Reviews on Recent Clinical Trials, 2018, *13*, 15-26

REVIEW ARTICLE

Point-of-Care Lung Ultrasound in Critically ill Patients

Gentle S. Shrestha[1*], Dameera Weeratunga[2] and Kylie Baker[3]

[1]*Department of Anaesthesiology, Tribhuvan University Teaching Hospital, Maharajgunj, Kathmandu, Nepal;* [2]*De Soysa Hospital for Women, Colombo, Sri Lanka;* [3]*University of Queensland, St. Lucia QLD 4072, Australia*

ARTICLE HISTORY

Received: July 05, 2017
Revised: August 13, 2017
Accepted: August 16, 2017

DOI:
10.2174/1574887112666170911125750

Abstract: ***Background*:** Lung ultrasound is increasingly being used by the bedside physicians to complement the findings of physical examination. Lung ultrasound is non-invasive, devoid of radiation exposure and can be performed rapidly and repeatedly as needed at bedside. This review aims to elucidate the evidence base and the future directions for bedside point-of-care lung ultrasound in critically ill patients.

***Methods*:** Research articles, review papers and online contents related to point-of-care ultrasound in critically ill patients were reviewed.

***Results*:** The diagnostic accuracy of lung ultrasound for common conditions like pleural effusion, pneumothorax, pulmonary edema and pneumonia is superior to chest radiograph and is comparable to chest CT scan. Lung ultrasound is helpful to evaluate the progress of lung pathology and response to treatment, over time. Ultrasound guidance for thoracocentesis decreases the complication rates.

***Conclusion*:** Bedside lung ultrasound in critically ill patients can serve as a tool to diagnose common lung pathologies, monitor its course and guide clinical management.

Keywords: Chest radiograph, clinical management, critically ill, lung ultrasound, point-of-care, radiation exposure.

1. INTRODUCTION

Management of critically ill patients in the emergency and critical care setting is challenging and imaging techniques are essential for optimizing diagnostic and therapeutic procedures in these patients. In the last two decades the use of bedside ultrasound techniques for critically ill patient management has become popular due to the availability of less expensive and more portable ultrasound machines. Point of care ultra sound (POCUS) is increasingly being recognized as the superior imaging option in the emergency and critical care setting [1-3].

Even though the bedside ultrasound utilization in the emergency and critical care setting became increasingly popular in the last two decades, lung ultrasound (LUS) was not widely recognized until very recently. The reason was that lung was considered poorly accessible by ultrasound due to the presence of pulmonary air within a bony thoracic cage resulting in poor transmission of ultrasound beams and production of artifacts. Traditionally, bedside chest radiography (CXR) and thoracic computed tomography (CT) were used as the lung imaging techniques to detect pathologies. Drawbacks of CXR are technical difficulties leading to limited accuracy and exposure of the patient and staff to radiation. For CT there is an added need for mobilization of the patient, exposure of the patient to higher radiation, difficulty in repeatability and high cost [2]. Recently, it has been shown that LUS performs better than CXR and is a reasonable alternative to thoracic CT for diagnosing common lung pathologies (interstitial syndrome, lung consolidation, pleural effusion and pneumothorax) in emergency and critical care setting (Table **1**). The advantages of LUS are that it can be done at bedside easily without need of patient mobilization, it is noninvasive, does not utilize ionizing radiation and is easily reproducible [4].

In this review, we focus on basic LUS technique, LUS pattern of normal lung, LUS signs and patterns of different lung pathologies, use of LUS in management of dyspnoeic patient and use of LUS to assist and guide procedures. We recommend reviewing the international consensus guidelines (2012) to clarify the nomenclature changes, before reading original research written since 2012 [1].

2. TECHNIQUE AND FINDINGS

The ultrasound machine has different probes with different frequencies. The probe for each examination should be chosen for the lung region where pathology is suspected. A high frequency probe improves the resolution but sacrifices the depth of penetration. Hence a high frequency linear vascular probe (frequency range 7.5 - 10MHz) is suitable to perform a detailed examination of the chest wall and pleura, while the low frequency curvilinear probe (frequency range 3.5 - 5MHz) is best to examine deeper structures below pleura. However, for convenience, many studies suggest a single probe for complete LUS examination in emergency and critical care setting [1]. Lichtenstein *et al*. recommends a

*Address correspondence to this author at the Department of Anaesthesiology, Tribhuvan University Teaching Hospital, Maharajgunj, Kathmandu, Nepal; Tel: +977-9841248584; E-mail: gentlesunder@hotmail.com

1876-1038/18 $58.00+.00

Table 1. Performance of LUS and CXR in diagnosing common lung pathologies.

Pathology	Review / Meta Analysis	Reference Standard	Sensitivity %		Specificity %	
			LUS	CXR	LUS	CXR
Pneumonia	Ye X, *et al*. 2015 [5]	Diagnosis at hospital discharge	95	77	90	91
Pneumothorax	Alrajab S, *et al*. 2013 [6]	CT scan of the chest	79	40	98	99
	Alrajhi K, *et al*. 2012 [7]	CT scan of the chest or release of air on chest tube insertion	91	50	98	99
Pleural effusion	Yousefifard M, *et al*. 2016 [8]	CT scan of the chest	94	51	98	91

5MHz micro-convex probe as the ideal single probefor bedside LUS [9].

The sonographic modes used in LUS are real-time B-mode (brightness mode) and M-mode (time-motion). Real-time B mode generates cross-sectional, two-dimensional images from the reflected ultrasound waves while M-mode records motion of the interfaces towards and away from the transducer. Doppler (color) technique is not usually required for LUS examination, but found to be useful when differentiating lower region lung pathology (like consolidation) from nearby organs like liver and spleen.

LUS includes the viewing of chest wall, pleural space, diaphragm and the lung parenchyma. All the intercostal spaces provide windows for LUS examination. In a simplified examination, one particular point per lung region can be examined, keeping the probe perpendicular to the ribs in the longitudinal plane [10]. The international consensus guidelines (2012) have proposed a screening eight-zone LUS examination [1]. In this protocol, each anterior chest wall separates in to two regions; anterior and lateral, by using parasternal line, anterior axillary line and posterior axillary line as anatomical landmarks and then each of those regions subdivided in to upper and basal parts, finally making a total eight regions (Fig. **1**). If pathology is detected on this simple screening exam, one can adjust the probe to examine along the intercostal space (oblique scan) in the abnormal region to further define the extent of pathology. Alternatively, Lichtenstein *et al.* has described three specific locations in the chest wall calling them 'BLUE points' (upper BLUE point, lower BLUE point and PLAPS point), for performance of fast LUS in patients with acute respiratory failure [11]. These points are used when performing the BLUE (Bedside Lung Ultrasonography in an Emergency) protocol [9].

The time spent to perform a single LUS examination ranges between 2 minutes to 15 minutes with average of 5 minutes in different studies [6, 7]. It was recorded at 3 minutes in the BLUE protocol [11].

3. NORMAL PATTERN

As ultrasound waves are not conducted through the air filled tissues, ultrasound examination of the normal lung does not show the lung parenchyma beyond the pleura. Instead artifacts are produced due to the interaction between air and fluid filled lung tissue, resulting in specific ultrasound patterns. The common lung pathologies cause lung parenchymal changes with reduced lung aeration and/or pleural surface changes. This alters ultrasound lung pattern from normal enabling detection of pathology *via* LUS. The basis of LUS is analysis of a limited number of artifacts resulting in particular ultrasound patterns rather than direct visualization of the lung parenchyma.

