracture is present, this line is disrupted by a step or gap and reverberation echoes occur at the point of the fracture (known as 'the lighthouse phenomenon') (fig. 1). Fractures may be associated with a visible haematoma, a reactive pleural effusion or subpleural parenchymal changes from lung contusion. A recent systematic review suggests that TUS is more sensitive than chest radiography (CXR) in diagnosing rib fractures; however it can be painful and time-consuming, may be technically challenging in obese patients and the first ribs and retroscapular areas are incompletely visible. TUS may have a useful role in assessing focal areas of rib pain [46].

Metastatic disease to the ribs causes destruction of the bone cortex, resulting in an irregular cortical appearance and loss of the usual rib shadows. In this instance, the infiltrated bone structure may be more visible and appear hypoechoic and heterogenous [47].

*Intercostal muscles*

The intercostal muscles can be directly visualised between the ribs. Even though the role of TUS assessment of intercostal muscle function is yet to be established, studies have reported several possible clinical implications. In a study by Wallbridge et al. muscle thickness and echogenicity was found to correlate with spirometry assessment of severity in patients with chronic obstructive pulmonary disease (COPD)[48]. Intercostal muscle assessment has also been reported as a possible tool for assessing respiratory workload in mechanically ventilated patients and for predicting failure of spontaneous breathing trials after supported ventilation [49-51].

*Intercostal vessels*

Distal to the apex of the rib posteriorly, the intercostal vessels run in the subcostal groove, but their course may be tortuous particularly in the elderly. Colour flow Doppler, using a linear probe allows good visualisation of the vessels and in theory may reduce vascular injury during pleural intervention [52].

However, the technique is operator and experience dependent and its reliability and accuracy has been questioned.

*Table 2. Recommendations for future research: Chest wall and parietal pleura*

| Area of future research | Question |
|---|---|
| **Trauma patients** | What is the role for TUS in the diagnosis of rib fractures? |
| **Malignancy** | What is the accuracy of TUS for pleural and chest wall invasion by peripheral lung cancers? |
| **Invasive procedures** | Does TUS of intercostal vessels actually reduce frequency of vessel injury? |

*Conclusions*

TUS is a useful clinical tool for assessing the chest wall and parietal pleura. Further studies are required to ascertain its clinical utility and impact in specific clinical scenarios.

**3. Pleural effusion**

TUS has been used to assess suspected pleural effusion for at least 40 years [53-55]. Recently, a desire for better identification, classification and quantification of pleural fluid, coupled with rapid improvements in technology, has driven the widespread adoption of TUS amongst many pulmonologists. Indeed, being able to locate fluid with US to guide intervention is now seen as a core skill for trainees [56].

*Benefits of TUS over other modalities*

Basic, grey-scale TUS can identify much smaller volumes of fluid in comparison to other modalities, particularly CXR [57, 58]. It can do so reliably (meta-analysis data suggests a sensitivity of 93% and specificity of 96%) [59] in real-time at the bedside, with very high spatial resolution. The addition of colour Doppler may enhance assessment and improve differentiation of fluid from pleural thickening [60, 61].

*Point-of-care versus diagnostic imaging*

TUS is most commonly used as a point-of-care test to guide intervention for pleural effusions and there is strong evidence to suggest this improves safety and can guide management decisions [62-64]. With sufficient experience, more formal diagnostic imaging is possible. While the ultrasonographic appearance of the fluid in itself cannot be considered diagnostic of the underlying disease, other typical TUS findings may help support a diagnosis (e.g. irregular nodularity on the diaphragm in malignant pleural effusion) (fig. 2) [65].

*Visualising fluid and estimating volume*

Pleural effusions are most completely imaged with low frequency US transducers which allow for better understanding of fluid location and depth relative to deeper organs. Such frequencies are usually associated with curvilinear (typically 2-6 MHz) or sector (typically 1-3 MHz) probes. [66] Care must be taken with image processing settings, particularly gain, as these may adversely influence interpretation of fluid characteristics if incorrect [67]. The following four categories, described by Yang et al. are commonly referred to when describing effusion appearance: anechoic, complex non-septated, complex septated, and homogeneous echogenic (fig. 2)[68].

Freely mobile fluid will often be most easy to scan with the probe placed on the posterior or lateral chest, with the patient sat upright to allow the effusion to pool inferiorly. In some circumstances, particularly in those who are recumbent on the intensive care unit, finding a suitable window may be more challenging.

Basic estimations of fluid volume may be useful when trying to quantify treatment effects of non-invasive therapy (such as diuretics for cardiac impairment) or when deciding whether to drain an effusion in a ventilated patient. Several simple equations have been devised to try and estimate fluid volume based on US appearances. Hassan et al. tested the accuracy of five of these in 46 patients, and determined the most accurate to involve the total height of the effusion (H) in cm and the distance from bottom of the lung to apex of the diaphragm (C) in cm:

(H+C) cm x 70 ml/cm = effusion volume ml

This calculation was found to have an 83% accuracy when predicting fluid volume [69].

*Transudative disease versus exudative disease*

Although not specific, presentation with bilateral effusions or associated ascites are strongly associated with transudates [70, 71]. Effusions due to transudative processes tend to have lower concentrations of complex molecules, particularly proteins. On TUS, this often makes the fluid appear anechoic (fig. 2). This is not specific, however, with one series finding 14% of transudates to be echogenic [72]. By contrast, effusions which are exudates will almost always demonstrate echogenicity, complexity, or both [72-74]. There is also a strong correlation between 'swirling' and exudative processes, although again this is not a specific sign (fig. 2)[75-77].

*Features of malignant disease*

There are no effusion features specific to malignant effusions although many will show exudate characteristics and swirling is also frequently noted [74, 75]. Anechoic appearances have been described in around 10% of cases [65]. Chronicity or more active malignancy may lead to the formation of fibrous septations and/or loculation [74]. The presence of an effusion in conjunction with pleural or diaphragmatic nodularity is almost always indicative of malignancy, although such signs may be subtle (fig. 2) [65].

*Features of pleural infection*

Septation and/or loculation are suggestive of pleural infection requiring drainage in the appropriate clinical context (fig. 2) [63], and may indicate a greater likelihood of failing fibrinolytic therapy [78]. One small series described the "suspended microbubble" sign and found it to be highly sensitive and specific for frank empyema [79]. In tuberculous effusions, complex septated appearances have a positive predictive value of 84% at 12 months for residual pleural thickening [80]. For 'simple' parapneumonic effusions, no fluid signs are known to be associated with eventual need for treatment [81] but in a small paediatric series, a greater degree of echogenicity was associated with positive fluid culture, the need for more procedures, and longer duration of treatment [82].

*Imaging atelectatic lung within fluid*

The presence of even a relatively small effusion may cause compressive atelectasis, and this allows the non-aerated lung to be assessed by US [83]. Atelectatic segments have been described as resembling a 'J' or a 'hockey stick' (fig. 2), and within them it may be possible to appreciate malignant lesions. There is also evidence to suggest that M-mode measurements taken from atelectatic lung may be predictive of non-expandable lung [84].

*Table 3. Recommendations for future research: Pleural effusion*

| Area of future research | Question |
|---|---|
| **Non-expandable lung** | Are there any TUS techniques which might help to predict the development of non-expandable lung? |
| **Improved diagnostics** | Can the use of newer technology or contrast material improve the diagnostic utility of TUS in characterizing effusions? |
| **Point-of-care** | Can point-of-care TUS for the detection of pleural effusions become standard practice for non-pulmonologists or radiologists? |

*Conclusions*

The immediate and accurate identification of fluid prior to intervention remains the primary purpose of most TUS. Ongoing developments in technology, leading to even greater portability and higher resolution, will likely improve our ability to identify and characterise effusions, especially at an early stage, as may the use of fluid contrast agents, which remains relatively rare.

**4. Pneumothorax**

*Overview of the evidence and current practice*

Pneumothorax has traditionally been identified on erect CXR. However, there has been increasing interest in the use of TUS in the identification of pneumothorax, particularly in the context of trauma and critical care [12]. The difficulty with TUS in pneumothorax is due to the high impedance of the tissue/air interface causing most of the US waves to be reflected. Therefore, both air in the lung and air in the pleural space create a bright line at the pleural surface. However, there are three specific features of TUS described in pneumothorax: a lack of “lung sliding”, the absence of “B-lines”, and identification of a “lung point” [85-87].

Lung sliding is a ”sparkling” of the pleural line as the lung moves with respiration [88]. If lung sliding is identified, then pneumothorax can be excluded in that area. Conversely, the absence of lung sliding is not specific for pneumothorax. Lung sliding can also be assessed using M-mode [89]. Lung sliding distal to the pleural line creates a granular pattern distal to the pleural line, referred to as the “seashore sign”. The absence of lung sliding creates lines known as the “bar-code” or “stratosphere” sign (fig. 3). Importantly, loss of lung sliding can be caused by hyperinflation or bullous emphysema in COPD [90] and pleural adhesions.

“B-lines” (otherwise known as ”comet-tails”) are vertical artefacts projecting distally from the pleural line due to imperfections at the lung surface (fig. 3) [91]. The presence of B-lines excludes pneumothorax, but their absence does not confirm it.

The “Lung point” is an ultrasonographic sign which attempts to locate the junction between the pneumothorax and area with no air between the visceral and parietal pleural, i.e. where the visceral and parietal pleural part company [92]. With a stationary probe, the lung point refers to a pattern of repeated transitions between no lung sliding or B-lines (pneumothorax) into a demonstrable area of sliding (lung). It has been suggested that identification of the lung point is 100% specific for pneumothorax [92], and, by marking the lung point at multiple locations on the chest wall, this can be used to determine pneumothorax size [93]. However, a lung point is only seen in partial pneumothoraces and will be dependent on patient position.

TUS for pneumothorax can be challenging in small loculated pneumothoraces, and impossible in the context of significant subcutaneous emphysema where air in the subcutaneous tissue reflects all US waves (fig. 1).

Studies have been published on the utility of TUS in pneumothorax diagnosis for over 20 years. The majority of these have been prospective case series comparing imaging modalities in diagnosing pneumothorax in the context of trauma, iatrogenic (post-image guided biopsy) or in critical care, but no randomised controlled trials have assessed clinical effect or outcome. Currently, four meta-analyses have been published pooling data comparing the accuracy of TUS for pneumothorax compared to CXR [94-97]. Pooled sensitivity for TUS was 78–90% and pooled specificity was >98%. CXR performed poorly with a pooled sensitivity of 39–52%, but a similar specificity. However, these results must be taken in context; the vast majority of studies included mainly trauma patients lying in a supine position in the emergency department (ED), which will naturally reduce the sensitivity of the CXR comparator.

There was significant heterogeneity among all four meta-analyses, with one metanalysis suggesting it was due to operator performance [94], but a number of other factors could contribute. Importantly, pneumothoraces in trauma patients missed on supine CXR could have been occult. The diagnosis of occult pneumothorax has not been shown to impact clinical outcome and may indeed lead to over treatment (e.g. pleural drainage may not be required).

The identification of pneumothorax post-lung biopsy was specifically assessed in three studies: Chung et al. performed high resolution CT (HRCT) scans on 97 patients after fluoroscopic-guided lung biopsy, identifying pneumothorax in 36% [98]. The authors conclude a sensitivity of 80% for TUS but did not discriminate the size of pneumothorax; thus, these studies are likely to be identifying a number of small, clinically insignificant pneumothoraces on CT (in keeping with the higher than usual pneumothorax rate). Reissig et al studied 53 patients post transbronchial biopsy during bronchoscopy, with TUS identifying pneumothorax in all four (7.5%) cases [99]. Sartori et al also concluded that the sensitivity for TUS was 100% by examining 285 patients post-TUS-guided lung biopsy [100]. In this series only eight (2.8%) patients had pneumothorax, all of whom were identified by TUS; although CT was only performed when there was a discrepancy between TUS and CXR.

Another application of TUS could be in determining when pneumothoraces have resolved after chest tube drainage. One study suggested that TUS was superior to CXR [101], but was limited by being a single centre study with small patients numbers (n=44).

*Table 4. Recommendations for future research: Pneumothorax*

| Area of future research | Question |
|---|---|
| **Trauma patients** | Can early TUS detection of pneumothorax positively impact the patient's outcome? |
| **Post-lung biopsy** | Can TUS be used to identify iatrogenic pneumothorax requiring drainage? |
| **Pneumothorax – resolution** | Is TUS more sensitive than CXR in showing resolution of pneumothorax after successful drainage? (i.e. can we reduce the need for CXR?) |

| **Pneumothorax – predicting recurrence** | Can a lack of lung sliding on TUS at early follow-up predict long term recurrence? |
|---|---|

*Conclusions*

The utility of TUS in diagnosing pneumothorax has been reported in many prospective case series mostly in the context of trauma, iatrogenic (post-image guided biopsy) or in critical care. Four meta-analyses suggest TUS has a better sensitivity for pneumothorax compared to CXR but there are no randomised controlled trials assessing clinical effect or outcome, and the performance may be operator dependent. The development of well-designed clinical trials will help to guide practice in the future.

**5. Interstitial syndrome**

*Overview of the evidence and current practice*

The interstitial syndrome (IS) describes a composite TUS finding that represents an increased density of the lung interstitium secondary to a diffuse underlying disease or condition [102, 103]. The space and tissues around the alveolar sacs compose the lung interstitium and includes the alveolar epithelium, pulmonary capillary endothelium, basement membrane, perivascular- and perilymphatic tissues. If one or more of these tissues are affected in both lungs, IS may be present.

Presence and quantification of B-lines constitute the cornerstone finding when aiming to identify and confirm IS [104]. B-lines arise due to continuous reflection of the US beam between increased lung density areas and non-aerated areas near the pleural line [105, 106], and are defined as vertical reverberation artefacts originating from the pleural line in synchrony with lung sliding, extending uninterrupted to the edge of the screen without fading (fig. 3) [107]. Several TUS scanning approaches involving a different number of scanning zones to detect IS have been recommended [5, 16, 17, 27, 108-112], but the majority are expansions of Volpicielli et al. defining IS when $\geq$3 B-lines in >2 anterior or lateral lung interstitial spaces are present in each hemithorax [107]. In many settings cardiogenic and non-cardiogenic pulmonary oedema are the most common causative IS conditions, but other conditions such as acute respiratory distress syndrome (ARDS) also causes IS to be present [113]. In these conditions, IS arises due to hydrostasis or capillary leak with protein accumulation in the interstitium leading to interstitial and alveolar oedema [114]. A meta-analysis of 1,827 patients found TUS to be more sensitive to detect IS in dyspnoeic patients with acute HF (AHF) than CXR (88% vs. 73%), but with

comparable specificities (90%) [115]. In a prospective multicentre study including 1,005 patients attending ED with acute dyspnea, Pivetta et al. found that adding TUS to a standard diagnostic regime was superior to detect IS as part of AHF [116]. Two randomised clinical trials (RCT) support these findings: Laursen et al. compared usual clinical assessment and diagnostics with an approach using point-of-care US of the lung, heart and deep veins alongside usual clinical assessment and diagnostics. A significantly higher proportion received a correct diagnosis (88.0% vs. 63.7%) and treatment (78.0% vs. 56.7%) in the US group compared to the usual clinical assessment and diagnostics group [5]. Pivetta et al. demonstrated an approach using TUS had a higher diagnostic accuracy than an approach using CXR and NT-proBNP (AUC 0.95 vs. 0.87, $p < 0.01$) for the diagnosis of AHF [117]. In the context of an intensive care setting, Bataille et al. however found that the presence of IS was poor in discriminating between cardiogenic pulmonary oedema and pneumonia, unless supplementary echocardiography was performed [118]. Whether the results of the two RCT's can be generalized to other settings with more highly selected patients and whether TUS in the case of presence of IS should be routinely combined with echocardiography or focused cardiac ultrasound require further investigation.

In addition to IS, pleural oedema and the development of pleural fibrosis may occur in ARDS giving rise to pleural irregularity and decreased lung sliding [23, 119]. However, extrapolation of data regarding diagnostic accuracy of IS detected in AHF may not necessarily be applied to IS in ARDS [120]. This also applies to patients undergoing dialysis, although a clear association between interstitial oedema identified by IS and fluid overload has been shown [121, 122]. Hence, besides its relevance as a diagnostic add-on modality in these 'wet B-line' conditions, TUS shows operational applicability to monitor IS dynamics and guide treatment [123-126].

In interstitial lung diseases (ILD), IS arises from ongoing inflammation or formation of fibrosis following collagen accumulation in the interstitium resulting in distorted lung architecture with compromised alveolar aeration [106]. ILD represents a heterogeneous disease category involving idiopathic and connective tissue disease (CTD) related subtypes [110, 127]. The applicability of TUS to detect IS based on the number of B-lines has primarily been assessed within CTD-ILDs secondary to scleroderma, rheumatoid arthritis, Sjogren's- and antisynthethase syndrome [108, 109, 128, 129]. In several of these studies, an increased number of B-lines correlated with disease severity better than HRCT [110, 128]. Furthermore, the presence of pleural irregularity and increased distance between B-lines were associated with increasing fibrosis and reduced lung physiological parameters such as total lung capacity (TLC) and diffusion capacity of the lung for carbon monoxide (DLCO) (fig. 3)[110]. Similar findings are

observed in idiopathic ILDs [11]. A recent review proposed that TUS identified IS can be used to determine the distribution of an usual interstitial pneumonia pattern when comparing to a HRCT [130]. Though some studies have observed high diagnostic accuracies of TUS-related IS in ILDs compared to HRCT [109], it is questionable whether these are representative due to small study cohorts, misclassification of disease, and disease behaviour [131, 132].

