Lung ultrasound: a useful tool in the assessment of the dyspnoeic patient in the emergency department. Fact or fiction?

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ABSTRACT

Patients with respiratory distress present a frequent and challenging dilemma for emergency physicians (EPs). The accurate diagnosis and treatment of the underlying pathology is vitally important in these sick patients to ensure the best outcome and minimise harm from unnecessary treatments. Within the last decade, studies have shown lung ultrasonography (LU) to be valuable in the accurate diagnosis of a variety of lung pathologies, including cardiogenic pulmonary oedema, pleural effusion, pneumothorax, haemothorax and pneumonia. However, despite advances in techniques and the evidence for the use of LU in the diagnosis of respiratory pathology, it remains poorly understood and rarely used by EPs. This clinical review article provides an overview of LU and its relevance as a diagnostic aid to the detection of respiratory pathology in the Emergency Department (ED).

INTRODUCTION

Background

Dyspnoea is a common presentation in the ED.[1 2] When treating these often critically ill patients, EPs often need to make rapid diagnoses and treatment plans with limited clinical information.[1] In these patients, clinical evaluation with history taking and physical examination alone has been shown to be non-specific or inconclusive, and CXR findings can be misleading and delayed, especially with portable machines.[1 3 4]

Ultrasonography (US) has been used as an imaging technique for more than 50 years. Until recently, the role of US in the diagnosis and management of respiratory diseases was thought to be limited due to the presence of air in the respiratory tract and the solid structures of the thoracic cage that impeded the passage of US waves and created artefact. However, clinicians have begun to realise that these artefacts are actually diagnostically useful in characterising a variety of lung pathologies.[5] As a result, point-of-care ultrasound is becoming a reliable tool to aid in rapid diagnosis of a variety of lung pathologies including cardiogenic pulmonary oedema, pleural effusion, pneumothorax and lung consolidation.[1–10]

More recently lung ultrasonography (LU) has also been used in prehospital environment as well as remote and high altitude areas to aid the diagnosis of lung pathology.[11–13]

Importance and goals of this investigation

Despite being a quick, non-ionising radiation bedside test, the use of LU in respiratory distress remains poorly understood and not widely accepted in EDs. This article aims to review the published evidence for the use of LU in respiratory disease to ascertain whether it merits a position in the arsenal of an emergency physician (EP) faced with these challenging and sick patients.

METHODS

Search strategy

Initial literatures search was conducted using The NHS Evidence Health Resources Library (OVID interface) to search:

- AMED—1985 to February 2016
- BNI—1985 to February 2016
- EMBASE—1980 to February 2016
- MEDLINE—1950 to February 2016
- CINAHL—1981 to February 2016

A similar search was done by the librarians at University Hospitals Coventry and Warwickshire.

The following sources were also investigated for grey literature:

- PubMed database
- Google Scholar search
- Cochrane Review

In addition, bibliographies of all papers found were hand searched for relevant articles.

Prior to each revision a new literature search was conducted to ensure that the article was current and up-to-date.

Studies included were those in which ultrasound was conducted by EPs and intensivist with training in LU or radiologists.

Analysis

Calculation of likelihood ratios was performed using Microsoft Excel.

Literature review and clinical experience

LU in the diagnosis of pulmonary oedema

A B-line is an artefact generated by the air–fluid interface in the presence of extra-alveolar fluid (figure 1).[14] These vertical narrow-based lines arise from the pleural line and extend to the edge of the US screen. Short non-pathological reverberation artefacts can be seen in normal lungs and arise only from the pleural line and do not extend to the base of the US screen.

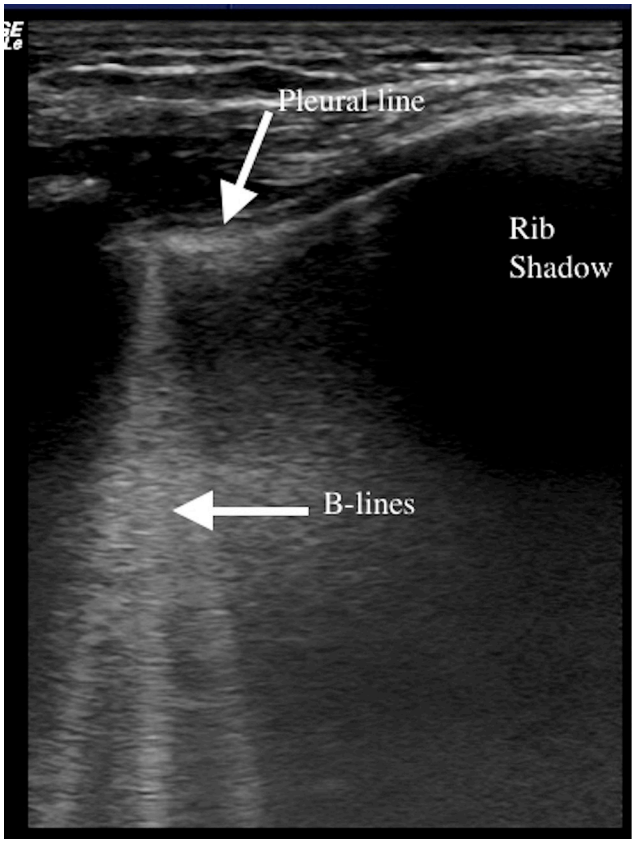

Figure 1 A lung ultrasonography scan of a single intercostal space showing B-lines (white vertical lines)— curved array.[13]

For a video demonstrating B-lines please view: https://vimeo.com/124660727

The B-line was first described in 1997 as a diagnostic sign for pulmonary oedema by the French intensivist Daniel Lichtenstein, who demonstrated that LU could be used to diagnose the presence of alveolar-interstitial syndrome with high levels of specificity and sensitivity.[5] In a further study, the same investigator was also able to show LU was effective in differentiating between pulmonary oedema and chronic obstructive pulmonary disease.[15] Subsequent studies carried out by other researchers validated B-lines as an accurate sign for detecting pulmonary oedema by comparing it to results obtained from CXR, CT and invasive measurements of pulmonary oedema.[16–20]

A 2006 study by Volpicelli *et al*[20] investigated the utility of B-lines in the diagnosis of pulmonary oedema in 300 consecutive patients in the ED setting. Eight anterolateral ultrasound chest intercostal scans were obtained for each patient. B-line sensitivity of 85.7% and a specificity of 97.7% was shown in recognition of radiological pulmonary oedema.

In 2007, a study of 340 patients demonstrated that B-lines were significantly related to the severity of heart failure measured by the New York Heart Association (NYHA) functional classification I to IV. Successful treatment resulted in improvement in NYHA classification and a decreased B-lines score, thereby demonstrating that B-lines could be used as a tool for monitoring changes in extravascular lung water.[21] Another study demonstrated that LU alone allowed diagnosis of the aetiology of acute respiratory failure in 90.5% of cases.[6] This finding was confirmed by a separate team of researchers who compared the diagnostic performance of LU to bedside CXR for the detection of various lung pathologies in 44 mechanically ventilated patients in the intensive care setting.[22] Using CT as the gold standard, CXR was shown to have a sensitivity of 46% and a specificity of 80% in diagnosing pulmonary oedema, whereas LU was shown to have a sensitivity of 94% and specificity of 93%.

