Lung Ultrasonography

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Abstract: Lung ultrasonography has excellent utility for the diagnosis of various thoracic diseases. It is easy to learn and has become attractive to intensivist and pulmonary physicians. This section will review key components of lung ultrasonography.

The authors note that Dr. Daniel Lichtenstein is responsible for the major developments of lung ultrasonography. He published a series of landmark studies in 1990's that defined all of the elements of the field; in addition, he developed the basic semiology of lung ultrasonography.

Keywords: Lung sliding, A-lines, B-Lines, Alveolar consolidation, Lung point, application of lung ultrasonography.

PHYSICS OF LUNG ULTRASONOGRAPHY

Interpreting ultrasound images requires understanding the fundamentals of ultrasound transmission and image production. The reader is referred to standard texts for the detail discussions of physics of diagnostic ultrasonography [1, 2]. Lung ultrasound presents special problems due to the interaction of aerated lung with ultrasound transmission. Due to major differences in velocity and acoustic impedance of ultrasound wave between air filled lung and tissue, there is a major reflection of ultrasound wave at any interface between air and tissue. In addition, air has a high attenuation coefficient for ultrasound transmission. Hence, well aerated lung appears as homogenous gray picture on the ultrasound screen.

Normal lung is filled with air so that a distinct image of aerated lung is not possible with ultrasonography. However, when lung is airless, it appears as a discreet tissue density. For example, an area of alveolar consolidation will appear as a hyperechoic structure with lung ultrasound. The findings of lung ultrasound abnormalities largely depend on the ratio of air to fluid within the imaged structure [3, 4].

THE ULTRASOUND MACHINE

Lung ultrasonography can be done with virtually any two dimensional (2-D) ultrasound machine. Older models from 1990's produce very serviceable images, as do modern portable units that are designed for intensive care unit (ICU) work. A phased array 3.5 MHz to 5.0MHz cardiac transducer is suitable; as it may have multiple other applications in the ICU, such as for abdominal, thoracic and cardiac ultrasonography. A 7.5 MHz linear vascular transducer also has utility; however, it lacks sufficient penetration for the evaluation of deep structures within the chest [5]. A small portable machine has a major advantage in the intensive care unit environment.

PERFORMING LUNG ULTRASONOGRAPHY

By standard convention, lung ultrasonography is performed with the transducer orientated perpendicular to the chest wall with the scanning plane in longitudinal axis. The transducer orientation marker is directed toward the head of the patient such that the cephalad direction is always projected to left side of the screen. The transducer is moved in a methodical fashion in a series of scan lines along the chest wall. The examiner divides the chest into to an anterior, lateral, and posterior scanning field. The anterior thoracic field is bordered by the sternum and anterior axillary line. The lateral field is between the anterior and the posterior axillary line. The posterior field is bordered by the posterior axillary line and the spine. In general, the critically ill patient is scanned in supine position, so that only anterior and lateral scanning fields are available. Characteristically, the examiner will lay down two longitudinal scan lines in the anterior field that include several intercostal spaces followed by several scan lines in the lateral field (see Figs. **1**, **2**). The posterior field scanning can be accomplished in the supine patient, this requires pushing the transducer posteriorly and angulating the transducer toward the center of the body (Fig. **3**). Full ultrasound study of the posterior field requires that the critically ill patient be placed in the lateral decubitus position. Alternatively, the patient may be scanned in a semi-upright position with the ipsilateral arm pulled across the body in order to expose part of the posterior hemithorax. It is crucial, when examining the lateral thorax, to identify the hemi-diaphragm, which is an important landmark separating the abdomen from the chest (see Fig. **4**). By using an organized scan line and field approach, the examiner can construct a three dimensional model of the thoracic compartment from the multiple two dimensional images.

BASIC FINDINGS OF ULTRASONOGRAPHY

When the transducer is placed in the long axis to examine between adjacent intercostal spaces, the resultant image has characteristic features. Rib shadows are present on either side of the image with a horizontal hyperechoic line positioned 0.5 cm deep to the rib (Fig. **5**). This is the pleural interface. The basic image can be obtained from multiple interspaces with line and field scanning technique. The basic findings of lung ultrasonography are as follows:

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Fig. (1). Examination of anterior lung field.

