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

Yashvi Wimalasena,1,2,3 Laura Kocierz,4 Dan Strong,4 Joanna Watterson,1 Brian Burns1,3

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 in the detection of respiratory pathology in the 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.1,4

Ultrasoundography (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.3,4 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 literature 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.

Literature search was repeated prior to each revision to ensure an up-to-date as possible review article.

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.

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. 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. 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.

A 2006 study by Volpicelli et al 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. Another study demonstrated that LU alone allowed diagnosis of the aetiology of acute respiratory failure in 90.5% of cases. 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.

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. Additionally, ultrasound B-lines have been shown to be as a reliable predictor of the cardiogenic origin of dyspnoea as natriuretic peptides.

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. Multiple prospective, blinded observational studies have demonstrated that CPO was identifiable from LU, even in residents with minimal exposure to LU. Furthermore, interobserver agreement in the evaluation of B-lines using bedside LU is high, even between expert and novice physician sonographers.

Using a structured eight-zone scanning technique first advocated by Volpicelli et al, 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. 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. 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.  

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

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/43654299

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
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. A-lines are horizontal linear artefacts below the pleural line and occur in both normal lung and pneumothorax. The A-line sign is seen with A-lines present and the absence of B-lines. 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. 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. Finally,

<table>
<thead>
<tr>
<th>Study (first author)</th>
<th>n</th>
<th>US sensitivity/specificity</th>
<th>US LR+/LR−</th>
<th>Gold standard</th>
<th>Sonographer type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lichtenstein4</td>
<td>250</td>
<td>93.4/93</td>
<td>13/0.071</td>
<td>CXR</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Agricola4</td>
<td>20</td>
<td>90/86</td>
<td>6.4/0.12</td>
<td>CXR/PICCO/Echo</td>
<td>Cardiologist</td>
</tr>
<tr>
<td>Volpicelli10</td>
<td>300</td>
<td>85/98</td>
<td>43/0.15</td>
<td>CXR/CT/Final diagnosis</td>
<td>EP or radiologist</td>
</tr>
<tr>
<td>Gargani28</td>
<td>149</td>
<td>81/85</td>
<td>5.4/0.22</td>
<td>NT-proBNP</td>
<td>Sonographer not otherwise specified</td>
</tr>
<tr>
<td>Lichtenstein4</td>
<td>301</td>
<td>97/95</td>
<td>19/0.032</td>
<td>Final clinical diagnosis</td>
<td>Experienced intensivists</td>
</tr>
<tr>
<td>Liteplo7</td>
<td>100</td>
<td>58/85</td>
<td>3.9/0.49</td>
<td>Final clinical diagnosis</td>
<td>EP or LU-trained student</td>
</tr>
<tr>
<td>Maines18</td>
<td>23</td>
<td>83/91</td>
<td>9.2/0.19</td>
<td>ICD measure</td>
<td>Experienced physicians not otherwise specified</td>
</tr>
<tr>
<td>Vitturi21</td>
<td>152</td>
<td>97/79</td>
<td>4.6/0.038</td>
<td>Final clinical diagnosis</td>
<td>Not specified</td>
</tr>
<tr>
<td>Prosen12</td>
<td>248</td>
<td>100/95</td>
<td>20/0</td>
<td>Final clinical diagnosis</td>
<td>EP</td>
</tr>
<tr>
<td>Xiroouchaki12</td>
<td>42</td>
<td>46/80</td>
<td>2.3/0.68</td>
<td>CT</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Cibinel33</td>
<td>56</td>
<td>93.6/84</td>
<td>5.9/0.076</td>
<td>Final clinical diagnosis</td>
<td>EP</td>
</tr>
<tr>
<td>Al Deeb23</td>
<td>1075</td>
<td>94.1/92.4</td>
<td>12/0.064</td>
<td>Meta-analysis</td>
<td>Meta-analysis - physicians or medical students</td>
</tr>
<tr>
<td>Chiem27</td>
<td>380</td>
<td>87/49 (one positive lung zone)</td>
<td>1.7/0.3</td>
<td>Final clinical diagnosis</td>
<td>Novice EP</td>
</tr>
<tr>
<td>Pivetta64</td>
<td>1005</td>
<td>97/97.4</td>
<td>37/0.031</td>
<td>Final clinical diagnosis</td>
<td>EP</td>
</tr>
</tbody>
</table>

EP, emergency physician; LR+, positive likelihood ratio; LR−, negative likelihood ratio; LU, lung ultrasonography; US, ultrasonography.

