Lung Ultrasound for Critical Care Physiotherapists: A Narrative Review

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Abstract

Background. In critical care, part of the physiotherapist’s respiratory assessment aims to identify parenchymal pulmonary pathology, which may be amenable to respiratory physiotherapy. In addition to clinical assessment, the tools that are most readily available to the respiratory physiotherapist to distinguish between acute pulmonary pathologies include auscultation and chest Xray. The limited diagnostic accuracy of these tools may not allow for the accurate differentiation between conditions such as lung collapse, consolidation and pleural effusion. Although computed tomography allows for this differentiation, it requires patient transport and exposes the patient to increased risk and high levels of radiation. Diagnostic lung ultrasound (LUS) has emerged as a highly sensitive bedside diagnostic tool with high level evidence to support its use for the differentiation of various common acute pulmonary pathologies. In this review, the diagnostic performances of auscultation, chest Xray and LUS are reviewed, and the usefulness of LUS as an adjunct to respiratory physiotherapy assessment is discussed. The issues surrounding training physiotherapists and the implementation of LUS are also explored. Methods. The method used is a narrative review of the literature. Conclusion. To our knowledge, LUS is not routinely utilized by critical care physiotherapists. However, its superior sensitivity and specificity would enable the physiotherapist to make an accurate, timely and point of care diagnosis of lung pathology and determine whether the pathology is amenable to respiratory physiotherapy. Copyright © 2014 John Wiley & Sons, Ltd.

Keywords
chest ultrasonography; critical care; diagnostic accuracy; lung ultrasound; physiotherapy

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Introduction

The outcome measures used by physiotherapists in critical care often focus on short-term, global measures of respiratory physiology (e.g. lung/thoracic compliance) and do not incorporate major patient outcomes (Hanekom et al., 2007). There is conflicting evidence on the impact of chest physiotherapy on major patient outcomes such as mortality, time on mechanical ventilation or intensive care unit (ICU) length of stay (Stiller, 2013). The more recent incorporation of evidence-based clinical management algorithms for the detection and management of pulmonary dysfunction by physiotherapists (Hanekom et al., 2011) results in the more consistent application of interventions in critical care by physiotherapists with improvements in patient outcomes (Hanekom et al., 2012). However, physiotherapists within critical care
can further enhance respiratory management through more accurate identification of acute parenchymal pulmonary pathology that may be more amenable to respiratory physiotherapy.

The accuracy of the physiotherapist’s clinical impression and diagnosis of acute pulmonary pathology, typically formed on the basis of clinical assessment, lung auscultation and chest x-ray (CXR) interpretation within critical care is unknown. The limited diagnostic accuracy of some of these tools, especially in the critically ill patient, may not allow for accurate differentiation between conditions such as lung collapse, consolidation and pleural effusion. This lack of diagnostic accuracy raises important questions about whether treatments are appropriate and effective and may clarify the findings of earlier physiotherapy trials where both the inclusion and outcome criteria were based on CXR outcome alone (Stiller et al., 1990; Stiller et al., 1996).

There is increasing high level evidence to support the use of diagnostic lung ultrasound (LUS), as practised by bedside medical staff, to either supplement or as an alternative to CXR within critical care. This shift is due to the emerging evidence of the superior diagnostic accuracy of LUS to differentiate between pleural, alveolar and interstitial pathologies and provide information on diaphragmatic movement at the bedside, in real time and with no ionising radiation exposure. Critical care physiotherapists need to rapidly determine whether pathology is amenable to physiotherapy intervention (e.g. lung collapse) and whether physiotherapy interventions have been effective (e.g. hyperinflation techniques). Until now, physiotherapy assessment has relied on tools, including auscultation and CXRs. Bedsides, LUS is a portable, accurate, non-invasive adjunct to physiotherapy assessment, facilitating timely diagnosis and treatment evaluation without exposure to ionising radiation. To our knowledge, LUS is not yet commonly used by physiotherapists, but its utility outside of medicine warrants further exploration. The aim of this review is to appraise the diagnostic performances of auscultation, CXR and LUS on parenchymal and pleural pathologies and to explore the issues surrounding the implementation of LUS into physiotherapy practice.

