RESEARCH PAPER | Medical Science | Volume : 5 | Issue : 2 | Feb 2015 | ISSN - 2249-555X

ROLE OF BEDSIDE LUNG ULTRASOUND BY PULMONOLOGIST IN RESPIRATORY CRITICAL CARE : A SYSTEMATIC REVIEW

KEYWORDS: lung ultrasound, critical care, respiratory failure

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ABSTRACT *During the last twenty years ultrasound of the lung has developed steadily from being a least preferred diagnostic modality for lung pathology to becoming a trusted aide of the pulmonologist. When integrated with clinical impression and physical examination bedside ultrasound of the chest can provide a quick diagnosis to the pulmonologist in critical care settings. The objective of this review was to evaluate the latest clinical and therapeutic applications of bedside lung ultrasound specifically useful for treating pulmonologist in respiratory critical care.*

1. Introduction

Ultrasonography of the lung is a non invasive, inexpensive and easily available bedside diagnostic modality which is steadily becoming a trusted aide of the pulmonologist especially in respiratory critical care. Since 1992, Dr D Lichtenstein , one of the pioneers in the field of lung sonography contributed immensely by publishing numerous landmark articles that built the basic concepts of lung sonography.[Lichtenstein D,1993] Although ultrasound is traditionally used by radiologists, there is growing evidence of use of lung ultrasound by pulmonologists as a "point of care sonography" [Moore , and Copel , 2011]. The main advantage of lung ultrasound is that it is performed immediately at the bedside by the treating pulmonologist thus complementing physical examination and clinical impression. It bridges the technological gap between the basic imaging, portable bedside chest X ray and the gold standard CT Scan. The objective of this review is to evaluate the clinical application, usefulness of bedside lung ultrasound by treating pulmonologist and its latest applications in respiratory critical care.

2. Methods

A systematic review of all articles published in English in last ten years was done by searching pubmed, cochrane reviews and standard text books using Mesh terms "ultrasonography", "critical care", and "lung .The review was conducted in Dec 2014 and included all English-language articles published since 2004 till the date of the electronic search. Textbooks on pulmonology were reviewed as well as those on the use of ultrasound in intensive care settings, together with related articles published in specialized journals.

3. Basic principle and technique of lung sonography

Ultrasound is a form of inaudible sound energy used for diagnostic purposes at a frequency range of 2-20 MHz, generated by piezoelectric crystals., generating waves that are transmitted, attenuated, or reflected by tissues.

All diagnostic ultrasound methods are based on the principle that ultrasound is reflected by an interface between media with different acoustic impedance. In normal conditions, with aerated lungs, no image is visible, because no acoustic mismatch may reflect the beam, which is rapidly dissipated by air [Lichtenstein DA ,2007]. The only detectable structure is the pleura, visualized as a hyperechoic horizontal line, moving synchronously with respiration .Lung ultrasound is based on the fact that every acute disease eg pulmonary edema, pulmonary fibrosis, etc reduces lung aeration, the acoustic mismatch needed to reflect the ultrasound beam is created and generates distinct, predictable patterns; which allows the diagnosis of different conditions.

4. Equipment requirements

Lung ultrasound examination(LUS) can be easily performed at the patients bedside using any ultrasound machine with 2 D scanner without doppler imaging, using any transducer(curved array, linear array, convex ,microconvex). A3.5-5MHz curved-array transducer, preferably small (for better adaptation to the intercostal spaces), is appropriate[Koenig, Narasimhan and Mayo ,2011].This offers adequate penetration and resolution of deep structures in the thorax. High frequency 7.5-10 MHz linear vascular transducer is used for pleural surface and chest wall.

5. Method of Ultrasound examination

Patients can be examined in supine and sitting position. The anterior and posterior axillary lines are the reference points for the examination, dividing the thorax into three zones, which are generally subdivided into upper and lower sections [Volpicelli , Mussa and Garofalo , 2006] By convention, lung ultrasound is performed in the longitudinal plane, with the transducer perpendicular to the skin surface. In sitting position scan is performed by holding the probe firmly perpendicular to chest wall and moving cephalad to caudal along longitudinal scan lines, anterior, midaxillary and posterior scan lines.[Koenig et al]

6. Ultrasound findings of normal lung

The original work of Dr Daniel Lichtenstein in the 1990s defined all the important findings of lung ultrasonography [Lichtenstein ,1993] and has been fully validated by subsequent investigators. For purposes of efficient reporting, his nomenclature is standard in the field. Ten basic signs[Table 1 about here] have been identified ,the knowledge of which is mandatory for diagnosis of acute respiratory failure and other acute conditions. When performing lung ultrasonography, when the transducer is placed over an interspace the rib shadows are located on either side of the screen [Table 1 and Fig1 about here]. The pleural line is identified approximately 5 mm deep to the rib cortex.