A recent meta-analysis reviewed seven studies and 1075 patients in which LU was found to have a sensitivity of 94.1% (95% CI 81.3% to 98.3%) and a specificity of 92.4% (95% CI 84.2% to 96.4%) for detecting pulmonary oedema. In this meta-analysis, two studies were completed in the ED, two in the intensive care unit, two in inpatient wards and one in the prehospital setting. The seven studies were rated as average to excellent methodological quality.[23] Additionally, ultrasound B-lines have been shown to be as a reliable predictor of the cardiogenic origin of dyspnoea as natriuretic peptides.[24 25]

In trials conducted on the efficacy of LU in the diagnosis of cardiogenic pulmonary oedema (CPO), LU was shown to take less than 3 min to perform and produce interpretable images in nearly 100% of cases.[5 15 16 18] Multiple prospective, blinded observational studies have demonstrated that CPO was identifiable from LU, even in residents with minimal exposure to LU.[26 27] Furthermore, interobserver agreement in the evaluation of B-lines using bedside LU is high, even between expert and novice physician sonographers.[28]

Using a structured eight-zone scanning technique first advocated by Volpicelli *et al*[20], B-line per rib space is accepted to be a normal variant, with three or more being a positive result that occurs with interstitial and alveolar thickening predominantly from becoming oedematous with fluid. Liteplo *et al*[2] found that if at least two zones were positive for B-lines bilaterally in an eight-zone scan, the positive likelihood ratio (LR+) of pulmonary oedema was 3.88 (99% CI 1.55 to 9.73) and negative likelihood ratio (LR−) was 0.5 (95% CI 0.30 to 0.82). On sensitivity analysis, the positive likelihood ratio was infinite if all eight zones were positive for B-lines, and 0.22 (95% CI 0.06 to 0.80) if no zones were positive. Liteplo *et al*[2] also performed a two-zone assessment of B-lines in the diagnosis of congestive heart failure, in which interval likelihood ratio were 4.73 (95% CI 2.10 to 10.63) when inferior lateral zones were positive bilaterally and 0.3 (95% CI 0.13 to 0.71) when these were negative. These changed to 8.04 (95% CI 1.76 to 37.33) and 0.11 (95% CI 0.02 to 0.69), respectively, when congruent with NT-ProBNP.

Although B-lines correlate with pulmonary oedema and congestive heart failure diagnoses, there are other causes of interstitial and alveolar thickening that can provide false positives such as interstitial pneumonia or pneumonitis and diffuse parenchymal lung disease (pulmonary fibrosis).

A summary of studies that have used B-lines in the detection of pulmonary oedema is shown in Table 1. Positive (LR+) and negative (LR−) likelihood ratios are reported.

LU in the diagnosis of pneumothorax

In a pneumothorax, air is contained between the parietal and visceral pleura, which prevents visualisation of deeper structures. Therefore, the diagnosis of pneumothorax by LU requires observation of five artefact signs, which are most sensitive when used in combination.[8 29]

- Absence of lung slide
- Absence of B-lines
- Absence of lung pulse
- Presence of A-lines
- Presence of the lung point

Table 1 Lung ultrasound in the diagnosis of cardiogenic pulmonary oedema

Study (first author)	n	US sensitivity/specificity	US LR+/LR–	Gold standard	Sonographer type
Lichtenstein[5]	250	93.4/93	13/0.071	CXR	Experienced intensivist
Lichtenstein[15]	146	100/92	13/0	CXR	Experienced intensivist
Agricola[16]	20	90/86	6.4/0.12	CXR/PiCCO/Echo	Cardiologist
Volpicelli[20]	300	85/98	43/0.15	CXR/CT/Final diagnosis	EP or radiologist
Gargani[24]	149	81/85	5.4/0.22	NT-proBNP	Sonographer not otherwise specified
Lichtenstein[6]	301	97/95	19/0.032	Final clinical diagnosis	Experienced intensivists
Liteplo[2]	100	58/85	3.9/0.49	Final clinical diagnosis	EP or LU- trained student
Maines[19]	23	83/91	9.2/0.19	ICD measure	Experienced physicians not otherwise specified
Vitturi[61]	152	97/79	4.6/0.038	Final clinical diagnosis	Not specified
Prosen[62]	248	100/95	20/0	Final clinical diagnosis	EP
Xirouchaki[22]	42	46/80	2.3/0.68	CT	Experienced intensivist
Cibinel[63]	56	93.6/84	5.9/0.076	Final clinical diagnosis	EP
Al Deeb[23]	1075	94.1/92.4	12/0.064	Meta-analysis	Meta-analysis- physicians or medical students
Chiem[27]	380	87/49 (one positive lung zone)	1.7/0.3	Final clinical diagnosis	Novice EP
Pivetta[64]	1005	97/97.4	37/0.031	Final clinical diagnosis	EP

EP, emergency physician; LR+, positive likelihood ratio; LR-, negative likelihood ratio; LU, lung ultrasonography; US, ultrasonography, ICD, intrathoracic impedance device; NT-proBNP, N-terminal pro-brain natriuretic peptide

For a B mode video of a pneumothorax that demonstrates bat wing sign, lung sliding, A-lines, B-lines and Lung point please look at: https://vimeo.com/45654299

The lung slide is a horizontal movement of the pleural line and occurs when the two pleural layers are apposed. This pleural movement is seen during expiration and inspiration on a normal B mode scan. When a normal lung is visualised in the M mode a 'sea shore' appearance is seen where the pleura appears as horizontal lines and the underlying lung as grainy (figure 2). In the absence of lung sliding, the M mode appearance takes on the shape of a barcode with uniform horizontal lines and no 'grainy' section (figure 3). The absence of a lung slide is a sensitive predictor of a pneumothorax; however, further signs are required to increase the specificity as other conditions can also cause absence of lung slide.[8 29]

A-lines are horizontal linear artefacts below the pleural line and occur in both normal lung and pneumothorax. The A-line