**Auscultation**

Lung auscultation is routinely used by physiotherapists to assess the respiratory status of patients and as an outcome measure to monitor the effectiveness of interventions. It is immediately available, free and poses minimal discomfort to patients. The subjective nature of the tool, however, has lead to the questioning of the accuracy and reliability of the physiotherapist’s interpretation of normal and abnormal lung sounds. In studies of experienced cardiorespiratory physiotherapists, accuracy in interpreting tape-recorded lung sounds was found to be as low as 39.2% (Allingame et al., 1995). Furthermore, intra-rater reliability of auscultation was poor (28%), and somewhat surprisingly, increased years of clinical experience did not correlate with increased reliability. Studies using teaching stethoscopes (Brooks and Thomas, 1995) also reported low inter-rater reliability for the interpretation of lung sounds (kappa = –0.02 to 0.59).

Poor diagnostic accuracy and reliability of lung auscultation have been demonstrated in other health professionals, indicating that the limitations of auscultation are not unique to physiotherapists. In a study of medical staff, Lichtenstein et al (2004a) compared lung auscultation findings with computed tomography (CT) results and reported relatively low accuracy of auscultation in identifying pleural effusion, alveolar consolidation and alveolar interstitial syndrome (61%, 36% and 55%, respectively). In a study of internal medical registrars in the emergency department, the addition of lung auscultation to their subjective history taking only improved their diagnosis in 1% of patients and actually worsened it in 2.8% (Leuppi et al., 2005).

Given the limitations of auscultation, it is not surprising that physiotherapists also rely on other measures to evaluate the indications for treatment and effect of treatments (e.g. clinical examination, SpO2 levels, arterial blood gases and CXRs). Unfortunately, these tools also have issues with sensitivity and timeliness, which may further cloud the physiotherapist’s interpretation of indications for treatment and treatment efficacy. Although auscultation may be immediately available and low cost, its lack of diagnostic accuracy, coupled with its low inter-rater reliability, beckons the need for a more accurate and reliable assessment tool.

**Chest x-ray**

There are several issues with the physiotherapist’s reliance on the portable CXR to detect and monitor acute pulmonary pathology. First, the routine daily CXR is no longer the norm for intensive care (Lakhal et al.,
2012), but even in ICUs where daily CXR remains common, these images may not be taken at the time of the physiotherapist’s clinical assessment and intervention. The physiotherapist’s focus on pathology identified during the ‘real-time’ imaging of the portable CXR requires the unrealistic assumption that the pathology has remained static. Thus, if intervention is based in part on the most recent CXR images, the physiotherapist may erroneously attempt to treat pathologies, which have either spontaneously resolved, may not require physiotherapy or inadvertently fail to treat newly developed areas of lung collapse.

Second, and more importantly, the portable CXR has limited diagnostic accuracy for the detection of common lung pathology in the intubated and mechanically ventilated patient when compared with CT and indeed real-time LUS. A summary of the diagnostic performance of CXR compared with CT in the ICU is presented in Table 1. The sensitivity and specificity of CXR compared with CT scan averaged 42% and 89% to detect pleural effusion, 53% and 90% to detect interstitial syndrome, 53% and 90% to detect lung consolidation, 32% and 93% to detect lung contusion and 50% and 99% to detect pneumothorax, respectively.

Third, the clinician’s reliance on the portable CXR requires patients to be exposed to significant amounts of radiation, with cumulative effects likely for long-stay intensive care patients. The benefit of a relatively blunt and time-delayed diagnostic instrument must be weighed against the risk of cumulative radiation exposure.

The diagnostic limitations of CXR may also clarify the findings of previous studies of the effects of physiotherapy in intensive care patients. For example, the identification of lung pathology such as acute lobar collapse and the expected improvements with lung recruitment may differ depending upon the diagnostic tool used (e.g. CXR vs. LUS). Hence, with previous research, the inclusion criterion of CXR diagnosis of lobar collapse may have also inadvertently included patients with pleural effusions, which are not amenable to physiotherapy intervention. This limitation may in part explain the lack or delays of improvement observed with some patients (Stiller et al., 1996).

