Lung US: how to do it better.

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Learning objectives

To describe how to optimize lung ultrasound (US) technique and what are the main findings of a chest US study.

We review the role of US in evaluation of the lung. The aim is to define lung US indications and clinical applications, as well as main normal and pathological findings of a chest US study. Moreover, we highlight lung US technical and settings aspects, in order to obtain the best visualization of static and dynamic signs of lung US semeiotic.
Background

Chest evaluation is typically based on radiography (RX) and Computed Tomography (CT).

For a long period of time, US showed only restricted indications in lung assessment (e.g. study of the soft tissues of the chest wall or pleural effusion identification and characterization), because of intrinsic limitations of the technique itself. As a matter of fact, US waves are almost totally reflected, in presence of tissues interfaces with high difference in acoustic impedance. Lung shows several of these interfaces (e.g. soft tissue of the chest wall vs lung parenchyma; soft-tissue of the chest wall vs ribs), thus making impossible its direct morphological study by means of US [1].

Nowadays, lung US is increasingly used by several medical specialists and it is considered as an alternative and complementary tool to RX and CT. Indeed, it provides a real-time static and dynamic assessment of the chest, allowing a direct correlation with clinical signs and symptoms. Moreover, it is a reproducible, non time-consuming and low cost examination. At last, it reduces radiations’ exposure, thanks to the lack of ionizing radiation [2].

However, there are still no uniform guidelines on how to conduct an optimal lung US examination, in order to obtain the best US images.
Findings and procedure details

**Indications to lung US**

In lung US, evaluation of artifacts and real images should be performed, in order to obtain an accurate diagnosis. Lung US is particularly helpful in presence of air or fluid collections in the pleural space, when the alveolar air content is decreased and interstitial fluids are increased. Lung US can be useful in identification of several lung disorders, especially when used in emergency and critical care settings [1].

In trauma settings, patient stability and hemodynamic status are crucial in order to discriminate when to use lung US. In trauma patients, who are in stable condition, CT is the imaging modality of choice and US can be performed as a FAST (focused assessment with sonography for trauma) or E-FAST (E-FAST extended focused assessment with sonography for trauma) examination. On the other hand, in highly unstable patients, portable RX and US play an important role in assessment of potential life-threatening conditions.

In stable non-traumatic patients with acute thoracic symptoms, chest RX is the first-line imaging modality and CT is performed when there is a clinical suspect of pulmonary embolism or acute aortic syndromes [2; 3; 4].

**Main indications to perform lung US include:**

- Evaluation of pleural effusion
- Evaluation of pneumothorax (PNX)
- Evaluation of patients with acute respiratory syndrome
- Evaluation of chest wall
- Evaluation of pleura
- Evaluation of lung diseases
- Evaluation of alveolar-interstitial syndrome
- Guidance for diagnostic and therapeutic thoracentesis
- Guidance for placement of thoracostomy tubes

**Main normal and pathological findings**

Lung and thoracic wall study can be performed with patient in supine or sitting position, using longitudinal (probe placed perpendicular to the long axis of the ribs) or paraxial (probe placed parallel to the intercostal space) scanning planes (Fig. 1). Lung US is based on identification and interpretation of several static and dynamic signs. These are either, consistent with normal anatomy and physiology (direct signs) or artefactual, resulting from distortion of US beam (indirect signs).
Main signs of lung US semiotic are:

- Bat sign
- Lung sliding
- Absence of lung sliding
- Lung point
- Lung hepatization
- Air bronchogram and dynamic air bronchogram
- A-lines
- B-lines
- E-lines
- Z-lines
- Seashore sign
- Sinusoid sign
- Stratosphere sign
- Power slide

**Bat Sign**

The bat sign represents the normal anatomy of the thoracic wall. It is seen on longitudinal US scanning planes and it consists of two convex hyperechoic lines with posterior acoustic shadowing (two adjacent ribs) and one hyperechoic line, placed deeper in the intercostal space (pleural line) (Fig. 2) [2].