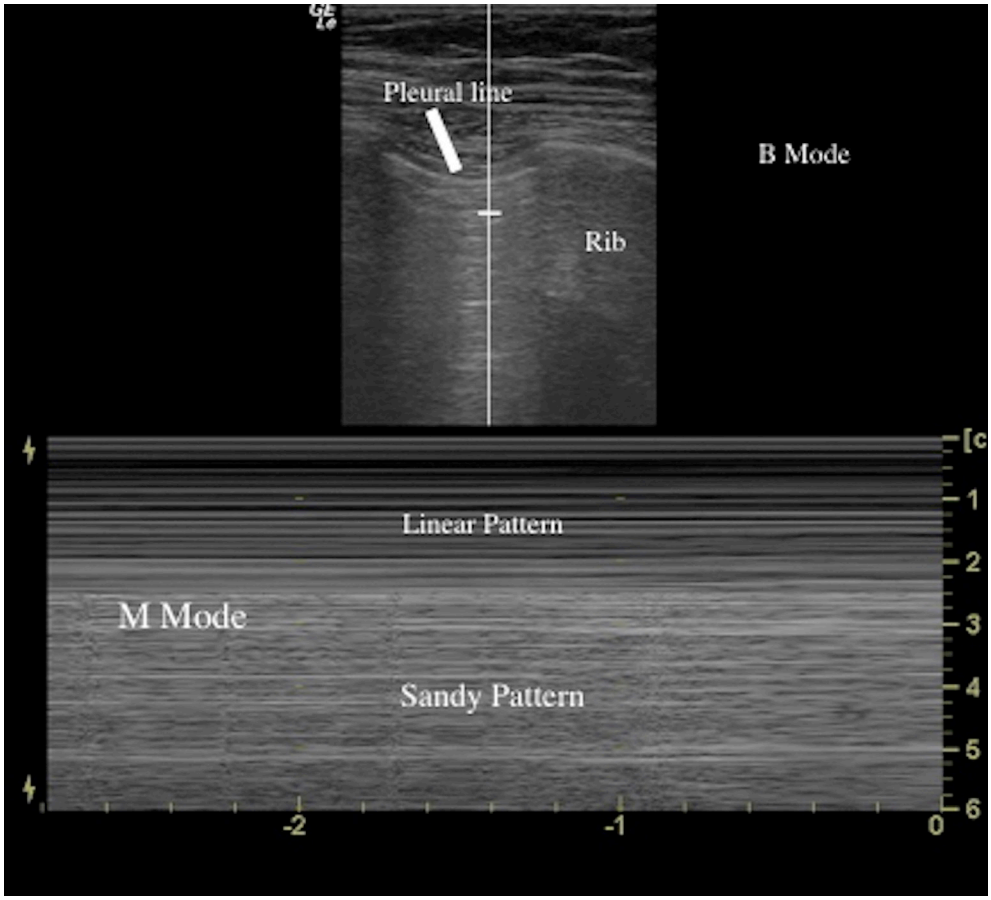

Figure 2 B and M mode scan of a normal lung. Note the 'sea-shore' appearance on the M mode image (linear array).[13]

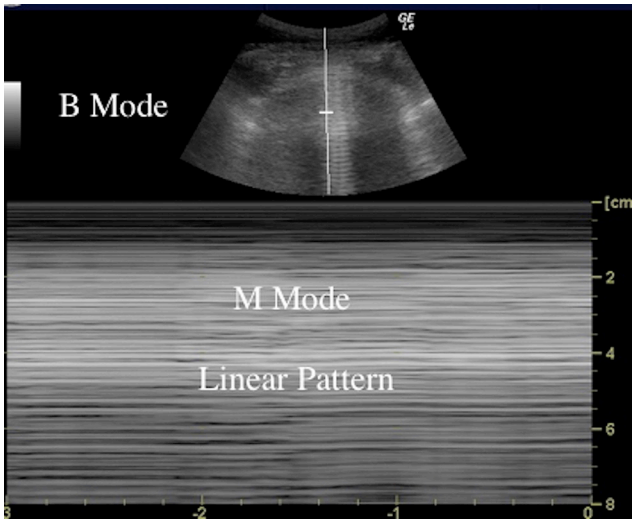

Figure 3 Ultrasonography B and M mode depiction of a pneumothorax. Note the 'bar-code' appearance of the M mode image (linear array).[13]

sign is seen with A-lines present and the absence of B-lines.[30] As B-lines arise from the pleura as a result of contrasting adjacent acoustic impedance between tissue or fluid and air within the lungs, these are absent in a pneumothorax.[5 8 31 32] The lung pulse is a vertical movement of the pleural line due to transmission of ventricular contractions through expanded lung to the pleura. The lung pulse is therefore absent in a pneumothorax.[8] Finally, the lung point is seen at the edge of the pneumothorax where the lung again normally apposes the parietal pleura. When an ultrasound pattern suggestive of pneumothorax is seen, the probe can be moved inferolaterally to a point where lung sliding or B-lines are seen again. This point signifies where the lung readheres to the parietal pleura. Recognition of the lung point has a positive predictive value of 100% and can demonstrate the extent of the pneumothorax; however, it has a low sensitivity because the lung point of a large pneumothorax may not be seen on the anterior chest.[8 10 29 33–35]

The identification of a pneumothorax involves the detection of sliding and artefacts and requires a tissue air interface at the level of the pleura. Therefore, other conditions with lung and pleura adherence can result in false positive results such as in acute respiratory distress syndrome (ARDS), pleural malignancy, pulmonary fibrosis, pulmonary contusions and chronic obstructive pulmonary disease (COPD).[8 22]

In a trial conducted to assess the efficacy of LU to diagnose a pneumothorax, the combination of A-lines and absent lung slide at the anterior chest wall in a supine patient had a sensitivity of 100% and specificity of 96.5%.[5 32] By contrast, detection of lung sliding on the anterior-inferior haemithorax in the supine patient allows a pneumothorax to be excluded with a negative predictive value of 100% and specificity between 60% in ARDS patients due to the adherence of pleural surfaces to 91% specificity in the general population.[8 31 36] A previous study by Lichtenstein *et al*[5] found absence of B-lines has a sensitivity of 100% for pneumothorax detection. However, the absence of B-lines had a specificity of only 60%, as other conditions can also result in the absence of B-lines.[5]

LU has been used to diagnose pneumothorax with an overall sensitivity of 75%–100% in all except one study (table 2). However, when either absence of B-lines or the combination of A-lines and absent lung slide are found, then the sensitivity of pneumothorax detection is 100%.[5 8] When the studies were interrogated the missed pneumothoraces in the LU groups were small and therefore these sensitive signs had been missed, preventing pneumothorax detection. LU has a high specificity for ruling out pneumothorax of between 94% and 100% (table 2). The main reasons listed in the current studies for false positives were cases of subcutaneous emphysema, severe COPD or suboptimal methodology without all five artefacts being considered before the diagnosis of pneumothorax was made.