The diagnostic and practical limitations of both portable CXR and auscultation bring us to the evolution of a new diagnostic tool for critical care physiotherapists. Although diagnostic ultrasound is not new to the physiotherapy profession (McKiernan et al., 2010), to the best of our knowledge, it is not routinely utilized by physiotherapists to examine the pleura and lungs in the critical care setting.

### Table 1. Diagnostic performance of CXR when compared with CT in ICU

<table>
<thead>
<tr>
<th>Pathology</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleural effusion</td>
<td>23–42</td>
<td>94–97</td>
<td>(Rocco et al., 2008)</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>81</td>
<td>(Xirouchaki et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>85</td>
<td>(Lichtenstein et al., 2004a)</td>
</tr>
<tr>
<td>Interstitial syndrome</td>
<td>46</td>
<td>80</td>
<td>(Xirouchaki et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>100</td>
<td>(Lichtenstein et al., 2004a)</td>
</tr>
<tr>
<td>Lung consolidation</td>
<td>38</td>
<td>89</td>
<td>(Xirouchaki et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>68</td>
<td>95</td>
<td>(Lichtenstein et al., 2004a)</td>
</tr>
<tr>
<td>Contusion</td>
<td>24–39</td>
<td>89–96</td>
<td>(Rocco et al., 2008)</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>50.2</td>
<td>99.4</td>
<td>(Alrajhi et al., 2012)</td>
</tr>
<tr>
<td></td>
<td>(95 CI, 43.5–57.0)</td>
<td>(95 CI, 98.3–99.8)</td>
<td>(Xirouchaki et al., 2011)</td>
</tr>
</tbody>
</table>

*indicates meta-analysis.
♦ indicates CT or air release on chest tube insertion used as reference standard.
CXR, chest x-ray; CT, computed tomography; ICU, intensive care unit; CI, confidence interval.

### Overview of lung ultrasound

The application of ultrasound to the lung is relatively new within the medical profession. It was previously thought that air, which cannot be visualized by ultrasound, was an obstacle to the attainment of meaningful images. It is now widely accepted that the artefacts, which are produced by the intimate relationship between air and water in the tissues, pleural spaces and lung itself are consistent and interpretable.
(Lichtenstein, 2007; Volpicelli, 2013). Comprehensive descriptions of these artefacts (or ‘signs’) and the pathology they represent are available elsewhere (Lichtenstein, 2007; Nalos et al., 2010).

There is considerable and mounting evidence from the medical literature to support both the diagnostic superiority and feasibility of LUS. LUS has been found to have both high sensitivity and specificity in diagnosing common pulmonary pathology within the critical care setting. The diagnostic performances of LUS when compared with CT in the ICU are summarized in Table 2. The sensitivity and specificity of LUS compared with CT averaged 94% and 97% to detect pleural effusion, 96% and 91% to detect interstitial syndrome, 94% and 92% to lung consolidation, 88% and 93% to detect lung contusion and 83% and 96% to detect pneumothorax, respectively.

In addition to increased accuracy, LUS has many other advantages as an assessment and monitoring tool. Arguably, the greatest advantage of LUS is that it can be used at the bedside and provides real-time feedback to the operator and the patient. This means that the critical care physiotherapist can monitor before, during and after their intervention to see whether manual or ventilator lung hyperinflation, for example, is successful in re-expanding a collapsed lung (Cavaliere et al., 2011). LUS may be used as visual feedback during deep breathing, for example, to facilitate greater diaphragmatic movement (Yamaguti et al., 2010).

Furthermore, LUS does not emit any ionising radiation and does not require patient transport to CT which is not always appropriate in a critically ill, deteriorating patient. Table 3 compares the methods that are available to critical care physiotherapists, including bedside availability.

