Chest Ultrasound

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INTRODUCTION

Chest diagnostic imaging is essential when dealing with a critically ill patient. At present, direct visualization of the lung parenchyma is performed with a chest x-ray (CXR) and computed tomography (CT), with the patient in the supine position. In the ICU, chest x-rays is only performed on patients in the supine position. The x-ray beam is positioned directly onto the chest at a film distance of less than sixfeet. In fact, when the x-ray beam does not falltangentially on the diaphragm dome and the mediastinal structures, a correct diagnosis of the “silhouette sign” may not be achieved. Hence itmay result in diagnostic errors regarding pleural effusions, parenchymal consolidation, and alveolar interstitial syndrome.[1]

Chest sonography is made feasible by the interpretation of ultrasound artifacts that arise from the chest wall and pleural surface. A brief review of the relevant normal anatomy will provide the framework to facilitate an understanding of the various patterns one may encounter when performing lung sonography.[2]

The parietal and visceral pleurae appear as a single hyperechoic “pleural line” just deep to the internal intercostal muscles. This line will “slide” or oscillate from side to side on the ultrasound screen, representing movement of the pleural surfaces as the lung expands and contracts during the respiratory cycle. Normal lung parenchyma is not visualized because it is composed primarily of air, which scatters and impedes the transmission of sound waves. The dramatic difference in the acoustic characteristics of soft tissues and the lung makes the lung surface a particularly strong reflector of ultrasound waves, and is responsible for creating a number of reverberation artifacts that provide valuable information about the lung’s current pathophysiology.[3]

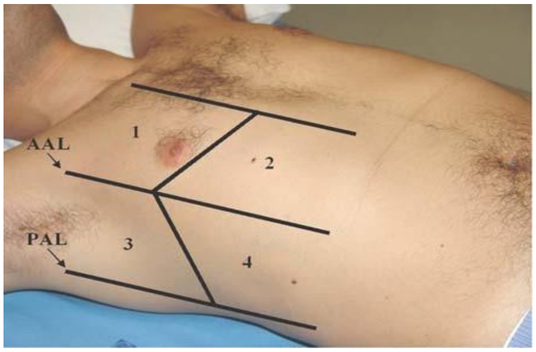
The more the ultrasound waves are reflected back the brighter the image:

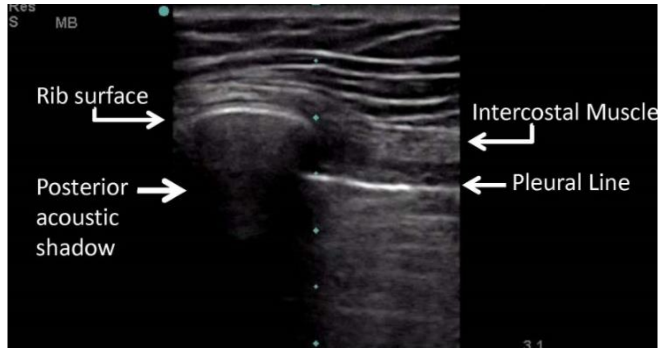
- Hyperechoic (bright): air, diaphragm, periostium.
- Echogenic: liver,kidney,muscle.
- Hypoechoic: (dark) fluid, bloodfat.

BASIC AND TECHNICAL REQUIMENT

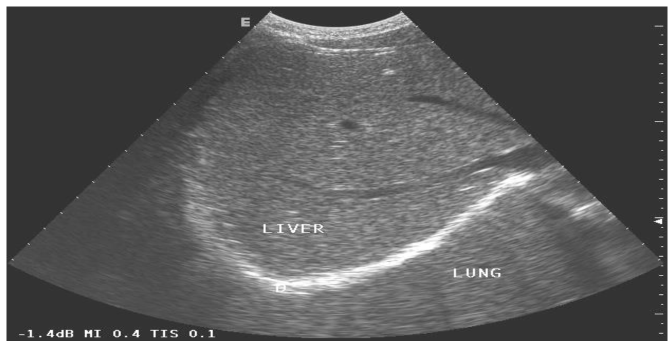
There has been a great deal of controversy regarding the optimal choice of transducer for lung sonography. In recent years, however, prospective studies using high-frequency linear, low-frequency curvilinear and low-frequency sector transducers have demonstrated that the performance and interpretation of lung sonography is not transducerspecific. Curvilinear low frequency transducer (3-5 MHz) is used best for clear A and B line determination. High frequency (12-15 MHz) because of better resolution can be used for assessing lung sliding. Lower frequency transducers will provide more depth penetration but will sacrifice image quality; high-frequency transducers provide better resolution but will sacrifice depth penetration. Phased array cardiac probes are even better in this regard. We generally use pediatric cardiac phased array or curvilinear (5-8 MHz) probe and for demonstrating lung sliding and high frequency linear probe (12-15 MHz) for pleural pathology.[4]