Overall when these five clinical signs are used in combination, a pneumothorax can be accurately detected at the bedside. LU detection of pneumothorax has a better diagnostic performance than CXR and comparable performance with thoracic CT.[8 22 34] The combination of LU diagnostic accuracy, reduced radiation, complexity and cost should enable LU to be regarded

Table 2 Lung ultrasound in the diagnosis of pneumothorax

Study (first author)	n	Sensitivity (%)	Specificity (%)	Ultrasound LR+/LR–	Gold standard	Sonographer type
Kirkpatrick[54]	225	US 49 CXR 21	US 100 CXR 99	Undefined/0.51	CT	Novice trauma surgeons
Knudtson[65]	328	US 92	US 99	92/0.081	CXR	Trauma surgeons
Chung[33]	97	US 80 CXR 47	US 94 CXR 94	13/0.21	CT	Experienced radiologists
Lichtenstein[66]	200	US 95	US 94	16/0.053	CT	Intensivists
Zhang[10]	135	US 86 CXR 27	US 97 CXR 100	29/0.14	CT and chest drain	EP
Sartori[67]	285	US 100 CXR 87	US 100 CXR 100	Undefined/0	CT	Experienced physicians not otherwise specified
Lichtenstein[6]	260	US 81	US 100	Undefined/0.19	Final clinical diagnosis	Experienced intensivists
Nagarsheth[34]	79	US 81 CXR 31	US 100 CXR 100	Undefined/0.19	CT	Novice surgeon
Ding[68]	7569	US 88 CR 52	US 99 CR 100	88/0.12	CT or air escape (meta-analysis)	Meta-analysis varied
Alrajhi[69]	1048	US 91 CXR 50	US 98 CXR 99	46/0.092	CT or air escape (meta-analysis)	Meta-analysis varied
Xirouchaki[22]	84	US 75 CXR 0	US 93 CXR 99	11/0.27	CT	Experienced intensivist

EP, emergency physician; LR+, positive likelihood ratio; LR-, negative likelihood ratio; US, ultrasonography.

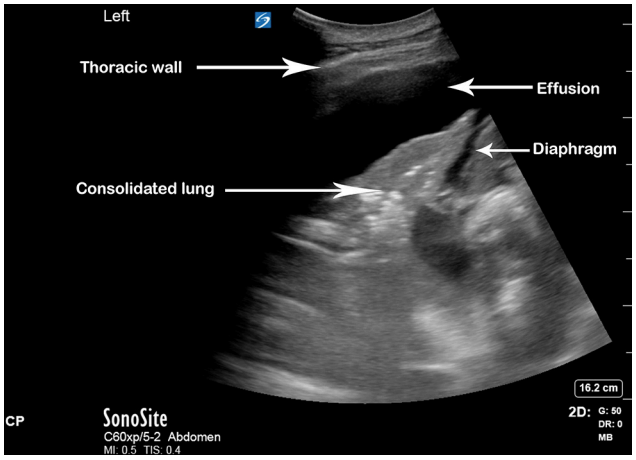

Figure 4 Lung ultrasonography scan showing lung consolidation and parapneumonic effusion secondary to basal pneumonia (curved array).

as a visual stethoscope for pneumothorax detection in the ED. Table 2 summarises the evidence for the use of LU in detecting a pneumothorax.

LU in the diagnosis of lung consolidation

Consolidation must make contact with the pleura in order to be detectable by LU because the presence of aerated lung at the pleural edge renders the lung impenetrable to imaging. This is important to remember in using LU but does not often present an issue because it is usual for consolidation to make contact with the pleura.[37]

In a study including 260 dyspnoeic patients, of which 83 had a diagnosis of pneumonia, Lichtenstein found several features that suggest consolidation with 89% sensitivity and 94% specificity.[6]

- Anterior alveolar consolidations
- Anterior diffuse B-lines with abolished lung sliding
- Anterior asymmetric interstitial patterns
- Posterior consolidations or effusions without anterior diffuse B-lines

Alveolar consolidation results in a tissue pattern that looks very similar in echo-texture to liver parenchyma (hepatisation) and is thus referred to as 'liver sign' (figure 4). The area will have boundaries that superficially are the pleural line (or the deep border of any associated effusion), and a deep border that will either have an indistinct 'shredded' appearance due to adjacent aerated lung or be well defined if consolidation reaches the other lobar borders.[7 38]

The presence of multiple B-lines suggests excess fluid within the tissues and an 'interstitial syndrome'. If associated with the absence of normal lung sliding, this infers an inflammatory process in the vicinity, which may be due to infection, trauma or other causes, but in context will indicate consolidation or contusion. Asymmetry or the density of B-lines compared with the contralateral side similarly indicates a localised inflammatory process.[3 6 7 39]

It has also been reported in one study that by examining the dynamic behaviour of air bronchograms visible within consolidated lung, it is possible to distinguish between atelectasis (resorbative collapse without expansion of bronchioles during inspiratory phase) and infective pneumonias (with patent airways where airways can be seen to dynamically open during inspiration).[38] This distinction could help to identify patients that may benefit from bronchoscopy to relieve obstructive mucous plugging and has already been considered in monitoring re-expansion in ventilator-associated pneumonias.[40]

A recent (2016) meta-analysis by Llamas-Álvarez *et al*[41] published in *Chest* analysed 16 studies with 2359 participants. Because of the subjective nature of LU and heterogeneity in sensitivity and specificity reports in the literature, the authors chose not to publish pooled estimates of these data. However, they concluded that LU can help to accurately diagnose pneumonia, and it may be promising as an adjuvant resource to traditional approaches.

Although LU assessment of consolidation has been investigated over the last decade, a single author has led many of the studies. Many are based on the ICU setting rather than the ED, and most have a composite gold standard. Further research is required to validate the use of ultrasound in the diagnosis of consolidation due to pneumonia or resorbative atelectasis.

For a tutorial video on LU for consolidation visit www.ultrasoundpodcast.com/tag/lung/

A summary of studies that have used LU in the detection of lung consolidation is shown in table 3.

LU in pleural effusion

On LU, a pleural effusion is a hypoechoic or echoic area between the parietal and visceral pleura that changes shape with respiration as shown in (figure 5).[42–45] Fluid acts as an acoustic window allowing visualisation of a 'V-line' of vertebral bodies and the posterior thoracic wall. V-lines aid the confirmation of free pleural fluid in the supine patient.[39 46]

The use of LU for pleural effusion identification has long been well recognised with sensitivity above 90%.[22 47 48] Bedside US guidance significantly increases the probability of successful pleural fluid aspiration, reduces the risk of organ puncture and is recommended for use in these procedures by the British Thoracic Society.[44]

Table 3 Lung ultrasound in the diagnosis of lung consolidation

Study (first author)	n	US sensitivity/specificity (%)	Ultrasound LR+/LR−	Gold standard	Sonographer type
Lichtenstein[3]	32	93/100	Undefined/0.07	CT	Experienced intensivist
Lichtenstein[7]	118	90/98	45/0.1	CT	Experienced intensivists
Lichtenstein[6]	260	89/94	15/0.12	Final clinical diagnosis	Experienced intensivists
Xirouchaki[22]	42	100/78	4.5/0	CT	Experienced intensivist
Corterello[4]	81 (pneumonia)	98/95	20/0.021	Final clinical diagnosis	Experienced EP
Chavez[70]	1172 (pneumonia)	94/96	24/0.063	CXR, CT or clinical criteria (meta-analysis)	Meta-analysis varied
Nazerian[71]	285	83/96	21/0.18	CT	Experienced EP or internist
Llamas-Álvarez[41]	2359	80–90/70–90	Not calculated	Meta-analysis	Meta-analysis varied

EP, emergency physician; LR+, positive likelihood ratio; LR-, negative likelihood ratio; US, ultrasonography.