The use of TUS for assessment of patients with coronavirus disease 2019 (COVID-19) has been reported in some initial studies following the outbreak of the pandemic. The typical pattern being reported as being presence of B-lines, IS and lung consolidation [133-135]. The currently published literature is however still relatively scarce and further studies are urgently needed [40, 134].

*Table 5. Recommendations for future research: Interstitial syndrome*

| Area of future research | Question |
|---|---|
| **ILD patients - identification** | Can early TUS detection of IS in ILD suspected patients reduce latency in ILD diagnosis? |
| **IS monitoring and impact** | Can TUS be used to monitor treatment and/or disease development?<br>Studies assessing clinical impact of TUS identified IS are warranted. |
| **IS detection validity** | In patients with IS, does the number of B-lines per LIS relate to underlying cause of disease and disease severity? |
| **IS causality prediction** | Can the combination of IS with visceral pleural pathology be used to distinguish between underlying pulmonary or extrapulmonary conditions? |
| **COVID-19** | What is the role of TUS in screening, diagnosis and monitoring of COVID-19? |

*Conclusions*

The presence of IS is a dynamic surrogate marker of a disease or condition affecting the lung interstitium. As the genesis of IS does not clearly permit the differentiation between 'wet' and 'connective' B-lines, the role of TUS is as an integrated clinical add-on modality together with supplemental diagnostic work-up in order to determine an underlying diagnosis, It may also be used to monitor disease behaviour and treatment response. However, available knowledge on TUS' validity to identify IS in selected disease categories is lacking. This warrants further prospective large-scale studies to determine diagnostic cut-off points for TUS-detected IS before clarifying its clinical use in controlled trials.

**6. Lung consolidation**

*Overview of the evidence and current practice*

The sonographic pattern of lung consolidation has been defined as a subpleural echo-poor region or one with tissue-like echotexture [1]. Animal and human studies have demonstrated that consolidation as it appears at TUS is the result of an increase in density of lung tissue, eventually resulting in complete de-aeration [24, 136]. This is the sole condition in which the lung can be visualized as a solid organ. Since many conditions (e.g. pneumonia, malignancy, pulmonary embolism, atelectasis, contusion, aspiration) may result in complete de-aeration of the lung tissue, lung consolidation is in itself a non-specific finding. Lung consolidation should be differentiated from the presence of B-lines in which the density of the lung tissue is increased but the lung parenchyma remains at least partially aerated and therefore does not allow visualisation of the lung parenchyma.

In order to visualise lung consolidation by the use of TUS, the de-aerated lung area needs to be in contact with the chest wall (with or without interposition of fluid) in a "lung zone" which can be assessed transthoracically. Nonetheless, the diagnostic accuracy of TUS for lung consolidation has been shown to be higher than CXR when CT is used as the reference standard [137]. Studies with more robust designs limiting potential biases are however still warranted [138].

Studies assessing different aspects of using TUS for diagnosing pneumonia, especially community acquired pneumonia, have been published since the 1980's, with a steady increase with the more widespread availability of point-of-care US [26, 139-147]. In a meta-analysis by Orso et al. with a combined sample size of 5,108 patients, the pooled diagnostic accuracy of TUS for diagnosing pneumonia in the ED was: sensitivity 92% (95% confidence interval (CI) 87-96%), specificity 94% (95%CI

87-97%) (fig. 4) [148]. The use of TUS integrated with clinical assessment and other diagnostic modalities including CXR seems to increase the overall diagnostic accuracy, but little is known of the clinical impact of TUS for diagnosing pneumonia [5, 149, 150]. Based on a study by Jones at al it seems that TUS can safely replace the CXR as the initial imaging modality of pneumonia in children and thus reduce radiation exposure [151]. The study did however report frequent use of CXR in the TUS group. Despite studies favouring the use of TUS over CXR for diagnosing pneumonia in adults, the optimal combination of TUS and CXR from a diagnostic and safety perspective has not been established. Several confounding factors in the intensive care setting make TUS diagnosis of pneumonia more complex, reducing the diagnostic accuracy; in this setting, a constellation of TUS additional signs and preliminary microbiological findings conversely yields a high diagnostic accuracy [147].

Despite the fact that using TUS for the diagnosis of pulmonary embolism (PE) was described more than 50 years ago, research in the area has primarily evolved within the last two decades, with several descriptive and diagnostic accuracy studies [15, 29, 152-166]. In a meta-analysis of TUS' diagnostic accuracy for PE, Squizzato et al. reported a bivariate weighted mean sensitivity and specificity of 87.0% (95%CI 79.5-92.0%) and 81.8% (95%CI 71.0-89.3%), respectively [167]. Based on these findings, TUS seems superior to other forms of mono-organ US for diagnosing PE [168, 169]. Several studies have advocated a whole-body-ultrasonography approach combining assessment of the lungs, heart and deep veins in patients with suspected PE or respiratory symptoms. This multi-organ approach is superior to what has been described using a mono-organ approach, but randomized trials assessing potential clinical impact and safety aspects are yet to be published [5, 22, 27, 29, 165, 170].

Several studies describing the use of TUS for assessing various other specific causes of lung consolidation (e.g. atelectasis, tumors, contusion) have been published. The findings and utility of TUS for assessing these conditions may be highly clinically relevant (e.g. assessment of invasive growth) but most of the studies are of a descriptive nature or with relatively small sample sizes (fig. 4) [19, 44, 171-182].

While most of the previous research has aimed to assess the use of TUS as a diagnostic tool, increasing attention is being directed at TUS' abilities as a monitoring tool [183]. The basic principles on how TUS can be used in real-time to monitor a gradual change from normal pattern to interstitial syndrome, lung consolidation, and subsequent reversal of these findings have been well described using a whole lung lavage model [24]. Several TUS monitoring studies have reported promising and clinically relevant results, especially in the intensive care setting of Acute Respiratory Distress Syndrome (ARDS), ventilator-associated pneumonia, and weaning from mechanical ventilation. However, there is still a

lack of robust data on TUS oriented management in improving clinical outcomes [6, 112, 124, 141, 184-190].

*Table 6. Recommendations for future research: Lung consolidation*

| Area of future research | Question |
|---|---|
| **Inter- and intra-observer agreement** | What is the inter- and intra-observer agreement for diagnosing conditions causing lung consolidation in a population of unselected patients with various different lung diseases? |
| **Clinical impact** | Can the apparent good diagnostic accuracy of TUS also lead to improvement in clinically relevant outcomes? |
| **Implementation** | If TUS is to be implemented in clinical practice, how should it then be ideally used alongside other diagnostic modalities? |
| **Monitoring** | Can the use of TUS for monitoring consolidation lead to improvement in clinically relevant outcomes? |

*Conclusions*

Based on currently published studies, TUS has a role as a bedside tool for assessing patients with possible or known lung consolidation, and potentially as a monitoring tool. Future research should focus on TUS' effect on clinically relevant outcomes and how TUS is ideally used alongside other diagnostic modalities.

**7. Diaphragm**

*Overview of the evidence and current practice*

Diaphragm mobility and thickness have been correlated with respiratory muscle strength and lung function in healthy subjects [191, 192]. In 27 patients with hemidiaphragm paralysis, diaphragm mobility during quiet breathing, thickness at functional residual capacity (FRC) and TLC, and diaphragmatic thickening fraction (TF = diaphragmatic thickness variation during respiration) were decreased on the

side of the hemidiaphragm paralysis when compared to the non-paralysed hemidiaphragm [193]. TUS was more sensitive than fluoroscopy to detect hemidiaphragm movement abnormalities, with 4/30 technical failures for fluoroscopy and no failures for TUS [194]. Even though the diaphragm has traditionally been assessed using conventional B- or M-mode, a few studies have indicated that more advanced techniques (e.g. Area method, speckle tracking) might prove more accurate and feasible [195-197].

*TUS assessment of the diaphragm in the intensive care unit*

Spontaneous breathing trials (SBT) are used to predict weaning outcomes in patients on mechanical ventilation (MV); however, 13-26% of those extubated after successful SBT need rescue non-invasive ventilation or are re-intubated within 48-72 hours [198, 199]. Ventilation-induced diaphragm dysfunction is often observed in patients who are difficult to wean off MV, and can be assessed by TUS by measuring diaphragm thickness at end expiration, or more dynamic evaluation of TF or diaphragm excursion (DE) at the zone of apposition of the pleural and peritoneal membranes. Data on TUS parameters and weaning is varied; in a systematic review including 19 studies and 1,071 patients on invasive MV for at least 24 hours, the area under the operating curve for TF was 0.87, with a pooled diagnostic odd's ratio (DOR) 21 (95% CI 11-40), and pooled sensitivity for DE was 75%, DOR 10 (95% CI 4-24)[200]. Another meta-analysis (13 studies and 742 patients) reported pooled sensitivity of 90%, specificity 80%, and DOR 32.5 (95% CI 18.6 - 56.8) for TF, and 80%, 70%, 10.6 (95% CI 4.2 - 27.1) respectively for DE [201]. Low TF was a good predictor of weaning outcome with consistency across studies, and higher DOR suggests that TF has better diagnostic accuracy than DE. Both TF and DE are reproducible [195, 200, 202-206]. In a large multicentre RCT by Vivier et al, diaphragmatic dysfunction identified by TUS was however not associated with an increased risk of extubation failure [207]. Hence, further studies are needed to establish the exact role of TUS assessment of the diaphragm in mechanically ventilated patients.

*Pleural effusion*

The mechanism of breathlessness in pleural effusion is not fully understood. Pleural effusion adversely affects the diaphragm's ability to generate negative pressure, and this is postulated to be a cause of breathlessness. In 14 MV patients on pressure support ventilation with a pleural effusion, respiratory rate decreased, tidal volume increased, and diaphragm displacement and thickening increased after pleural fluid aspiration, with correlation between volume of effusion drained and increase in tidal

diaphragm thickening [208]. When TUS was performed before and after thoracoscopy (14/19 MPE), larger effusion volumes were associated with impaired diaphragm movement compared to effusions with normal diaphragm movement [209]. After pleural aspiration, patients with paradoxical movement of the hemidiaphragm (n=21) had a small but significant improvement in forced expiratory volume in 1 second ($FEV_1$), forced vital capacity (FVC), $PaO_2$, A-a oxygen gradient, and dyspnoea, whereas those without paradoxical movement of the diaphragm (n=41) did not [210]. In a larger study (n=145) of patients with symptomatic pleural effusions, Muruganandan et al. showed TUS demonstrating abnormal hemi-diaphragm shape and movement prior to thoracentesis were independently associated with relief of breathlessness post-drainage [211]. These results suggest diaphragm flattening or abnormal movement are strong indications for aspiration to restore normal diaphragm position and shape, and TUS can aid in this assessment.

*Other*

Diaphragm mobility has been shown to be decreased in COPD patients compared to healthy subjects. DE correlates with lung function [212, 213], and TF in acute exacerbations of COPD complicated by respiratory acidosis correlated with non-invasive ventilation (NIV) failure, longer intensive care unit stay, prolonged MV, need for tracheotomy and mortality [214, 215]. TF predicted nocturnal hypoxaemia in COPD with mild or no daytime hypoxaemia [216].

A review of respiratory muscle imaging modalities in neuromuscular disorders (NMD) identified 9 studies (n=292 patients) that used US [217]. Diaphragm thickness was significantly lower in patients with NMD than in healthy controls [218, 219], and in amyotrophic lateral sclerosis was positively correlated with vital capacity, and negatively correlated with $PaCO_2$, with good interobserver reliability [220].

*Table 7. Recommendations for future research: Diaphragm*

| Area of future research | Question |
|---|---|
| **Novel imaging in transdiaphragmatic pressure assessment** | Does Speckle tracking measurement correlate with transdiaphragmatic pressure? |
| **Novel imaging in diaphragm function assessment** | Is an assessment of the entire hemidiaphragm dome movement using |

| | |
|---|---|
| | the Area method better than a single point measurement using M-mode? |
| **Ventilation** | Can TUS be used to assess patient-ventilator asynchrony? |
| **Risk of extubation failure** | Does TUS have a role for predicting risk of extubation failure? |

*Conclusions*

TUS assessment of the diaphragm has been assessed in various clinical settings. Studies are however mostly small observational studies, the findings of which are not yet well validated, and it is as yet unclear whether TUS findings can be translated to clinically meaningful outcomes. In addition, most studies are either done in healthy volunteers or in small highly selected populations. More data from larger studies is necessary.

**8. US guided procedures**

*Overview of the evidence and current practice*

The increased use of TUS has transformed the scope of procedures the interventional pulmonologist is able to offer. Studies have consistently demonstrated that TUS is safer than clinical examination in direct comparison [221], and reduces risk and cost of iatrogenic complications [222-224]. The current position of most international guidelines is that all pleural procedures (for fluid) should be performed under TUS guidance [3]. Clinical research has highlighted the diagnostic and therapeutic value of pleural interventions in improving key outcomes [225, 226], further challenging the physician to extend their procedural boundaries with the aid of TUS, to meet an increasing patient demand and improve accessibility.

As well as pre-procedure TUS guiding optimal pleural puncture site, real-time US imaging can facilitate thoracentesis of small effusions, where most experts suggest at least 1cm depth is required to be safe [42]. In the setting of loculated effusions, the introducer needle of the aspiration catheter can be guided towards the largest collection of fluid, whilst being used to traverse and break up septations along its course [227]. Post-procedure US can rule out pneumothorax with up to 100% negative predictive value

[85]. The use of colour Doppler can screen for the intercostal artery at the site of intervention pre-procedure as well as confirm absence of post-procedure haemorrhage [228, 229].

TUS provides similar procedural benefits in chest tube insertion. TUS is not currently recommended to guide drainage of pneumothorax. Currently used techniques for chest tube insertion are 'Seldinger' (or guide-wire), blunt dissection and the trocar method. Most of the data suggests that 12-French (F) drain is an appropriate size for the majority of pleural drainage indications, providing a balance of safety, effectiveness and patient comfort [230, 231]. A retrospective analysis of the largest prospective RCT of pleural infection to date (MIST-1; n=405) [232], showed that there was no significant difference in frequency of death or surgery in patients managed with small bore (<15F) chest tubes [231]. In addition, their suitability for intrapleural fibrinolysis makes them an appropriate treatment choice [233]. The optimal size of chest tube for pleurodesis is still an area of controversy with some studies suggesting small bore (<14F) drains may be less effective [234, 235]. Based on these studies the pulmonologist will be able to handle the majority of indications for chest tube insertions by the use of TUS guided insertion of small bore chest tubes.

Indwelling pleural catheters (IPCs) have had a huge impact on the management of recurrent malignant pleural effusions [236], with ongoing studies looking to delineate their place in benign effusions. While TUS plays an established role in guiding initial insertion, it may potentially guide the selection of patients who may be more suitable for IPCs rather than drainage and pleurodesis. The identification of non-expandable lung has been traditionally achieved through drainage of pleural fluid followed by a CXR demonstrating pneumothorax *ex vacuo* or using pleural manometry [237]. Recently published data suggests that speckle tracking imaging analysis and M-mode can identify entrapped lung prior to effusion drainage, allowing upfront choice of definitive management option [84].

Local anaesthetic thoracoscopy (LAT) has now become the gold standard investigation of an undiagnosed unilateral pleural effusion and/or suspected malignancy [238], with an increasing number of centres having routine access [239]. TUS is a vital accessory to LAT, allowing the operator to assess volume of fluid, presence/absence of lung sliding, degree of septation as well as characterising the nature of pleural and diaphragmatic thickening and nodularity. The operator is then able to target entry point for maximal success or conversion to an alternative intervention in the same visit, e.g. if effusion volume deemed to be inadequate. In this circumstance, TUS can facilitate artificial pneumothorax-induction in suitable patients, using real-time introduction of a Boutin needle or blunt dissection [240, 241]. Another option in this setting, and increasingly conducted by physicians in recent years, is TUS-

guided closed pleural biopsy (fig. 4). This technique is particularly advantageous in the elderly or frail patient, as a less invasive alternative to LAT. In the hands of an experienced operator, TUS-guided pleural biopsy outcomes are comparable to those conducted by specialised colleagues in radiology [4]. To date, there is no robust evidence to determine whether newer core-cutting needles are superior to traditional reverse bevel (e.g. Abrams) needles.

TUS-guided lung biopsy conducted by pulmonologists is not only safe and feasible with comparable yields [242, 243], but may also be advantageous over radiologist-led CT guided biopsy due to shorter procedure times, quicker access, and limited risk of complications [244-246] (fig. 4). The supplementary use of more advanced ultrasound modalities such as contrast-enhanced US and elastography could have a role for selecting patients with a high risk of malignancy for subsequent biopsy and to guide the choice of biopsy site thereby increasing the diagnostic yield of the biopsy procedure [247-251].

Pulmonologists performing focused US of structures related to the chest (e.g. neck) and subsequent US guided biopsy has been described and potentially provides a rapid, less invasive method for obtaining a diagnosis and staging patients with suspected thoracic malignancy [252-255]. A potential role has also been described in other diseases with extrapulmonary involvement (e.g. sarcoidosis, tuberculosis) [256-258].

*Table 8. Recommendations for future research: US guided procedures*

| Area of future research | Question |
|---|---|
| **Contrast-enhanced US-guided biopsy** | Can contrast-enhanced US improve diagnostic yield from TUS-guided biopsy through differentiating benign and malignant pleural disease? |
| **Tissue elastography-guided biopsy** | Can TUS elastography reliably allow non-invasive differentiation between benign (soft) and malignant (hard) tissue (pleura/lung) to guide TUS biopsy? |
| **US-guided intervention based on US-guided assessment of breathlessness** | Therapeutic pleural aspiration based on US guided assessment of breathlessness to |

| | |
|---|---|
| | differentiate from non-pleural effusion related breathlessness |

*Conclusions*

TUS is portable, cost-effective and adds diagnostic and therapeutic value in guiding pleural interventions. As an increasing number of practitioners continue to extend the scope and complexity of procedures they undertake, it is important to recognise limitations, both of operator and environment, and remain safe and evidence-based at all times.