Figure 2  B and M mode scan of a normal lung. Note the ‘sea-shore’ appearance on the M mode image (linear array).
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%.

By contrast, detection of lung sliding on the anterior-inferior haemothorax 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.

A previous study by Lichtenstein et al 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.

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%. 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. The combination of LU diagnostic accuracy, reduced radiation, complexity and cost should enable LU to be regarded 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 pleura 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.

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 ARDS, pleural malignancy, pulmonary fibrosis, pulmonary contusions and chronic obstructive pulmonary disease (COPD).

<table>
<thead>
<tr>
<th>Study (first author)</th>
<th>n</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Ultrasound LR+/LR− Gold standard</th>
<th>Sonographer type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kirkpatrick44</td>
<td>225</td>
<td>US 49</td>
<td>US 100</td>
<td>undefined/0.51</td>
<td>CT Novice trauma surgeons</td>
</tr>
<tr>
<td>Knudtson65</td>
<td>328</td>
<td>US 92</td>
<td>US 99</td>
<td>92/0.081</td>
<td>CXR Trauma surgeons</td>
</tr>
<tr>
<td>Chung33</td>
<td>97</td>
<td>US 80</td>
<td>US 94</td>
<td>13/0.21</td>
<td>CT Experienced radiologists</td>
</tr>
<tr>
<td>Lichtenstein66</td>
<td>200</td>
<td>US 95</td>
<td>US 94</td>
<td>16/0.053</td>
<td>CT Intensivists</td>
</tr>
<tr>
<td>Zhang10</td>
<td>135</td>
<td>US 86</td>
<td>US 97</td>
<td>29/0.14</td>
<td>CT and chest drain EP</td>
</tr>
<tr>
<td>Sartori67</td>
<td>285</td>
<td>US 100</td>
<td>US 100</td>
<td>undefined/0</td>
<td>CT Experienced physicians not otherwise specified</td>
</tr>
<tr>
<td>Lichtenstein6</td>
<td>260</td>
<td>US 81</td>
<td>US 100</td>
<td>undefined/0.19</td>
<td>Final clinical diagnosis Experienced intensivists</td>
</tr>
<tr>
<td>Nagarsheth34</td>
<td>79</td>
<td>US 81</td>
<td>US 100</td>
<td>undefined/0.19</td>
<td>CT Novice surgeon</td>
</tr>
<tr>
<td>Ding69</td>
<td>7569</td>
<td>US 88</td>
<td>US 99</td>
<td>88/0.12</td>
<td>CT or air escape (meta-analysis) Meta-analysis varied</td>
</tr>
<tr>
<td>Alrajhi70</td>
<td>1048</td>
<td>US 91</td>
<td>US 98</td>
<td>46/0.092</td>
<td>CT or air escape (meta-analysis) Meta-analysis varied</td>
</tr>
<tr>
<td>Xiouchaki72</td>
<td>84</td>
<td>US 75</td>
<td>US 93</td>
<td>11/0.27</td>
<td>CT Experienced intensivist</td>
</tr>
</tbody>
</table>

EP, emergency physician; LR+, positive likelihood ratio; LR−, negative likelihood ratio; US, ultrasonography.
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.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.5 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).41 42 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 al41 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.