**Lung Sliding and Absence of Lung Sliding**

Lung sliding indicates the movement of the visceral pleura against the parietal pleura, during respiratory cycle (Fig. 3). In real time US, it can be seen as a discreet twinkling of the hyperechoic pleural line. The presence of lung sliding indicates that visceral and parietal pleura are close and that lung volume is changing [5]. In some pathological conditions, such as PNX, pneumonectomy, pleural adhesions, one-lung intubation or subpleural bullae, lung sliding can be reduced or absent. This sign is particularly important in the diagnosis of PNX: as a matter of fact, abolished lung siding is strongly suggestive for presence of air in the pleural cavity. Air separates the two pleural layers, which do not move one against another (Fig. 4) [2].

**Lung point**

The term "lung point" indicates the border at which normal parietal and visceral pleura separatetobe PNX. Lung point can be identified by means of either, B- or M-mode imaging, because they both highlight the contrast between normal and abnormal signs (Fig. 5). At real time US, lung expands and moves in the transducer field during inspiration. On the contrary, lung loses volume and moves out of the transducer field during expiration.
Location of lung point is used to determine the extent of PNX. If lung sliding is absent anteriorly, the transducer should be moved more laterally and posteriorly on the chest wall in an attempt to identify the lung-point. More lateral or posterior is the position of the lung-point, greater is the PNX [5].

Lung point has a 100% specificity for the diagnosis of PNX [2; 4], but its sensitivity is reported to be 66% [6]. This sign is not present in case of total lung collapse.

**Lung Hepatization**

Lung hepatization is referred to a tissue like pattern of the lung, seen on a standard US examination and it illustrates asonographical appearance of lung consolidation (Fig. 7). It can only be visualized when pathological processes reach the pleura. Consolidation is usually delimited by pleural line, adjacent normally aerated lung and, eventually, pleural effusion. Usually, the line, that separates aerated parenchyma from the affected lung, shows an irregular shape [7; 8].

**Dynamic air bronchogram**

Within the consolidation, hyperechoic punctiform or linear scatter artifacts can be recognized [8]. These images correspond to the air in bronchial lumen and represent the so called US air bronchogram (Fig. 8). In case of pneumonia, air bubbles move through bronchi during respiratory cycle: this sign is known as dynamic air bronchogram [7] and can help in distinguishing pneumonia from atelectasis [6].

**A-Lines**

A-lines are hyperechoic, equidistant lines, which are parallel to the pleural line and appear to lie within the lung parenchyma (Fig. 9). A-lines represent reverberation artifacts between probe and pleural line [9]. Several reverberations lead to creation of several A-lines, at regular intervals below the pleural line. A-lines indicate the presence of air in lung or pleural cavity (physiological or PNX) [6].

**B-Lines**

B-lines are referred to vertical, hyperechoic lines, that extend from the pleural line to the edge of the screen. They move synchronously with lung sliding and erase A-lines (Fig. 10). B-lines are caused by reverberation artifacts [9], due to thickening of interlobular septa and lung interstitium (increased fluid content, fibrosis) [1]. B-lines are considered multiple when they are at least three with a convex probe or at least six with a linear probe [2].
**Z-Lines**

In contrast to B- and E-lines, Z-lines are short, vertical hyperechoic lines, arising from pleural line, which do not reach the edge of the screen (Fig. 11). They neither move synchronously with lung sliding nor erase A-lines. Z-lines are caused by the so-called comet-tail artifact. They can be identified in normal lung and have been described as being without meaning [5]. PNX can be ruled out in presence of Z- or B-lines at the site of the scan [2].

**E-Lines**

E-lines, similarly to B-lines, represent hyperechoic vertical reverberation artifacts [9], which extend, without fading, from areas of subcutaneous emphysema to the edge of the screen. When E-lines are present, pleural line and bat sign cannot be recognized, due to the presence of air that causes almost complete reflection of US beam [6].