Fig. (2). Examination of lateral lung field.

Fig. (3). Partial examination of posterior lung field.

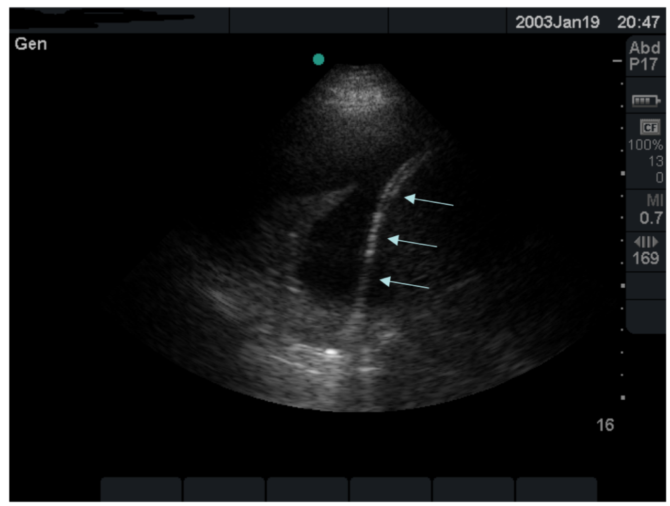

Fig. (4). Image showing hyperechoic curvilinear structure which is the diaphragm (thin green arrows). The diaphragm is well demarcated by an adjacent pleural effusion. Longitudinal axis view, mid-axillary line 8^{th} intercostal space using 3.5 MHz transducer.

Lung Sliding [6-8]

Lung Sliding is described in full detail in the chapter on pleural ultrasonography.

A-Lines

A-lines are horizontal hyperechoic lines that are parallel and deep to the pleural line (Fig. **6**, also see chapter on pleural ultrasound). Their distance from the pleural line is a multiplicative of the distance from the skin surface to the pleura line, because they represent reverberation artifacts. A-lines indicate that the underlying lung is well aerated; they are correlated with normal lung parenchyma on computerized tomography (CT) chest [9]. Alternatively, pneumothorax presents with A-lines; as the pneumothorax space is filled with air as is normal lung. To distinguish between A-lines associated with pneumothorax and A-lines associated with aerated lung, the examiner must search for lung sliding. Lung sliding with A-lines represents normal aeration pattern at the site of transducer application. A-lines with absent lung sliding represents a possible pneumothorax.

B-Lines

B-lines are hyperechoic vertical lines that arise from the pleural line that spread to the lower edge of the screen image without fading, that moves in synchrony with the pleural line, and that efface A-lines at any point of intersection (video **1**). They may occur as single lines, or in groups that are designated as lung rockets. They are also called comet-tail artifact [10]. B lines indicate abnormality of the interlobular septae or the presence of ground glass abnormality in the subpleural area (without consolidation) [11-15]. They are strongly correlated with alveolar/intersti-

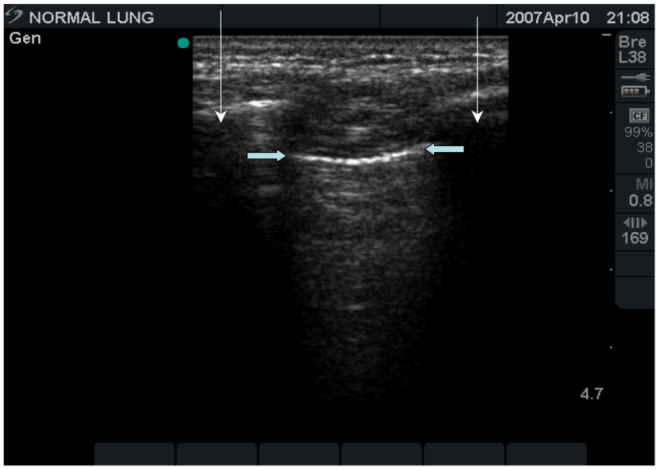

Fig. (5). Image showing standard features of lung ultrasonography, rib shadows on either side of image (thin white arrows) and the pleural line (thick green arrows). Longitudinal axis view with transducer held in perpendicular to the skin surface and centered in the interspace between two ribs.