**9. Training**

*Overview of the evidence and current practice*

TUS has no direct complications or risks, but important decisions are made based on TUS and competent operators are essential to achieve a high diagnostic accuracy [259-261]. Structured and evidence-based training and assessment of new operators are necessary to ensure competence [2, 262]. A systematic review in training methods and assessment in TUS was published in 2018 with 16 included articles [262]. Since then, 12 articles were published and eligible for inclusion in this statement.

Procedural competence in TUS is often taught at the bed-side, during rounds by an experienced colleague, or at courses with a fixed time frame [3, 263-266]. Unfortunately, the clinical setting can be an un-systematic and stressful environment where learning is dependent on the simultaneous availability of suitable patients and skilled supervisors. Several TUS courses exist, but the fixed time frame makes it impossible to guarantee all trainees reach competence in scanning a range of different pathologies. Additionally, implementation and integration of the technical procedure is just as important as learning the procedure itself, meaning that feedback and clinical discussions with other US operators are important.

Simulation or phantom-based training provides a stress-free and standardized learning environment where individual trainees can continue practicing their technical skills and hand-eye coordination until they have acquired necessary competencies [267, 268]. Trainees' hands-on training time is maximized and the need for expert supervision is reduced which can make simulation-based training more effective and economically advantageous [269].

Hands-on training, whether on simulators or by scanning simulated patients or healthy volunteers, must be based on solid theoretical knowledge to improve the efficacy of training and must be followed by supervised refinement of skills in the clinic until independent competency is acquired. A fixed timeframe or an arbitrary number of performed/supervised procedures do not equal obtained competence; all trainees learn at different learning paces [270].

The European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB), and Royal College of Radiologists have made recommendations about what topics to include in a theoretical curriculum (table 9) [265, 266]. Several studies assess new operators' theoretical knowledge by using theoretical tests covering the same topics, or nearly the same topics [263, 271-273]. Many different learning methods have been used; e.g. classroom-based lectures, group sessions, web-based sessions, or individual homework with books or papers [273-276]. All studies showed increased knowledge regardless of the learning method used, but only one study presented validity evidence for the theoretical test that was used [277].

*Table 9. Comparing the recommendations on theoretical knowledge needed for completion of level 1 practitioner in TUS by different organisations.*

| **The Royal College of Radiologists UK** | **EFSUMB** |
|---|---|
| *Physics and technology, US technique and administration* | *Physics, US techniques and administration* |
| *Sectional and ultrasonic anatomy* | *Anatomy* |
| Right and left hemidiaphragms | Right and left hemidiaphragms |
| Heart | Heart |
| Liver and spleen | Liver and spleen |
| Rib and intercostal space | Rib and intercostal space |
| | Superior and anterior mediastinum |
| | Chest wall |
| | Supraclavicular region |

| | |
|---|---|
| *Pathology in relation to US*<br>Pleural effusion<br>Pleural thickening<br>Consolidated lung<br>Paralysed hemidiaphragm<br>Pericardial effusion | *Pathology in relation to US*<br>Pleural effusion<br>Pleural thickening<br>Consolidated lung<br>Paralysed hemidiaphragm<br>Pericardial effusion<br>Pneumothorax<br>Chest wall abnormalities |

Practical hands-on training was included in a majority of studies [263, 264, 272, 274-276, 278-282]. Several hands-on training modalities are represented and probably useful, including animal models, virtual reality simulators, phantoms, and humans (healthy volunteers or patients with pulmonary disease/symptoms). However, the study designs and methods were heterogeneous, outcomes measures without evidence of validity were used, and results were difficult to compare. Two studies have presented simulator models with validity evidence for practical assessment [283, 284], several tools for assessment in a clinical setting were identified [285-287], and a guide for a minimum training standard with both theoretical and practical training by experienced TUS operators is proposed [288].

*Gaps in knowledge and/or evidence in training and assessing TUS*

Just as physicians are expected to treat and practise according to best medical evidence, educators should use the best available evidence to guide their education in the best possible direction [289]. Geographical, financial, and administrative aspects can affect the possibilities to educate on the highest possible level. No studies have assessed the effect of different hands-on training modalities, the educational intervention on an institutional level, or used patient outcomes as a primary endpoint. These studies are needed to propose recommendations on a European level.

*Table 10. Recommendations for future research: Training*

| Area of future research | Question |
|---|---|
| **Comparison of clinical assessment tools** | What advantages and disadvantages do |

| | |
|---|---|
| | the current assessment tools have and which is more effective in an educational setting? |
| **Patient related outcome of an educational intervention** | Can an educational intervention increase patient outcome? |
| **Effect of an educational intervention on clinical decision making** | Can an educational intervention in TUS improve the integration of TUS with the clinical decision-making process? |
| **Patient communication** | How can patient communication during TUS be trained during a TUS course and subsequently assessed? |

*Conclusion*

A TUS curriculum should be well planned and evidence-based similar to the requirement for clinical practice. The ERS have launched such a training program in 2020. Heterogeneous case load, scarcity of expert supervision, and different learning paces are major challenges to education in a clinical setting. Suitable, objective assessments with solid evidence of validity are necessary to ensure competence at each step before independent practice moving towards competency-based training and Entrusted Professional Activities.

**10. Patient perspectives**

*Overview of the evidence*

The literature search could not identify any quantitative or qualitative studies specifically addressing this topic. Four articles were included for review addressing patient discomfort and satisfaction with US in emergency department settings and included but were not limited to TUS [290-293]. Key themes identified were high patient satisfaction, low levels of discomfort with bedside US, and patient-provider interactions.

*Patient satisfaction*

Bedside US in the emergency department was found to increase patient satisfaction in two studies [290, 291]. Heating the US gel did not significantly increase patient satisfaction, overall satisfaction with the emergency department visit, or patient perceptions of physician professionalism [293]. Patient feedback indicated that bedside scanning is also welcome outside the emergency setting, particularly if the patient is having trouble breathing as it avoids the additional strain of visiting multiple hospital departments. Patients may take comfort from understanding the lower risks of ultrasound when compared to other imaging techniques, such as CT. Exposure to radiation is of concern to patients, particularly if multiple scans are required over time.

*Discomfort*

The majority of patients do not experience discomfort during point-of-care US of the heart, lungs and deep veins [292]. An increased level of discomfort was most often due to an underlying condition (e.g. rib fracture) or the result of an intervention (e.g. resuscitation) causing localised pain. Most patients, including those who experience some discomfort, would be willing to accept US assessment in future. Professionals should inform patients with an underlying condition that they may experience discomfort before performing US.

*Patient-provider interactions*

Bedside US may improve communication between patients and professionals by offering the chance to explain examination results and provide a clearer understanding of the patient's diagnosis [290, 291]. Professionals' communication skills play a crucial role in patient experience of imaging. Professionals should be mindful of the language they use and avoid jargon when discussing the procedure and results.

*Table 11. Recommendations for future research: Patient perspectives*

| Area of future research | Question |
|---|---|
| **Patient experiences** | What are the patient experiences of TUS in a variety of settings (e.g. emergency department, intensive care unit, outpatient clinic) |
| **Patient preferences** | What are the patient experiences and preferences of TUS alongside other |

| | |
|---|---|
| | diagnostic and imaging tools (e.g. sequencing, overall burden of diagnostic testing) |
| **Patients with lung conditions** | What are the experiences and preferences of TUS for patients with existing lung conditions? |
| **Patient information** | What are patients' information needs before, during and after TUS? |
| **Communication techniques** | What are the most effective communication techniques between professionals and patients undergoing TUS? |

*Conclusions*

TUS is acceptable to most patients in emergency department settings. Further qualitative studies are needed to fully understand patient experiences and preferences of TUS.

**Overall conclusions**

Continued clinical use and research has established TUS as a key-tool and skill for the modern pulmonologist. The increased availability of US equipment has helped facilitate the implementation and use of TUS across Europe and world-wide. Since US examinations historically have been provided by other specialties, many of the national and international respiratory societies have no tradition or recommendations for the use of TUS. The clinical use of TUS by pulmonologists is therefore in many ways far ahead of the guidelines and recommendations. A potential advantage of TUS is the relatively short pathway from research to clinical implementation, with the major disadvantage however being a general lack of consensus, and research results being implemented without sufficient scientific evidence to support such implementation. In order to achieve a further "professionalisation" of pulmonologists performing TUS, societal guidelines and recommendations from national and international respiratory societies are called for. The aim of this task force statement was to provide a state-of-the art summary guide for the pulmonologist of the current use of TUS and to identify key future research areas. This first

official ERS statement on TUS is an important step to further advance professionalisation of TUS at an international level, which will in turn benefit the many patients being assessed by physicians in this way on a daily basis.

**Acknowledgements**

We thank David Rigau Comas for providing valuable methodological assistance and support during the making of the statement.

**References**


1. Volpicelli G, Elbarbary M, Blaivas M, Lichtenstein DA, Mathis G, Kirkpatrick AW, Melniker L, Gargani L, Noble VE, Via G, Dean A, Tsung JW, Soldati G, Copetti R, Bouhemad B, Reissig A, Agricola E, Rouby JJ, Arbelot C, Liteplo A, Sargsyan A, Silva F, Hoppmann R, Breitkreutz R, Seibel A, Neri L, Storti E, Petrovic T, International Liaison Committee on Lung Ultrasound for International Consensus Conference on Lung U. International evidence-based recommendations for point-of-care lung ultrasound. *Intensive care medicine* 2012: 38(4): 577-591.
2. Laursen CB RN, Volpicelli G. ERS Monograph - Thoracic Ultrasound. *In:* Society ER, ed., 2018.
3. Havelock T, Teoh R, Laws D, Gleeson F, Group BTSPDG. Pleural procedures and thoracic ultrasound: British Thoracic Society Pleural Disease Guideline 2010. *Thorax* 2010: 65 Suppl 2: ii61-76.
4. Hallifax RJ, Corcoran JP, Ahmed A, Nagendran M, Rostom H, Hassan N, Maruthappu M, Psallidas I, Manuel A, Gleeson FV, Rahman NM. Physician-based ultrasound-guided biopsy for diagnosing pleural disease. *Chest* 2014: 146(4): 1001-1006.
5. Laursen CB, Sloth E, Lassen AT, Christensen R, Lambrechtsen J, Madsen PH, Henriksen DP, Davidsen JR, Rasmussen F. Point-of-care ultrasonography in patients admitted with respiratory symptoms: a single-blind, randomised controlled trial. *The Lancet Respiratory medicine* 2014: 2(8): 638-646.
6. Bouhemad B, Liu ZH, Arbelot C, Zhang M, Ferarri F, Le-Guen M, Girard M, Lu Q, Rouby JJ. Ultrasound assessment of antibiotic-induced pulmonary reaeration in ventilator-associated pneumonia. *Critical care medicine* 2010: 38(1): 84-92.
7. Mathis G, Sparchez Z, Volpicelli G. EFSUMB - European Course Book. Chest Sonography. 2010 [cited; Available from: http://www.efsumb.org/intro/home.asp
8. Via G, Hussain A, Wells M, Reardon R, ElBarbary M, Noble VE, Tsung JW, Neskovic AN, Price S, Oren-Grinberg A, Liteplo A, Cordioli R, Naqvi N, Rola P, Poelaert J, Gulic TG, Sloth E, Labovitz A, Kimura B, Breitkreutz R, Masani N, Bowra J, Talmor D, Guarracino F, Goudie A, Xiaoting W, Chawla R, Galderisi M, Blaivas M, Petrovic T, Storti E, Neri L, Melniker L. International evidence-based recommendations for focused cardiac ultrasound. *Journal of the American Society of Echocardiography : official publication of the American Society of Echocardiography* 2014: 27(7): 683 e681-683 e633.
9. Targhetta R. Ultrasonographic approach to diagnosing hydropneumothorax. *CHEST Journal* 1992: 101(4): 931.
10. Targhetta R, Chavagneux R, Bourgeois JM, Dauzat M, Balmes P, Pourcelot L. Sonographic approach to diagnosing pulmonary consolidation. *Journal of ultrasound in medicine : official journal of the American Institute of Ultrasound in Medicine* 1992: 11(12): 667-672.
11. Reissig A, Kroegel C. Transthoracic sonography of diffuse parenchymal lung disease: the role of comet tail artifacts. *Journal of ultrasound in medicine : official journal of the American Institute of Ultrasound in Medicine* 2003: 22(2): 173-180.
12. Kirkpatrick AW, Sirois M, Laupland KB, Liu D, Rowan K, Ball CG, Hameed SM, Brown R, Simons R, Dulchavsky SA, Hamiilton DR, Nicolaou S. Hand-Held Thoracic Sonography for Detecting Post-Traumatic Pneumothoraces: The Extended Focused Assessment With

Sonography For Trauma (EFAST). *The Journal of Trauma: Injury, Infection, and Critical Care* 2004: 57(2): 288-295.
13. Jambrik Z, Monti S, Coppola V, Agricola E, Mottola G, Miniati M, Picano E. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. *The American journal of cardiology* 2004: 93(10): 1265-1270.
14. Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine* 2005: 12(9): 844-849.
15. Mathis G, Blank W, Reissig A, Lechleitner P, Reuss J, Schuler A, Beckh S. Thoracic ultrasound for diagnosing pulmonary embolism: a prospective multicenter study of 352 patients. *Chest* 2005: 128(3): 1531-1538.
16. Agricola E, Bove T, Oppizzi M, Marino G, Zangrillo A, Margonato A, Picano E. "Ultrasound comet-tail images": a marker of pulmonary edema: a comparative study with wedge pressure and extravascular lung water. *Chest* 2005: 127(5): 1690-1695.
17. Volpicelli G, Mussa A, Garofalo G, Cardinale L, Casoli G, Perotto F, Fava C, Frascisco M. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. *The American journal of emergency medicine* 2006: 24(6): 689-696.
18. Bedetti G, Gargani L, Corbisiero A, Frassi F, Poggianti E, Mottola G. Evaluation of ultrasound lung comets by hand-held echocardiography. *Cardiovascular ultrasound* 2006: 4: 34.
19. Soldati G, Testa A, Silva FR, Carbone L, Portale G, Silveri NG. Chest ultrasonography in lung contusion. *Chest* 2006: 130(2): 533-538.
20. Picano E, Frassi F, Agricola E, Gligorova S, Gargani L, Mottola G. Ultrasound lung comets: a clinically useful sign of extravascular lung water. *Journal of the American Society of Echocardiography : official publication of the American Society of Echocardiography* 2006: 19(3): 356-363.
21. Fagenholz PJ, Gutman JA, Murray AF, Noble VE, Thomas SH, Harris NS. Chest ultrasonography for the diagnosis and monitoring of high-altitude pulmonary edema. *Chest* 2007: 131(4): 1013-1018.
22. Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest* 2008: 134(1): 117-125.
23. Copetti R, Soldati G, Copetti P. Chest sonography: a useful tool to differentiate acute cardiogenic pulmonary edema from acute respiratory distress syndrome. *Cardiovascular ultrasound* 2008: 6: 16.
24. Via G, Lichtenstein D, Mojoli F, Rodi G, Neri L, Storti E, Klersy C, Iotti G, Braschi A. Whole lung lavage: a unique model for ultrasound assessment of lung aeration changes. *Intensive care medicine* 2010: 36(6): 999-1007.
25. Prosen G, Klemen P, Strnad M, Grmec S. Combination of lung ultrasound (a comet-tail sign) and N-terminal pro-brain natriuretic peptide in differentiating acute heart failure from chronic obstructive pulmonary disease and asthma as cause of acute dyspnea in prehospital emergency setting. *Critical care* 2011: 15(2): R114.
26. Reissig A, Copetti R, Mathis G, Mempel C, Schuler A, Zechner P, Aliberti S, Neumann R, Kroegel C, Hoyer H. Lung ultrasound in the diagnosis and follow-up of community-acquired pneumonia: a prospective, multicenter, diagnostic accuracy study. *Chest* 2012: 142(4): 965-972.