Usually the dorsal and lateral images are obtained with the patient sitting, whereas the supine position is used for visualizing the ventral side. Raising the arms and crossing them behind the head causes intercostal spaces to be extended and facilitates access. During every stage of examination, the user should determine the breath-related moving of the pleura, the so-called sliding sign.[4]





From the abdomen, in subcostal section by the transhepatic route on the right side and to a lesser extent through the spleen on the left side, the diaphragm is examined. The axilla should be examined in the supine position with the arm abducted over the head. From the supraclavidular access, the region of the brachial plexus, the subvlavian vessels and the lung tip can be viewed, and from suprasternal, the anterior upper mediastinum can be viewed.[4]

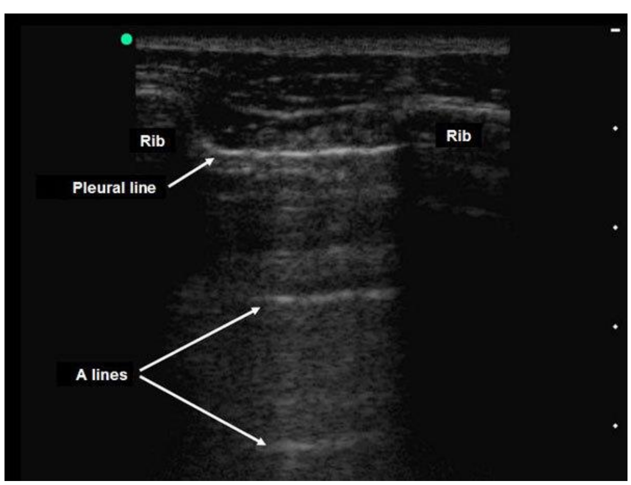


A-Lines

A-lines occur when sound waves pass through the superficial soft tissues and cross the pleural line encountering air (as in a pneumothorax) or tissue that is almost completely composed of air (as in normal lung, or pathologic states that do typically affect the lung parenchyma such as asthma or chronic obstructive pulmonary disease). These waves are reflected strongly by this tissue/air interface and reverberate, or “bounce” back and forth, between the transducer and lung surface.

A Lines:

- Horizontal lines parallel to the pleural line.
- Seen in normal lung parenchyma.
- If A lines present without lung sliding – Pneumothorax should be suspected.

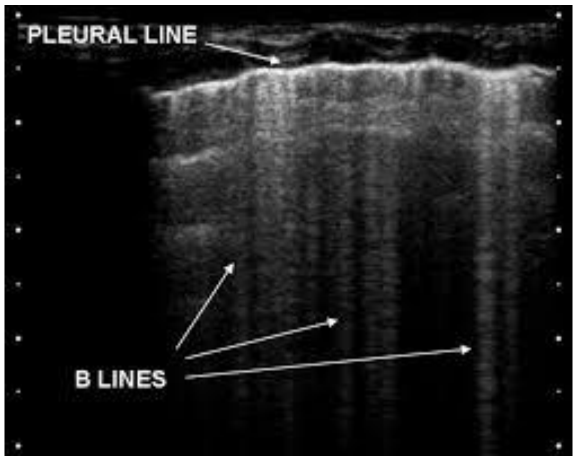


B-Lines

B-lines occur when sound waves pass through the superficial soft tissues and cross the pleural line encountering a mixture of air and water (as in pulmonary edema, pneumonia, lung contusion, acute respiratory distress syndrome, etc.). In this instance, the mixed density of the lung parenchyma causes reverberation artifact within the lung, giving rise to discrete laser-like vertical hyperechoic reverberation artifacts that arise from the pleural line, extend to the bottom of the screen without fading, and move synchronously with lung sliding. When several B lines are visible the term "Lung rocket`s" is used.

B lines:

- Arise from the pleural line and extend up to bottom of screen.
- Move with lung sliding.
- Correlate with alveolar interstitial pattern



PLEURAL DISEASE

Normal sonographic appearance

The pleural space is superficial and can be easy examined by ultrasound using either a direct intercostal or an abdominal approach, and using high frequency 5-12 MHz linear probes applied directly to an interscostal space.[5]

The visceral pleura is a fine echogenic line which is normally included in the thick line of total reflection of ultrasound waves at the air-filled lung. The bright, linear interface produced by the air filled lung covered by visceral pleura moves with the respiration backwards and forwards, known as "the gliding sign". Small, uneven irregularities at the visceral pleural surface produce reverberations named comet tail artifacts.[6]

The pleural cavity has an echo-free to hypoechoic appearance due to the presence of a small amount of fluid. *The parietal pleura* appears as a fine, sometimes weak echogenic line, often obscured by reverberation artifacts, and may be divided into 2 layers: the parietal pleura and the external endothoracic fascia[6]