**Seashore Sign**

In M-mode imaging, the normal appearance of the lung resembles the one of the seashore. Stationary extrapleural structures, seen as lines parallel to the transducer surface, represent the sea. On the other hand, lung parenchyma that moves during respiratory cycle generates a grainy image, which stands for the sand of the seashore sign (Fig. 12). This M-mode sign is an analogue of the lung sliding on B-mode imaging [2;6].

**Sinusoid Sign**

In presence of pleural effusion, parietal and visceral pleura are separated, due to fluid contained in pleural cavity. During inspiration, lung moves toward the parietal pleura and creates a cyclic apparent reduction of the interpleural distance. This periodic change in pleural effusion on M-mode imaging represents sinusoid sign (Fig. 13). Identification of sinusoid sign is suggestive for a low viscosity pleural effusion [6].

**Stratosphere (barcode) sign**

Also in presence of PNX, parietal and visceral pleura are separated, due to air contained in pleural cavity. On M-mode imaging, absence of lung parenchyma motion below the pleural line generates multiple horizontal parallel lines which substitute the sandy appearance of the sea-shore sign. This aspect resembles the one of a barcode or stratosphere and represents barcode - stratosphere sign (Fig. 14) [2; 6;10].

**Power slide**
The power slide is the Power Doppler analogue of lung sliding on B-mode imaging. It is a visible colour signal underneath the pleural line (Fig. 15) [2]. As power Doppler imaging is highly sensitive also to the subtle movement, this sign can be helpful in identification of lung sliding, even when its direct visualization on B-mode imaging may be difficult. The colour signal can be generated also when the transducer is not held in a steady manner or patient moves, leading to false positive cases [10].

**Clinical applications**

**Diseases of the pleura**

**PNX**

PNX is a pathological collection of air in pleural cavity. In this condition, air is placed between parietal and visceral pleurae. PNX can be caused by thoracic trauma, can occur spontaneously or can be iatrogenic. In presence of PNX, a variety of static and dynamic signs should be analysed. The latters, especially lung sliding, are the most important signs to be evaluated. However, absence of the lung sliding can be associated with several pathological conditions (e.g.: pneumonectomy, one-lung intubation, pleuroparenchymal adhesion or subpleural bullae), thus making this sign sensitive but not specific [2; 5; 11].

**US pattern of PNX consists of:**

- Absence of lung sliding
- Stratosphere sign on M-Mode imaging
- Absence of B-lines
- Presence of A-lines
- Presence of lung point
- Absence of Power slide

**Pleural effusion**

Pleural effusion refers to the presence of fluid in pleural cavity. Lung US has high sensitivity (89%-100%) and specificity (96%-100%) for detection of pleural effusion and is able to diagnose also limited amount of fluid (5-20 ml) in pleural cavity. Another advantage of lung US is its ability in determining the nature of a pleural effusion, which can be either transudative or exudative. A variety of pathological conditions can cause pleural effusion, such as infection or inflammation of lung and pleura, congestive heart failure, cirrhosis, hypoalbuminemia, trauma or other systemic diseases [2].
Simple pleural effusion appears as anechoic fluid between visceral and parietal pleura (Fig.16). The nature of simple effusion is either transudative or exudative. The latter can be either, anechoic or hyperechoic.

Thoracic empyema is a pathological condition in which pus is found in the pleural space. US appearance of empyema is related to the evolutive stage of the collection. In early stage, it appears as anechoic or hypoechoic pleural fluid. In later stage, hyperechoic, often septated or loculated collection appears and may be accompanied by pleural thickening. Compared to CT, US can better demonstrate internal septa and can be used as a guide for diagnostic or therapeutic thoracentesis [2].

Hemothorax is a type of pleural effusion in which blood accumulates in pleural space. It is usually traumatic in origin and frequently associated with rib fractures and pulmonary parenchymal injuries. US is 92% sensitive and 100% specific for detection of hemothorax in trauma patient [12].