27. Laursen CB, Sloth E, Lambrechtsen J, Lassen AT, Madsen PH, Henriksen DP, Davidsen JR, Rasmussen F. Focused sonography of the heart, lungs, and deep veins identifies missed life-threatening conditions in admitted patients with acute respiratory symptoms. *Chest* 2013: 144(6): 1868-1875.
28. Laursen CB, Hanselmann A, Posth S, Mikkelsen S, Videbaek L, Berg H. Prehospital lung ultrasound for the diagnosis of cardiogenic pulmonary oedema: a pilot study. *Scandinavian journal of trauma, resuscitation and emergency medicine* 2016: 24(1): 96.
29. Nazerian P, Volpicelli G, Gigli C, Becattini C, Sferrazza Papa GF, Grifoni S, Vanni S, Ultrasound Wells study g. Diagnostic performance of Wells score combined with point-of-care lung and venous ultrasound in suspected pulmonary embolism. *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine* 2016.
30. Dalen H, Gundersen GH, Skjetne K, Haug HH, Kleinau JO, Norekval TM, Graven T. Feasibility and reliability of pocket-size ultrasound examinations of the pleural cavities and vena cava inferior performed by nurses in an outpatient heart failure clinic. *Eur J Cardiovasc Nurs* 2015: 14(4): 286-293.
31. Graven T, Wahba A, Hammer AM, Sagen O, Olsen O, Skjetne K, Kleinau JO, Dalen H. Focused ultrasound of the pleural cavities and the pericardium by nurses after cardiac surgery. *Scandinavian cardiovascular journal : SCJ* 2015: 49(1): 56-63.
32. Volpicelli G, Cardinale L, Mussa A, Valeria C. Diagnosis of cardiogenic pulmonary edema by sonography limited to the anterior lung. *Chest* 2009: 135(3): 883; author reply 883-884.
33. Frasure SE, Matilsky DK, Siadecki SD, Platz E, Saul T, Lewiss RE. Impact of patient positioning on lung ultrasound findings in acute heart failure. *Eur Heart J Acute Cardiovasc Care* 2015: 4(4): 326-332.
34. Scali MC, Zagatina A, Simova I, Zhuravskaya N, Ciampi Q, Paterni M, Marzilli M, Carpeggiani C, Picano E. B-lines with Lung Ultrasound: The Optimal Scan Technique at Rest and During Stress. *Ultrasound Med Biol* 2017: 43(11): 2558-2566.
35. Anderson KL, Fields JM, Panebianco NL, Jenq KY, Marin J, Dean AJ. Inter-rater reliability of quantifying pleural B-lines using multiple counting methods. *Journal of ultrasound in medicine : official journal of the American Institute of Ultrasound in Medicine* 2013: 32(1): 115-120.
36. Ketelaars R, Gulpinar E, Roes T, Kuut M, van Geffen GJ. Which ultrasound transducer type is best for diagnosing pneumothorax? *Crit Ultrasound J* 2018: 10(1): 27.
37. Bobbia X, Chabannon M, Chevallier T, de La Coussaye JE, Lefrant JY, Pujol S, Claret PG, Zieleskiewicz L, Roger C, Muller L. Assessment of five different probes for lung ultrasound in critically ill patients: A pilot study. *Am J Emerg Med* 2018: 36(7): 1265-1269.
38. Helland G, Gaspari R, Licciardo S, Sanseverino A, Torres U, Emhoff T, Blehar D. Comparison of Four Views to Single-view Ultrasound Protocols to Identify Clinically Significant Pneumothorax. *Acad Emerg Med* 2016: 23(10): 1170-1175.
39. Tasci O, Hatipoglu ON, Cagli B, Ermis V. Sonography of the chest using linear-array versus sector transducers: Correlation with auscultation, chest radiography, and computed tomography. *J Clin Ultrasound* 2016: 44(6): 383-389.
40. World Federation for Ultrasound in M, Biology Safety C, Abramowicz JS, Basseal JM. World Federation for Ultrasound in Medicine and Biology Position Statement: How to Perform a Safe Ultrasound Examination and Clean Equipment in the Context of COVID-19. *Ultrasound in medicine & biology* 2020: 46(7): 1821-1826.

41. Carter BW, Benveniste MF, Betancourt SL, de Groot PM, Lichtenberger JP, 3rd, Amini B, Abbott GF. Imaging Evaluation of Malignant Chest Wall Neoplasms. *Radiographics* 2016: 36(5): 1285-1306.
42. Marchetti G, Arondi S, Baglivo F, Lonni S, Quadri F, Valsecchi A, Venturoli N, Ceruti P. New insights in the use of pleural ultrasonography for diagnosis and treatment of pleural disease. *Clin Respir J* 2018: 12(6): 1993-2005.
43. Mullan CP, Madan R, Trotman-Dickenson B, Qian X, Jacobson FL, Hunsaker A. Radiology of chest wall masses. *AJR American journal of roentgenology* 2011: 197(3): W460-470.
44. 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(4): 881-886.
45. Sripathi S, Mahajan A. Comparative study evaluating the role of color Doppler sonography and computed tomography in predicting chest wall invasion by lung tumors. *Journal of ultrasound in medicine : official journal of the American Institute of Ultrasound in Medicine* 2013: 32(9): 1539-1546.
46. Battle C, Hayward S, Eggert S, Evans PA. Comparison of the use of lung ultrasound and chest radiography in the diagnosis of rib fractures: a systematic review. *Emergency medicine journal : EMJ* 2019: 36(3): 185-190.
47. Tobin C, Lee YCG, Gleeson F, Rahman N, Feller-Kopman D. Pleural Ultrasound for Clinicians: A Text and E-book. CRC Press, 2014.
48. Wallbridge P, Parry SM, Das S, Law C, Hammerschlag G, Irving L, Hew M, Steinfort D. Parasternal intercostal muscle ultrasound in chronic obstructive pulmonary disease correlates with spirometric severity. *Sci Rep* 2018: 8(1): 15274.
49. Nakanishi N, Oto J, Ueno Y, Nakataki E, Itagaki T, Nishimura M. Change in diaphragm and intercostal muscle thickness in mechanically ventilated patients: a prospective observational ultrasonography study. *J Intensive Care* 2019: 7: 56.
50. Umbrello M, Formenti P, Lusardi AC, Guanziroli M, Caccioppola A, Coppola S, Chiumello D. Oesophageal pressure and respiratory muscle ultrasonographic measurements indicate inspiratory effort during pressure support ventilation. *British journal of anaesthesia* 2020: 125(1): e148-e157.
51. Dres M, Dube BP, Goligher E, Vorona S, Demiri S, Morawiec E, Mayaux J, Brochard L, Similowski T, Demoule A. Usefulness of Parasternal Intercostal Muscle Ultrasound during Weaning from Mechanical Ventilation. *Anesthesiology* 2020: 132(5): 1114-1125.
52. Kanai M, Sekiguchi H. Avoiding vessel laceration in thoracentesis: a role of vascular ultrasound with color Doppler. *Chest* 2015: 147(1): e5-e7.
53. Adams FV, Galati V. M-mode ultrasonic localization of pleural effusion. Use in patients with nondiagnostic physical and roentgenographic examinations. *JAMA* 1978: 239(17): 1761-1764.
54. Gryminski J, Krakowka P, Lypacewicz G. The diagnosis of pleural effusion by ultrasonic and radiologic techniques. *Chest* 1976: 70(1): 33-37.
55. Doust BD, Baum JK, Maklad NF, Doust VL. Ultrasonic evaluation of pleural opacities. *Radiology* 1975: 114(1): 135-140.
56. Respiratory Medicine. 2019 [cited 2019 2/7]; Available from: https://www.jrcptb.org.uk/specialties/respiratory-medicine
57. Kocijancic I. Diagnostic imaging of small amounts of pleural fluid: pleural effusion vs. physiologic pleural fluid. *Collegium antropologicum* 2007: 31(4): 1195-1199.

58. Kocijancic I, Vidmar K, Ivanovi-Herceg Z. Chest sonography versus lateral decubitus radiography in the diagnosis of small pleural effusions. *Journal of clinical ultrasound : JCU* 2003: 31(2): 69-74.
59. Grimberg A, Shigueoka DC, Atallah AN, Ajzen S, Iared W. Diagnostic accuracy of sonography for pleural effusion: systematic review. *Sao Paulo medical journal = Revista paulista de medicina* 2010: 128(2): 90-95.
60. Wu RG, Yuan A, Liaw YS, Chang DB, Yu CJ, Wu HD, Kuo SH, Luh KT, Yang PC. Image comparison of real-time gray-scale ultrasound and color Doppler ultrasound for use in diagnosis of minimal pleural effusion. *American journal of respiratory and critical care medicine* 1994: 150(2): 510-514.
61. Kalokairinou-Motogna M, Maratou K, Paianid I, Soldatos T, Antipa E, Tsikkini A, Baltas CS. Application of color Doppler ultrasound in the study of small pleural effusion. *Medical ultrasonography* 2010: 12(1): 12-16.
62. Stevic R, Colic N, Bascarevic S, Kostic M, Moskovljevic D, Savic M, Ercegovac M. Sonographic Indicators for Treatment Choice and Follow-Up in Patients with Pleural Effusion. *Canadian respiratory journal* 2018: 2018: 9761583.
63. Svigals PZ, Chopra A, Ravenel JG, Nietert PJ, Huggins JT. The accuracy of pleural ultrasonography in diagnosing complicated parapneumonic pleural effusions. *Thorax* 2017: 72(1): 94-95.
64. Diacon AH, Brutsche MH, Soler M. Accuracy of pleural puncture sites: a prospective comparison of clinical examination with ultrasound. *Chest* 2003: 123(2): 436-441.
65. Qureshi NR, Rahman NM, Gleeson FV. Thoracic ultrasound in the diagnosis of malignant pleural effusion. *Thorax* 2009: 64(2): 139-143.
66. Qureshi NR. Basic Physics of Diagnostic Ultrasound and Control ("Knobology"). *In:* Tobin CL, Lee YCG, Gleeson FV, Feller-Kopman D, Rahman NM, eds. Pleural Ultrasound for Clinicians. CRC Press, FL, USA, 2014.
67. Chen HJ, Tu CY, Ling SJ, Chen W, Chiu KL, Hsia TC, Shih CM, Hsu WH. Sonographic appearances in transudative pleural effusions: not always an anechoic pattern. *Ultrasound in medicine & biology* 2008: 34(3): 362-369.
68. Yang PC, Luh KT, Chang DB, Wu HD, Yu CJ, Kuo SH. Value of sonography in determining the nature of pleural effusion: analysis of 320 cases. *AJR American journal of roentgenology* 1992: 159(1): 29-33.
69. Hassan M, Rizk R, Essam H, Abouelnour A. Validation of equations for pleural effusion volume estimation by ultrasonography. *Journal of ultrasound* 2017: 20(4): 267-271.
70. Kataoka H. Ultrasound pleural effusion sign as a useful marker for identifying heart failure worsening in established heart failure patients during follow-up. *Congestive heart failure* 2012: 18(5): 272-277.
71. Gurung P, Goldblatt M, Huggins JT, Doelken P, Nietert PJ, Sahn SA. Pleural fluid analysis and radiographic, sonographic, and echocardiographic characteristics of hepatic hydrothorax. *Chest* 2011: 140(2): 448-453.
72. Sajadieh H, Afzali F, Sajadieh V, Sajadieh A. Ultrasound as an alternative to aspiration for determining the nature of pleural effusion, especially in older people. *Annals of the New York Academy of Sciences* 2004: 1019: 585-592.
73. Evans AL, Gleeson FV. Radiology in pleural disease: state of the art. *Respirology* 2004: 9(3): 300-312.

74. Gorg C, Restrepo I, Schwerk WB. Sonography of malignant pleural effusion. *European radiology* 1997: 7(8): 1195-1198.
75. Bugalho A, Ferreira D, Dias SS, Schuhmann M, Branco JC, Marques Gomes MJ, Eberhardt R. The diagnostic value of transthoracic ultrasonographic features in predicting malignancy in undiagnosed pleural effusions: a prospective observational study. *Respiration; international review of thoracic diseases* 2014: 87(4): 270-278.
76. Chian CF, Su WL, Soh LH, Yan HC, Perng WC, Wu CP. Echogenic swirling pattern as a predictor of malignant pleural effusions in patients with malignancies. *Chest* 2004: 126(1): 129-134.
77. Lane AB, Petteys S, Ginn M, Nations JA. Clinical Importance of Echogenic Swirling Pleural Effusions. *Journal of ultrasound in medicine : official journal of the American Institute of Ultrasound in Medicine* 2016: 35(4): 843-847.
78. Park CS, Chung WM, Lim MK, Cho CH, Suh CH, Chung WK. Transcatheter instillation of urokinase into loculated pleural effusion: analysis of treatment effect. *AJR American journal of roentgenology* 1996: 167(3): 649-652.
79. Lin FC, Chou CW, Chang SC. Usefulness of the suspended microbubble sign in differentiating empyemic and nonempyemic hydropneumothorax. *Journal of ultrasound in medicine : official journal of the American Institute of Ultrasound in Medicine* 2001: 20(12): 1341-1345.
80. Lai YF, Su MC, Weng HH, Wu JT, Chiu CT. Sonographic septation: a predictor of sequelae of tuberculous pleurisy after treatment. *Thorax* 2009: 64(9): 806-809.
81. Kearney SE, Davies CW, Davies RJ, Gleeson FV. Computed tomography and ultrasound in parapneumonic effusions and empyema. *Clinical radiology* 2000: 55(7): 542-547.
82. James CA, Braswell LE, Pezeshkmehr AH, Roberson PK, Parks JA, Moore MB. Stratifying fibrinolytic dosing in pediatric parapneumonic effusion based on ultrasound grade correlation. *Pediatric radiology* 2017: 47(1): 89-95.
83. Hallifax RJ, Rahman NM. Image Interpretation: Pleural Effusions. *In:* Tobin CL, Lee YCG, Gleeson FV, Feller-Kopman D, Rahman NM, eds. Pleural Ultrasound for Clinicians. CRC Press, FL, USA, 2014.
84. Salamonsen MR, Lo AKC, Ng ACT, Bashirzadeh F, Wang WYS, Fielding DIK. Novel use of pleural ultrasound can identify malignant entrapped lung prior to effusion drainage. *Chest* 2014: 146(5): 1286-1293.
85. Lichtenstein DA. A Bedside Ultrasound Sign Ruling Out Pneumothorax in the Critically Ill. Lung Sliding. *CHEST Journal* 1995: 108(5): 1345.
86. Lichtenstein D, Meziere G, Biderman P, Gepner A. The comet-tail artifact: an ultrasound sign ruling out pneumothorax. *Intensive care medicine* 1999: 25(4): 383-388.
87. Lichtenstein D, Meziere G, Biderman P, Gepner A. The "lung point": an ultrasound sign specific to pneumothorax. *Intensive care medicine* 2000: 26(10): 1434-1440.
88. Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung sliding. *Chest* 1995: 108(5): 1345-1348.
89. Hallifax RJ, Talwar A, Wrightson JM, Edey A, Gleeson FV. State-of-the-art: Radiological investigation of pleural disease. *Respir Med* 2017: 124: 88-99.
90. Slater A, Goodwin M, Anderson KE, Gleeson FV. COPD can mimic the appearance of pneumothorax on thoracic ultrasound. *Chest* 2006: 129(3): 545-550.

91. Lichtenstein D, Meziere G, Biderman P, Gepner A. The comet-tail artifact: an ultrasound sign ruling out pneumothorax. *Intensive Care Med* 1999: 25(4): 383-388.
92. Hew M, Tay TR. The efficacy of bedside chest ultrasound: from accuracy to outcomes. *Eur Respir Rev* 2016: 25(141): 230-246.
93. Volpicelli G, Boero E, Sverzellati N, Cardinale L, Busso M, Boccuzzi F, Tullio M, Lamorte A, Stefanone V, Ferrari G, Veltri A, Frascisco MF. Semi-quantification of pneumothorax volume by lung ultrasound. *Intensive Care Med* 2014: 40(10): 1460-1467.
94. Ding W, Shen Y, Yang J, He X, Zhang M. Diagnosis of pneumothorax by radiography and ultrasonography: a meta-analysis. *Chest* 2011: 140(4): 859-866.
95. Alrajhi K, Woo MY, Vaillancourt C. Test characteristics of ultrasonography for the detection of pneumothorax: a systematic review and meta-analysis. *Chest* 2012: 141(3): 703-708.
96. Alrajab S, Youssef AM, Akkus NI, Caldito G. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. *Crit Care* 2013: 17(5): R208.
97. Ebrahimi A, Yousefifard M, Mohammad Kazemi H, Rasouli HR, Asady H, Moghadas Jafari A, Hosseini M. Diagnostic Accuracy of Chest Ultrasonography versus Chest Radiography for Identification of Pneumothorax: A Systematic Review and Meta-Analysis. *Tanaffos* 2014: 13(4): 29-40.
98. Chung MJ, Goo JM, Im JG, Cho JM, Cho SB, Kim SJ. Value of high-resolution ultrasound in detecting a pneumothorax. *Eur Radiol* 2005: 15(5): 930-935.
99. Reissig A, Kroegel C. Accuracy of transthoracic sonography in excluding post-interventional pneumothorax and hydropneumothorax. Comparison to chest radiography. *European journal of radiology* 2005: 53(3): 463-470.
100. Sartori S, Tombesi P, Trevisani L, Nielsen I, Tassinari D, Abbasciano V. Accuracy of transthoracic sonography in detection of pneumothorax after sonographically guided lung biopsy: prospective comparison with chest radiography. *AJR Am J Roentgenol* 2007: 188(1): 37-41.
101. Galbois A, Ait-Oufella H, JL B, Kofman T, Bottero J, Viennot S, Rabate C, Jabbouri S, Bouzeman A, B. G, Offenstadt G, Maury E. Pleural ultrasound compared with chest radiographic detection of pneumothorax resolution after drainage. *Chest* 2010: 138(3): 648-655.
102. Lichtenstein D, Meziere G, Biderman P, Gepner A, Barre O. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. *American journal of respiratory and critical care medicine* 1997: 156(5): 1640-1646.
103. Lichtenstein DA. BLUE-protocol and FALLS-protocol: two applications of lung ultrasound in the critically ill. *Chest* 2015: 147(6): 1659-1670.
104. Soldati G, Demi M. The use of lung ultrasound images for the differential diagnosis of pulmonary and cardiac interstitial pathology. *Journal of ultrasound* 2017: 20(2): 91-96.
105. Volpicelli G. Lung sonography. *J Ultrasound Med* 2013: 32(1): 165-171.
106. Dietrich CF, Mathis G, Blaivas M, Volpicelli G, Seibel A, Wastl D, Atkinson NS, Cui XW, Fan M, Yi D. Lung B-line artefacts and their use. *J Thorac Dis* 2016: 8(6): 1356-1365.
107. Volpicelli G, Elbarbary M, Blaivas M, Lichtenstein DA, Mathis G, Kirkpatrick AW, Melniker L, Gargani L, Noble VE, Via G, Dean A, Tsung JW, Soldati G, Copetti R, Bouhemad B, Reissig A, Agricola E, Rouby JJ, Arbelot C, Liteplo A, Sargsyan A, Silva F, Hoppmann R, Breitkreutz R, Seibel A, Neri L, Storti E, Petrovic T. International evidence-based