**Table 3** Lung ultrasound in the diagnosis of lung consolidation

<table>
<thead>
<tr>
<th>Study (first author)</th>
<th>n</th>
<th>US sensitivity/specificity (%)</th>
<th>Ultrasound LR+/LR−</th>
<th>Gold standard</th>
<th>Sonographer type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lichtenstein44</td>
<td>32</td>
<td>93/100</td>
<td>Undefined/0.07</td>
<td>CT</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Lichtenstein45</td>
<td>118</td>
<td>90/98</td>
<td>45/0.1</td>
<td>CT</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Lichtenstein46</td>
<td>260</td>
<td>89/94</td>
<td>15/0.12</td>
<td>Final clinical diagnosis</td>
<td>Experienced intensivists</td>
</tr>
<tr>
<td>Xiouchaki22</td>
<td>42</td>
<td>100/78</td>
<td>4.5/0</td>
<td>CT</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Corterello47</td>
<td>81 (pneumonia)</td>
<td>98/95</td>
<td>20/0.021</td>
<td>Final clinical diagnosis</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Chavez48</td>
<td>1172 (pneumonia)</td>
<td>94/96</td>
<td>240/0.063</td>
<td>CXR, CT or clinical criteria (meta-analysis)</td>
<td>Meta-analysis varied</td>
</tr>
<tr>
<td>Nazerian71</td>
<td>285</td>
<td>83/96</td>
<td>21/0.18</td>
<td>CT</td>
<td>Experienced EP or internist</td>
</tr>
<tr>
<td>Llamas-Álvarez41</td>
<td>2359</td>
<td>80–90/70–90</td>
<td>Not calculated</td>
<td>Meta-analysis</td>
<td>Meta-analysis varied</td>
</tr>
</tbody>
</table>

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).

**Table 3** Lung ultrasound in the diagnosis of lung consolidation

<table>
<thead>
<tr>
<th>Study (first author)</th>
<th>n</th>
<th>US sensitivity/specificity (%)</th>
<th>Ultrasound LR+/LR−</th>
<th>Gold standard</th>
<th>Sonographer type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lichtenstein44</td>
<td>32</td>
<td>93/100</td>
<td>Undefined/0.07</td>
<td>CT</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Lichtenstein45</td>
<td>118</td>
<td>90/98</td>
<td>45/0.1</td>
<td>CT</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Lichtenstein46</td>
<td>260</td>
<td>89/94</td>
<td>15/0.12</td>
<td>Final clinical diagnosis</td>
<td>Experienced intensivists</td>
</tr>
<tr>
<td>Xiouchaki22</td>
<td>42</td>
<td>100/78</td>
<td>4.5/0</td>
<td>CT</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Corterello47</td>
<td>81 (pneumonia)</td>
<td>98/95</td>
<td>20/0.021</td>
<td>Final clinical diagnosis</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Chavez48</td>
<td>1172 (pneumonia)</td>
<td>94/96</td>
<td>240/0.063</td>
<td>CXR, CT or clinical criteria (meta-analysis)</td>
<td>Meta-analysis varied</td>
</tr>
<tr>
<td>Nazerian71</td>
<td>285</td>
<td>83/96</td>
<td>21/0.18</td>
<td>CT</td>
<td>Experienced EP or internist</td>
</tr>
<tr>
<td>Llamas-Álvarez41</td>
<td>2359</td>
<td>80–90/70–90</td>
<td>Not calculated</td>
<td>Meta-analysis</td>
<td>Meta-analysis varied</td>
</tr>
</tbody>
</table>

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

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 intercostal spaces are scanned on each hemithorax. 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)

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

Table 4 Lung ultrasound in the diagnosis of pleural effusion

<table>
<thead>
<tr>
<th>Study (first author)</th>
<th>n</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Ultrasound LR+/LR−</th>
<th>Gold standard</th>
<th>Sonographer type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ma22</td>
<td>240</td>
<td>US 96</td>
<td>US 100</td>
<td>Undefined/0.04</td>
<td>CT</td>
<td>EP</td>
</tr>
<tr>
<td>Rozyczki23</td>
<td>47</td>
<td>US 84</td>
<td>US 100</td>
<td>Undefined/0.16</td>
<td>CT</td>
<td>Surgeons</td>
</tr>
<tr>
<td>Abboud4</td>
<td>142</td>
<td>US 12</td>
<td>US 98</td>
<td>6/0.9</td>
<td>CT</td>
<td>Experienced EP</td>
</tr>
<tr>
<td>Lichenstein3</td>
<td>32</td>
<td>US 92</td>
<td>US 93</td>
<td>13/0.086</td>
<td>CT</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Brooks75</td>
<td>61</td>
<td>US 92</td>
<td>US 100</td>
<td>Undefined/0.08</td>
<td>Composite gold standard</td>
<td>Experienced EP or surgeon</td>
</tr>
<tr>
<td>Xirouchaki22</td>
<td>42</td>
<td>US 100</td>
<td>US 81</td>
<td>Undefined/0</td>
<td>CT</td>
<td>Experienced intensivist</td>
</tr>
<tr>
<td>Schleder76</td>
<td>24</td>
<td>Hand US 91</td>
<td>Hand US 100</td>
<td>Undefined/0.09</td>
<td>High-end US</td>
<td>Intensivist</td>
</tr>
</tbody>
</table>