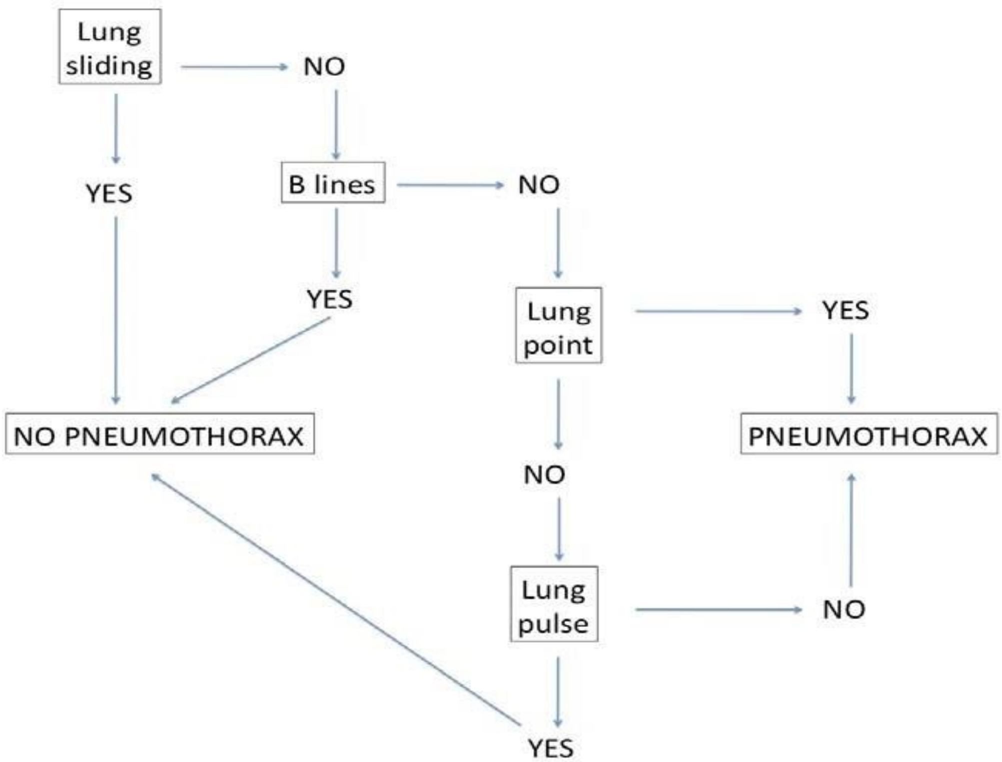
Abdominal approach: The diaphragm shows a bright, curving echogenic line that moves with respiration. When the lung above the diaphragm is filled with air the curved surface of the diaphragm lung interface acts as a specular reflector and produces a mirror image of the liver or spleen above the diaphragm.[7]

Pneumothorax

- The benefit of thoracic ultrasound for pneumothorax is striking (highly accurate, extremely quick to be performed at bedside and much more sensitive than chest radiography or physical examination)
- Based on a combination of 4 sonographic signs: the lung sliding, the B lines, the lung point and the lung pulse.
- Should be performed on the supine patient.
- The point on the chest where the probe detects again the sliding is the *lung point*. The lung point allows pneumothorax to be confirmed, but sensitivity is low because in case of complete lung retraction it cannot be visualized.

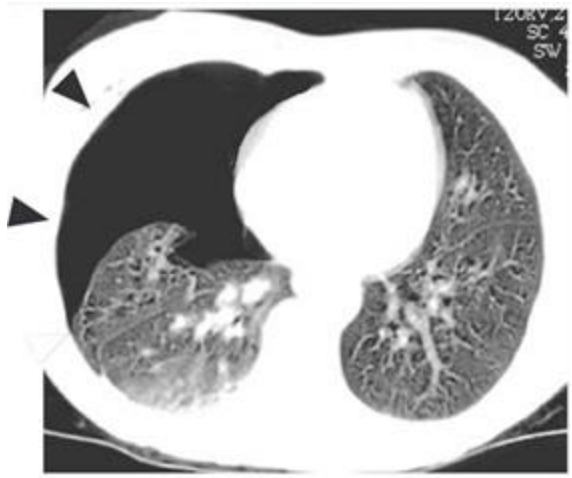
- When lung sliding, B lines and lung point are absent, the confirmation of pneumothorax can be achieved only when the pleural line does not beat synchronous with the cardiac activity (*lung pulse*).
- Particularly important in two different scenarios, which is where patients are unstable or in cardiac arrest, or where ultrasound shows its great usefulness is the diagnosis of radio occult pneumothoraces.
- The lung point should be used to confirm the diagnosis and evaluate the percentage of lung collapse.
- The Lung Point Since the air in the pleural space moves anterior and the lung collapses to a dependent position posteriorly, there is a point, usually in the lateral regions where the lung and air may be visualized in the same view. On moving from anterior to lateral, a pneumothorax pattern gives way to a fl eeting appearance of lung pattern in a particular location of the chest wall. 'Lung point has a sensitivity of 66% and a specifi city of 100%' Lung pulse sign has been explained earlier to rule out pneumothorax.[8,9,10]