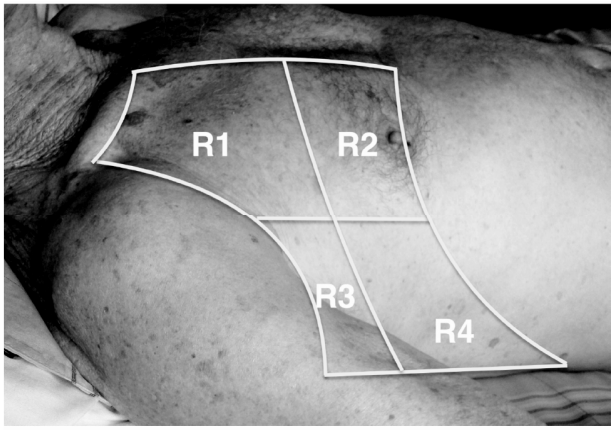

Fig. (1). Eight zone lung ultrasound examination: Each anterior chest wall is separated into two regions; anterior and lateral, by using parasternal line, anterior axillary line and posterior axillary line as anatomical landmarks and then each of those regions are subdivided into upper and basal parts (R1-R4).

In LUS, the probe is usually positioned with its marker directed to the head of the patient and perpendicular to the ribs in the longitudinal plane. The ribs can be identified by their posterior shadow. In between two ribs, about 0.5cm below the rib line, the pleural line is seen as the hyperechoic, sliding line that moves forward and backward with ventilation [2]. The sonographic image visualizing the pleural line in between two rib shadows in a longitudinal view is called the 'bat sign' (Fig. **2**) [12].

The horizontal sliding that can be seen at the pleural line is a result of the movement of the visceral pleura against the parietal pleura during the respiratory cycle and is called 'lung sliding' [12]. Presence of lung sliding confirms the presence of lung parenchyma and also ventilation. The M-mode view depicting a linear pattern of relatively motionless inter-costal tissue above the pleural line and a more granular pattern below it is called the 'seashore sign' (Fig. **3**) and confirms the lung sliding [12]. Cardiac movement transmitted to

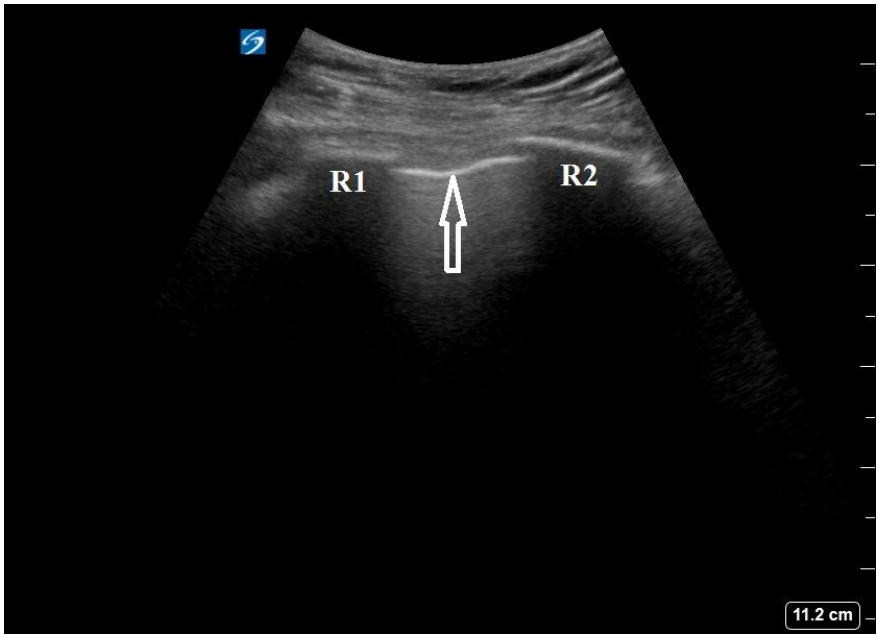

Fig. (2). Bat sign. A longitudinal scanning of the intercostal space depicting upper (R1) and lower (R2) ribs and the pleural line (indicated by vertical arrow).

the pleura causes vertical rhythmic pulsation on the pleural line and is called 'lung pulse'. In M-mode view, lung pulsation becomes more visible. In a B-mode view, motionless, regularly spaced horizontal lines below the pleural line can be seen. Those reverberation artifacts that repeat the pleural line are due to the presence of air filled tissues below the pleural line, causing multiple rebounds of ultrasound waves between pleura and probe. This pattern is most easily remembered as 'A-lines' (Fig. **4**) [2]. A normal ultrasound pattern (A-pattern) of the lung is defined by lung sliding with horizontal A-linesin B-mode view and presence of seashore sign in M-mode view [3, 9]. This normal pattern is correlated with pulmonary artery occlusion pressure (PAOP) equal or lower than 18 mmHg with 93% specificity and 97% positive predictive value [13].

'B lines' are the shining (laser like), well defined, vertical hyper-echoic lines that originate from pleural line, extend to the edge of the screen, obliterate most A-lines and move synchronously with the lung sliding (Fig. **5**) [1, 14]. These artifacts arise due to the interaction between fluid filled tissue and air. The presence of 3 B-lines, between two ribs (single pleural space) in the dependent regions of the lung is considered a normal finding [2, 15] but abnormal elsewhere in the lung. It is important to distinguish B-lines from other clinically insignificant, ill-defined vertical artifacts (Z-lines, I-lines). Lee *et al.* [16] described I-lines as vertical artifacts that arise from the pleural line, move with lung sliding but fade away before extending to edge of the screen while Z lines are vertical artifacts not related to pleural line, that do not move with lung sliding but instead blend with other artifacts.The terms lung comets, lung rockets and comet-tail artifacts have been used interchangeably in earlier LUS literature to describe both true B-lines and the other insignificant vertical artifacts. For this reason, we support the international consensus guidelines (2012) in their strict definition and exclusive use of the "B lines" [1].

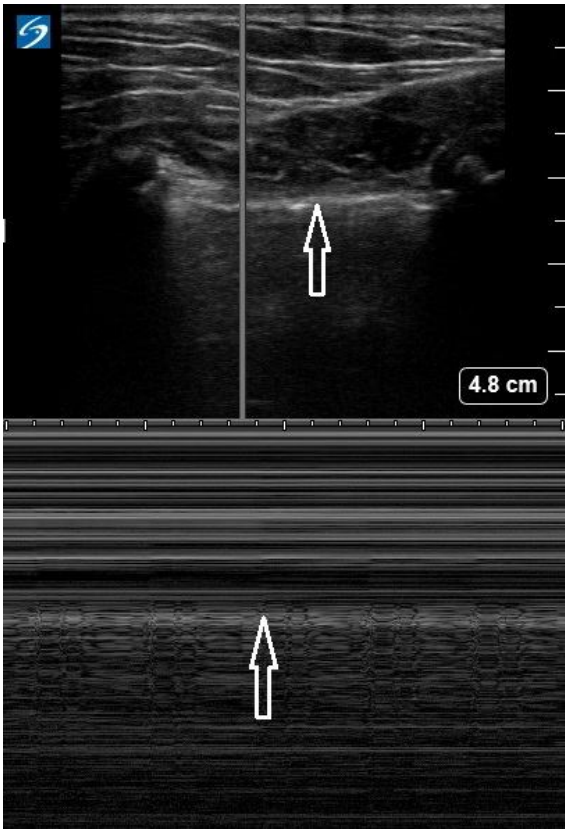

Fig. (3). Seashore sign. Pleural line is indicated by vertical arrows.