EP, emergency physician; LR+, positive likelihood ratio; LR−, negative likelihood ratio; US, ultrasonography.
A study is needed to look for further signs commonly seen in these two conditions. Lichtenstein’s BLUE protocol is still the most commonly used.


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

<table>
<thead>
<tr>
<th>Sign</th>
<th>Images</th>
<th>Description</th>
<th>Pathology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding sign</td>
<td>Figure 2</td>
<td>Movement between the two layers of the pleura during normal respiration</td>
<td>Normal</td>
</tr>
<tr>
<td>A-lines</td>
<td>Figure 6</td>
<td>Hyperechoic horizontal lines parallel to pleural line occurring at regular intervals below the pleura Artefacts from reverberations between probe and pleura</td>
<td>Seen in normal lungs as well as pneumothorax and emphysematous lungs</td>
</tr>
<tr>
<td>B-lines</td>
<td>Figure 1</td>
<td>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</td>
<td>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</td>
</tr>
<tr>
<td>Z-lines</td>
<td>-</td>
<td>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</td>
<td>Normal or pneumothorax</td>
</tr>
<tr>
<td>V-lines</td>
<td></td>
<td>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</td>
<td>Pleural fluid</td>
</tr>
<tr>
<td>E-lines</td>
<td>-</td>
<td>Comet tail artefacts that are superficial to the pleural line</td>
<td>Echogenic foreign bodies or subcutaneous emphysema</td>
</tr>
<tr>
<td>Stratosphere sign</td>
<td>Figure 2</td>
<td>The loss of lung sliding beneath the pleura</td>
<td>Pneumothorax</td>
</tr>
<tr>
<td>Liver sign (mirror sign)</td>
<td>Figure 4</td>
<td>Tissue similar in consistency to liver tissue seen on US</td>
<td>Lung consolidation absent in pleural effusion</td>
</tr>
<tr>
<td>Sea shore sign (M mode)</td>
<td>Figure 2</td>
<td>Pleura appears as horizontal lines and the underlying lung as grainy, making up the sea and sandy shore, respectively</td>
<td>Normal M mode appearance of lung</td>
</tr>
<tr>
<td>Bar code sign (M mode)</td>
<td>Figure 3</td>
<td>Bar code-like appearance throughout M mode</td>
<td>Pneumothorax</td>
</tr>
</tbody>
</table>

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, 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 peripneumonic effusion or diagnosis.\(^{8}\) 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 example in remote high altitude clinics to diagnose and treat acute dyspnoea. This will be particularly valuable in prehospital and remote environments where portable and handheld US may be available while conventional CXR is not.

**Acknowledgements**

The authors acknowledge Dr Kylie Baker for the comments and review of this paper.

**Contributors**

YW instigated, coordinated and wrote content for this paper. LF, DS, JW and BB all provided content for this paper.

**Competing interests**

None declared.

**Provenance and peer review**

Not commissioned; externally peer reviewed.

© Article author(s) (or their employer(s) unless otherwise stated in the text of the article) 2017. All rights reserved. No commercial use is permitted unless otherwise expressly granted.

**REFERENCES**


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.


学霸图书馆

www.xuebalib.com

本文献由“学霸图书馆-文献云下载”收集自网络，仅供学习交流使用。

学霸图书馆（www.xuebalib.com）是一个“整合众多图书馆数据库资源，提供一站式文献检索和下载服务”的24小时在线不限IP图书馆。

图书馆致力于便利、促进学习与科研，提供最强文献下载服务。

图书馆导航:

图书馆首页 文献云下载 图书馆入口 外文数据库大全 疑难文献辅助工具