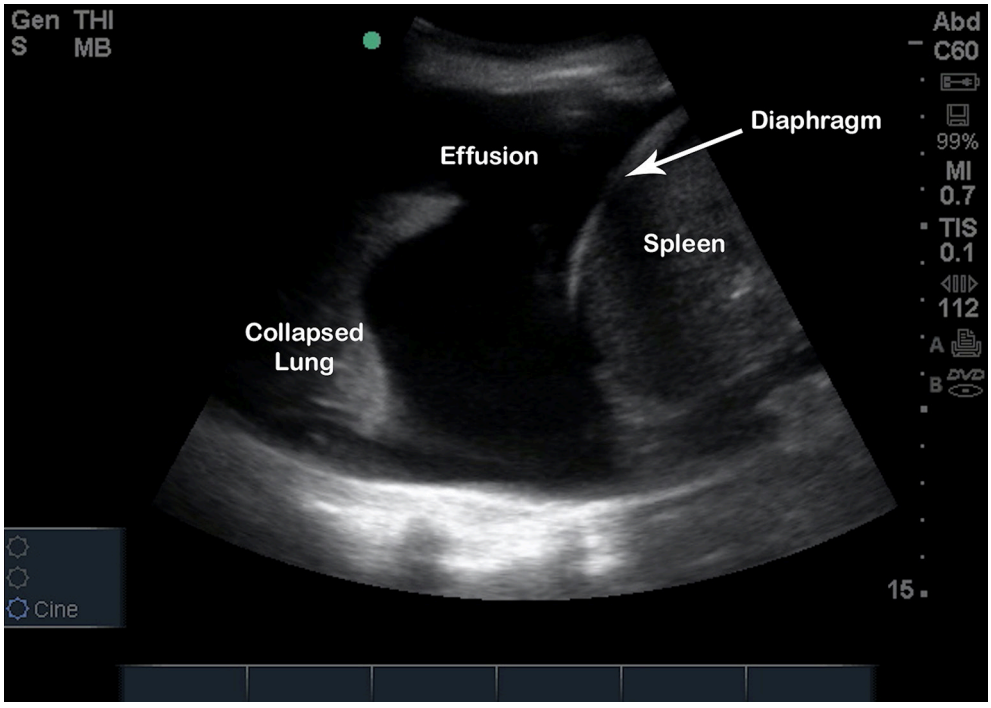

Figure 5 Lung ultrasound scan showing a large pleural effusion (curved array).

LU has a higher sensitivity for pleural effusion detection compared with either clinical examination or CXR, including lateral decubitus films.[44 49 50] Small pleural effusions may not be visible on a CXR. A previous study found over 175 mL of fluid is required to cause blunting of costo-phrenic angles on an upright CXR.[42] In contrast, US is more sensitive for the detection of pleural fluid with the ability to detect 20 mL of fluid.[46 51 52]

Portable US is readily accessible and produces a high diagnostic yield compared with other imaging modalities for pleural effusion detection and should therefore be used both for diagnosis and aspiration of pleural fluid in symptomatic patients.

For a video on lung US tips for pleural effusion please visit http://www.ultrasoundpodcast.com/tag/lung/

A summary of studies that have used LU in the detection of pleural effusion is shown in table 4.

How to perform LU in the ED

In performing LU, the probe most widely used in the current literature is the convex phased array low frequency (2–5 MHz) probe.[3 15 37 53] Other studies have used higher frequency linear transducers (5–10 MHz)[54–56] or cardiac phased arrays (2–4 MHz).[3 57] However, in the experience of the authors, LU can be performed with most US probes. LU is conducted with the patient in a supine or 45° position. Ultrasonography gel should be applied to each intercostal space that will be examined. The transducer is set at a depth of 4–10 cm, and the lungs are visualised through the intercostal spaces. When performing the scan, the probe should be positioned so that the ultrasound beam is perpendicular to the pleural surface to optimise artefacts. To help identify the intercostal space, the probe should be oriented longitudinally. In between the two ribs, there is a hyperechoic line >0.5 cm deeper to the probe. This line is the interface between the soft tissues of the chest wall and the aerated lung—the 'pleural' line. The 'pleural line,' represents the parietal and visceral pleural interface. Together, the upper rib, pleural line and lower rib form a characteristic pattern: the 'bat wing sign' (figure 6).

Once the pleura and underlying lung are identified, the probe should be turned to the transverse position to visualise a larger pleural area. The number of lung zones scanned can vary from a comprehensive 28-zone examination to an abbreviated 8-zone study. For bedside rapid ED use, the 8-zone or 10-zone examination is often sufficient as it can provide a diagnosis in most cases.[20] In the eight-zone technique, two anterior and two lateral

Table 4 Lung ultrasound in the diagnosis of pleural effusion

Study (first author)	n	Sensitivity (%)	Specificity (%)	Ultrasound LR+/LR−	Gold standard	Sonographer type
Ma[72]	240	US 96	US 100	Undefined/0.04	CT	EP
Rozycki[73]	47	US 84	US 100	Undefined/0.16	CT	Surgeons
Abboud[74]	142	US 12	US 98	6/0.9	CT	Experienced EP
Lichenstein[3]	32	US 92	US 93	13/0.086	CT	Experienced intensivist
Brooks[75]	61	US 92	US 100	Undefined/0.08	Composite gold standard	Experienced EP or surgeon
Xirouchaki[22]	42	US 100 CXR 65	US 100 CXR 81	Undefined/0	CT	Experienced intensivist
Schleder[76]	24	Hand US 91 CXR 74	Hand US 100 CXR 31	Undefined/0.09	High-end US	Intensivist

EP, emergency physician; LR+, positive likelihood ratio; LR-, negative likelihood ratio; US, ultrasonography.