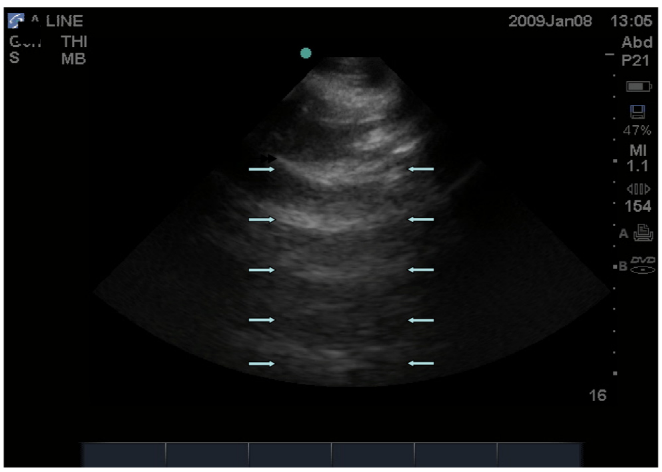

Fig. (6). Image showing multiple A-lines (thin green arrows). Longitudinal axis view with transducer held in perpendicular to the skin surface and centered in the interspace between two ribs.

tial pattern on chest CT [9]. The presence of B lines indicates the absence of pneumothorax at the site of transducer application [16]. B lines arise at the visceral pleural surface and so their presence indicates fully inflated lung.

Alveolar Consolidation

Alveolar consolidation results in lung parenchyma that is airless. For this reason, alveolar consolidation appears on lung ultrasonography as an area of tissue density [17, 18] (Fig. **7** and video **2**). It has sonographic features that are similar to the liver; hence, the term hepatization has been used to describe this finding on lung ultrasonography. Areas of alveolar consolidation can readily be identified with lung ultrasonography to the lobar and segmental level. Alveolar consolidation may have hyperechoic foci which represents air bronchograms [19]. The presence of air bronchograms within an area of alveolar consolidation, if mobile with respiratory cycling, suggest that the bronchus supplying the area is patent (dynamic air bronchogram). It the air bronchogram is immobile with respiratory cycling (static air bronchogram) this suggests that the air is trapped and isolated from the rest of bronchial tree [20]. For example, this may occur with endobronchial obstruction of a lobe resulting in lobar atelectasis. This will cause an area of alveolar consolidation with static or absent air bronchogram with in it.

Fig. (7). Image showing alveolar consolidation pattern. Longitudinal axis view, mid-axillary line 8th intercostal space using 3.5 MHz transducer.

Dynamic air bronchograms represent air inside the bronchus which moves during the respiratory cycle. It excludes bronchial occlusion and is typical of consolidation related to pneumonia.

Lung consolidation on ultrasound correlates strongly with chest CT [9]. The presence of alveolar consolidation on ultrasound does not imply a specific diagnosis. It may occur as a result of pneumonia, atelectasis, or compression by pleural effusion. Ultrasonography identifies the finding, while the clinician makes the diagnosis.

Lung Point

A pneumothorax does not generally lead to complete lung collapse. The lung may collapse partially, such that some part of the lung is still be apposed to the inside of the chest wall. Ultrasonography may be used to identify the point at which the collapse lung is apposed to the parietal pleura. This finding is called the lung point (Video **3**). Identification of lung point is 100% specific for pneumothorax [21]. It is an insensitive indicator, as it may be absent with complete pneumothorax. In addition, it requires an experienced ultrasonographer to locate the lung point. The examiner searches for the lung point by slowly moving the transducer laterally in the supine patient. Initially, there will be absence of lung sliding in the pneumothorax space. More laterally, there will be consistent lung sliding where the parietal and visceral pleura are still in contact. The examiner seeks to identify the precise point where lung sliding occurs intermittently in the intercostal space. With respiratory cycling, the collapsed lung slides intermittently in the pneumothorax space; this is the lung point. The correlate of lung point is the curtain sign seen with pleural effusion (see the pleural ultrasound chapter)