US appearance of hemothorax varies according to the time passed from initial injury (anechoic, hypoechoic, or hyperechoic).

**US signs of pleural effusion are:**

- Presence of simple or complex pleural fluid (anechoic, hypoechoic, hyperechoic)
- Absence of lung sliding
- Sinusoid sign on M-Mode imaging

**Diffuse pleural thickening**

Pleural thickening involves visceral pleura, encasing the lung and causing restriction of ventilation. Diffuse pleural thickening is suggestive for pleural fibrosis or a pleural malignancy. US appearance of a pleural plaque is that of a homogeneous non-infiltrating pleural tissue that displaces the lung from the chest wall and has well demarcated margins. Depending on the duration of fibrosis, pleural lesions can present different echogenicity. Pleural plaques in early stage usually appear as hypoechoic lesions, which become more echoic in later stage. Calcifications can be seen in thickened pleura, more frequently in tuberculosis or empyema. US differentiation between benign pleural lesions and malignancy ones is rarely possible due to their similar US appearance [13].

**Sonographical pattern of pleural thickening includes:**

- Homogeneous hypoechoic lesion
- Pleural calcifications

**Pleural tumors**
Also benign and malignant pleural lesions can be seen on thoracic US. Benign pleural tumours are rare and appear as round, hypoechoic or moderately echogenic lesions, with sharp margins and with a thin capsule (Fig. 17). Also small effusions and calcifications can be seen.

Pleural metastases are hypoechoic to moderately hyperechoic lesions, that may be round or polypoid, with a broad base and well-demarcated borders, but they may also infiltrate lung or chest wall. Usually, metastases are associated with pleural effusions.

Pleural mesothelioma (usually related to asbestos exposure) is a rare aggressive pleural tumour that invades chest wall or diaphragm and spreads to the contralateral pleura or pericardium. Sonographic signs of mesothelioma include diffuse nodular and irregular pleural thickening, with calcifications, and pleural effusion [13].

**US pattern of benign pleural tumors consists of:**

- Hypoechoic to moderately hyperechoic lesions
- Sharp margins
- Thin capsule
- Pleural effusion
- Pleural calcifications

**US pattern of malignant pleural tumors includes:**

- Hypoechoic moderately hyperechoic irregular pleural thickening or lesions
- Pleural effusion
- Pleural calcifications
- Chest wall invasion

**Diseases of the lung**

Lung US can be helpful in detection of a wide variety of pathological lung conditions that are in contact with the pleura, such as pneumonia, atelectasis, pulmonary infarction and contusion [2].

**Pneumonia**

Pneumonia is an infection of lung parenchyma and it is one of the most frequent findings in emergency department. Lung consolidations lead to an increase of the alveolar fluid [6]. The diagnosis is based on clinical and imaging findings at chest RX (first-line imaging modality) [2].

Lung consolidations are subpleural in 98% of cases but they can arise at any site as well, thus making US sensitivity strictly dependent on site, size and time spent [6].
US features of pulmonary consolidation are:

- Lung hepatization
- Dynamic air bronchogram
- Pleural effusion may be present
- Lung sliding

**Pulmonary infarction**

In presence of pulmonary embolism, subpleural consolidations may represent pulmonary infarction. At US, pulmonary infarction may appear as a multifocal, wedge- or triangle-shaped heterogeneous hypoechoic subpleural lesion, localized mainly in the lower lobes [2].

**US signs of pulmonary infarction includes:**

- Heterogeneous hypoechoic subpleural lesions
- Multifocal wedge- or triangle-shaped
- Predominantly in the lower lobes
- Pleural effusion
- Lung sliding
- A Lines

**Pulmonary Contusion**

Thoracic trauma (blunt trauma, explosion) frequently leads to pulmonary contusion. This condition results in gas exchange impairment, due to injury to the alveolar capillaries, and subsequent accumulation of blood and fluid in the alveoli. On lung US, pulmonary contusion may be seen as subpleural irregular hypoechoic lesions or multiple B-lines.