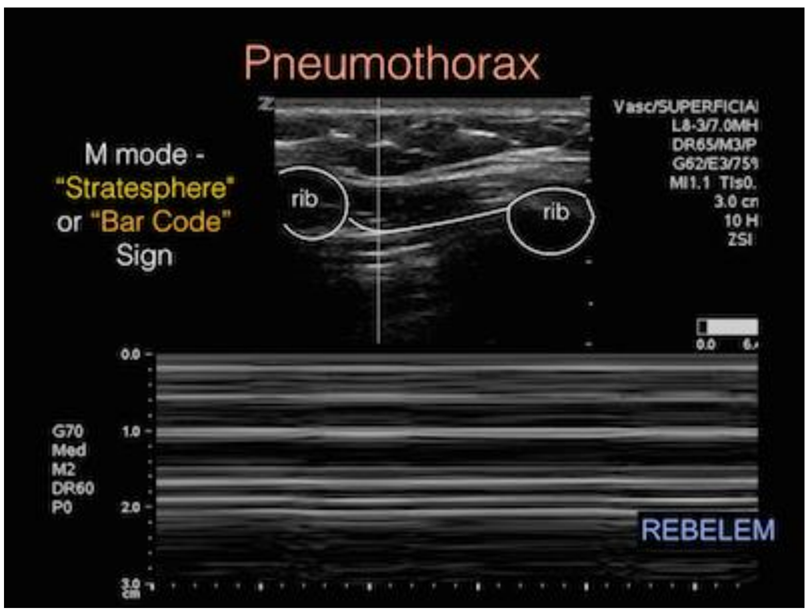
Flow-chart showing the procedure for the sonographic diagnosis of pneumothorax using a combination of the four key signs: lung sliding, B lines, lung point and lung pulse.



The ultrasound examination for pneumothorax should be performed on a single site on both sides of the upper chest (white crosses), where air should be collected for reasons of gravity.

Corresponding CT scan showing right sided pneumothorax. The black arrows show two chest areas where lung sliding cannot be visualized. The white arrow indicates the area where sliding is again visualized, the lung point.





Pleural effusion

Signs of pleural fluid

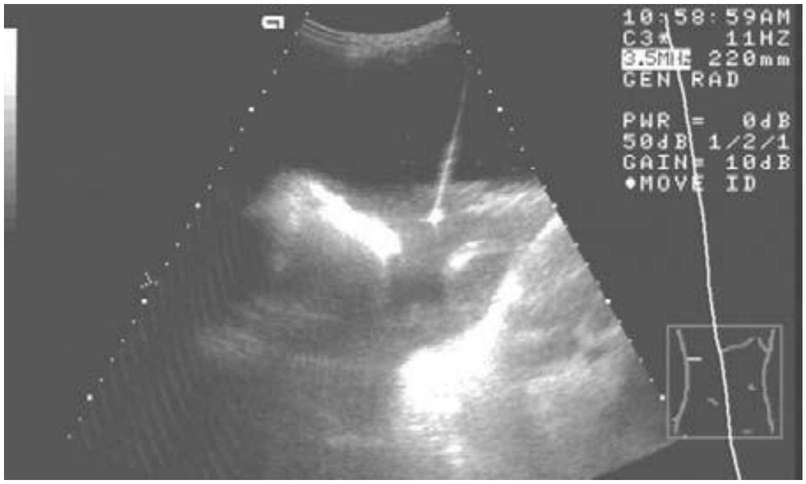
Pleural effusion was the first pathological alteration visualized by ultrasound. In abdominal ultrasonography both the right and left diaphragmatic pleura can be imaged through the liver or spleen and pleural fluid may be depicted in those areas. The ultrasonographic hallmark of pleural fluid is an echo-free zone between the parietal and visceral pleura. The use of a direct intercostal approach with high resolution linear array transducers allows the detection of even minute amounts of pleural fluid.[5]

Sonographic signs of pleural fluid:

1. Echo-free zone separating the visceral and parietal pleura
2. Echo-free zone displaying a change of form during breathing
3. Floating and moving echogenic particles
4. Moving septations within the pleural space

5. Moving lung within the fluid
6. "Fluid color" sign – on Doppler sonography

The diagnosis of large and medium pleural effusions is easily made by ultrasonography. However, small amounts of liquid, especially those located between the chest wall and diaphragm or in the vicinity of a hypoechoic pleural thickening are detected with great difficulty. In such cases the use of the above mentioned criteria (2-6) could be very helpful. It has a high sensitivity (89.2 %) and specificity (100%) for detecting minimal or loculated effusions.[5]