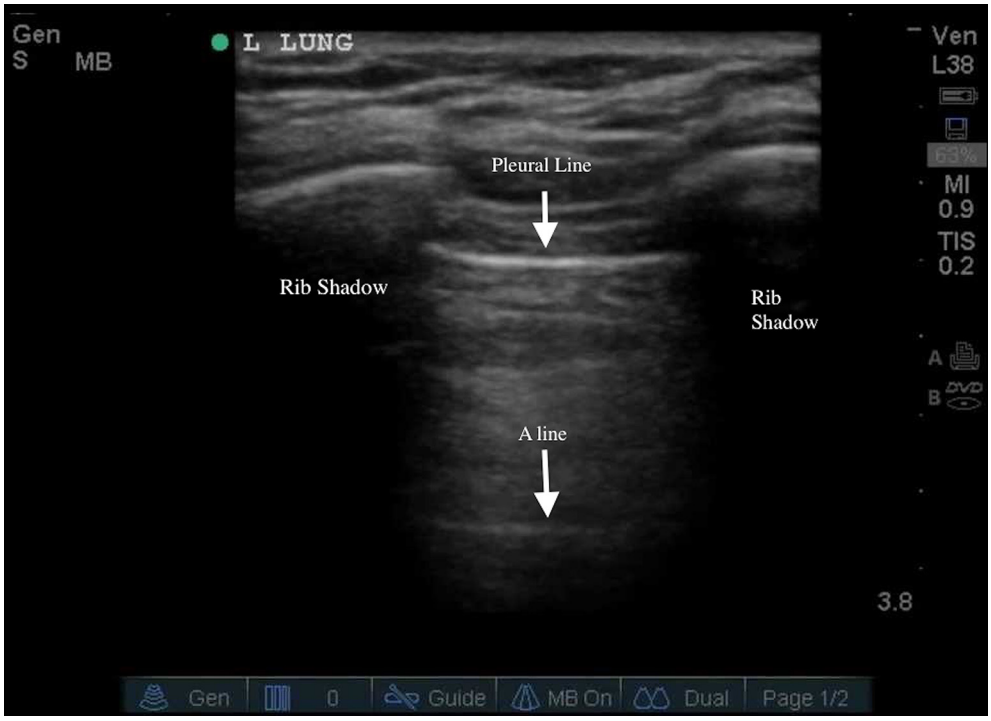

Figure 6 A normal lung ultrasonogram of a single intercostal space. This image demonstrates the bat wing sign and A-lines (linear array).[13]

intercostal spaces are scanned on each haemithorax. For the 10-zone technique, a posterior segment is also scanned below each scapula. The initial examination is normally conducted using the default two-dimensional B mode; however, if a pneumothorax or pleural effusion is suspected, an M mode (time–motion) study is needed to look for further signs commonly seen in these two conditions.[58] Lichtenstein's BLUE protocol is still the most commonly used.[59]

Lung US tutorial video: https://www.youtube.com/watch?v=VzgX9ihnmec and http://www.ultrasoundpodcast.com/2016/05/lung-ultrasound-basics-part-1-pneumothorax-pulmonary-edema-ultrasoundmd-foamed-also-www-cabofest2017-com/

Table 5 provides a summary of US signs that may be seen when performing an LU examination and explains their significance.

Advantages of LU in the ED

A key advantage of using LU in the ED is that it can be done in real time at the patients' bedside as part of the initial respiratory assessment of the patient. It is easily repeatable,

Table 5 Summary of lung ultrasound signs and their interpretation

Sign	Images	Description	Pathology
Sliding sign	Figure 2	Movement between the two layers of the pleura during normal respiration	Normal
A-lines	Figure 6	Hyperechoic horizontal lines parallel to pleural line occurring at regular intervals below the pleura Artefacts from reverberations between probe and pleura	Seen in normal lungs as well as pneumothorax and emphysematous lungs
B-lines	Figure 1	Hyperechoic artefacts that originate at the pleural line and extend from the probe to the edge of the screen, without fading and perpendicular to the pleural line Artefacts that occur when the interstitium and alveoli are thickened predominantly from becoming oedematous with fluid	Presence of three or more B-lines per intercostal space is evidence of interstitial fluid. If seen diffusely in two or more zones bilaterally is usually indicative of pulmonary oedema
Z-lines	-	Hyperechoic artefact that originates at and perpendicular to the pleural line but does not extend to the edge of the ultrasound window and are shorter, wider and less defined than B-lines	Normal or pneumothorax
V-lines (spine sign)	-	Fluid acts as an acoustic window to enable visualisation of the V-line of vertebral bodies and the posterior thoracic wall in a supine patient	Pleural fluid
E-lines	-	Comet tail artefacts that are superficial to the pleural line	Echogenic foreign bodies or subcutaneous emphysema
Stratosphere sign	Figure 2	The loss of lung sliding beneath the pleura	Pneumothorax
Liver sign (mirror sign)	Figure 4	Tissue similar in consistency to liver tissue seen on US	Lung consolidation absent in pleural effusion
Sea shore sign (M mode)	Figure 2	Pleura appears as horizontal lines and the underlying lung as grainy, making up the sea and sandy shore, respectively	Normal M mode appearance of lung
Bar code sign (M mode)	Figure 3	Bar code-like appearance throughout M mode	Pneumothorax

reproducible and reliable and is particularly sensitive in imaging the chest wall, pleura and pleural spaces because of their superficial locations. It is radiation free and cost-effective, and combined with the low sensitivities of CXR, it will provide vital additional information in treating these often very sick patients in EDs.

Limitations of using LU in the ED

The main limitations of LU lie in the areas of training, operator variability and reliability. Although most studies showed LU to have low intraobserver and interobserver variability, the majority of these scans were performed by clinicians with considerable experience in sonography. Whether these results can be replicated in EDs every day remains to be seen.

Other potential application for LU

LU can add valuable clinical information in the prehospital environment and remote areas where CXR is not available, for example in remote high altitude clinics to diagnose and monitor high altitude pulmonary oedema or in the prehospital trauma setting to detect a pneumothorax in critically injured patients.[11–13] LU also has application limited resource countries that do not have ready access to radiology. Here ultrasound can guide clinical assessment or even allow remote expert real-time interpretation of images to guide therapy, for example, draining a perineumonic effusion or diagnosis.[60] Prehospital LU in trauma allows triage and rapid detection or exclusion of pneumothorax that can guide appropriate intervention or non-intervention in the context of high operator accuracy/reliability.

CONCLUSION

The evidence suggests that LU can be used to accurately diagnose a range of chest conditions. That accuracy will be dependent on training, skill and interpretation knowledge. Much of the evidence should be interpreted with caution given it arises from centres with proven track record and expertise in LU. As more EPs become trained and experienced in US skills, LU will become an additional diagnostic tool; a prototype tricorder for diagnosing critically ill patients presenting with dyspnoea. This will be particularly valuable in prehospital and remote environments where portable and handheld US may be available while conventional CXR is not.