7. Clinical Application

Bedside lung ultrasound can become a routinely used tool for the pulmonoogist by applying the fast protocols devised by Dr D Lichtenstein for diagnosis of Acute Respiratory failure(BLUE Protocol) and acute circulatory failure(FALLS protocol) [Lichenstein,1993] . International evidence-based recommendations for point-of-care lung ultrasound have been published to guide implementation and standardization in all relevant settings. [Elbarbary , Melniker and Volpicelli ,2010, Giovanni ,Mahmoud and

,Michael ,2012]

(i) Approach to a case of Respiratory Failure or BLUE PROTOCOL : A standardized evaluation of patients with dyspnea, respiratory failure or both based on the profile of lung ultrasound findings, together with screening for leg vein thrombosis is designated the "blue protocol" [Lichtenstein DA.2010]. It reached an immediate diagnosis in acute respiratory failure 90.5% of cases. Summarizing the blue protocol, Predominant A lines plus lung sliding indicated asthma or COPD with 89% sensitivity and 97% specificity. Multiple anterior diffuse B lines with lung sliding indicated pulmonary edema with 97% sensitivity and 95% specificity. A normal anterior profile plus deep venous thrombosis indicated pulmonary embolism with 81% sensitivity and 99% specificity. Anterior absent lung sliding plus A lines plus lung point indicated pneumothorax with 81% sensitivity and 100% specificity. Anterior alveolar consolidations, anterior diffuse B lines with abolished lung sliding, anterior asymmetric interstitial patterns, posterior consolidations or effusions without anterior diffuse B lines indicated pneumonia with 89% sensitivity .

(ii) Pleural Effusion : For the detection of effusion, lung ultrasound is more

accurate than supine radiography and is as accurate as CT It can be diagnosed by the quad sign and sinusoid sign [Giovanni etal,2012]. Ultrasonography has been shown to be superior to CT scan in detecting septations in pleural effusions [Peris , Tutino ,and Zagli,2010]**.**

(ii) Pneumothorax: Lung ultrasound more accurately rules in the diagnosis

of pneumothorax than supine anterior chest radiography (CXR). Several studies [Saucier , Motyka and,Killu , 2010, Wilkerson RG, Stone MB,2010], have demonstrated the superiority of lung ultrasound over chest X-rays taken in the supine position in ruling out pneumothorax The presence of lung point or a normal lung area in contact with an area with no lung sliding or A lines has a 100% specificity for pneumothorax. In the M –mode below the pleural line ,a linear pattern is seen instead of a granular pattern called barcode sign. [Ding , Shen ,and Yang , 2011]

(iii) Interstitial Syndrome: Multiple B-lines (described above)are the sonographic sign of lung interstitial syndrome. Causes of interstitial syndrome include Pulmonary edema of various causes, Interstitial pneumonia ,Diffuse parenchymal lung disease (pulmonary fibrosis.Presence of three or more B lines in a longitudinal plane between two ribs is defined as a positive region.. The presence of B-lines in nondependent lung regions is useful for the differential diagnosis between cardiogenic and noncardiogenic dyspnea.[Giovanni et al.2012]

(iv) Pulmonary consolidation: The tissue like sign has a specificity of 98.5% in diagnosis of consolidation. The presence of shred sign has a 90% sensitivity for the diagnosis of parenchymal consolidation. Light (hyperechoic) punctiform images can be seen within the consolidation showing presence of air bronchogram. In mechanically ventilated patients lung ultrasound should be considered as it is more accurate than portable chest radiography in the detection of consolidation.

(v) Acute Respiratory Distress Syndrome (ARDS): Acute respiratory distress syndrome(ARDS) is a common syndrome of diffuse lung injury with a high mortality rate. Sonographic findings that are indicative of ARDS include : anterior subpleural consolidation, abscence or reduction of lung sliding, spared areas of normal parenchyma, pleural line abnormalities (irregular thickened fragmented pleural line) and non homogeneous distribution of B-lines.