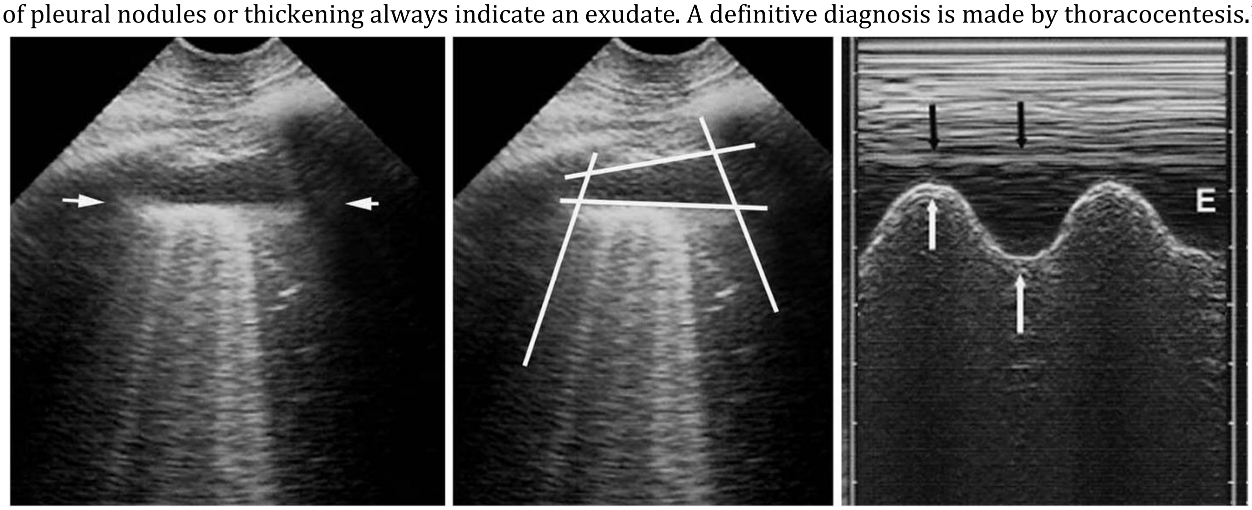


Detection limit and volume estimation

Very small volumes of pleural fluid (as little as 5 ml) can be identified sonographically in the angle between the chest wall and diaphragm with patients in standing or sitting positions. There are several modalities to measure the volume of pleural effusion by means of sonography. The best accuracy is achieved by planimetric measurements of the square dimensions of effusions in various longitudinal and transversal sections. For sitting patients a good method is to calculate the sum of the basal lung to diaphragm distance and the lateral height of the effusion and to multiply the sum by 70. In the supine patients the measurement of the volume is made using the formula 50x-800, where x is the thickness of the dorsal fluid layer in millimeters measured at a right angle to the chest wall. In routine clinical follow up, it is sufficient to measure the subpulmonary and lateral fluid level in the case of medium size effusions and to perform planimetry in the case of small angular effusions.[5]

Types of effusion

Transudates do not contain any components inside and are thus echo-free. *Exudates* contain cells, protein, fibrin or blood and are often echogenic, sometimes with septations or fibrin strands inside. The additional findings of pleural nodules or thickening always indicate an exudate. A definitive diagnosis is made by thoracocentesis.[1]



Complicated pleural effusions

Infected parapneumonic effusions, septated or loculated pleural effusions are described as complicated ones. Ultrasonography is a very good method for vizualising loculations or septations but cannot diagnose infection which is evidenced only by puncture or aspiration.[11]

Parapneumonic effusion is an exudative effusion associated with pneumonia (in approximately 40% of cases) or a lung abscess. A small amount of fluid is seen in the pleural space and the visceral pleura is thickened and hypoechoic demonstrating signs of inflammation.[11]

In empyema, there is gross pus with bacteria or other infectious organisms in the pleural space. Three stages of empyema have been described: In the *exudative stage,* multiloculated effusions with large floating echoes with different echogenicity of the contents may be seen. The f*ibrinopurulent stage* is characterized by fibrin deposition on the pleura which is moderately thickened in a capsule-like fashion. In the final *organized stage,* a rigid membrane around the lung, called pleural peel is produced.[11]

Hemothorax is seen in patients with underlying lung or pleural malignancy or after chest trauma. Fresh blood collection may be echo-poor whereas older ones are echogenic, with both fine echoes and large echogenic structures representing clots.[5]