4. CLINICAL APPLICATIONS

LUS examination proves useful to diagnose and differentiate lung parenchymal and pleural disorders. In lung pa-

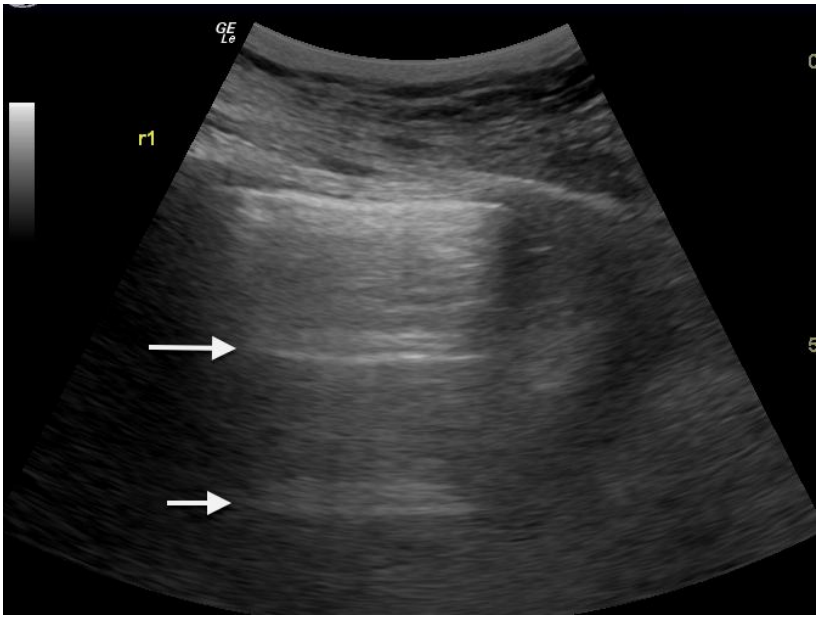

Fig. (4). A-lines: indicated by horizontal arrows.

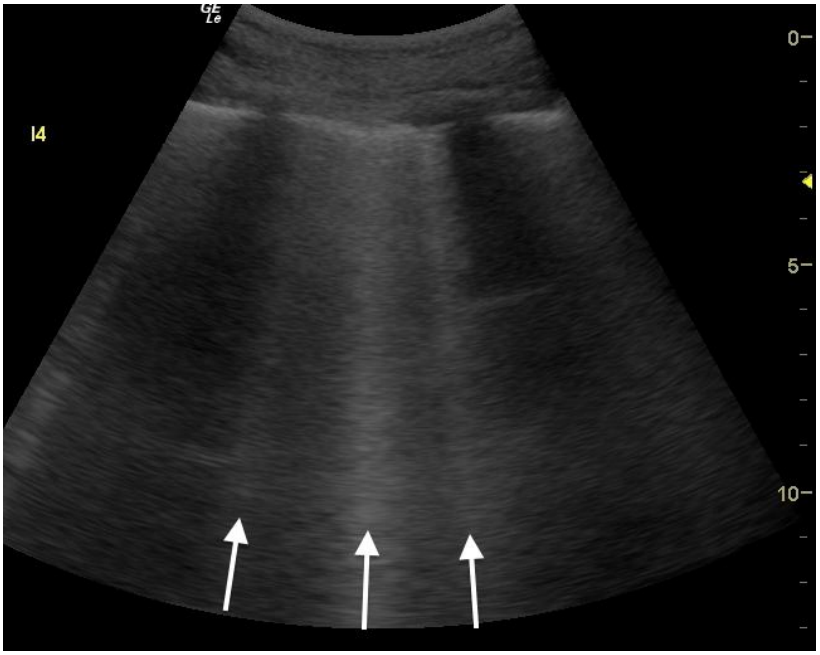

Fig. (5). B-lines: shining (laser like), well defined, vertical hyper-echoic lines originating from pleural line and extending to the edge of the screen (indicated by vertical arrows).

thologies, fluids gravitate to dependent regions while gas rises to the highest region of the chest cavity. Performing a thorough LUS examination in selected lung regions according to the suspected lung pathology increases the sensitivity and specificity of LUS for detecting the lung pathology.

5. LUNG PARENCHYMAL DISORDERS

LUS interrogation for lung parenchymal disorders is the search for areas that have decreased lung aeration. It has been found that loss of aeration in single lung regions qualitatively estimated by LUS correlates well with the CT findings [1].

5.1. Interstitial Syndrome

The interstitial syndrome includes a group of either acute or chronic diseases of the lung, which cause loss of lung aeration. If LUS shows three or more vertical B-lines with loss of A-lines in between 2 ribs, it is pathological and indi-

cates decreased lung aeration, termed interstitial syndrome [1, 17]. This ultrasound pattern is called "B pattern" [1] and has 93% accuracy compared to CXR and 100% accuracy concordance with CT, for the diagnosis of radiological interstitial syndrome [15].

Interstitial syndrome means that there is interlobular septa thickening or 'ground glass' appearance on radiological imaging. This implies increased extra vascular lung water or density in either or both the interstitium and the alveolar air spaces. The degree of aeration loss, distribution of parenchymal involvement (focal or diffuse) and signs contemporaneous with B-lines (pleural involvement, consolidation) differ between diseases, making it possible to differentiate them with LUS. The number of vertical B-lines in LUS images has found to correlate with the degree of lung aeration loss [15, 18]. It has been postulated that multiple B-lines 7 mm apart are caused by moderate decrease in lung aeration due to thickened interlobular septa, which is characteristic to interstitial edema [2, 15, 18]. In contrast, B-lines that are 3mm or less apart are caused by severe decrease in lung aeration due to fluid (transudate) filled alveoli, which correspond to the CT view of ground-glass opacities and are more characteristic of alveolar edema [2, 15, 18].

The presence of multiple, diffuse bilateral B-lines indicate diffuse lung disease such as pulmonary edema (of various causes), interstitial pneumonia, pneumonitis or pulmonary fibrosis [1]. The presence of localised B-lines in otherwise normal lung indicate interstitial syndrome caused by focal lung disease (pneumonia, pneumonitis, atelectasis, pulmonary contusion, radiation fibrosis, pulmonary infarction or neoplasm) [1].

Lung ultrasonography has been found more accurate than CXR, to diagnose and rule out interstitial syndrome [1, 15, 18, 19].

5.2. Lung Consolidation

When the air in the alveoli is completely replaced by fluid or inflammatory exudate and/or cellular infiltrates, it is called lung consolidation. Loss of aeration now favors ultrasound transmission through the lung tissues. Sub-pleural (non lobar) consolidation ultrasonically appears as poorly defined, wedge shaped hypoechoic structures [18, 20] and the deeply seated irregular shredded boundary between consolidated and aerated lung is called shred sign [21]. Lobar consolidation appears ultrasonically as a solid organ pattern (image similar to liver/spleen) and called tissue-like sign [18, 20]. Together both shred sign and tissue-like sign have proved 90% sensitive and 98% specific for diagnosing alveolar consolidation [21]. Although LUS does not rule out consolidation that does not reach the pleura [1], lung consolidation arising at any site is found to influence the pleura in 98% of the cases [21], proving its ability to indicate most consolidations. Lung ultrasonography has been found more accurate than CXR, to diagnose and rule out lung consolidation [1, 5].

Ultrasound consolidation is a common end point of many pathological conditions, including pneumonia, atelectasis (compressive/obstructive), lung contusion, lung tumor infiltration and pulmonary embolism [1]. When air filled bronchi appear as linear hyperechoic artifacts, within the hypoechoic structure (consolidation), this pattern is named 'air-bronchograms' (Fig. **6**) [22]. When an air-bronchogram becomes dynamic (movement >1mm during inspiration), it suggests pneumonia and if static it indicates atelectasis [23]. It has been shown that the dynamic air-bronchogram has good specificity (94%), but poor sensitivity (61%) to differentiate pneumonia from atelectasis [23]. In addition, the bronchogram appears as multiple bright dots or branching linear structures in the region of consolidation, whereas it appears as crowded, parallel running bright line in the region of atelectasis [24]. In mechanically ventilated patients, it has been found that LUS is more accurate than CXR in diagnosing and distinguishing different types of consolidations [1, 18]. The vascular pattern within the consolidation, as assessed by color Doppler ultrasound has been found useful in differentiating different pathologies causing consolidation [25].