(vi) Monitoring the response to interventions : Lung ultrasound is also useful in monitoring the response to interventions. Evaluation of patients with renal failure and pulmonary congestion demonstrated that the reduction in the number of B-lines was proportional to the reduction in the volume of extravascular lung water, which was accompanied by clinical improvement of the patients.

(vii) Hemodynamic assessment of circulatory failure using lung ultrasound: FALLS Protocol(Fluid Administration Limited by Lung Sonography) is a protocol developed by Dr D Lichestien [Lichenstein,1993] for diagnosis and management of acute circulatory failure. It can be used to differentiate between different causes of shock combining both cardiac and lung sonography. when a pulmonary artery occlusion pressure(PAOP) of 18 mmHg is reached during fluid therapy, B-lines replace A-lines [Lichtenstein , Mezière and Lagoueyte 2009] . Cardiogenic shock from the left heart is defined by low cardiac output and high PAOP and presence of a B-profile. Patients with the A-profile or equivalents,proving dry lungs, are called FALLS-responders. They are those who must, receive fluids The FALLS-protocol is used to begin fluid administration. The change fromA- to B-lines indicates the endpoint for fluid therapy. If there is no improvement in circulatory failure it indicates septic shock.

(vii) Ultrasound guided procedures: Bedside Thoracocentesis and biopsy done under ultrasound guidance specially in patients on positive pressure ventilation has a reduced incidence of iatrogenic pneumothorax and better yield.

(viii) Other applications : Lung ultrasound can be useful in the evaluation of diaphragmatic function, through the evaluation of diaphragmatic movement during a deep inhalation Lung ultrasound can confirm correct endotracheal tube placement by showing the presence of bilateral lung sliding, a promising application of the method. Peris et al. evaluated the implementation of a protocol for routine lung ultrasound examination of patients admitted to the ICU and found a reduction in the total number of X-rays and CT scans taken [Peris , Tutino and Zagli ,2010]

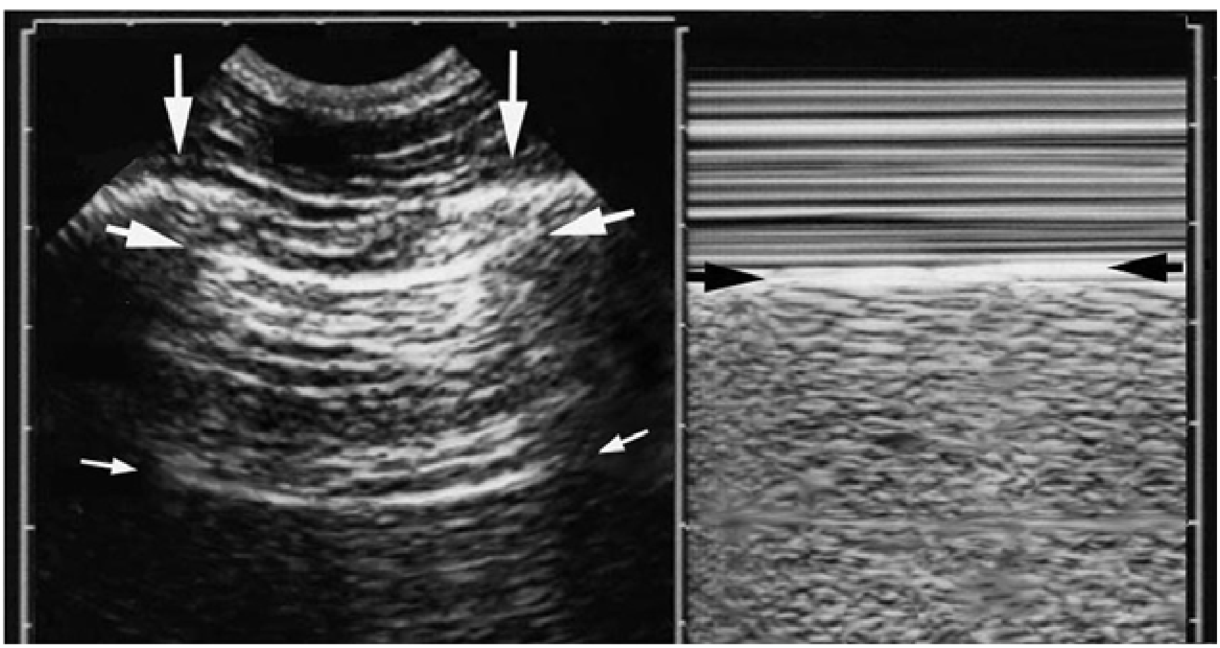
(ix) Limitations: As lung ultrasound by pulmonologists is a newly .developed tool there is a lack of specific criteria for training and certification. Lung ultrasound examination being essentially dynamic, it is difficult to document and store lung ultrasound findings for subsequent comparison. The presence of obesity, dressings, or subcutaneous emphysema obstructs the use of lung ultrasound. It is essential to maintain a strict disinfection protocol to prevent the transmission of infection.