recommendations for point-of-care lung ultrasound. *Intensive Care Med* 2012: 38(4): 577-591.
108. Gargani L, Doveri M, D'Errico L, Frassi F, Bazzichi ML, Delle Sedie A, Scali MC, Monti S, Mondillo S, Bombardieri S, Caramella D, Picano E. Ultrasound lung comets in systemic sclerosis: a chest sonography hallmark of pulmonary interstitial fibrosis. *Rheumatology* 2009: 48(11): 1382-1387.
109. Barskova T, Gargani L, Guiducci S, Randone SB, Bruni C, Carnesecchi G, Conforti ML, Porta F, Pignone A, Caramella D, Picano E, Cerinic MM. Lung ultrasound for the screening of interstitial lung disease in very early systemic sclerosis. *AnnRheumDis* 2013: 72(3): 390-395.
110. Hasan AA, Makhlouf HA. B-lines: Transthoracic chest ultrasound signs useful in assessment of interstitial lung diseases. *Ann Thorac Med* 2014: 9(2): 99-103.
111. Davidsen JR, Bendstrup E, Henriksen DP, Graumann O, Laursen CB. Lung ultrasound has limited diagnostic value in rare cystic lung diseases: a cross-sectional study. *Eur Clin Respir J* 2017: 4(1): 1330111.
112. Davidsen JR, Schultz HHL, Henriksen DP, Iversen M, Kalhauge A, Carlsen J, Perch M, Graumann O, Laursen CB. Lung Ultrasound in the Assessment of Pulmonary Complications After Lung Transplantation. *Ultraschall Med* 2018.
113. Gargani L. Interstitial syndrome. *In:* Laursen CB, Rahman NM, Volpicelli G, eds. . *Thoracic Ultrasund [ERS Monograph] Sheffield, European Respiratory Society, 2018*: pp. 75-86 [https://doi.org/10.1183/2312508X.10006517].
114. DeFouw DO, Berendsen PB. Morphological changes in isolated perfused dog lungs after acute hydrostatic edema. *Circ Res* 1978: 43(1): 72-82.
115. Maw AM, Hassanin A, Ho PM, McInnes MDF, Moss A, Juarez-Colunga E, Soni NJ, Miglioranza MH, Platz E, DeSanto K, Sertich AP, Salame G, Daugherty SL. 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 network open* 2019: 2(3): e190703.
116. Pivetta E, Goffi A, Lupia E, Tizzani M, Porrino G, Ferreri E, Volpicelli G, Balzaretti P, Banderali A, Iacobucci A, Locatelli S, Casoli G, Stone MB, Maule MM, Baldi I, Merletti F, Cibinel GA, Baron P, Battista S, Buonafede G, Busso V, Conterno A, Del Rizzo P, Ferrera P, Pecetto PF, Moiraghi C, Morello F, Steri F, Ciccone G, Calasso C, Caserta MA, Civita M, Condo C, D'Alessandro V, Del Colle S, Ferrero S, Griot G, Laurita E, Lazzero A, Lo Curto F, Michelazzo M, Nicosia V, Palmari N, Ricchiardi A, Rolfo A, Rostagno R, Bar F, Boero E, Frascisco M, Micossi I, Mussa A, Stefanone V, Agricola R, Cordero G, Corradi F, Runzo C, Soragna A, Sciullo D, Vercillo D, Allione A, Artana N, Corsini F, Dutto L, Lauria G, Morgillo T, Tartaglino B, Bergandi D, Cassetta I, Masera C, Garrone M, Ghiselli G, Ausiello L, Barutta L, Bernardi E, Bono A, Forno D, Lamorte A, Lison D, Lorenzati B, Maggio E, Masi I, Maggiorotto M, Novelli G, Panero F, Perotto M, Ravazzoli M, Saglio E, Soardo F, Tizzani A, Tizzani P, Tullio M, Ulla M, Romagnoli E. Lung Ultrasound-Implemented Diagnosis of Acute Decompensated Heart Failure in the ED: A SIMEU Multicenter Study. *Chest* 2015: 148(1): 202-210.
117. Pivetta E, Goffi A, Nazerian P, Castagno D, Tozzetti C, Tizzani P, Tizzani M, Porrino G, Ferreri E, Busso V, Morello F, Paglieri C, Masoero M, Cassine E, Bovaro F, Grifoni S, Maule MM, Lupia E, Study Group on Lung Ultrasound from the M, Careggi H. Lung ultrasound integrated with clinical assessment for the diagnosis of acute decompensated heart failure

in the emergency department: a randomized controlled trial. *European journal of heart failure* 2019: 21(6): 754-766.
118. Bataille B, Riu B, Ferre F, Moussot PE, Mari A, Brunel E, Ruiz J, Mora M, Fourcade O, Genestal M, Silva S. Integrated use of bedside lung ultrasound and echocardiography in acute respiratory failure: a prospective observational study in ICU. *Chest* 2014: 146(6): 1586-1593.
119. Pesenti A, Musch G, Lichtenstein D, Mojoli F, Amato MBP, Cinnella G, Gattinoni L, Quintel M. Imaging in acute respiratory distress syndrome. *Intensive Care Med* 2016: 42(5): 686-698.
120. Bello G, Blanco P. Lung Ultrasonography for Assessing Lung Aeration in Acute Respiratory Distress Syndrome: A Narrative Review. *J Ultrasound Med* 2019: 38(1): 27-37.
121. Noble VE, Murray AF, Capp R, Sylvia-Reardon MH, Steele DJR, Liteplo A. Ultrasound assessment for extravascular lung water in patients undergoing hemodialysis. Time course for resolution. *Chest* 2009: 135(6): 1433-1439.
122. Panuccio V, Enia G, Tripepi R, Torino C, Garozzo M, Battaglia GG, Marcantoni C, Infantone L, Giordano G, De Giorgi ML, Lupia M, Bruzzese V, Zoccali C. Chest ultrasound and hidden lung congestion in peritoneal dialysis patients. *Nephrology, dialysis, transplantation : official publication of the European Dialysis and Transplant Association - European Renal Association* 2012: 27(9): 3601-3605.
123. Miglioranza MH, Picano E, Badano LP, Sant'Anna R, Rover M, Zaffaroni F, Sicari R, Kalil RK, Leiria TL, Gargani L. Pulmonary congestion evaluated by lung ultrasound predicts decompensation in heart failure outpatients. *Int J Cardiol* 2017: 240: 271-278.
124. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby JJ. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. *American journal of respiratory and critical care medicine* 2011: 183(3): 341-347.
125. Cortellaro F, Ceriani E, Spinelli M, Campanella C, Bossi I, Coen D, Casazza G, Cogliati C. Lung ultrasound for monitoring cardiogenic pulmonary edema. *Intern Emerg Med* 2017: 12(7): 1011-1017.
126. Trezzi M, Torzillo D, Ceriani E, Costantino G, Caruso S, Damavandi PT, Genderini A, Cicardi M, Montano N, Cogliati C. Lung ultrasonography for the assessment of rapid extravascular water variation: evidence from hemodialysis patients. *Intern Emerg Med* 2013: 8(5): 409-415.
127. Travis WD, Costabel U, Hansell DM, King TE, Jr., Lynch DA, Nicholson AG, Ryerson CJ, Ryu JH, Selman M, Wells AU, Behr J, Bouros D, Brown KK, Colby TV, Collard HR, Cordeiro CR, Cottin V, Crestani B, Drent M, Dudden RF, Egan J, Flaherty K, Hogaboam C, Inoue Y, Johkoh T, Kim DS, Kitaichi M, Loyd J, Martinez FJ, Myers J, Protzko S, Raghu G, Richeldi L, Sverzellati N, Swigris J, Valeyre D. An official American Thoracic Society/European Respiratory Society statement: Update of the international multidisciplinary classification of the idiopathic interstitial pneumonias. *AmJ RespirCrit Care Med* 2013: 188(6): 733-748.
128. Pinal-Fernandez I, Pallisa-Nunez E, Selva-O'Callaghan A, Castella-Fierro E, Simeon-Aznar CP, Fonollosa-Pla V, Vilardell-Tarres M. Pleural irregularity, a new ultrasound sign for the study of interstitial lung disease in systemic sclerosis and antisynthetase syndrome. *Clin Exp Rheumatol* 2015: 33(4 Suppl 91): S136-141.
129. Tardella M, Gutierrez M, Salaffi F, Carotti M, Ariani A, Bertolazzi C, Filippucci E, Grassi W. Ultrasound in the assessment of pulmonary fibrosis in connective tissue

disorders: correlation with high-resolution computed tomography. *J Rheumatol* 2012: 39(8): 1641-1647.
130. Manolescu D, Davidescu L, Traila D, Oancea C, Tudorache V. The reliability of lung ultrasound in assessment of idiopathic pulmonary fibrosis. *Clin Interv Aging* 2018: 13: 437-449.
131. Wang Y, Gargani L, Barskova T, Furst DE, Cerinic MM. Usefulness of lung ultrasound B-lines in connective tissue disease-associated interstitial lung disease: a literature review. *Arthritis Res Ther* 2017: 19(1): 206.
132. Soldati G, Demi M, Smargiassi A, Inchingolo R, Demi L. The role of ultrasound lung artifacts in the diagnosis of respiratory diseases. *Expert Rev Respir Med* 2019: 13(2): 163-172.
133. Lomoro P, Verde F, Zerboni F, Simonetti I, Borghi C, Fachinetti C, Natalizi A, Martegani A. COVID-19 pneumonia manifestations at the admission on chest ultrasound, radiographs, and CT: single-center study and comprehensive radiologic literature review. *Eur J Radiol Open* 2020: 7: 100231.
134. Piscaglia F, Stefanini F, Cantisani V, Sidhu PS, Barr R, Berzigotti A, Chammas MC, Correas JM, Dietrich CF, Feinstein S, Huang P, Jenssen C, Kono Y, Kudo M, Liang P, Lyshchik A, Nolsoe C, Xie X, Tovoli F. Benefits, Open questions and Challenges of the use of Ultrasound in the COVID-19 pandemic era. The views of a panel of worldwide international experts. *Ultraschall in der Medizin* 2020: 41(3): 228-236.
135. Lu W, Zhang S, Chen B, Chen J, Xian J, Lin Y, Shan H, Su ZZ. A Clinical Study of Noninvasive Assessment of Lung Lesions in Patients with Coronavirus Disease-19 (COVID-19) by Bedside Ultrasound. *Ultraschall in der Medizin* 2020: 41(3): 300-307.
136. Soldati G, Inchingolo R, Smargiassi A, Sher S, Nenna R, Inchingolo CD, Valente S. Ex vivo lung sonography: morphologic-ultrasound relationship. *Ultrasound in medicine & biology* 2012: 38(7): 1169-1179.
137. Nazerian P, Volpicelli G, Vanni S, Gigli C, Betti L, Bartolucci M, Zanobetti M, Ermini FR, Iannello C, Grifoni S. Accuracy of lung ultrasound for the diagnosis of consolidations when compared to chest computed tomography. *The American journal of emergency medicine* 2015: 33(5): 620-625.
138. Hew M, Corcoran JP, Harriss EK, Rahman NM, Mallett S. The diagnostic accuracy of chest ultrasound for CT-detected radiographic consolidation in hospitalised adults with acute respiratory failure: a systematic review. *BMJ open* 2015: 5(5): e007838.
139. Weinberg B, Diakoumakis EE, Kass EG, Seife B, Zvi ZB. The air bronchogram: sonographic demonstration. *AJR American journal of roentgenology* 1986: 147(3): 593-595.
140. Gehmacher O, Mathis G, Kopf A, Scheier M. Ultrasound imaging of pneumonia. *Ultrasound in medicine & biology* 1995: 21(9): 1119-1122.
141. Reissig A, Kroegel C. Sonographic diagnosis and follow-up of pneumonia: a prospective study. *Respiration; international review of thoracic diseases* 2007: 74(5): 537-547.
142. Copetti R, Cattarossi L. Ultrasound diagnosis of pneumonia in children. *La Radiologia medica* 2008: 113(2): 190-198.
143. Iuri D, De Candia A, Bazzocchi M. Evaluation of the lung in children with suspected pneumonia: usefulness of ultrasonography. *La Radiologia medica* 2009: 114(2): 321-330.

144. Parlamento S, Copetti R, Di Bartolomeo S. Evaluation of lung ultrasound for the diagnosis of pneumonia in the ED. *The American journal of emergency medicine* 2009: 27(4): 379-384.
145. Sperandeo M, Carnevale V, Muscarella S, Sperandeo G, Varriale A, Filabozzi P, Piattelli ML, D'Alessandro V, Copetti M, Pellegrini F, Dimitri L, Vendemiale G. Clinical application of transthoracic ultrasonography in inpatients with pneumonia. *European journal of clinical investigation* 2011: 41(1): 1-7.
146. Shah VP, Tunik MG, Tsung JW. Prospective Evaluation of Point-of-Care Ultrasonography for the Diagnosis of Pneumonia in Children and Young Adults. *Archives of pediatrics & adolescent medicine* 2012: 1-7.
147. Mongodi S, Via G, Girard M, Rouquette I, Misset B, Braschi A, Mojoli F, Bouhemad B. Lung Ultrasound for Early Diagnosis of Ventilator-Associated Pneumonia. *Chest* 2016: 149(4): 969-980.
148. Orso D, Guglielmo N, Copetti R. Lung ultrasound in diagnosing pneumonia in the emergency department: a systematic review and meta-analysis. *European journal of emergency medicine : official journal of the European Society for Emergency Medicine* 2018: 25(5): 312-321.
149. Zanobetti M, Scorpiniti M, Gigli C, Nazerian P, Vanni S, Innocenti F, Stefanone VT, Savinelli C, Coppa A, Bigiarini S, Caldi F, Tassinari I, Conti A, Grifoni S, Pini R. Point-of-Care Ultrasonography for Evaluation of Acute Dyspnea in the ED. *Chest* 2017: 151(6): 1295-1301.
150. Mantuani D, Frazee BW, Fahimi J, Nagdev A. Point-of-Care Multi-Organ Ultrasound Improves Diagnostic Accuracy in Adults Presenting to the Emergency Department with Acute Dyspnea. *The western journal of emergency medicine* 2016: 17(1): 46-53.
151. Jones BP, Tay ET, Elikashvili I, Sanders JE, Paul AZ, Nelson BP, Spina LA, Tsung JW. Feasibility and Safety of Substituting Lung Ultrasonography for Chest Radiography When Diagnosing Pneumonia in Children: A Randomized Controlled Trial. *Chest* 2016: 150(1): 131-138.
152. Miller LD, Joyner CR, Jr., Dudrick SJ, Eskin DJ. Clinical use of ultrasound in the early diagnosis of pulmonary embolism. *Annals of surgery* 1967: 166(3): 381-393.
153. Mathis G, Metzler J, Feurstein M, Fussenegger D, Sutterlutti G. [Lung infarcts detected with ultrasonography]. *Ultraschall in der Medizin* 1990: 11(6): 281-283.
154. Kroschel U, Seitz K, Reuss J, Rettenmaier G. [Sonographic imaging of lung emboli. Results of a prospective study]. *Ultraschall in der Medizin* 1991: 12(6): 263-268.
155. Mathis G, Dirschmid K. Pulmonary infarction: sonographic appearance with pathologic correlation. *European journal of radiology* 1993: 17(3): 170-174.
156. Mathis G, Bitschnau R, Gehmacher O, Scheier M, Kopf A, Schwarzler B, Amann T, Doringer W, Hergan K. Chest ultrasound in diagnosis of pulmonary embolism in comparison to helical CT. *Ultraschall in der Medizin* 1999: 20(2): 54-59.
157. Reissig A, Heyne JP, Kroegel C. [Diagnosis of pulmonary embolism by transthoracic sonography. Sono-morphologic characterization of pulmonary lesions and comparison with spiral computed tomography]. *Deutsche medizinische Wochenschrift (1946)* 2000: 125(49): 1487-1491.
158. Reissig A. Sonography of Lung and Pleura in Pulmonary Embolism : Sonomorphologic Characterization and Comparison With Spiral CT Scanning. *Chest* 2001: 120(6): 1977-1983.