Although there are occasions when LUS is technically difficult or impossible (for example, due to morbid obesity, over burns, dressings or subcutaneous emphysema), in the majority of patients, the physiotherapist could readily use LUS to identify appropriate pathology and hence guide the treatment approach. In cases where acute pulmonary oedema (APO), pleural effusion or pneumothorax is detected, the physiotherapist could use LUS to rapidly ascertain that physiotherapy is likely to be fruitless and also direct further medical evaluation. Conversely, in cases where lung collapse may be recruitable, the physiotherapist could deliver a more appropriate ‘real-time’ monitored treatment thereby directly influencing physiotherapy management.

### Training and competence in LUS

Many of the studies assessing diagnostic accuracy utilize experienced or expert physician sonographers. While there is some attempt to standardize the skills required to achieve competence in LUS amongst critical care physicians (Mayo et al., 2009) and the standards by

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**Table 2. Diagnostic performance of LUS compared with CT or other valid reference standard in ICU**

<table>
<thead>
<tr>
<th>Pathology</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleural effusion</td>
<td>92–94</td>
<td>95–99</td>
<td>(Rocco et al., 2008)</td>
</tr>
<tr>
<td></td>
<td>93</td>
<td>96</td>
<td>(Grimberg et al., 2010)</td>
</tr>
<tr>
<td></td>
<td>(95 CI, 89–96)</td>
<td>(95 CI, 95–98)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>100</td>
<td>(Xirouchaki et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>92</td>
<td>93</td>
<td>(Lichtenstein et al., 2004a)</td>
</tr>
<tr>
<td>Interstitial syndrome</td>
<td>94</td>
<td>93</td>
<td>(Xirouchaki et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>98</td>
<td>88</td>
<td>(Lichtenstein et al., 2004a)</td>
</tr>
<tr>
<td>Lung consolidation</td>
<td>90</td>
<td>98</td>
<td>(Lichtenstein et al., 2004b)</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>78</td>
<td>(Xirouchaki et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>93</td>
<td>100</td>
<td>(Lichtenstein et al., 2004a)</td>
</tr>
<tr>
<td>Contusion</td>
<td>86–89</td>
<td>89–97</td>
<td>(Rocco et al., 2008)</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>90.9</td>
<td>98.2</td>
<td>(Alrajhi et al., 2012)</td>
</tr>
<tr>
<td></td>
<td>(95 CI, 86.5–93.9)</td>
<td>(95 CI, 97.0–99.0)</td>
<td>(Xirouchaki et al., 2011)</td>
</tr>
</tbody>
</table>

*Indicates meta-analysis;*

*indicates CT or air release on chest tube insertion used as reference standard;*

*indicates CT or thoracic drainage used as reference standard.

LUS, lung ultrasound; CT, computed tomography; ICU, intensive care unit; CI, confidence interval.
which they are trained (Cholley et al., 2011), the timeframes required to achieve competence are less clear. It has been suggested that at least 100 chest ultrasound procedures (Reissig et al., 2012) or 3 months of supervised practice (Tutino et al., 2010) is required for competence, while others suggest that if ‘several’ ultrasound procedures are done daily, competence in identifying pleural effusion, lung consolidation and alveolar interstitial syndrome can be achieved within 6 weeks (Bouhemad et al., 2007). Tutino et al. (2010) suggest that 7 months may be needed to achieve adequate skills to accurately report on LUS imaging. As LUS is utilized in various clinical settings (e.g. critical care, emergency department, outpatient clinics and operating theatres), the obvious differences in the approach, techniques utilized and nomenclature adopted have prompted a recent consensus process (Volpicelli et al., 2012). The aim was to elaborate a unified approach and language for six major areas, including terminology, technology, technique, clinical outcomes, cost effectiveness and future research. These international recommendations will prove to be an essential template and standard for physiotherapy to adopt when developing and instituting LUS as part of routine clinical management within the critical care setting.