5.3. Acute Respiratory Distress Syndrome (ARDS)

LUS features of ARDS are non-homogenous distribution of B-lines, pleural line abnormalities (irregular thickened fragmented), anterior sub pleural consolidation and absence or reduction of lung sliding with spared areas of normal parenchyma [1]. Early in the course of the disease, these findings tend to demonstrate a gravitational preponderance that changes with position change [26]. The distribution of pathology is also notably more patchy than the changes seen in chronic fibrosing lung conditions [27].

5.4. Pulmonary Fibrosis

LUS features of pulmonary fibrosis depend on the connective tissue disorder with which they are associated. Although quoted characteristics mimic those seen in the more acute Respiratory Distress Syndrome (ARDS) there is more tendency for contiguous, symmetrical pathology, unless the predisposing injury was ARDS itself [28]. The context of patient presentation helps to differentiate chronic fibrosing conditions from ARDS.

5.5. Atelectasis

Atelectasis of pulmonary collapse means complete loss of aeration in part or whole lung. A large effusion causes compressive atelectasis while lower airway obstruction causes obstructive atelectasis. Early atelectasis shows consolidation with tissue-like sign and loss of lung sliding while air trapped within atelectasis may form static air-bronchograms [16]. Several studies have proposed other signs to diagnose atelectasis. They include a change in imaging location of the heart, abolition of diaphragm dynamic movement, change in imaging location of the diaphragm (elevated by 2cm) and the presence of a small (<250ml) pleural effusion [28-30].

5.6. Pulmonary Embolism (PE)

An area of pulmonary infarction due to the pulmonary embolism shows on ultrasound images as a peripheral (pleurally based), triangular/wedge or rounded, hypo-echoic, homogenous lesion [30]. Associated pleural effusion adjacent

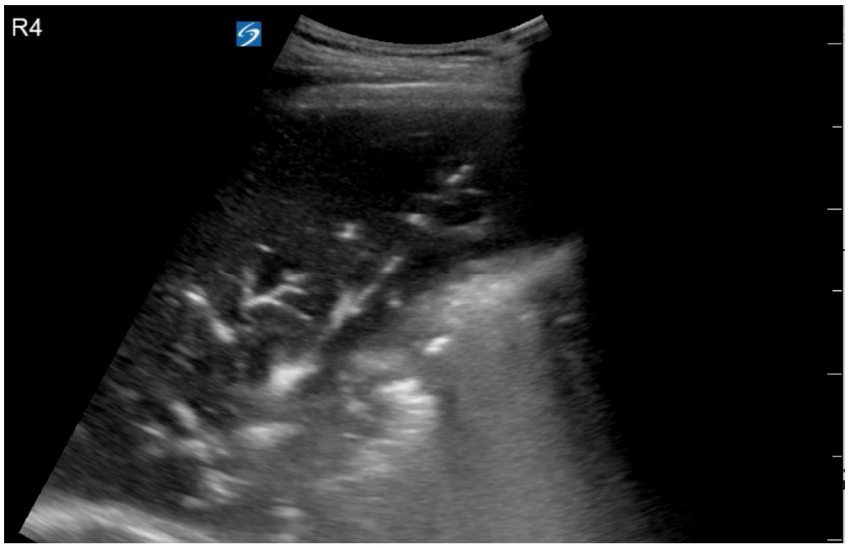

Fig. (6). Air bronchogram.

to the infarcted area may be seen and has been used as additional criteria to diagnose PE [31]. With time the infarcted area will be infiltrated by inflammatory cells and will appear as consolidation. A study has compared LUS with CT angiography in 69 patients with clinical suspicion of PE, of whom 44 had documented PE. They found sensitivity and specificity for LUS were 80% and 92% and for spiral CT were 82% and 100% respectively for diagnosing PE [32]. A meta-analysis that analyzed 7 studies has found that LUS has overall 87% sensitivity and 82% specificity for diagnosing PE [31]. Improved specificity (99%) but same sensitivity (81%) was seen in the BLUE protocol when LUS combines with venous ultrasonographyto diagnose PE, after excluding other causes of acute severe respiratory failure [9]. With the current data LUS can considered as an alternative-imaging test to exclude PE in low risk patients, when CTPA is contra-indicated or unavailable.

5.7. Pediatric Lung Ultrasound

Due to its safety and portability, lung ultrasound has been studied in neonatology and pediatrics. In neonatal and pediatric lung ultrasound most signs remain the same but the clinical relevance is altered by the different disease spectrum [1]. Detailed reiteration of specific test characteristics is beyond the purview of this predominantly adult paper, but two important areas are mentioned, pneumonias in children and neonatal respiratory distress.

As with adult pneumonia, pediatric pneumonia is manifest with consolidations and air bronchograms [33, 34]. These are thought to be indicative of bacterial infection, while localized B lines, confluent B lines and pleural line abnormalities are considered suggestive of viral respiratory illness [35, 36]. Further research is needed to ascertain the clinical relevance of subpleural consolidations less than 1cm in diameter, which are rarely visible on chest x-ray [36].

The 2012 consensus guidelines recommended that in children with a clinical suspicion of pneumonia, a positive lung scan obviated the need for chest x-ray. Subsequent work supports this stance [36-38]. One pediatric meta-analysis has estimated very strong test characteristics for lung ultrasound in pneumonia diagnosis, exceeding the adult estimates [37], however the authors point out the heterogeneity of contributing studies. A recent RCT supports the safety and feasibility of lung ultrasound as a method to decrease chest x-ray use [36].

Neonatal respiratory distress syndromes manifest with pleural line abnormalities, confluent B lines, consolidations and effusions, while the ‘double lung point’ indicates the more benign transient tachypnea of the newborn [1, 39].

In neonatology literature, the ‘double lung point’ sign was described in 2007 by Copetti *et al*, as a means of discriminating transient tachypnea of the newborn from more sinister respiratory distress syndromes [40]. Double Lung Point was described on a longitudinal view where a distinct transition point can be displayed demarcating grey aerated intercostal spaces from those with dependent confluent B lines. One small and one large study have since reiterated its validity [39, 41].

Some confusion has arisen, in that three recently published case studies have used the term ‘Double Lung Point’ to describe a very different phenomenon, identifying small areas of free pleural air [42-44]. The consensus guidelines of 2012 cite the Copetti *et al*’s paper and laud his finding without ratifying the nomenclature [1, 40]. It would be wise to avoid the term ‘double lung point’ until consensus is reached.

6. PLEURAL DISORDERS

6.1. Pleural Effusion

Ultrasonically pleural effusion can be identified by using a low frequency transducer, which shows hypoechoic or anechoic, homogeneous collection in the dependent part of the thoracic cavity above the diaphragm (Fig. **7**) [2]. The deep boundary of the collection is usually regular, roughly parallel

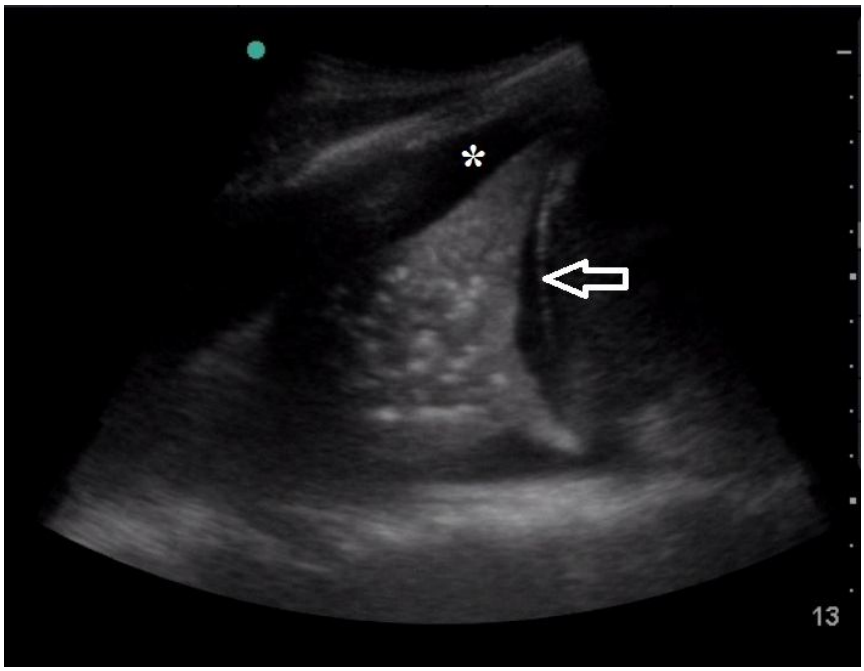

Fig. (7). Pleural effusion: anechoic collection (marked by asterisk) above the diaphragm (marked by horizontal arrow).