159. Lechleitner P, Riedl B, Raneburger W, Gamper G, Theurl A, Lederer A. Chest sonography in the diagnosis of pulmonary embolism: a comparison with MRI angiography and ventilation perfusion scintigraphy. *Ultraschall in der Medizin* 2002: 23(6): 373-378.
160. Reissig A, Kroegel C. Transthoracic Ultrasound of Lung and Pleura in the Diagnosis of Pulmonary Embolism: A Novel Non-Invasive Bedside Approach. *Respiration; international review of thoracic diseases* 2003: 70(5): 441-452.
161. Reißig A, Heyne J-P, Kroegel C. Ancillary lung parenchymal findings at spiral CT scanning in pulmonary embolism. Relationship to chest sonography. *European journal of radiology* 2004: 49(3): 250-257.
162. Volpicelli G, Caramello V, Cardinale L, Cravino M. Diagnosis of radio-occult pulmonary conditions by real-time chest ultrasonography in patients with pleuritic pain. *Ultrasound in medicine & biology* 2008: 34(11): 1717-1723.
163. Pfeil A, Reissig A, Heyne JP, Wolf G, Kaiser WA, Kroegel C, Hansch A. Transthoracic sonography in comparison to multislice computed tomography in detection of peripheral pulmonary embolism. *Lung* 2010: 188(1): 43-50.
164. Volpicelli G, Cardinale L, Berchialla P, Mussa A, Bar F, Frascisco MF. A comparison of different diagnostic tests in the bedside evaluation of pleuritic pain in the ED. *The American journal of emergency medicine* 2012: 30(2): 317-324.
165. Nazerian P, Vanni S, Volpicelli G, Gigli C, Zanobetti M, Bartolucci M, Ciavattone A, Lamorte A, Veltri A, Fabbri A, Grifoni S. Accuracy of point-of-care multiorgan ultrasonography for the diagnosis of pulmonary embolism. *Chest* 2013.
166. Koenig S, Chandra S, Alaverdian A, Dibello C, Mayo PH, Narasimhan M. Ultrasound Assessment of Pulmonary Embolism in Patients Receiving Computerized Tomography Pulmonary Angiography. *Chest* 2013.
167. Squizzato A, Rancan E, Dentali F, Bonzini M, Guasti L, Steidl L, Mathis G, Ageno W. Diagnostic accuracy of lung ultrasound for pulmonary embolism: a systematic review and meta-analysis. *Journal of thrombosis and haemostasis : JTH* 2013: 11(7): 1269-1278.
168. Da Costa Rodrigues J, Alzuphar S, Combescure C, Le Gal G, Perrier A. Diagnostic characteristics of lower limb venous compression ultrasonography in suspected pulmonary embolism: a meta-analysis. *J Thromb Haemost* 2016: 14(9): 1765-1772.
169. Fields JM, Davis J, Girson L, Au A, Potts J, Morgan CJ, Vetter I, Riesenberg LA. Transthoracic Echocardiography for Diagnosing Pulmonary Embolism: A Systematic Review and Meta-Analysis. *J Am Soc Echocardiogr* 2017: 30(7): 714-723 e714.
170. Volpicelli G, Lamorte A, Tullio M, Cardinale L, Giraudo M, Stefanone V, Boero E, Nazerian P, Pozzi R, Frascisco MF. Point-of-care multiorgan ultrasonography for the evaluation of undifferentiated hypotension in the emergency department. *Intensive care medicine* 2013: 39(7): 1290-1298.
171. Lin MS, Hwang JJ, Chong IW, Wang TH, Huang MS, Tsai MS, Chen KL. Ultrasonography of chest diseases: analysis of 154 cases. *Gaoxiong yi xue ke xue za zhi = The Kaohsiung journal of medical sciences* 1992: 8(10): 525-534.
172. Yang PC, Luh KT, Chang DB, Yu CJ, Kuo SH, Wu HD. Ultrasonographic evaluation of pulmonary consolidation. *The American review of respiratory disease* 1992: 146(3): 757-762.
173. Lichtenstein DA, Lascols N, Prin S, Meziere G. The "lung pulse": an early ultrasound sign of complete atelectasis. *Intensive care medicine* 2003: 29(12): 2187-2192.

174. Karabinis A, Saranteas T, Karakitsos D, Lichtenstein D, Poularas J, Yang C, Stefanadis C. The 'cardiac-lung mass' artifact: an echocardiographic sign of lung atelectasis and/or pleural effusion. *Critical care* 2008: 12(5): R122.
175. Cavaliere F, Biasucci D, Costa R, Soave M, Addabbo G, Proietti R. Chest ultrasounds to guide manual reexpansion of a postoperative pulmonary atelectasis: a case report. *Minerva anestesiologica* 2011: 77(7): 750-753.
176. Chen HJ, Yu YH, Tu CY, Chen CH, Hsia TC, Tsai KD, Shih CM, Hsu WH. Ultrasound in peripheral pulmonary air-fluid lesions. Color Doppler imaging as an aid in differentiating empyema and abscess. *Chest* 2009: 135(6): 1426-1432.
177. Suzuki N, Saitoh T, Kitamura S. Tumor invasion of the chest wall in lung cancer: diagnosis with US. *Radiology* 1993: 187(1): 39-42.
178. Yuan A, Chang DB, Yu CJ, Kuo SH, Luh KT, Yang PC. Color Doppler sonography of benign and malignant pulmonary masses. *AJR American journal of roentgenology* 1994: 163(3): 545-549.
179. Chira R, Chira A, Mircea PA. Intrathoracic tumors in contact with the chest wall--ultrasonographic and computed tomography comparative evaluation. *Medical ultrasonography* 2012: 14(2): 115-119.
180. Hyacinthe AC, Broux C, Francony G, Genty C, Bouzat P, Jacquot C, Albaladejo P, Ferretti GR, Bosson JL, Payen JF. Diagnostic accuracy of ultrasonography in the acute assessment of common thoracic lesions after trauma. *Chest* 2012: 141(5): 1177-1183.
181. Wustner A, Gehmacher O, Hammerle S, Schenkenbach C, Hafele H, Mathis G. [Ultrasound diagnosis in blunt thoracic trauma]. *Ultraschall in der Medizin* 2005: 26(4): 285-290.
182. Lin FC, Chou CW, Chang SC. Differentiating pyopneumothorax and peripheral lung abscess: chest ultrasonography. *The American journal of the medical sciences* 2004: 327(6): 330-335.
183. 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(11): 1282-1296.
184. Arbelot C, Ferrari F, Bouhemad B, Rouby JJ. Lung ultrasound in acute respiratory distress syndrome and acute lung injury. *Current opinion in critical care* 2008: 14(1): 70-74.
185. Soummer A, Perbet S, Brisson H, Arbelot C, Constantin JM, Lu Q, Rouby JJ, Lung Ultrasound Study G. Ultrasound assessment of lung aeration loss during a successful weaning trial predicts postextubation distress*. *Critical care medicine* 2012: 40(7): 2064-2072.
186. Haddam M, Zieleskiewicz L, Perbet S, Baldovini A, Guervilly C, Arbelot C, Noel A, Vigne C, Hammad E, Antonini F, Lehingue S, Peytel E, Lu Q, Bouhemad B, Golmard JL, Langeron O, Martin C, Muller L, Rouby JJ, Constantin JM, Papazian L, Leone M, Network CAEC, AzuRea Collaborative N. Lung ultrasonography for assessment of oxygenation response to prone position ventilation in ARDS. *Intensive Care Med* 2016: 42(10): 1546-1556.
187. Prat G, Guinard S, Bizien N, Nowak E, Tonnelier JM, Alavi Z, Renault A, Boles JM, L'Her E. Can lung ultrasonography predict prone positioning response in acute respiratory distress syndrome patients? *J Crit Care* 2016: 32: 36-41.

188. Mongodi S, Bouhemad B, Orlando A, Stella A, Tavazzi G, Via G, Iotti GA, Braschi A, Mojoli F. Modified Lung Ultrasound Score for Assessing and Monitoring Pulmonary Aeration. *Ultraschall Med* 2017: 38(5): 530-537.
189. Chiumello D, Mongodi S, Algieri I, Vergani GL, Orlando A, Via G, Crimella F, Cressoni M, Mojoli F. Assessment of Lung Aeration and Recruitment by CT Scan and Ultrasound in Acute Respiratory Distress Syndrome Patients. *Crit Care Med* 2018: 46(11): 1761-1768.
190. Haji K, Haji D, Canty DJ, Royse AG, Green C, Royse CF. The impact of heart, lung and diaphragmatic ultrasound on prediction of failed extubation from mechanical ventilation in critically ill patients: a prospective observational pilot study. *Crit Ultrasound J* 2018: 10(1): 13.
191. Cardenas LZ, Santana PV, Caruso P, Ribeiro de Carvalho CR, Pereira de Albuquerque AL. Diaphragmatic Ultrasound Correlates with Inspiratory Muscle Strength and Pulmonary Function in Healthy Subjects. *Ultrasound in medicine & biology* 2018: 44(4): 786-793.
192. Holtzhausen S, Unger M, Lupton-Smith A, Hanekom S. An investigation into the use of ultrasound as a surrogate measure of diaphragm function. *Heart & lung : the journal of critical care* 2018: 47(4): 418-424.
193. Caleffi-Pereira M, Pletsch-Assuncao R, Cardenas LZ, Santana PV, Ferreira JG, Iamonti VC, Caruso P, Fernandez A, de Carvalho CRR, Albuquerque ALP. Unilateral diaphragm paralysis: a dysfunction restricted not just to one hemidiaphragm. *BMC Pulm Med* 2018: 18(1): 126.
194. Houston JG, Fleet M, Cowan MD, McMillan NC. Comparison of ultrasound with fluoroscopy in the assessment of suspected hemidiaphragmatic movement abnormality. *Clinical radiology* 1995: 50(2): 95-98.
195. Skaarup SH, Lokke A, Laursen CB. The Area method: a new method for ultrasound assessment of diaphragmatic movement. *Crit Ultrasound J* 2018: 10(1): 15.
196. Ye X, Xiao H, Bai W, Liang Y, Chen M, Zhang S. Two-dimensional strain ultrasound speckle tracking as a novel approach for the evaluation of right hemidiaphragmatic longitudinal deformation. *Exp Ther Med* 2013: 6(2): 368-372.
197. Orde SR, Boon AJ, Firth DG, Villarraga HR, Sekiguchi H. Diaphragm assessment by two dimensional speckle tracking imaging in normal subjects. *BMC Anesthesiol* 2016: 16(1): 43.
198. Ouanes-Besbes L, Dachraoui F, Ouanes I, Bouneb R, Jalloul F, Dlala M, Najjar MF, Abroug F. NT-proBNP levels at spontaneous breathing trial help in the prediction of post-extubation respiratory distress. *Intensive care medicine* 2012: 38(5): 788-795.
199. Frutos-Vivar F, Ferguson ND, Esteban A, Epstein SK, Arabi Y, Apezteguia C, Gonzalez M, Hill NS, Nava S, D'Empaire G, Anzueto A. Risk factors for extubation failure in patients following a successful spontaneous breathing trial. *Chest* 2006: 130(6): 1664-1671.
200. Llamas-Alvarez AM, Tenza-Lozano EM, Latour-Perez J. Diaphragm and Lung Ultrasound to Predict Weaning Outcome: Systematic Review and Meta-Analysis. *Chest* 2017: 152(6): 1140-1150.
201. Li C, Li X, Han H, Cui H, Wang G, Wang Z. Diaphragmatic ultrasonography for predicting ventilator weaning: A meta-analysis. *Medicine (Baltimore)* 2018: 97(22): e10968.
202. Scarlata S, Mancini D, Laudisio A, Benigni A, Antonelli Incalzi R. Reproducibility and Clinical Correlates of Supine Diaphragmatic Motion Measured by M-Mode Ultrasonography

in Healthy Volunteers. *Respiration; international review of thoracic diseases* 2018: 96(3): 259-266.
203. Brown C, Tseng SC, Mitchell K, Roddey T. Body Position Affects Ultrasonographic Measurement of Diaphragm Contractility. *Cardiopulm Phys Ther J* 2018: 29(4): 166-172.
204. Scarlata S, Mancini D, Laudisio A, Raffaele AI. Reproducibility of diaphragmatic thickness measured by M-mode ultrasonography in healthy volunteers. *Respir Physiol Neurobiol* 2019: 260: 58-62.
205. Pirompanich P, Romsaiyut S. Use of diaphragm thickening fraction combined with rapid shallow breathing index for predicting success of weaning from mechanical ventilator in medical patients. *J Intensive Care* 2018: 6: 6.
206. Dhungana A, Khilnani G, Hadda V, Guleria R. Reproducibility of diaphragm thickness measurements by ultrasonography in patients on mechanical ventilation. *World J Crit Care Med* 2017: 6(4): 185-189.
207. Vivier E, Muller M, Putegnat JB, Steyer J, Barrau S, Boissier F, Bourdin G, Mekontso-Dessap A, Levrat A, Pommier C, Thille AW. Inability of Diaphragm Ultrasound to Predict Extubation Failure: A Multicenter Study. *Chest* 2019: 155(6): 1131-1139.
208. Umbrello M, Mistraletti G, Galimberti A, Piva IR, Cozzi O, Formenti P. Drainage of pleural effusion improves diaphragmatic function in mechanically ventilated patients. *Crit Care Resusc* 2017: 19(1): 64-70.
209. Garske LA, Kunarajah K, Zimmerman PV, Adams L, Stewart IB. In patients with unilateral pleural effusion, restricted lung inflation is the principal predictor of increased dyspnoea. *PloS one* 2018: 13(10): e0202621.
210. Wang LM, Cherng JM, Wang JS. Improved lung function after thoracocentesis in patients with paradoxical movement of a hemidiaphragm secondary to a large pleural effusion. *Respirology* 2007: 12(5): 719-723.
211. Muruganandan S, Azzopardi M, Thomas R, Fitzgerald DB, Kuok YJ, Cheah HM, Read CA, Budgeon CA, Eastwood PR, Jenkins S, Singh B, Murray K, Lee YCG. The Pleural Effusion And Symptom Evaluation (PLEASE) study of breathlessness in patients with a symptomatic pleural effusion. *The European respiratory journal : official journal of the European Society for Clinical Respiratory Physiology* 2020: 55(5).
212. Hida T, Yamada Y, Ueyama M, Araki T, Nishino M, Kurosaki A, Jinzaki M, Honda H, Hatabu H, Kudoh S. Decreased and slower diaphragmatic motion during forced breathing in severe COPD patients: Time-resolved quantitative analysis using dynamic chest radiography with a flat panel detector system. *European journal of radiology* 2019: 112: 28-36.
213. Souza RMP, Cardim AB, Maia TO, Rocha LG, Bezerra SD, Marinho PEM. Inspiratory muscle strength, diaphragmatic mobility, and body composition in chronic obstructive pulmonary disease. *Physiother Res Int* 2019: 24(2): e1766.
214. Antenora F, Fantini R, Iattoni A, Castaniere I, Sdanganelli A, Livrieri F, Tonelli R, Zona S, Monelli M, Clini EM, Marchioni A. Prevalence and outcomes of diaphragmatic dysfunction assessed by ultrasound technology during acute exacerbation of COPD: A pilot study. *Respirology* 2017: 22(2): 338-344.
215. Marchioni A, Castaniere I, Tonelli R, Fantini R, Fontana M, Tabbi L, Viani A, Giaroni F, Ruggieri V, Cerri S, Clini E. Ultrasound-assessed diaphragmatic impairment is a predictor of outcomes in patients with acute exacerbation of chronic obstructive pulmonary disease undergoing noninvasive ventilation. *Critical care* 2018: 22(1): 109.

216. Okura K, Kawagoshi A, Iwakura M, Sugawara K, Takahashi H, Kashiwagura T, Homma M, Satake M, Shioya T. Contractile capability of the diaphragm assessed by ultrasonography predicts nocturnal oxygen saturation in COPD. *Respirology* 2017: 22(2): 301-306.
217. Harlaar L, Ciet P, van der Ploeg AT, Brusse E, van der Beek N, Wielopolski PA, de Bruijne M, Tiddens H, van Doorn PA. Imaging of respiratory muscles in neuromuscular disease: A review. *Neuromuscular disorders : NMD* 2018: 28(3): 246-256.
218. Laviola M, Priori R, D'Angelo MG, Aliverti A. Assessment of diaphragmatic thickness by ultrasonography in Duchenne muscular dystrophy (DMD) patients. *PloS one* 2018: 13(7): e0200582.
219. Hiwatani Y, Sakata M, Miwa H. Ultrasonography of the diaphragm in amyotrophic lateral sclerosis: clinical significance in assessment of respiratory functions. *Amyotroph Lateral Scler Frontotemporal Degener* 2013: 14(2): 127-131.
220. Amundsen BH, Helle-Valle T, Edvardsen T, Torp H, Crosby J, Lyseggen E, Stoylen A, Ihlen H, Lima JA, Smiseth OA, Slordahl SA. Noninvasive myocardial strain measurement by speckle tracking echocardiography: validation against sonomicrometry and tagged magnetic resonance imaging. *Journal of the American College of Cardiology* 2006: 47(4): 789-793.
221. Diacon AH. Accuracy of Pleural Puncture Sites: A Prospective Comparison of Clinical Examination With Ultrasound. *Chest* 2003: 123(2): 436-441.
222. Duncan DR, Morgenthaler TI, Ryu JH, Daniels CE. Reducing iatrogenic risk in thoracentesis: establishing best practice via experiential training in a zero-risk environment. *Chest* 2009: 135(5): 1315-1320.
223. Mercaldi CJ, Lanes SF. Ultrasound guidance decreases complications and improves the cost of care among patients undergoing thoracentesis and paracentesis. *Chest* 2013: 143(2): 532-538.
224. Millington SJ, Koenig S. Better With Ultrasound: Pleural Procedures in Critically Ill Patients. *Chest* 2018: 153(1): 224-232.
225. Bhatnagar R, Corcoran JP, Maldonado F, Feller-Kopman D, Janssen J, Astoul P, Rahman NM. Advanced medical interventions in pleural disease. *Eur Respir Rev* 2016: 25(140): 199-213.
226. Psallidas I, Yousuf A, Talwar A, Hallifax RJ, Mishra EK, Corcoran JP, Ali N, Rahman NM. Assessment of patient-reported outcome measures in pleural interventions. *BMJ Open Respir Res* 2017: 4(1): e000171.
227. Shojaee S, Argento AC. Ultrasound-guided pleural access. *Semin Respir Crit Care Med* 2014: 35(6): 693-705.
228. Salamonsen M, Dobeli K, McGrath D, Readdy C, Ware R, Steinke K, Fielding D. Physician-performed ultrasound can accurately screen for a vulnerable intercostal artery prior to chest drainage procedures. *Respirology* 2013: 18(6): 942-947.
229. Corcoran JP, Psallidas I, Wrightson JM, Hallifax RJ, Rahman NM. Pleural procedural complications: prevention and management. *Journal of thoracic disease* 2015: 7(6): 1058-1067.
230. Rahman NM, Pepperell J, Rehal S, Saba T, Tang A, Ali N, West A, Hettiarachchi G, Mukherjee D, Samuel J, Bentley A, Dowson L, Miles J, Ryan CF, Yoneda KY, Chauhan A, Corcoran JP, Psallidas I, Wrightson JM, Hallifax R, Davies HE, Lee YC, Dobson M, Hedley EL, Seaton D, Russell N, Chapman M, McFadyen BM, Shaw RA, Davies RJ, Maskell NA, Nunn AJ,