As LUS is not routinely used by physiotherapists to assess the lungs, the level of training and the timeframe required for critical care physiotherapists to reach competence are unknown. In other areas of physiotherapy utilizing ultrasound, it has been identified that there is no standard training required or developed. Subsequently, the areas covered in formal and informal training packages are variable and can omit important content (Potter et al., 2012) leading to operators with variable skills in image acquisition and interpretation. To prevent this in critical care, physiotherapist LUS training should follow an established pathway with pre-determined skills required to attain competence. For bedside LUS to be useful to the critical care physiotherapist and safe for the patient, the identification of and differentiation between pneumothorax, pleural effusion, lung consolidation, lung collapse and alveolar interstitial syndrome should be the primary focus of training. Further, clarification around robust clinical processes for image acquisition, storing, reporting, auditing and sharing would also need to be addressed, as would the scope of practice challenge that LUS would provide to existing governance structures. For example, if the physiotherapist identified an acute pulmonary condition that may require urgent medical attention/intervention such as a pneumothorax or significant pleural effusion, then either follow-up imaging by a radiologist or trained sonographer may be required during training, until an appropriate level of agreed competency has been established. In the long term, however, in order for LUS to be a feasible option in the high-demand setting of an ICU, physiotherapists will need to become independent operators of LUS.

### Discussion

Critical care physiotherapists may currently use combinations of clinical examination, auscultation and CXR interpretation to form a diagnosis of a patient’s respiratory pathology and to evaluate treatment effectiveness. As described earlier, these tools are limited by low diagnostic accuracy, timeliness and poor inter-rater reliability. Therefore, the true effectiveness of physiotherapy treatment in critical care settings could be either under-estimated or over-estimated, potentially leading...
to excessive or inadequate treatment. In contrast, LUS offers significant advantages over both auscultation and CXR as a real-time assessment and monitoring tool. These advantages include immediate bedside availability, low radiation exposure and superior diagnostic accuracy. High-quality ultrasound machines may be commonly available in tertiary ICUs for use by physicians associated with invasive or diagnostic procedures, therefore, the use of LUS by critical care physiotherapists may be feasible.

As pleural and lung pathology can be clearly visualised with LUS, it would be most beneficial in cases where the patient’s main clinical problem is unclear. On the basis of our experience, we suggest using LUS to answer a focused clinical question to guide specific management: ‘is the lung recruitable?’, ‘how much of the opacity observed on the CXR is the result of a pleural effusion?’ In these cases, LUS has the potential to influence physiotherapy treatment. For example, significant sputum retention and APO can sound similar on auscultation, and in both cases, clinical assessment can reveal increased work of breathing and a moist cough. If APO is suspected, the morning CXR is likely to be of little use to the physiotherapist given the speed at which it can develop and the static nature of a CXR. If LUS was used in this example to answer the clinical question: ‘is there evidence of retained secretions?’ a focused ultrasound assessment would reveal two very distinct patterns: diffuse B-lines in the case of APO and dynamic air-bronchograms in the case of sputum retention. This differentiation would allow the physiotherapist to confidently suspect one diagnosis over the other, thereby directing the physiotherapist to the most effective treatment.

In the case of more than one pathology being present, for example, collapse with concomitant pleural effusion, the physiotherapist could use LUS to evaluate whether lung recruitment techniques or patient mobilization is effective in re-expanding the collapsed lung despite the presence of the pleural effusion. This immediate visual feedback would steer the physiotherapist towards ongoing treatment if the collapsed segment is recruitable. Conversely, if the physiotherapist is unable to see lung recruitment in this instance, treatment of the collapse could be suspended and treatment redirected to the patient’s other amenable problems, thereby increasing the efficiency of the physiotherapy session. With such a powerful diagnostic and monitoring tool influencing treatment, perhaps physiotherapy will be more influential on some of the key lung pathologies and then may be seen to impact on major patient outcomes such as mortality, time on mechanical ventilation or ICU length of stay.