LUNG CONSOLIDATION

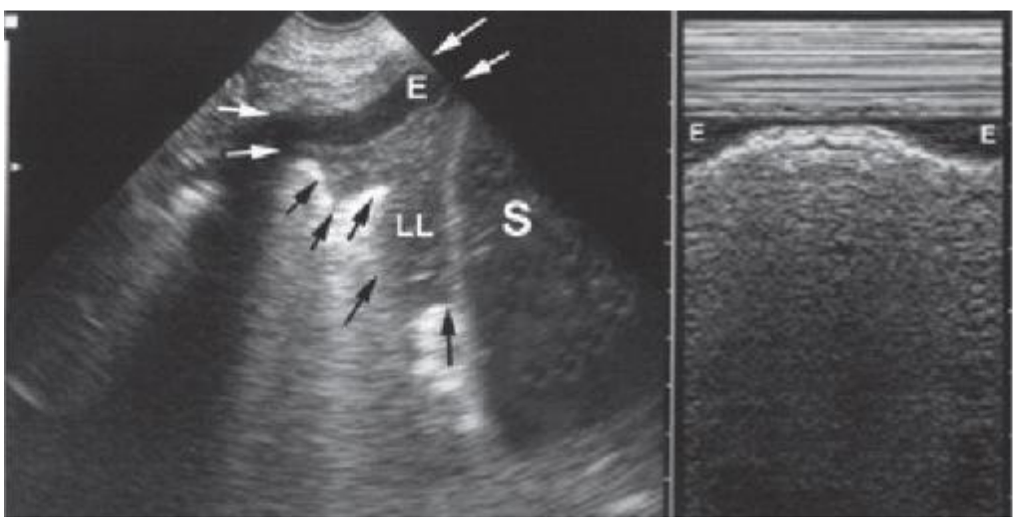
- Pulmonary processes can only be visualized when they come up to the pleura, are accessible via a sound window, and no subcutaneous emphysema or pneumothorax is present.
- Purely central processes cannot be sonographically visualized

Pneumonia

- In early congestive stage of pneumonia, the echo texture of the consolidated lung is similar to the liver.
- Viral or fungal pneumonias are quite often more poorly ventilated and reveal less marked air bronchograms.
- Pneumonia is characterized by an irregular, serrated and somewhat blurred margin.
- The fluid bronchogram is characterized by anechoic/hypoechoid branched tubular structures in the course of the bronchial tree.
- On colour-coded duplex sonography, pneumonia has a typical appearance: circulation is uniformly increased and branched, vessels have a normal course. If a patient does not respond to treatment with antibiotics, the pathogen can be acquired by means of ultrasound-guided aspiration.
- When pneumonia is in the healing phase, the infiltrated lung tissue is increasingly ventilated. The pneumonia recedes on the ultrasound image and appears smaller than on chest radiograph, according better to the clinical course.[12,13,14]

Sonographic findings in pneumonia:

- Liver like in the early stage
- Air bronchogram
- Lenticular air trappings
- Fluid bronchogram (poststenotic)
- Blurred and serrated margins
- Reverberation echos in the margin
- Hypoechoic abscess formation

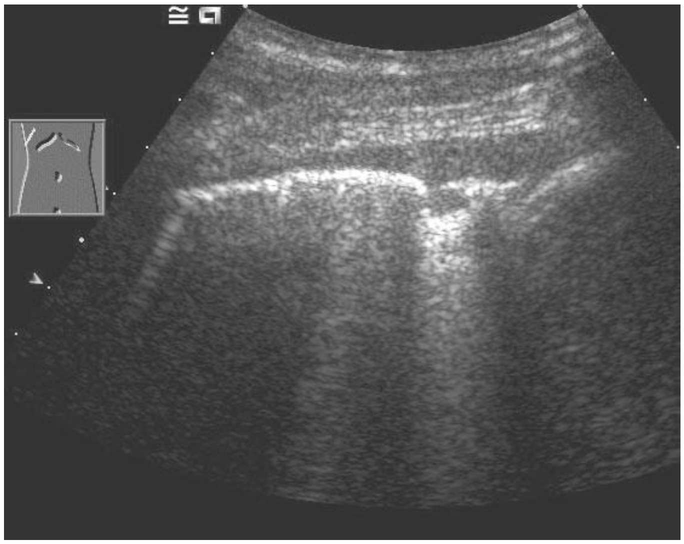


Tuberculosis

– Pulmonary tuberculosis is polymorphic on x-ray as well as on chest sonography.
– Tuberculosis lung lesions can be round or irregulary shaped and of a relatively homogeneuous texture. The imaging of these lesions may be facilitated by the presence of a pleural effusion.
– Miliary tuberculosis is characterized by a nodular dissemination in terms of multiple subpleural nodules measuring several millimetres in size.
– The patient's response to tuberculostatic treatment can be evaluated by sonography

Sonographic findings in tuberculosis

- Pleural effusion
- Fragmentation of visceral pleura
- Subpleural infiltrations of various forms
- Air bronchogram in cases of larger infiltrations
- Broad reflection artefact in cavities