Miller RF. Effect of Opioids vs NSAIDs and Larger vs Smaller Chest Tube Size on Pain Control and Pleurodesis Efficacy Among Patients With Malignant Pleural Effusion: The TIME1 Randomized Clinical Trial. *JAMA : the journal of the American Medical Association* 2015: 314(24): 2641-2653.
231. Rahman NM, Maskell NA, Davies CW, Hedley EL, Nunn AJ, Gleeson FV, Davies RJ. The relationship between chest tube size and clinical outcome in pleural infection. *Chest* 2010: 137(3): 536-543.
232. Maskell NA, Davies CW, Nunn AJ, Hedley EL, Gleeson FV, Miller R, Gabe R, Rees GL, Peto TE, Woodhead MA, Lane DJ, Darbyshire JH, Davies RJ, First Multicenter Intrapleural Sepsis Trial G. U.K. Controlled trial of intrapleural streptokinase for pleural infection. *The New England journal of medicine* 2005: 352(9): 865-874.
233. Rahman NM, Maskell NA, West A, Teoh R, Arnold A, Mackinlay C, Peckham D, Davies CW, Ali N, Kinnear W, Bentley A, Kahan BC, Wrightson JM, Davies HE, Hooper CE, Lee YC, Hedley EL, Crosthwaite N, Choo L, Helm EJ, Gleeson FV, Nunn AJ, Davies RJ. Intrapleural use of tissue plasminogen activator and DNase in pleural infection. *The New England journal of medicine* 2011: 365(6): 518-526.
234. Hallifax RJ, Psallidas I, Rahman NM. Chest Drain Size: the Debate Continues. *Curr Pulmonol Rep* 2017: 6(1): 26-29.
235. Thethi I, Ramirez S, Shen W, Zhang D, Mohamad M, Kaphle U, Kheir F. Effect of chest tube size on pleurodesis efficacy in malignant pleural effusion: a meta-analysis of randomized controlled trials. *Journal of thoracic disease* 2018: 10(1): 355-362.
236. Bhatnagar R, Keenan EK, Morley AJ, Kahan BC, Stanton AE, Haris M, Harrison RN, Mustafa RA, Bishop LJ, Ahmed L, West A, Holme J, Evison M, Munavvar M, Sivasothy P, Herre J, Cooper D, Roberts M, Guhan A, Hooper C, Walters J, Saba TS, Chakrabarti B, Gunatilake S, Psallidas I, Walker SP, Bibby AC, Smith S, Stadon LJ, Zahan-Evans NJ, Lee YCG, Harvey JE, Rahman NM, Miller RF, Maskell NA. Outpatient Talc Administration by Indwelling Pleural Catheter for Malignant Effusion. *The New England journal of medicine* 2018: 378(14): 1313-1322.
237. Feller-Kopman D, Parker MJ, Schwartzstein RM. Assessment of pleural pressure in the evaluation of pleural effusions. *Chest* 2009: 135(1): 201-209.
238. Rahman NM, Ali NJ, Brown G, Chapman SJ, Davies RJ, Downer NJ, Gleeson FV, Howes TQ, Treasure T, Singh S, Phillips GD, British Thoracic Society Pleural Disease Guideline G. Local anaesthetic thoracoscopy: British Thoracic Society Pleural Disease Guideline 2010. *Thorax* 2010: 65 Suppl 2: ii54-60.
239. de Fonseka D, Bhatnagar R, Maskell NA. Local Anaesthetic (Medical) Thoracoscopy Services in the UK. *Respiration; international review of thoracic diseases* 2018: 96(6): 560-563.
240. Corcoran JP, Psallidas I, Hallifax RJ, Talwar A, Sykes A, Rahman NM. Ultrasound-guided pneumothorax induction prior to local anaesthetic thoracoscopy. *Thorax* 2015: 70(9): 906-908.
241. Marchetti G, Valsecchi A, Indellicati D, Arondi S, Trigiani M, Pinelli V. Ultrasound-guided medical thoracoscopy in the absence of pleural effusion. *Chest* 2015: 147(4): 1008-1012.
242. Meena N, Bartter T. Ultrasound-guided Percutaneous Needle Aspiration by Pulmonologists: A Study of Factors With Impact on Procedural Yield and Complications. *Journal of bronchology & interventional pulmonology* 2015: 22(3): 204-208.

243. Laursen CB, Naur TM, Bodtger U, Colella S, Naqibullah M, Minddal V, Konge L, Davidsen JR, Hansen NC, Graumann O, Clementsen PF. Ultrasound-guided Lung Biopsy in the Hands of Respiratory Physicians: Diagnostic Yield and Complications in 215 Consecutive Patients in 3 Centers. *Journal of bronchology & interventional pulmonology* 2016: 23(3): 220-228.
244. Lee MH, Lubner MG, Hinshaw JL, Pickhardt PJ. Ultrasound Guidance Versus CT Guidance for Peripheral Lung Biopsy: Performance According to Lesion Size and Pleural Contact. *AJR American journal of roentgenology* 2018: 210(3): W110-W117.
245. Sconfienza LM, Mauri G, Grossi F, Truini M, Serafini G, Sardanelli F, Murolo C. Pleural and Peripheral Lung Lesions: Comparison of US- and CT-guided Biopsy. *Radiology* 2012.
246. Yamamoto N, Watanabe T, Yamada K, Nakai T, Suzumura T, Sakagami K, Yoshimoto N, Sato K, Tanaka H, Mitsuoka S, Asai K, Kimura T, Kanazawa H, Hirata K, Kawaguchi T. Efficacy and safety of ultrasound (US) guided percutaneous needle biopsy for peripheral lung or pleural lesion: comparison with computed tomography (CT) guided needle biopsy. *Journal of thoracic disease* 2019: 11(3): 936-943.
247. Gorg C, Kring R, Bert T. Transcutaneous contrast-enhanced sonography of peripheral lung lesions. *AJR American journal of roentgenology* 2006: 187(4): W420-429.
248. Cao BS, Wu JH, Li XL, Deng J, Liao GQ. Sonographically guided transthoracic biopsy of peripheral lung and mediastinal lesions: role of contrast-enhanced sonography. *Journal of ultrasound in medicine : official journal of the American Institute of Ultrasound in Medicine* 2011: 30(11): 1479-1490.
249. Laursen CB, Graumann O, Moller TV, Davidsen JR. Contrast-enhanced Ultrasound-guided Transthoracic Lung Biopsy. *American journal of respiratory and critical care medicine* 2016: 194(5): e5-6.
250. Faruk T, Islam MK, Arefin S, Haq MZ. The Journey of Elastography: Background, Current Status, and Future Possibilities in Breast Cancer Diagnosis. *Clin Breast Cancer* 2015: 15(5): 313-324.
251. Sperandeo M, Trovato FM, Dimitri L, Catalano D, Simeone A, Martines GF, Piscitelli AP, Trovato GM. Lung transthoracic ultrasound elastography imaging and guided biopsies of subpleural cancer: a preliminary report. *Acta radiologica (Stockholm, Sweden : 1987)* 2015: 56(7): 798-805.
252. Fultz PJ, Feins RH, Strang JG, Wandtke JC, Johnstone DW, Watson TJ, Gottlieb RH, Voci SL, Rubens DJ. Detection and diagnosis of nonpalpable supraclavicular lymph nodes in lung cancer at CT and US. *Radiology* 2002: 222(1): 245-251.
253. van Overhagen H, Brakel K, Heijenbrok MW, van Kasteren JH, van de Moosdijk CN, Roldaan AC, van Gils AP, Hansen BE. Metastases in supraclavicular lymph nodes in lung cancer: assessment with palpation, US, and CT. *Radiology* 2004: 232(1): 75-80.
254. Prosch H, Strasser G, Sonka C, Oschatz E, Mashaal S, Mohn-Staudner A, Mostbeck GH. Cervical ultrasound (US) and US-guided lymph node biopsy as a routine procedure for staging of lung cancer. *Ultraschall in der Medizin* 2007: 28(6): 598-603.
255. Ahmed M, Daneshvar C, Breen D. Ultrasound-Guided Cervical Lymph Node Sampling Performed by Respiratory Physicians. *Biomed Hub* 2019: 4(2): 1-6.
256. Ahmed M, Daneshvar C, Breen D. Neck Ultrasound for the Detection of Cervical Lymphadenopathy in Sarcoidosis: An Alternative to Endobronchial Ultrasound. *Journal of bronchology & interventional pulmonology* 2019: 26(3): 225-227.

257. Fahim A, Qasim MM, Rosewarne D. Neck as mediastinal extension: Diagnosis of sarcoidosis by core biopsy of cervical lymph nodes. *Clin Respir J* 2020: 14(1): 16-20.
258. Kim DW, Jung SJ, Ha TK, Park HK. Individual and combined diagnostic accuracy of ultrasound diagnosis, ultrasound-guided fine-needle aspiration and polymerase chain reaction in identifying tuberculous lymph nodes in the neck. *Ultrasound in medicine & biology* 2013: 39(12): 2308-2314.
259. Ebrahimi A, Yousefifard M, Mohammad Kazemi H, Rasouli HR, Asady H, Moghadas Jafari A, Hosseini M. Diagnostic Accuracy of Chest Ultrasonography versus Chest Radiography for Identification of Pneumothorax: A Systematic Review and Meta-Analysis. *Tanaffos* 2014: 13(4): 29-40.
260. Chavez MA, Shams N, Ellington LE, Naithani N, Gilman RH, Steinhoff MC, Santosham M, Black RE, Price C, Gross M, Checkley W. Lung ultrasound for the diagnosis of pneumonia in adults: a systematic review and meta-analysis. *Respir Res* 2014: 15: 50.
261. Staub LJ, Mazzali Biscaro RR, Kaszubowski E, Maurici R. Lung Ultrasound for the Emergency Diagnosis of Pneumonia, Acute Heart Failure, and Exacerbations of Chronic Obstructive Pulmonary Disease/Asthma in Adults: A Systematic Review and Meta-analysis. *J Emerg Med* 2019: 56(1): 53-69.
262. Pietersen PI, Madsen KR, Graumann O, Konge L, Nielsen BU, Laursen CB. Lung ultrasound training: a systematic review of published literature in clinical lung ultrasound training. *Crit Ultrasound J* 2018: 10(1): 23.
263. Breitkreutz R, Dutine M, Scheiermann P, Hempel D, Kujumdshiev S, Ackermann H, Seeger FH, Seibel A, Walcher F, Hirche TO. Thorax, trachea, and lung ultrasonography in emergency and critical care medicine: assessment of an objective structured training concept. *Emerg Med Int* 2013: 2013: 312758.
264. Hulett CS, Pathak V, Katz JN, Montgomery SP, Chang LH. Development and preliminary assessment of a critical care ultrasound course in an adult pulmonary and critical care fellowship program. *Ann Am Thorac Soc* 2014: 11(5): 784-788.
265. Radiologists TRCo. Ultrasound training recommendations for medical and surgical specialities - Appendix 6: Thoracic ultrasound. *Clinical Radiology* 2017: 3rd Ed.
266. Biology EFoSfUiMa. Minimum tranining requirements for the practice of medical ultrasound in Europe - Appendix 11: Thoracic ultrasound. 2009.
267. Konge LL, L. Simulation-based training of surgical skills. *Perspect Med Educ* 2016: 5(1): 3-4.
268. McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. A critical review of simulation-based medical education research: 2003-2009. *Med Educ* 2010: 44(1): 50-63.
269. Konge L, Clementsen PF, Ringsted C, Minddal V, Larsen KR, Annema JT. Simulator training for endobronchial ultrasound: a randomised controlled trial. *The European respiratory journal : official journal of the European Society for Clinical Respiratory Physiology* 2015: 46(4): 1140-1149.
270. Kemp SV, El Batrawy SH, Harrison RN, Skwarski K, Munavvar M, Rosell A, Cusworth K, Shah PL. Learning curves for endobronchial ultrasound using cusum analysis. *Thorax* 2010: 65(6): 534-538.
271. Noble VE, Lamhaut L, Capp R, Bosson N, Liteplo A, Marx JS, Carli P. Evaluation of a thoracic ultrasound training module for the detection of pneumothorax and pulmonary edema by prehospital physician care providers. *BMC medical education* 2009: 9: 3.

272. Oveland NP, Sloth E, Andersen G, Lossius HM. A porcine pneumothorax model for teaching ultrasound diagnostics. *Acad Emerg Med* 2012: 19(5): 586-592.
273. Cuca C, Scheiermann P, Hempel D, Via G, Seibel A, Barth M, Hirche TO, Walcher F, Breitkreutz R. Assessment of a new e-learning system on thorax, trachea, and lung ultrasound. *Emerg Med Int* 2013: 2013: 145361.
274. See KC, Ong V, Wong SH, Leanda R, Santos J, Taculod J, Phua J, Teoh CM. Lung ultrasound training: curriculum implementation and learning trajectory among respiratory therapists. *Intensive care medicine* 2016: 42(1): 63-71.
275. Sanchez-de-Toledo J, Renter-Valdovinos L, Esteves M, Fonseca C, Villaverde I, Rosal M. Teaching Chest Ultrasound in an Experimental Porcine Model. *Pediatr Emerg Care* 2016: 32(11): 768-772.
276. Edrich T, Stopfkuchen-Evans M, Scheiermann P, Heim M, Chan W, Stone MB, Dankl D, Aichner J, Hinzmann D, Song P, Szabo AL, Frendl G, Vlassakov K, Varelmann D. A Comparison of Web-Based with Traditional Classroom-Based Training of Lung Ultrasound for the Exclusion of Pneumothorax. *Anesth Analg* 2016: 123(1): 123-128.
277. Pietersen PI, Konge L, Madsen KR, Bendixen M, Maskell NA, Rahman N, Graumann O, Laursen CB. Development of and Gathering Validity Evidence for a Theoretical Test in Thoracic Ultrasound. *Respiration* 2019: 98(3): 221-229.
278. Connolly K, Beier L, Langdorf MI, Anderson CL, Fox JC. Ultrafest: a novel approach to ultrasound in medical education leads to improvement in written and clinical examinations. *West J Emerg Med* 2015: 16(1): 143-148.
279. Dinh VA, Giri PC, Rathinavel I, Nguyen E, Hecht D, Dorotta I, Nguyen HB, Chrissian AA. Impact of a 2-Day Critical Care Ultrasound Course during Fellowship Training: A Pilot Study. *Crit Care Res Pract* 2015: 2015: 675041.
280. Heiberg J, Hansen LS, Wemmelund K, Sorensen AH, Ilkjaer C, Cloete E, Nolte D, Roodt F, Dyer R, Swanevelder J, Sloth E. Point-of-Care Clinical Ultrasound for Medical Students. *Ultrasound Int Open* 2015: 1(2): E58-66.
281. Greenstein YY, Littauer R, Narasimhan M, Mayo PH, Koenig SJ. Effectiveness of a Critical Care Ultrasonography Course. *Chest* 2017: 151(1): 34-40.
282. Abbasi S, Farsi D, Hafezimoghadam P, Fathi M, Zare MA. Accuracy of emergency physician-performed ultrasound in detecting traumatic pneumothorax after a 2-h training course. *Eur J Emerg Med* 2013: 20(3): 173-177.
283. Salamonsen M, McGrath D, Steiler G, Ware R, Colt H, Fielding D. A new instrument to assess physician skill at thoracic ultrasound, including pleural effusion markup. *Chest* 2013: 144(3): 930-934.
284. Pietersen PI, Konge L, Graumann O, Nielsen BU, Laursen CB. Developing and Gathering Validity Evidence for a Simulation-Based Test of Competencies in Lung Ultrasound. *Respiration* 2018: 1-8.
285. Millington SJ, Arntfield RT, Guo RJ, Koenig S, Kory P, Noble V, Mallemat H, Schoenherr JR. The Assessment of Competency in Thoracic Sonography (ACTS) scale: validation of a tool for point-of-care ultrasound. *Crit Ultrasound J* 2017: 9(1): 25.
286. Skaarup SH, Laursen CB, Bjerrum AS, Hilberg O. Objective and Structured Assessment of Lung Ultrasound Competence. A Multispecialty Delphi Consensus and Construct Validity Study. *Ann Am Thorac Soc* 2017: 14(4): 555-560.
287. Williamson JP, Twaddell SH, Lee YC, Salamonsen M, Hew M, Fielding D, Nguyen P, Steinfort D, Hopkins P, Smith N, Grainge C. Thoracic ultrasound recognition of competence:

A position paper of the Thoracic Society of Australia and New Zealand. *Respirology* 2017: 22(2): 405-408.
288. Evison M, Blyth KG, Bhatnagar R, Corcoran J, Saba T, Duncan T, Hallifax R, Ahmed L, West A, Pepperell JCT, Roberts M, Sivasothy P, Psallidas I, Clive AO, Latham J, Stanton AE, Maskell N, Rahman N. Providing safe and effective pleural medicine services in the UK: an aspirational statement from UK pleural physicians. *BMJ Open Respir Res* 2018: 5(1): e000307.
289. Downing SM YR. Assessment in Health Profesions Education Routledge - Taylor & Francis Group, New York, London, 2009.
290. Howard ZD, Noble VE, Marill KA, Sajed D, Rodrigues M, Bertuzzi B, Liteplo AS. Bedside Ultrasound Maximizes Patient Satisfaction. *J Emerg Med* 2013.
291. Lindelius A, Torngren S, Nilsson L, Pettersson H, Adami J. Randomized clinical trial of bedside ultrasound among patients with abdominal pain in the emergency department: impact on patient satisfaction and health care consumption. *Scandinavian journal of trauma, resuscitation and emergency medicine* 2009: 17: 60.
292. Laursen CB, Sloth E, Lassen AT, Davidsen JR, Lambrechtsen J, Henriksen DP, Madsen PH, Rasmussen F. Does point-of-care ultrasonography cause discomfort in patients admitted with respiratory symptoms? *Scandinavian journal of trauma, resuscitation and emergency medicine* 2015: 23: 46.
293. Krainin BM, Thaut LC, April MD, Curtis RA, Kaelin AL, Hardy GB, Weymouth WL, Srichandra J, Chin EJ, Summers SM. Heated Ultrasound Gel and Patient Satisfaction with Bedside Ultrasound Studies: The HUGS Trial. *The western journal of emergency medicine* 2017: 18(6): 1061-1067.