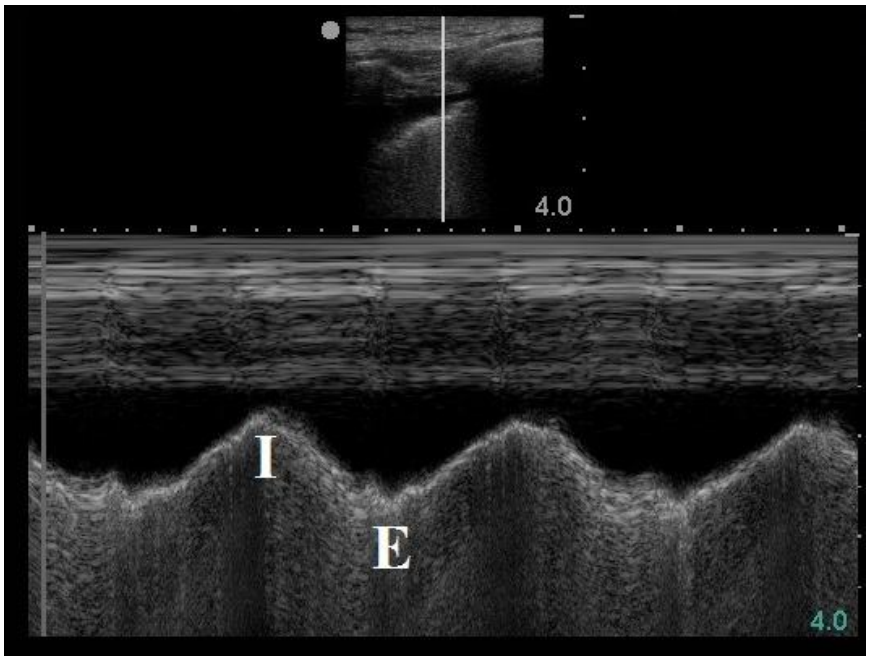

Fig. (8). Sinusoid sign: The lung line moves towards pleural line during inspiration (I) and away from pleural line during expiration (E).

to the pleural line; and is called the lung line (visceral pleura). The ultrasonic quad sign appears when the lung line and pleural line make a quadrilateral shape when combined with the adjacent two rib shadows [9, 14]. The M mode examination of this reveals the sinusoid sign, which occurs due to shifting of lung line towards the pleural line during each inspiration (Fig. **8**) [14, 18]. In a study LUS diagnosed pleural effusion with 93% sensitivity and 97% specificity [18, 45] and another proved sinusoid sign has 97% specificity for diagnosing pleural effusion [46]. LUS was found to diagnose pleural effusion more accurately than CXR [1, 8].

If the lung tissue adjacent to the pleural effusion remains aerated, it can be seen as a bright line and if the effusion compresses the adjacent lung tissue, it can be seen consolidated [2]. It is necessary to identify spleen or liver and the diaphragm when assessing the pleural effusion. Spleen and liver can be distinguished from the pleural effusion by using

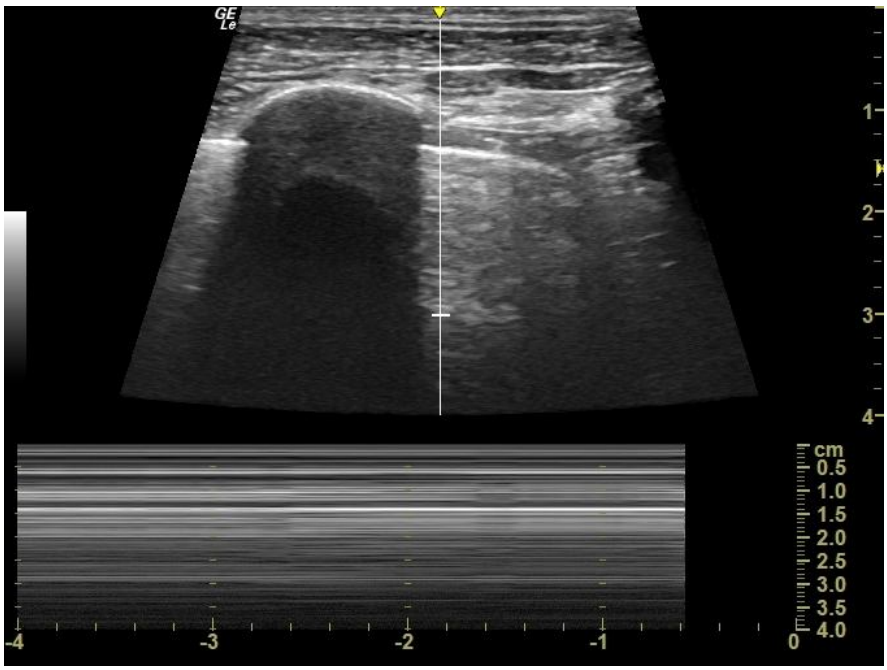

Fig. (9). Barcode sign.

the color Doppler, which shows intra-splenic and intra-hepatic blood vessels originating caudally within the image.

6.2. Pneumothorax

The absence of lung sliding - as would be seen when air separates the visceral pleura from the parietal is demonstrated on M-mode ultrasonography as a linear pattern in the tissue superficial to the pleural line and a similar linear pattern deep to the pleural line. This is known as 'stratosphere sign' or 'barcode sign' (Fig. **9**). Absence of lung sliding has 95% sensitivity, 100% negative predictive value and 87% positive predictive value in a general population [47]. Lung bullae, pleurodesis and other reasons for absent ventilation (cardiopulmonary arrest, apnea, esophageal intubation, one lung ventilation, *etc*) have been found to cause false positive diagnosis [1]. Hence the positive predictive value falls to 56% in the critically ill [48] and to 27% in patients with acute respiratory failure [9]. Presence of A-lines with absence of B-lines and abolished lung sliding is highly suggestive of pneumothorax, but can be due to pleurodesis or emphysematous bullae [49].

In the M-mode view, the point where the normal lung pattern (seashore sign) replaces the pneumothorax pattern (stratosphere sign) with inspiration is called 'lung point' (Fig. **10**) [48]. It occurs due to the inspiratory increase of parietal contact of the pleura and indicates that absence of lung sliding is not due to machine error [14]. It has 79% sensitivity for occult pneumothorax but excellent specificity [12]. The region of lung where the lung point found indicates the pneumothorax volume; moderate, if anterior; massive, if posterior or absent.