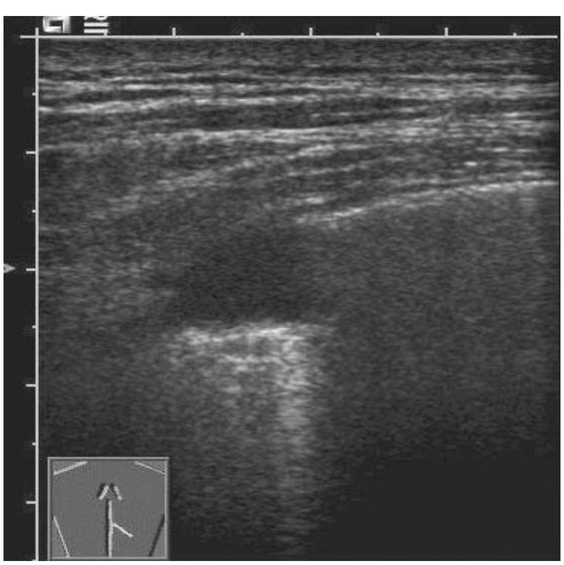


Diffuse parenchymal pulmonary diseases

- The framework lung cannot be imaged by sonography.
- For diffuse parenchymal lung diseases it was shown that multiple comet tails artefacts distributed over the entire lung in combination with a thickended, irregular/fragmented pleural line indicate the presence of interstitial changes.

Pulmonary embolism

Several minutes after occlusion of a pulmonary subartery → the surfactant collapses → interstitial fluid and erythrocytes flow into the alveolar space → ideal conditions for ultrasound imaging.[15]



Sonomorphology of peripheral pulmonary embolism

- Echopoor
- Well demarcated
- 1-3 (0.5-7) cm in size
- Pleural based
- Triangular > rounded
- Central bronchial reflexion (> 3 cm)
- Vascularization stop
- 2.5 lesions/patient on average
- 2/3 dorsobasal located
- Small pleural effusion

– The overall sensitivity of chest sonography in pulmonary embolism is 80%, the specificitiy 94%.

– Using US one can “kill three birds with one stone”: source, way and outcome of pulmonary embolism[22, 23].

Interstitial syndrome

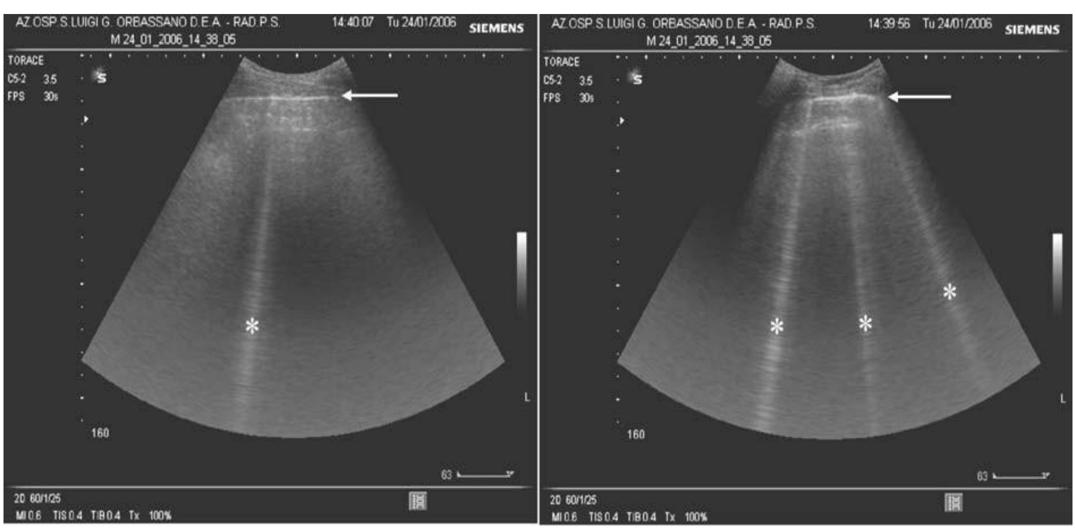
– The interstitial lung involvement in heart failure, ARDS, pulmonary fibrosis and interstitial lung infections is extremely easy to be detected by bedside thoracic ultrasound in critically ill and emergency medicine patients.

– The sonographic diagnosis of interstitial syndrome is highly useful in many clinical scenarios: differentiation between pulmonary edema and exacerbation of COPD during acute respiratory failure.

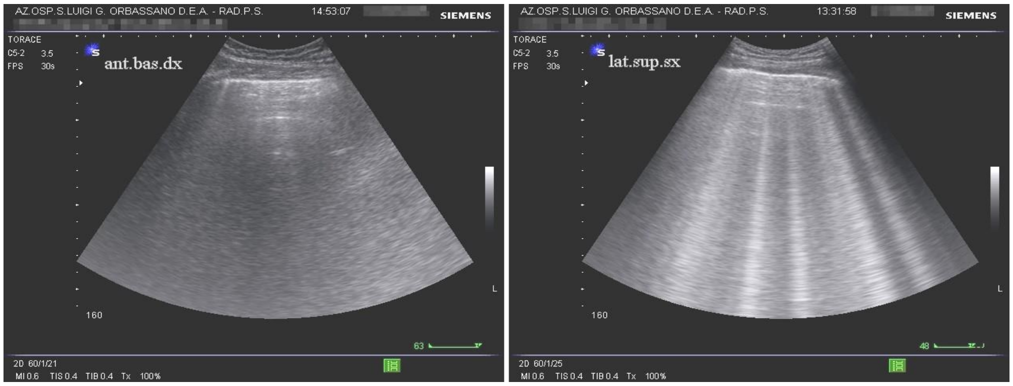
– The patient is examined in the supine or near-to-supine position, and the probe positioned on four chest areas per side: two anterior and two lateral.