(x)Conclusion : Lung sonography is now a well established tool in the armamentarium of pulmonologists with many typical signs as summarised in table 1 . Though still not widely incorporated in clinical practice, it has tremendous clinical utility, as a diagnostic tool patient's bedside. It performs better than a chest radiograph in many clinical scenarios, and decreases the need for transporting critically ill patients for sophisticated, costly test.For the pulmologist, ultrasound probe is the stethoscope of the future.

Volume : 5 | Issue : 2 | Feb 2015 | ISSN - 2249-555X

Table 1 : Salient Signs in Lung Ultrasound

SIGN	SIGNIFICANCE
1)**Bat Sign**-Pleural line with rib shadows makes a permanent land mark.	Helps to locate lung surface
2) **A lines**- repetitive horizontal hyperechoic artifacts arising from the pleural line.	generated by subpleural air.
3i)**Lung sliding**- The pleural line appears as a shimmering echogenic linear structure ,which moves with the respiratory or cardiac cycle. ii) **Seashore sign**-seen on M mode. characterized by a linear pattern-corresponding to the chest wall (no movement)-above the pleural line (light or hyperechoic) and a homogeneous granular pattern(Figure 2 as in here).	represents movement of the visceral pleura against the parietal pleura. generated by respiratory cycles and air movement-below the pleural line
4) **Quad sign**-a quadrangular image occupied centrally by hypoechoic or dark image (fluid),laterally by the posterior acoustic shadowing of the ribs,superiorly by chest wall and inferiorly by hypoechoic shadow of the lung parenchyma[	Shows presence of any kind of pleural effusion.
5) **Sinusoid sign** - the cyclical movement of the underlying lung parenchyma seen in M(motion) mode	Definite indication of pleural effusion along with quad sign
6) **Tissue like sign**- lung has a solid organ appearance	indicative of lung consolidation
7) **Shred sign**- where lung line is replaced by shredded line	indicative of lung consolidation which does not invade the whole lobe.
8)**B lines**- an artifact with seven features: discrete laser-like vertical reverberation artifacts ; arising from the pleural line(previously described as "comet tails"); hyperechoic; well defined; spreading up indefinitely; erasing A lines; and moving with lung sliding.	Indicates alveolar interstitial syndrome
9)**Stratosphere sign**- motionless pleural ine on B mode. M-mode shows a standardized stratified pattern below and above the pleural line	Indicative of pneumothorax
10)**Lung Point**-Sudden, on-off visualization of a lung pattern (lung sliding and/or B-lines)at a area where the collapsed expiratory lung increases its surface of contact on inspiration	Specific for pneumothorax



1 (a) 1(b)

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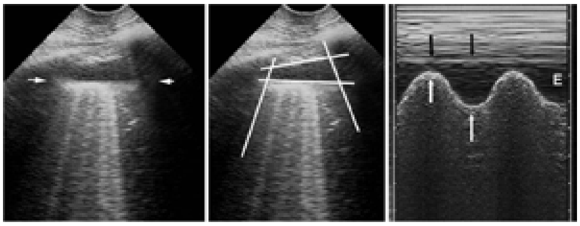
Figure 1 :(a) Ultrasound image of the normal lung. The ribs (vertical arrows) the pleural line (upper, horizontal arrows), a horizontal hyperechoic line, half a centimeter below the rib line in adults. horizontal repetition artifact of the pleural line has been called the A-line (lower, small horizontal arrows).**1(b)** : M-mode reveals the seashore sign. Above the pleural line, the motionless chest wall displays a stratified pattern. Below the pleural line, the dynamics of lung sliding show sandy pattern.



2(a) 2(b) 2(c)

Fig 2:(a) Lung USG showing pleural effusion(above arrow. **2(b) Quad sign**-a quadrangular image occupied centrally by hypoechoic or dark image (fluid),laterally by the posterior acoustic shadowing of the ribs, superiorly by chest wall and inferiorly by hypoechoic shadow of the lung parenchyma **2(c) Sinusoid sign** - the cyclical movement of the underlying lung parenchyma seen in M(motion) mode

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