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REFERENCES

1 Ünlüer EE, Karagöz A. Bedside lung ultrasound versus chest X-ray use in the emergency department. *Interv Med Appl Sci* 2014;6:175–7.
2 Liteplo AS, Marill KA, Villen T, *et al*. Emergency thoracic ultrasound in the differentiation of the etiology of shortness of breath (ETUDES): sonographic B-lines and N-terminal pro-brain-type natriuretic peptide in diagnosing congestive heart failure. *Acad Emerg Med* 2009;16:201–10.
3 Lichtenstein D, Goldstein I, Mourgeon E, *et al*. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. *Anesthesiology* 2004;100:9–15.
4 Cortellaro F, Colombo S, Coen D, *et al*. Lung ultrasound is an accurate diagnostic tool for the diagnosis of pneumonia in the emergency department. *Emerg Med J* 2012;29:19–23.
5 Lichtenstein D, Mézière G, Biderman P, *et al*. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. *Am J Respir Crit Care Med* 1997;156:1640–6.
6 Lichtenstein DA, Mezière GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest* 2008;134:117–25.
7 Lichtenstein DA, Lascols N, Mezière G, *et al*. Ultrasound diagnosis of alveolar consolidation in the critically ill. *Intensive Care Med* 2004;30:276–81.
8 Volpicelli G. Sonographic diagnosis of pneumothorax. *Intensive Care Med* 2011;37:224–32.
9 Husain LF, Hagopian L, Wayman D, *et al*. Sonographic diagnosis of pneumothorax. *J Emerg Trauma Shock* 2012;5:76–81.
10 Zhang M, Liu ZH, Yang JX, *et al*. Rapid detection of pneumothorax by ultrasonography in patients with multiple trauma. *Crit Care* 2006;10:R112.
11 Fagenholz PJ, Gutman JA, Murray AF, *et al*. Chest ultrasonography for the diagnosis and monitoring of high-altitude pulmonary edema. *Chest* 2007;131:1013–8.
12 Pratali L, Cavana M, Sicari R, *et al*. Frequent subclinical high-altitude pulmonary edema detected by chest sonography as ultrasound lung comets in recreational climbers. *Crit Care Med* 2010;38:1818–23.
13 Wimalasena Y, Windsor J, Edsell M. Using ultrasound lung comets in the diagnosis of high altitude pulmonary edema: fact or fiction? *Wilderness Environ Med* 2013;24:159–64.
14 Ziskin MC, Thickman DI, Goldenberg NJ, *et al*. The comet tail artifact. *J Ultrasound Med* 1982;1:1–7.
15 Lichtenstein D, Mezière G. A lung ultrasound sign allowing bedside distinction between pulmonary edema and COPD: the comet-tail artifact. *Intensive Care Med* 1998;24:1331–4.
16 Agricola E, Bove T, Oppizzi M, *et al*. "Ultrasound comet-tail images": a marker of pulmonary edema: a comparative study with wedge pressure and extravascular lung water. *Chest* 2005;127:1690–5.
17 Fonseca C, Mota T, Morais H, *et al*; EPICA Investigators. The value of the electrocardiogram and chest X-ray for confirming or refuting a suspected diagnosis of heart failure in the community. *Eur J Heart Fail* 2004;6:807–12.
18 Jambrik Z, Monti S, Coppola V, *et al*. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. *Am J Cardiol* 2004;93:1265–70.
19 Maines M, Catanzariti D, Angheben C, *et al*. Intrathoracic impedance and ultrasound lung comets in heart failure deterioration monitoring. *Pacing Clin Electrophysiol* 2011;34:968–74.
20 Volpicelli G, Mussa A, Garofalo G, *et al*. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. *Am J Emerg Med* 2006;24:689–96.
21 Frassi F, Gargani L, Gligorova S, *et al*. Clinical and echocardiographic determinants of ultrasound lung comets. *Eur J Echocardiogr* 2007;8:474–9.
22 Xirouchaki N, Magkanas E, Vaporidi K, *et al*. Lung ultrasound in critically ill patients: comparison with bedside chest radiography. *Intensive Care Med* 2011;37:1488–93.
23 Al Deeb M, Barbic S, Featherstone R, *et al*. Point-of-care ultrasonography for the diagnosis of acute cardiogenic pulmonary edema in patients presenting with acute dyspnea: a systematic review and meta-analysis. *Acad Emerg Med* 2014;21:843–52.
24 Gargani L, Frassi F, Soldati G, *et al*. Ultrasound lung comets for the differential diagnosis of acute cardiogenic dyspnoea: a comparison with natriuretic peptides. *Eur J Heart Fail* 2008;10:70–7.
25 Copetti R, Soldati G, Copetti P. Chest sonography: a useful tool to differentiate acute cardiogenic pulmonary edema from acute respiratory distress syndrome. *Cardiovasc Ultrasound* 2008;6:16.
26 Martindale JL, Noble VE, Liteplo A. Diagnosing pulmonary edema: lung ultrasound versus chest radiography. *Eur J Emerg Med* 2013;20:356–60.
27 Chiem AT, Chan CH, Ander DS, *et al*. Comparison of expert and novice sonographers' performance in focused lung ultrasonography in dyspnea (FLUID) to diagnose patients with acute heart failure syndrome. *Acad Emerg Med* 2015;22:564–73.
28 Gullett J, Donnelly JP, Sinert R, *et al*. Interobserver agreement in the evaluation of B-lines using bedside ultrasound. *J Crit Care* 2015;30:1395–9.
29 Reissig A, Copetti R, Kroegel C. Current role of emergency ultrasound of the chest. *Crit Care Med* 2011;39:839–45.
30 Galbois A, Ait-Oufella H, Baudel JL, *et al*. Pleural ultrasound compared with chest radiographic detection of pneumothorax resolution after drainage. *Chest* 2010;138:648–55.
31 Lichtenstein DA. Ultrasound in the management of thoracic disease. *Crit Care Med* 2007;3(Suppl 5):S250–61.
32 Lichtenstein D, Mezière G, Biderman P, *et al*. The comet-tail artifact: an ultrasound sign ruling out pneumothorax. *Intensive Care Med* 1999;25:383–8.
33 Chung MJ, Goo JM, Im JG, *et al*. Value of high-resolution ultrasound in detecting a pneumothorax. *Eur Radiol* 2005;15:930–5.
34 Nagarsheth K, Kurek S. Ultrasound detection of pneumothorax compared with chest X-ray and computed tomography scan. *Am Surg* 2011;77:480–4.
35 Reissig A, Kroegel C. Accuracy of transthoracic sonography in excluding post-interventional pneumothorax and hydropneumothorax. comparison to chest radiography. *Eur J Radiol* 2005;53:463–70.