LUS has already been shown to directly influence ICU medical management. Recently, Xiouchaki et al. (2014) investigated the impact of LUS on medical decision-making in ICU. In their study, LUSs were ordered in direct response to clinical questions of suspected pulmonary pathology (pneumothorax, pleural effusion, consolidation/atelectasis, pneumonia or pulmonary oedema) or in the case of unexplained and persistent deterioration of arterial blood gases. In all but one of the 253 LUS studies in which pathology was identified, 69.7% of these supported the primary physicians’ clinical suspicion and 21% revealed pathology that was not originally suspected. CT scans were ordered in only seven cases to assist the decision-making process, the results of which confirmed LUS findings and did not initiate any further changes to management. At no point was a CXR ordered to assist decision-making. Overall, invasive or non-invasive ICU management was changed directly as a result of the LUS imaging in 47% of cases, and the net reclassification improvement was calculated to be 85.6%, indicating that LUS had significant therapeutic impact by influencing the decision-making process in ICU. This study was the first of its kind to demonstrate the usefulness of LUS as an assessment and monitoring tool in the medical field. Because of the mounting evidence of the greater diagnostic performance of LUS compared with CXR, it is not surprising that daily CXRs are no longer ordered in some ICUs (Lakhal et al., 2012).

Interestingly in the study by Xiouchaki et al. (2014), one of the non-invasive treatments initiated by the primary physician in response to LUS findings was referral to physiotherapy. This begs the question why physiotherapists themselves are not using LUS to identify whether respiratory physiotherapy could be of benefit in the critically ill patient. As critical care physiotherapists, we do not develop skills in LUS, we risk compromising our clinical decisions and becoming once again reliant on medical staff for direction and interpretation of medical tests. Given physiotherapists’ comprehensive knowledge of anatomy and physiology, the addition of LUS to the physiotherapy skill repertoire appears to us to be the ideal evolution of the critical care physiotherapy role.
While there is mounting evidence that the diagnostic accuracy of LUS is superior to auscultation and CXR, what is unclear is the applicability of this increased accuracy to critical care physiotherapists and the content and level of training required to ensure physiotherapists reach this level of accuracy. The recent consensus statement by Volpicelli et al. (2012) stated that ultrasound diagnosis of lung consolidation and interstitial syndrome may be considered as a basic technique with a steep learning curve. It has also been suggested that the detection of pleural effusion is basic and may be acquired in minutes improving with experience (Doelken and Strange, 2003). However, given the novelty of LUS for physiotherapists, and the absence of a specific training program with a physiotherapy focus, hurdles still remain for critical care physiotherapists wishing to learn LUS techniques. Perhaps, the biggest challenge that may arise in the training pathway will be finding a suitable mentor to supervise and guide the physiotherapist LUS trainee through numerous LUS procedures and scans required to gain competency. It is possible that local medical, radiology or ultrasonography staff could support this process, but this would also require an inter-professional understanding of the role and focus of physiotherapy and a pre-established standard to which the physiotherapist will be compared with confirm competence that has been achieved. Nonetheless, it appears imperative that physiotherapists recognize the value of LUS in critical care and explore pathways to establish competence as a matter of priority in the near future. Another issue that requires clarification is the documentation and clinical governance aspects required, with physiotherapists potentially identifying acute pathology (pleural effusion or pneumothorax) that may warrant medical or invasive intervention. For example, whilst the physiotherapist is in training, a second opinion from an experienced sonographer or clinician may be mandatory with such clinical acute decisions.

**Conclusion**

LUS increases diagnostic accuracy in the critically ill patient for the identification of acute pulmonary pathology and in the absence of other real-time evaluation tools (apart from auscultation, with its limitations), the addition of LUS to physiotherapy assessment should enhance clinical management decisions. The minimum standards and methods required for training, documentation and clinical governance need to be further explored before LUS could be implemented by physiotherapists more widely. Future studies should explore the training requirements for critical care physiotherapists to achieve competence in LUS with a view to embedding it within physiotherapy practice within critical care. In addition, the utility of LUS as a research tool for evaluation of acute pulmonary pathology amenable to physiotherapy (such as acute lobar collapse) needs to be further explored.

**Conflict of interest**

The authors declare no conflict of interest.

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