– The diagnosis of the diffuse interstitial syndrome is based on 3 basic steps:
  - o Recognition of B lines, appearing on the screen as laser-like vertical echogenic artifacts arising from the pleural line, spreading up without fading to the edge of the screen and moving synchronous with lung sliding
  - o Diagnosis of a positive single scan, when B lines are multiple (at least three) and close (no more than 7 mm apart). Multiple B lines but far from each other are not significant.
  - o Diagnosis of a positive examination, defined as at least two positive scans per side

– B lines has been shown to be useful also to monitor pulmonary congestion in heart failure and hemodyalisis, to assess the extravascular lung water in cardiac patients, to stratify the prognostic risk in chest pain and dyspnea.[18,19,20]



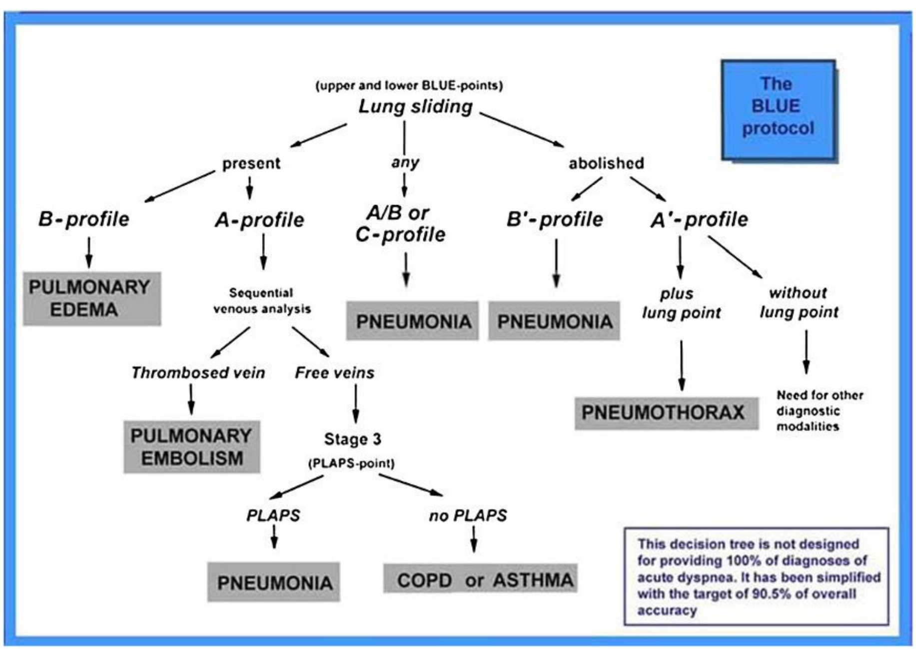
Oblique sonographic lung scans showing only one isolated b line (left panel) or multiple B lines far from each other (right panel). These patterns are still not significant of interstitial syndrome. White arrows: pleural line; asterisks: B lines.



The BLUE-protocol

Acute respiratory failure is a life-threatening condition whose cause is sometimes difficult to recognize immediately. Initial mistakes have deleterious consequences. The extreme patient's suffering legitimizes the use of any tool that expedites relief. Reducing the time needed to provide this relief is the aim of the BLUE-protocol. The BLUE-protocol, performed on dyspneic patients who will be admitted to the ICU, is a fast protocol: 3 minutes are required using suitable machines and the standardized points of analysis. Novices can take longer (this time depends on the simplicity and adequacy of their equipment, of the standardization of their training). Based on pathophysiology, it provides a step-by-step diagnosis of the main causes of acute respiratory failure, i.e., six diseases seen in 97% of patients in the emergency room, offering an overall 90.5% accuracy. The BLUE-protocol combines signs, associates them with a location, resulting in seven profiles.[21,22]

The A-profile associates anterior lung-sliding with A lines.
The A'-profile is an A-profile with abolished lung-sliding.
The B-profile associates anterior lung-sliding with lung-rockets.
The B'-profile is a B-profile with abolished lung-sliding.
The C profile indicates anterior lung consolidation
The A/B profile is a half A-profile at one lung, a half B-profile at another.
The PLAPS-profile designates PosteroLateral Alveolar and/or Pleural Syndrome.



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