36 Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. lung sliding. *Chest* 1995;108:1345–8.
37 Blaivas M. Lung ultrasound in evaluation of pneumonia. *J Ultrasound Med* 2012;31:823–6.
38 Lichtenstein D, Mezière G, Seitz J. The dynamic air bronchogram. A lung ultrasound sign of alveolar consolidation ruling out atelectasis. *Chest* 2009;135:1421–5.
39 Soldati G, Testa A, Silva FR, *et al*. Chest ultrasonography in lung contusion. *Chest* 2006;130:533–8.
40 Bouhemad B, Liu ZH, Arbelot C, *et al*. Ultrasound assessment of antibiotic-induced pulmonary reaeration in ventilator-associated pneumonia. *Crit Care Med* 2010;38:84–92.
41 Llamas-Álvarez AM, Tenza-Lozano EM, Latour-Pérez J. Accuracy of lung ultrasonography in the diagnosis of pneumonia in adults: systematic review and meta-analysis. *Chest* 2017;151:374–482.
42 Colins JD, Burwell D, Furmanski S, *et al*. Minimal detectable pleural effusions. A Roentgen pathology model. *Radiology* 1972;105:51–3.
43 Ellis JR, Gleeson FV. Non-traumatic thoracic emergencies: imaging and treatment of thoracic fluid collections (including pneumothorax). *Eur Radiol* 2002;12:1922–30.
44 Havelock T, Teoh R, Laws D, *et al*. BTS Pleural disease guideline group. pleural procedures and thoracic ultrasound: british thoracic society pleural disease guideline. *Thorax* 2010;65(Suppl 2):ii61–76.
45 Lomas DJ, Padley SG, Flower CD. The sonographic appearances of pleural fluid. *Br J Radiol* 1993;66:619–24.
46 Atkinson P, Milne J, Loubani O, *et al*. The V-line: a sonographic aid for the confirmation of pleural fluid. *Crit Ultrasound J* 2012;4:19.
47 Joyner CR, Herman RJ, Reid JM. Reflected ultrasound in the detection and localization of pleural effusion. *JAMA* 1967;200:399–402.
48 Remérand F, Dellamonica J, Mao Z, *et al*. Multiplane ultrasound approach to quantify pleural effusion at the bedside. *Intensive Care Med* 2010;36:656–64.
49 Eibenberger KL, Dock WI, Ammann ME, *et al*. Quantification of pleural effusions: sonography versus radiography. *Radiology* 1994;191:681–4.
50 Kocijancic I, Vidmar K, Ivanovi-Herceg Z. Chest sonography versus lateral decubitus radiography in the diagnosis of small pleural effusions. *J Clin Ultrasound* 2003;31:69–74.
51 Kalokairinou-Motogna M, Maratou K, Paianid I, *et al*. Application of color doppler ultrasound in the study of small pleural effusion. *Med Ultrason* 2010;12:12–16.
52 Röthlin MA, Näf R, Amgwerd M, *et al*. Ultrasound in blunt abdominal and thoracic trauma. *J Trauma* 1993;34:488–95.
53 Volpicelli G, Caramello V, Cardinale L, *et al*. Detection of sonographic B-lines in patients with normal lung or radiographic alveolar consolidation. *Med Sci Monit* 2008;14:CR122–8.
54 Kirkpatrick AW, Sirois M, Laupland KB, *et al*. Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the extended focused assessment with sonography for trauma (EFAST). *J Trauma* 2004;57:288–95.
55 Cunningham J, Kirkpatrick AW, Nicolaou S, *et al*. Enhanced recognition of "lung sliding" with power color Doppler imaging in the diagnosis of pneumothorax. *J Trauma* 2002;52:769–71.
56 Reissig A, Kroegel C. Transthoracic sonography of diffuse parenchymal lung disease: the role of comet tail artifacts. *J Ultrasound Med* 2003;22:173–80.
57 Balik M, Plasil P, Waldauf P, *et al*. Ultrasound estimation of volume of pleural fluid in mechanically ventilated patients. *Intensive Care Med* 2006;32:318–21.
58 Gillman LM, Kirkpatrick AW. Portable bedside ultrasound: the visual stethoscope of the 21st century. *Scand J Trauma Resusc Emerg Med* 2012;20:18.
59 Lichtenstein D. Critical USG: working group for echocardiography and ultrasonography of the Polish Society of Anesthesiology and Intensive Care (PSAIC). Modified BLUE protocol (Bedside lung ultrasonography in emergency) [Internet]. 2012. http://www.criticalusg.pl/en/lung-ultrasound/blue-protocol (cited 16 Dec 2016).
60 Choi BG, Mukherjee M, Dala P, *et al*. Interpretation of remotely downloaded pocket-size cardiac ultrasound images on a web-enabled smartphone: validation against workstation evaluation. *J Am Soc Echocardiogr* 2011;24:1325–30.
61 Vitturi N, Soattin M, Allemand E, *et al*. Thoracic ultrasonography: a new method for the work-up of patients with dyspnea. *J Ultrasound* 2011;14:147–51.
62 Prosen G, Klemen P, Štrnad M, *et al*. 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. *Crit Care* 2011;15:R114.
63 Cibinel GA, Casoli G, Elia F, *et al*. Diagnostic accuracy and reproducibility of pleural and lung ultrasound in discriminating cardiogenic causes of acute dyspnea in the emergency department. *Intern Emerg Med* 2012;7:65–70.
64 Pivetta E, Goffi A, Lupia E, *et al*; SIMEU Group for Lung Ultrasound in the Emergency Department in Piedmont. Lung ultrasound-implemented diagnosis of acute decompensated heart failure in the ED: a SIMEU multicenter study. *Chest* 2015;148:202–10.
65 Knudtson JL, Dort JM, Helmer SD, *et al*. Surgeon-performed ultrasound for pneumothorax in the trauma suite. *J Trauma* 2004;56:527–30.
66 Lichtenstein DA, Mezière G, Lascols N, *et al*. Ultrasound diagnosis of occult pneumothorax. *Crit Care Med* 2005;33:1231–8.
67 Sartori S, Tombesi P, Trevisani L, *et al*. Accuracy of transthoracic sonography in detection of pneumothorax after sonographically guided lung biopsy: prospective comparison with chest radiography. *AJR Am J Roentgenol* 2007;188:37–41.
68 Ding W, Shen Y, Yang J, *et al*. Diagnosis of pneumothorax by radiography and ultrasonography: a meta-analysis. *Chest* 2011;140:859–66.
69 Alrajhi K, Woo MY, Vaillancourt C. Test characteristics of ultrasonography for the detection of pneumothorax: a systematic review and meta-analysis. *Chest* 2012;141:703–8.
70 Chavez MA, Shams N, Ellington LE, *et al*. Lung ultrasound for the diagnosis of pneumonia in adults: a systematic review and meta-analysis. *Respir Res* 2014;15:50.
71 Nazerian P, Volpicelli G, Vanni S, *et al*. Accuracy of lung ultrasound for the diagnosis of consolidations when compared to chest computed tomography. *Am J Emerg Med* 2015;33:620–5.
72 Oj M, Mateer JR. Trauma ultrasound examination versus chest radiography in the detection of haemothorax. *Ann Emerg Med* 1997;29:315–6.
73 Rozycki GS, Pennington SD, Feliciano DV. Surgeon-performed ultrasound in the critical care setting: its use as an extension of the physical examination to detect pleural effusion. *J Trauma* 2001;50:636–42.
74 Abboud PA, Kendall J. Emergency department ultrasound for hemothorax after blunt traumatic injury. *J Emerg Med* 2003;25:181–4.
75 Brooks A, Davies B, Smethhurst M, *et al*. Emergency ultrasound in the acute assessment of haemothorax. *Emerg Med J* 2004;21:44–6.
76 Schleder S, Dornia C, Poschenrieder F, *et al*. Bedside diagnosis of pleural effusion with a latest generation hand-carried ultrasound device in intensive care patients. *Acta Radiol* 2012;53:556–60.