In emergency situations, it is strongly recommended that bedside LUS be performed rapidly by the physician in charge, as it is more efficient than bedside CXR for diagnosing pneumothorax [6, 7, 12] and also it is superior to CXR to rule out pneumothorax [1, 6, 7]. The time spent for diagnosing pneumothorax is shown to be reduced by using LUS compared to CXR, averaging 2.3 minutes for LUS and 19.9 minutes for CXR [50]. LUS as the part of the E-FAST (extended focused assessment with sonography in trauma) has detected up to 92% -100% of all pneumothoraces [51]. A meta-analysis shows that high frequency linear probe has performed better than the curvilinear probe in detecting pneumothorax [6].

Recently Volpicelli *et al*. described new ultrasonic signs that have been seen in complex pneumothorax [52]. When small amounts of pleural air are trapped, the outside edges are seen as two lung points on the opposite sides of the scan. This pattern has also been called "double lung point sign" [42-44]. The sonographic pattern of absent lung sliding with presence of B-lines and/or lung pulse with presence of lung point is introduced as diagnostic of septate pneumothorax. The sonographic pattern created by the air-fluid interface in hydro-pneumothorax combines both pleural effusion and pneumothorax patterns. The apposition of these patterns is called the hydro-point.

7. EVALUATE PATIENT PRESENTING WITH ACUTE RESPIRATORY FAILURE (ARF)

Lichtenstein *et al* has proposed BLUE protocol for diagnosing the main pathologies causing ARF (pulmonary edema, pneumothorax, pulmonary consolidation and pleural effusion), using rapid lung and venous ultrasound [9]. Three blue points bilaterally were proposed for a quick screening examination of the lung, taking about 3 minutes to perform [11]. It was shown to diagnose the main causes of ARF in 97% of patients admitted to ETU with an overall 90.5% accuracy, considering final diagnosis by ICU team as the refer-

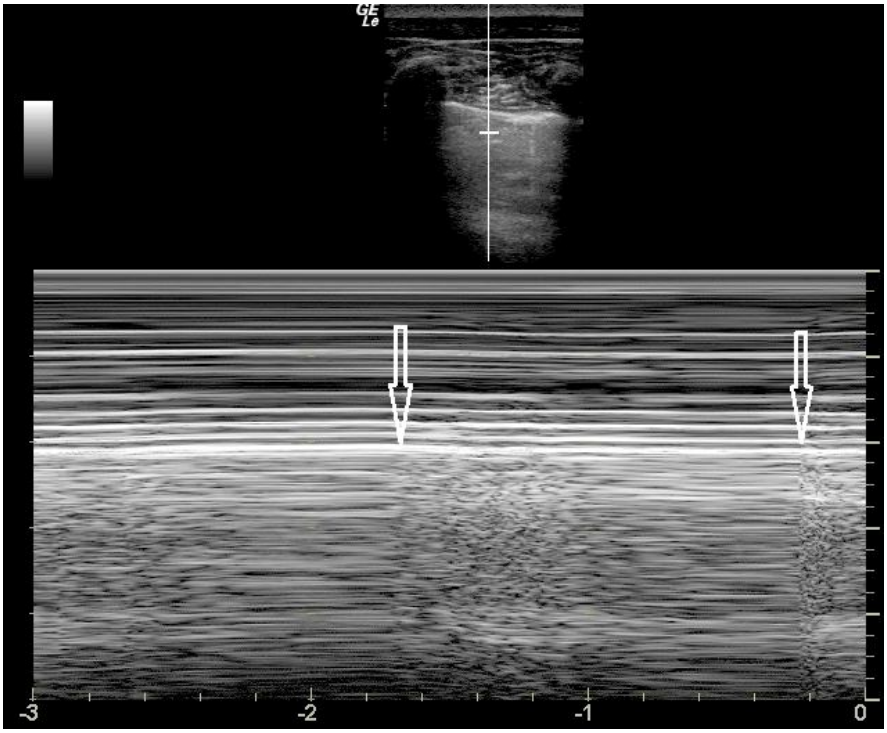

Fig. (10). Lung point: the point where normal lung pattern (Seashore sign) replaces the pneumothorax pattern (Barcode sign) during inspiration (indicated by vertical arrows).

ence standard [9]. RADIUS (Rapid Assessment of Dyspnea with Ultrasound) protocol also proposed LUS use in ARF to detect common lung pathologies [53]. RADIUS begins with cardiac evaluation followed by pulmonary evaluation, whereas the BLUE protocol commences with lung then precedes either to venous or cardiac views.

8. THERAPEUTIC INTERVENTIONS

8.1. Assessing Progress of the Disease and Response to Specific Treatment

As previously described, change in LUS images from A-pattern (A-profile) to B-pattern (B-profile) indicates a decrease in lung aeration while number of B-lines are correlated with the severity. Using this basic premise, studies have proved the capacity of LUS to assess disease progression and response to treatment. B-line evaluation has proven a good prognostic indicator of outcome or mortality in acute decompensated heart failure and left sided heart failure [1].

Lichtenstein *et al.*, in FALLS (Fluid Administration Limited by Lung ultra Sonography) protocol, proposed the use of LUS to guide fluid therapy in managing acute circulatory failure [17]. The team has shown the correlation between an A-profile [or equivalents (A/B-profile)] and a low pulmonary artery occlusion pressure (PAOP), while B lines appear when the PAOP reaches an 18-mmHg value [13]. This assumes unimpaired endothelial integrity. Here the patients with LUS A-pattern (A-profile or equivalent) are called FALLS responders and will benefit from fluid administration. LUS diagnosis of interstitial syndrome (change from A-pattern to B-pattern), due to fluid therapy is introduced as an early, clinically silent indicator (FALLS-end point) of volume repletion [17].

Bouhemad *et al*. has observed that repeated LUS could accurately estimate the lung re-aeration (using ultrasound re-aeration score) in positive end-expiratory pressure (PEEP) induced lung recruitment [54] and in ventilator induced pneumonia (VAP) treated with antimicrobial therapy [55] when compared to chest CT.

8.2. Guiding Procedures

LUS has been shown to enhance the percutaneous aspiration of pleural effusion for therapeutic or diagnostic purposes [18, 45]. It has been proved that when comparing the US criteria with the clinical criteria for selection of puncture site for thoracentesis, US reduced complications by 15% to 19% [56, 57]. A meta-analysis of 24 studies (from 1966 to 2009) found that overall risk of pneumothorax following thoracentesis was 6.0% (in individual studies it varied from 0% to 19%) but there was a significant reduction in incidence, when the procedure was guided by US (odds ratio 0.3) [58]. An article reviewing 23 studies (from 1978 to 2010) has shown that incidence of pneumothorax with thoracentesis ranged from 4.3% to 30% when the procedure was done without US guidance and reduced to 0% to 9.1% when US was used [59]. A study done in 2012 found a similar reduced incidence of pneumothorax following US guided thoracentesis (2.26% in US guided group and 3.09% in those not receiving US guidance). There was also a reduction in hospital stay and average cost of hospitalization in the US guided group [57].

LUS has proved helpful in deciding when to drain pneumothorax, lateral lung points found to correlate with 90% of need for drainage, while anterior lung point for 8% [12]. Ultrasound guidance is evidently useful for percutaneous aspiration or biopsy of pleural or lung lesions [21] and insertion of inter-costal catheters [60].

8.3. Prediction of Post-extubation Failure

Soummer *et al*. introduced standardized evaluation of lung aeration with lung ultrasound score using the presence of B-lines and consolidation to calculate the score [61]. He observed that greater loss of lung aeration (higher lung ultrasound score) was seen in patients who failed a spontaneous breathing trial and also in patients who developed post-extubation respiratory distress.

9. TRAINING AND LEARNING CURVE

Ultrasound examination is becoming the best imaging technique in the critical care and emergency settings, but it requires formal training aiming for necessary knowledge and skills. If one performs and audits several ultrasound examinations on a daily basis, the learning curve for acquiring skills for diagnosing alveolar interstitial syndrome, lung consolidation and pleural effusion is short (less than 6 weeks) [1, 2]. Accurate diagnosis of pneumothorax has a longer learning curve [1, 2].