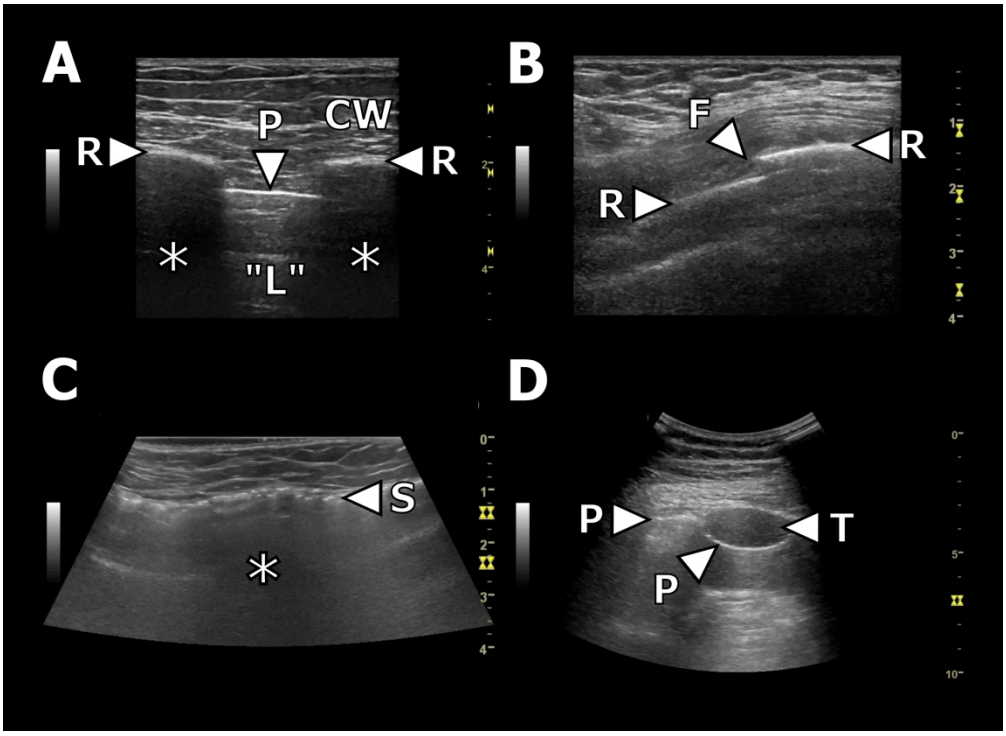


Figure 1. Normal findings and chest wall. A. Normal findings: The muscles, fascia and other soft tissues of the chest wall (CW) are located in the upper part of the image. The surfaces of the ribs (R) can be seen as two horizontal hyperechoic, white, lines with posterior "shadowing" (*). The pleuraline (P) is located just below the ribs. The lung tissue is filled with air and can therefore not be seen. The area ("L") which can be seen below the pleuraline is therefore not the lung tissue but artefacts. B. Rib fracture: The surface of the rib (R) can be seen as a horizontal, hyperechoic white line. A rib fracture (F) is present. C. Subcutaneous emphysema: Air in the chest wall is typically seen as hyperechoic lines or dots with posterior shadowing (*). When the air is placed along a fascia it can be mistaken for the pleuraline. When compared to A, the ribs can however not be visualised and the hyperechoic white line caused by the subcutaneous emphysema is much more superficially located (approx. 1 cm) than the pleuraline seen in A (approx. 2.5 cm). D. Benign pleural tumor: A parietal pleural tumor is present (T). It is seen as a hypoechoic, black, well demarcated structure located above the pleuraline (P).

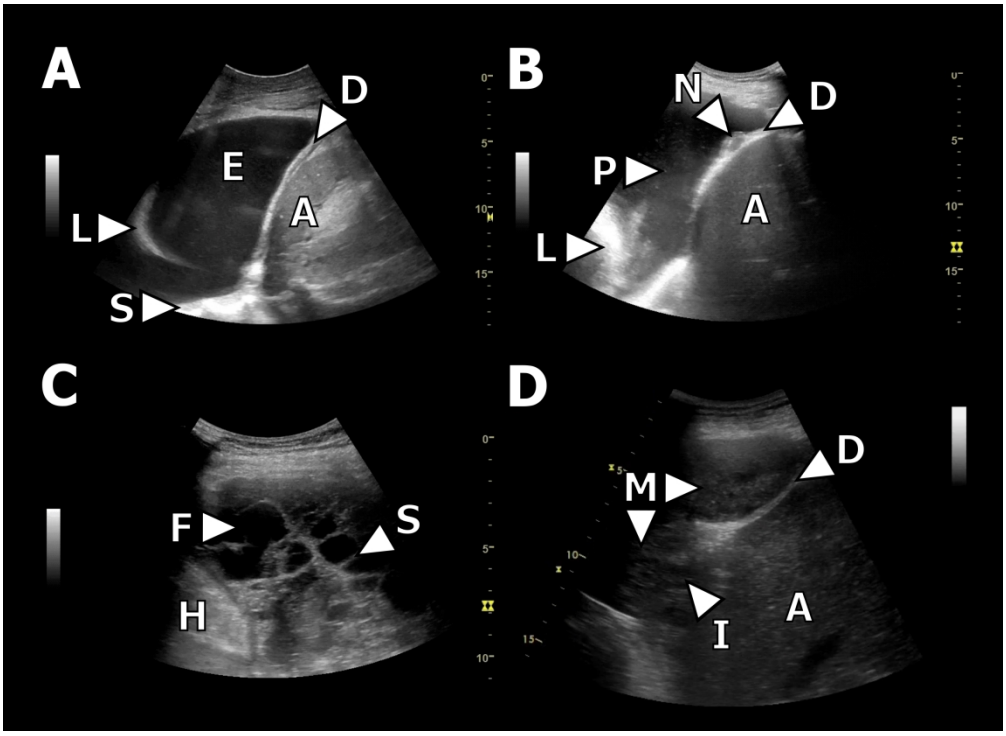


Figure 2. Pleural effusion and pleural malignancy: A. Simple pleural effusion: A simple, anechoic, pleural effusion (E) is present. There are no septations or visible structures floating within the effusion. The effusion can be used as an acoustic window to visualise underlying structures such as the lung (L), diaphragm (D) and thoracic spine (S). Abdominal structures such as the spleen (A) can be visualized below the diaphragm. B. Malignant pleural effusion: Image from a patient with a malignant pleural effusion. A large nodule (N) is present on the diaphragm. Hyperechoic "plankton" (P) can be seen floating within the effusion. The compressed lung (L) and the liver (A) can also be seen. C. Complex septated pleural effusion: A complex septated pleural effusion is present, containing areas of anechoic fluid (F) as well as several septa (S). The heart (H) can be seen in the lower left side of the image. D. Malignant pleural mesothelioma: A large malignant pleural mesothelioma (M) is present and seen as a relatively homogeneous structure, resembling that of the liver (A) placed below the diaphragm (D). Invasive growth (I) through the diaphragm and into the liver is present.

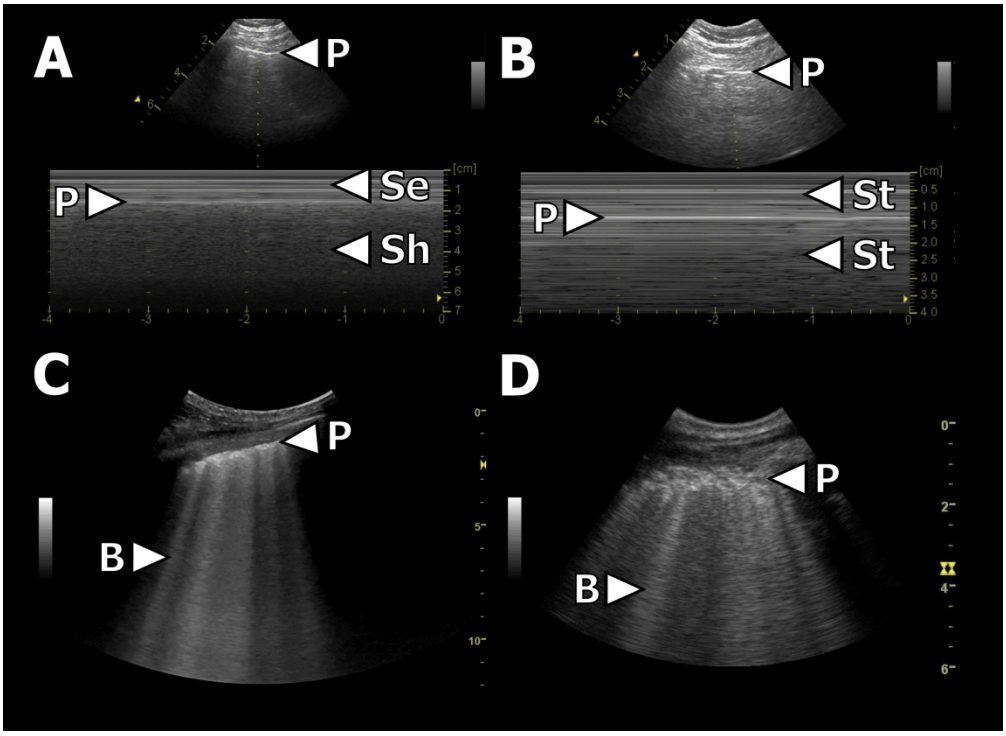


Figure 3. Pneumothorax and B-lines: A. Normal M-mode findings: At the top of the image, the M-mode line can be seen as being placed vertically through the pleuraline (P). In the corresponding M-mode image the pleuraline is seen as a hyperechoic line placed at the same distance from the transducer as can be seen in the 2D image (approx. 1.8 cm). The non-moving structures of the chest wall can in the M-mode image be seen as horizontal lines (Se) above the pleura line. In the presence of lung sliding, the area below the pleuraline in the M-mode image will have a grainy appearance. The pattern has been described as resembling a seashore and is therefore also known as "seashore sign". B. M-mode findings in pneumothorax: If lung sliding and lung pulse is absent, there will be no change in the area below the pleuraline in the 2D / B-mode image. When using M-mode this will be seen as horizontal lines (St) being present above and below the pleuraline (P). The M-mode pattern has been described as resembling a "barcode" or a "stratosphere" and is therefore also known as "barcode sign" or "stratosphere sign". The sign can be seen when a pneumothorax is present, but also in other conditions with absence of lung sliding and pulse (e.g. pleural adhesions). C. Multiple B-lines: Multiple B-lines (B) can be seen as vertical, hyperechoic, lines originating in the pleuraline and stretching all the way from the pleuraline to the bottom of the 2D / B-mode image. D. Idiopathic pulmonary fibrosis: TUS image of the lower lobe of a patient diagnosed with idiopathic pulmonary fibrosis. Multiple B-lines are present (B) and the pleuraline (P) appears severely thickened and fragmented.

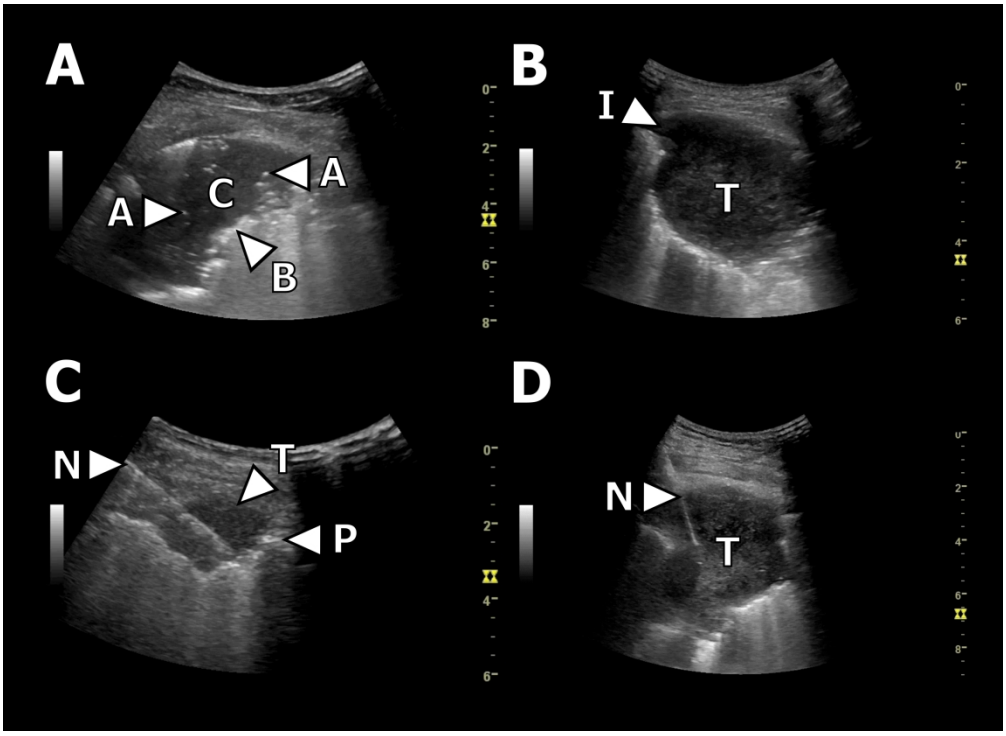


Figure 4. Consolidation and invasive procedures: A. Pneumonia: A lung consolidation is present (C). Air bronchograms (A) are present and can be seen as hyperechoic dots or lines within the consolidation. The border zone (B) to the air-filled parts of the lung tissue appear serrated and irregular. B-lines can often be seen in the area surrounding the consolidation. The sonomorphology is typical for a pneumonia. B. Lung tumor: A lung tumor (T) is present and can be seen as a rounded, well demarcated structure with a fairly homogenous, tissue-like appearance. Invasive growth (I) into the chest wall is present. C. US guided biopsy of a pleural tumor: A pleural tumor (T) can be seen superficial to the pleuraline (P). A needle has US guided been placed in the tumor in order to obtain a biopsy. The needle tip can be seen above the pleuraline, minimising the risk of pneumothorax. C. US guided biopsy of a lung tumor: A lung tumor (T) is present. A needle has US guided been placed in the tumor in order to obtain a biopsy. The needle tip has been placed in the margin of tumor but still with some distance to the normal air-filled lung. This has been done in order to avoid obtaining a biopsy from central necrotic areas of the lung and yet still attempting to minimise the risk of pneumothorax.

# Appendix: Search terms used for each statement topic

The specific search terms used for each of the statement topics are given below.

*Equipment and technique:*
(Ultrasound OR ultrasonic OR echography OR sonographic OR sonography) AND (chest OR thoracic OR thorax OR lung OR lungs OR pulmonal) AND (protocol OR technique OR zone)

*Chest wall and parietal pleura:*

(Ultraso OR sonograph) AND (chest OR thoracic OR thorax) AND (rib OR "parietal pleura")

*Pleural effusion:*

(Ultraso OR sonograp OR echograp) AND (pleural OR thorax OR thoracic OR chest OR intrathoracic or endothoracic OR transthoracic) AND (fluid OR effusion OR liquid OR exudate OR transudate)

*Pneumothorax:*

(Ultrasound OR ultrasono) AND (pneumothorax OR pneumothor)

*Interstitial syndrome:*

(Ultrasound OR ultrasonic OR echography OR sonographic OR sonography) AND (chest OR thoracic OR thorax OR lung OR lungs OR pulmonal) AND (interstitial syndrome)

*Lung consolidation:*
(Ultrasound OR Ultrasonic OR echography OR sonographic OR sonography) AND (chest OR thoracic OR thorax OR lung OR lungs OR pulmonal) AND (consolidation OR pneumonia OR pulmonary embolism OR contusion OR atelectasis)

*Diaphragm:*

(Diaphragm) AND (ultrasound OR sonography)

*US guided procedures:*

(Ultrasound OR US) AND (guided) AND (intervention OR procedure OR thoracentesis OR chest drain OR indwelling pleural catheter OR biopsy OR thoracoscopy) AND (lung OR pleural OR thoracic OR chest)
*Training:*

(Ultrasound OR ultrasonic OR echography OR sonographic OR sonography) AND (chest OR thoracic OR thorax OR lung OR lungs OR pulmonal) AND (training OR education OR simulation OR (virtual reality) OR assessment OR test)

*Patient perspectives:*

((Ultrasound OR ultrasonography) AND (thorax OR respiratory OR lung OR chest) AND (patient) AND (preference OR experience OR satisfaction OR perspective)