CLINICAL APPLICATIONS OF LUNG ULTRASONOGRAPHY

Lung Ultrasonography Pre and Post Procedure

Pneumothorax is a complication of thoracic procedures such as subclavian/internal jugular central venous catheters or thoracentesis. The diagnosis is often delayed while waiting for the portable chest radiograph. Before performing the procedure, the intensivist should always check for sliding lung by scanning the anterior chest fields. The presence of sliding lung excludes pneumothorax before the procedure. Following the procedure lung ultrasonography is repeated; the presence of sliding lung rules out procedure related pneumothorax. It is important to scan before the procedure, in order to document the presence of lung sliding because its absence post-procedure may result either from pneumothorax or other factors that are known to cause absence of lung sliding. The loss of lung sliding post procedure when it was present pre-procedure indicates procedure related pneumothorax.

Clarification of the Ambiguous Chest Radiograph

Portable chest radiographs in the ICU have major technical and diagnostic limitations [22-24]. Their inferior quality and delay in immediate availability present a challenge to the intensivist. Lung ultrasonography is superior to the standard supine, rotated, poorly penetrated anterior posterior chest films.

Evaluation of Acute Dyspnea

Respiratory failure is a common presentation of critical illness. The intensivist faces the challenge of rapid diagnosis of acutely dyspneic patient in the ICU, emergency department, and during rapid response event. Rapid diagnosis and treatment is crucial for patient outcome. Lung ultrasonography, being portable, can be quickly deployed at the bedside for dyspneic patient. Lichtenstein *et al.* have described a useful clinical protocol using ultrasound for the evaluation of acute dyspnea [25]. This can be performed in a few minutes and uses standard lung ultrasound findings to establish diagnosis and to guide treatment of the acutely ill patient with respiratory failure. When combined with goal directed cardiac ultrasonography, this protocol gives the front line intensivist a powerful tool to establish a management strategy at the point of care.

Endotracheal Intubation

Verification of endotracheal tube placement is a key element in the intubation sequence. On occasion, standard methods of verification (end tidal CO2, breath sounds, oxygen saturation) may not be adequate. Lung ultrasonography can be used to verify endotracheal tube position [26]. The presence of bilateral lung sliding with bagging in an apneic patient confirms the correct placement of the endotracheal tube; absence of bilateral lung sliding post intubation is strong evidence for esophageal tube placement [27]. Post intubation, the examiner checks for lung sliding while the patient is being given large tidal volumes with the bag valve device. Unilateral lung sliding following endotracheal intubation suggests a unilateral mainstem bronchial intubation. This commonly occurs as a right mainstem bronchial intubation, when the endotracheal tube had been advanced too far. In this case, air enters the right lung during bagging with right lung sliding. No air enters the left lung with bagging, as the left main stem bronchus is blocked off by the inflated endotracheal tube cuff. This results in absence of lung sliding on the left side, although lung pulse will be present on the left side [28]. The operator may carefully pull the endotracheal tube back until lung sliding is present bilaterally with bagging. This assumes that there is no other pathological process blocking the left main stem bronchus (e.g. tumor, foreign body, mucus plug).

CONCLUSION

Lung ultrasonography allows the intensivist to rapidly identify the presence or absence pneumothorax, normal lung aeration, alveolar interstitial pattern, lung consolidation and pleural effusion. It has utility in procedure safety, evaluation of ambiguous chest radiograph, management of the acutely dyspneic patient, and endotracheal intubation sequence. Lung ultrasonography is easy to learn and should be regarded as a basic skill for the critical care ultrasonographer.

SUPPLEMENTARY MATERIAL

This article contain 3 video files and it can be viewed at www.bentham.org/open/toccmj

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