10. LIMITATIONS

The LUS cannot yet be used to distinguish pathological conditions with increased lung air content. Emphysema, alveolar over-distention from mechanical ventilation or lesions located deep in the lung are poorly differentiated from normal lung because they have aerated lung between probe and lesion.

Almost all critically ill patients need to be examined in the supine position therefore there is difficulty in examining posterior lung regions. Even when the patient is rolled, the dorsal segments of upper lobes of the lungs are difficult to examine as they are obscured by the bony scapula [62].

LUS is patient dependent. It is difficult to perform lung ultrasound in obese patients due to the thickness of soft tissue between probe and region of interest [2]. The presence of subcutaneous emphysema or large thoracic dressing also disturbs the lung ultrasound examination [2].

Another limitation of ultrasound in ICU is its propensity for the probe to act as a vector for resistant pathogens even when used only on intact skin [63-68]. To overcome this, the machine and the probes should undergo repeated decontamination processes. To facilitate this process the keyboard of the machine should be made water resistant, but this feature is not always available in compact ultrasound machines. Some manufacturers provide plastic covers for the keyboard and screen. Sterile transducer covers should always be used for procedures.

11. FUTURE DIRECTIONS

It has been found that LUS combined with echocardiography (thoracic ultrasonography - TUS) has significantly better performance than LUS alone in the diagnosis of ARF [69]. Also it has been found that diagnosing common lung pathologies with LUS has lower specificity than sensitivity [1]. More studies are needed to evaluate LUS, to broaden the evidence base for diagnostic and therapeutic imaging techniques in the ICU. A scientific assessment of learning curves should be done in unselected physicians.

CONCLUSION

LUS has proved accurate for diagnosis of alveolar-interstitial syndrome [9, 15], consolidation [21], pleural effusion [2, 18, 70] and pneumothorax [12, 45, 47] with greater sensitivity and better specificity. Also LUS has proven its value in rapid recognition of the major causes of acute respiratory failure in >90% cases studied [9, 70] and for diagnosing circulatory failure [17]. Generally, ICU patients, for the diagnosis of most common lung pathologies, ultrasonography is considered a better imaging technique than CXR and an alternative imaging technique to thoracic CT. LUS decreases the number of CXR and thoracic CT ordered by ICUs that utilize ultrasound, ultimately reducing the cost of patient care in ICU [18].

If the clinician with the full clinical knowledge of the patient is able to perform the ultrasound at the bedside, it will help the clinician come to the final diagnosis of the patient's pathology more rapidly and to plan the treatment more effectively.

LUS serves as a tool to diagnose lung pathology, monitor its course and guide clinical management.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interests. Dr Baker teaches part time at an ultrasound training facility, and has received grants from Emergency Medicine Foundation (non-profit organization) for research into lung ultrasound.

ACKNOWLEDGEMENTS

On request of Dr. Baker, "Emergency Medical Foundation" of Australia has paid US$450 for making this review paper open access.

REFERENCES

[1] Volpicelli G, Elbarbary M, Blaivas M, *et al*. International evidence-based recommendations for point-of-care lung ultrasound. Intens Care Med 2012; 38: 577-091.

[2] Bouhemad B, Zhang M, Lu Q, Rouby JJ. Clinical review: Bedside lung ultrasound in critical care practice. Crit Care 2007; 11: 205.

[3] Lichtenstein DA. Ultrasound examination of the lungs in the intensive care unit. Pediatr Crit Care Med 2009; 10: 693-8.

[4] Dexheimer Neto FL, Dalcin Pde T, Teixeira C, Beltrami FG. Lung ultrasound in critically ill patients: A new diagnostic tool. J Bras Pneumol 2012; 38: 246-56.

[5] Ye X, Xiao H, Chen B, Zhang S. Accuracy of lung ultrasonography versus chest radiography for the diagnosis of adult community-acquired pneumonia: Review of the literature and meta-analysis. PLoS One 2015; 10: e0130066.

[6] Alrajab S, Youssef AM, Akkus NI, Caldito G. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: Review of the literature and meta-analysis. Crit Care 2013; 17: R208.

[7] 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.

[8] Yousefifard M, Baikpour M, Ghelichkhani P, *et al*. Screening performance characteristic of ultrasonography and radiography in detection of pleural effusion; A meta-analysis. Emerg (Tehran) 2016; 4: 1-10.

[9] Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: The BLUE protocol. Chest 2008; 134: 117-25.

[10] Volpicelli G, Cardinale L, Garofalo G, Veltri A. Usefulness of lung ultrasound in the bedside distinction between pulmonary edema and exacerbation of COPD. Emerg Radiol 2008; 15: 145-51.

[11] Lichtenstein DA, Meziere GA. The BLUE-points: Three standardized points used in the BLUE-protocol for ultrasound assessment of the lung in acute respiratory failure. Crit Ultrasound J 2011; 3: 109-10.

[12] Lichtenstein DA, Meziere G, Lascols N, *et al*. Ultrasound diagnosis of occult pneumothorax. Crit Care Med 2005; 33: 1231-8.

[13] Lichtenstein DA, Mezière GA, Lagoueyte JF, *et al*. A-lines and B-lines: lung ultrasound as a bedside tool for predicting pulmonary artery occlusion pressure in the critically ill. Chest 2009; 136: 1014-20.

[14] Lichtenstein D. Lung ultrasound in the critically ill. Curr Opin Crit Care 2014; 20: 315-22.

[15] Lichtenstein D, Meziere G, Biderman P, Gepner A, Barre O. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med1997; 156: 1640- 6.

[16] Lee FC. Lung ultrasound-a primary survey of the acutely dyspneic patient. J Intens Care 2016; 4: 57.

[17] Lichtenstein D. FALLS-protocol: Lung ultrasound in hemodynamic assessment of shock. Heart Lung Vessel 2013; 5: 142-7.

[18] Lichtenstein D, Glodstein 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.

[19] 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.

[20] Yang PC, Chang DB, Yu CJ, *et al*. Ultrasound guided percutaneous cutting biopsy for the diagnosis of pulmonary consolidations of unknown aetiology. Thorax1992; 47: 457-60.

[21] Lichtenstein DA, Lascols N, Meziere G, Gepner A. Ultrasound diagnosis of alveolar consolidation in the critically ill. Intens Care Med 2004; 30: 276- 81.

[22] Weinberg B, Diakoumakis EE, Kass EG, Seife B, Zvi ZB. The air bronchogram: Sonographic demonstration. Am J Roentgenol 1986; 147: 593-5.

[23] Lichtenstein D, Meziere G, Seitz J. The dynamic air bronchogram. An ultrasound sign of alveolar consolidation ruling out atelectasis. Chest 2009; 135: 1421-5.

[24] Barillari A, Franco FD, Colonna F. Chest ultrasound helps to diagnose pulmonary consolidation in pediatric patients. J Med Ultrasound 2011; 19: 27-31.

[25] Yuan A, Yang PC, Lee L, *et al*. Reactive pulmonary artery vasoconstriction in pulmonary consolidation evaluated by color Doppler ultrasonography. Ultrasound Med Biol 2000; 26: 49-56.

[26] Zhao Z, Jiang L, Xi X, *et al*. Prognostic value of extravascular lung water assessed with lung ultrasound score by chest sonography in patients with acute respiratory distress syndrome. BMC Pulm Med 2015; 15: 98.

[27] Smargiassi A, Inchingolo R, Soldati G, *et al*. The role of chest ultrasonography in the management of respiratory diseases: document II. Multidiscip Respir Med 2013; 8: 55.

[28] Lichtenstein DA, Lascols N, Prin S, Meziere G. The 'lung pulse': an early ultrasound sign of complete atelectasis. Intens Care Med 2003; 29: 2187-92.

[29] Lichtenstein DA. General ultrasound in the critically ill. 2005; Springer-Verlag Berlin Haidelberg New York. Pp 96-133.

[30] Shrestha GS. Point-of-care ultrasonography in critically ill patients. Kathmandu Univ Med J 2015; 49: 83-7.

[31] Squizzato A, Rancan E, Dentali F, *et al*. Diagnostic accuracy of lung ultrasound for pulmonary embolism: A systematic review and meta-analysis. J Thromb Haemost 2013; 11: 1269-78.

[32] Reissig A, Heyne JP, Kroegel C. Sonography of lung and pleura in pulmonary embolism: Sonomorphologic characterization and comparison with spiral CT scanning. Chest 2001; 120: 1977- 83.

[33] Shah VP, Tunik MG, Tsung JW. Prospective evaluation of point-of-care ultrasonography for the diagnosis of pneumonia in children and young adults. JAMA Pediatr 2013; 167: 119-25.

[34] Caiulo VA, Gargani L, Caiulo S, *et al*. Lung ultrasound characteristics of community-acquired pneumonia in hospitalized children. Pediatr Pulmonol 2013; 48: 280-7.

[35] Tsung JW, Kessler DO, Shah VP. Prospective application of clinician-performed lung ultrasonography during the 2009 H1N1 influenza A pandemic: Distinguishing viral from bacterial pneumonia. Crit Ultrasound J 2012; 4: 16.

[36] Jones BP, Tay ET, Elikashvili I, *et al*. Feasibility and safety of substituting lung ultrasonography for chest radiography when diagnosing pneumonia in children: A randomized controlled trial. Chest 2016; 150: 131-8.

[37] Pereda MA, Chavez MA, Hooper-Miele CC, *et al*. Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis. Pediatrics 2015; 135: 714-22.

[38] Alzahrani SA, Al-Salamah MA, Al-Masani WH, Elbarbary MA. Systematic review and meta-analysis for the use of ultrasound versus radiology in diagnosing of pneumonia. Crit Ultrasound J 2017; 9: 6.

[39] Liu J, Chen XX, Li XW, *et al*. Lung ultrasonography to diagnose transient tachypnea of the newborn. Chest 2016; 149: 1269-75.

[40] Copetti R, Cattarossi L. The 'double lung point': an ultrasound sign diagnostic of transient tachypnea of the newborn. Neonatology 2007; 91: 203-9.

[41] Liu J, Wang Y, Fu W, Yang CS, Huang JJ. Diagnosis of neonatal transient tachypnea and its differentiation from respiratory distress syndrome using lung ultrasound. Medicine (Baltimore) 2014; 93: e197.

[42] Volpicelli G, Audino B. The double lung point: An unusual sonographic sign of juvenile spontaneous pneumothorax. Am J Emerg Med 2011; 29: 355. e1-2.

[43] Aspler A, Pivetta E, Stone MB. Double-lung point sign in traumatic pneumothorax. Am J Emerg Med 2014; 32: 819. e1-2.

[44] Zhang Z. Double lung point in an 18-month-old child: A case report and literature review. J Thorac Dis 2015; 7: E50-3.

[45] Lichtenstein D, Hulot JS, Rabiller A, Tostivint I, Meziere G. Feasibility of ultrasound-aided thoracocentesis in mechanically ventilated patients. Intens Care Med 1999; 25: 955-8.

[46] Lichtenstein D. Should lung ultrasonography be more widely used in the assessment of acute respiratory disease? Expert Rev Respir Med. 2010; 4: 533-8.

[47] Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill: lung sliding. Chest 1995; 108: 1345-8.

[48] Lichtenstein D, Meziere G, Biderman P, Gepner A. The "lung point": An ultrasound sign specific to pneumothorax. Intens Care Med 2000; 26: 1434-40.

[49] Lichtenstein D, Meziere G, Biderman P, Gepner A. The comet- tail artifact: An ultrasound sign ruling out pneumothorax. Intensive Care Med 1999; 25: 383-8.

[50] Zhang M, Liu ZH, Yang JX, *et al*. Rapid detection of pneumothorax by ultrasonography in patients with multiple trauma. Crit Care 2006; 10: R112.

[51] Ball CG, Kirkpatrick AW, Feliciano DV. The occult pneumothorax: What have we learned? Can J Surg 2009; 52: E173-9.

[52] Volpicelli G, Boero E, Stefanone V, Storti E. Unusual new signs of pneumothorax at lung ultrasound. Crit Ultrasound J 2013; 5: 10.

[53] Manson W, Hafez NM. The rapid assessment of dyspnea with ultrasound: RADIUS. Ultrasound Clin 2011; 6: 261-76.

[54] Bouhemad B, Brisson H, Le-Guen M, *et al*. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. Am J Respir Crit Care Med 2011; 183: 341-7.

[55] 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.

[56] Diacon AH, Brutsche MH, Soler M. Accuracy of pleural puncture sites: a prospective comparison of clinical examination with ultrasound. Chest 2003; 123: 436-41.

[57] Mercaldi CJ, Lanes SF. Ultrasound guidance decreases complications and improves the cost of care among patients undergoing thoracentesis and paracentesis. Chest 2013; 143: 532-8.

[58] Gordon CE, Feller-Kopman D, Balk EM, Smetana GW. Pneumothorax following thoracentesis: A systematic review and meta-analysis. Arch Intern Med 2010; 170: 332-9.

[59] Sikora K, Perera P, Mailhot T, Mandavia D. Ultrasound for the detection of pleural effusions and guidance of the thoracentesis procedure. ISRN Emerg Med 2012; 2012: 1-10. Article ID 676524.

[60] Jenkins JA, Gharahbaghian L, Doniger SJ, *et al*. Sonographic identification of tube thoracostomy study (SITTS): Confirmation of intrathoracic placement. West J Emerg Med 2012; 13: 305-11.

[61] Soummer A, Perbet S, Brisson H, *et al*. Ultrasound assessment of lung aeration loss during a successful weaning trial predicts postextubation distress. Crit Care Med 2012; 40: 2064-72.

[62] Arbelot C, Ferrari F, Bouhemad B, Rouby JJ. Lung ultrasound in acute respiratory distress syndrome and acute lung injury. Curr Opin Crit Care 2008; 14: 70-4.

[63] Muradali D, Gold WL, Phillips A, Wilson S. Can ultrasound probes and coupling gel be a source of nosocomial infection in patients undergoing sonography? An *in vivo* and *in vitro* study. Am J Roentgenol 1995; 164: 1521-4.

[64] Patterson SL, Monga M, Silva JB, Bishop KD, Blanco JD. Microbiologic assessment of the transabdominal ultrasound transducer head. South Med J 1996; 89: 503-4.

[65] Tesch C, Froschle G. Sonography machines as a source of infection. Am J Roentgenol 1997; 168: 567-8.

[66] Fowler C, McCracken D. US probes: Risk of cross infection and ways to reduce it - comparison of cleaning methods. Radiology 1999; 213: 299-300.

[67] Ohara T, Itoh Y, Itoh K. Contaminated ultrasound probes: A possible source of nosocomial infections. J Hosp Infect 1999; 43: 73.

[68] Karadenz YM, Kilic D, Kara Altan S, Altinok D, Guney S. Evaluation of the role of ultrasound machines as a source of nosocomial and cross-infection. Invest Radiol 2001; 36: 554-8.

[69] Bataille B, Riu B, Ferre F, *et al*. Integrated use of bedside lung ultrasound and echocardiography in acute respiratory failure: A prospective observational study in ICU. Chest 2014; 146: 1586-93.

[70] Zanobetti M, Poggioni C, Pini R. Can chest ultrasonography replace standard chest radiography for evaluation of acute dyspnea in the ED? Chest 2011; 139: 1140-7.