In literature, it is reported that localized areas of multiple B-lines in a setting of blunt thoracic trauma show sensitivity of 94.6% and specificity of 96.1% for the diagnosis of pulmonary contusion. In addiction, the presence of asubpleural parenchymal lesion is thought to be much less sensitive (19%) but more specific (100%) for this condition [14].

**Sonographic pattern of pulmonary contusion consists of:**

- Subpleural irregular hypoechoic lesions (indistinct or sharp margins)
- Multiple B-lines

**Atelectasis**

Relaxation atelectasis is due to reduction of lung volume caused by pleural effusion. On the contrary, obstructive atelectasis appears asa homogeneous, hypoechoic lesion of the lung tissue (so called lung hepatization), generally without pleural effusion. Depending
on the duration of atelectasis, hypoechoic vascular lines, echogenic bronchial reflexes and fluid bronchogram can be seen. US pattern of obstructive atelectasis is similar to that of pneumonia but with a minor representation of air bronchogram [13].

**Sonographic pattern of relaxation atelectasis is based on the presence of:**

- Hypoechoic lesion in the presence of pleural effusion
- Absence of lung sliding
- Static air bronchogram

**Sonographic pattern of obstructive atelectasis consists of:**

- Lung hepatization
- Absence or small pleural effusion
- Fluid bronchograms
- Absence of lung sliding
- Minor representation of air bronchogram

**Alveolar interstitial syndrome**

Acute alveolar-interstitial syndrome includes a heterogeneous group of pathological conditions (pulmonary edema, ARDS, interstitial diseases) that affect pulmonary interstitium and lead to gas exchange impairment. In acute conditions, increased lung water leak into pulmonary interstitium and alveolar spaces induces a reduction of air content. At lung US, these abnormalities are visualized as multiple vertical hyperechoic lines, called B-lines [2].

**The sonographic pattern of alveolar-interstitial syndrome includes:**

- Presence of B-lines
- Obscured A-lines
- Presence of lung sliding (normal)
- Presence of sea-shore sign (normal)

Distribution of B-lines can be helpful, in order to discriminate causes of alveolar-interstitial syndrome [15], such as:

**Cardiogenic pulmonary edema:**

- Usually bilateral
- Homogeneous distribution
- Gravity-related (they start appearing in dependent areas)
- Rare subpleural consolidations

**Pulmonary fibrosis:**
• Start at the posterior lung basis
• Often associated with irregularity of the pleural line
• Presence of subpleural small consolidations

Congestion or overhydration, acute lung injury/ARDS:

• Heterogeneous and irregular distribution (multiple B-lines alternating with spared areas)
• Many subpleural consolidations
• Highly fragmented pleural line

Disease of the chest wall

Rib fracture

Also rib fractures can be visualized at US. They are seen as an irregularity and/or interruption of the anterior rib cortex, which may be associated with a local hematoma or soft-tissue swelling around the fracture site (Fig.18). The so called chimney phenomenon, that consists of reverberation artifacts at the fracture margins, represents an indirect sign of a non-displaced costal fracture. To avoid false positive cases, it is mandatory to be aware of the mimickers of rib fractures, such as normal gap at the costochondral junction, old deformity or partial callus formation.

Sonographic pattern of rib fractures includes:

• Irregularity and/or interruption of the anterior rib cortex
• Chimney phenomenon

Lung tumours

Also lung carcinomas and metastases can be visualized on US when they reach the pleura. They appear as hypoechoic or moderately echogenic inhomogeneous rounded or polycyclic lesions, sometimes with echopoor necrotic areas. Infiltration of the chest wall may be also seen. On colour-Doppler mode, tumour-vessels are irregular and corkscrew like. When evaluating lung nodules with contrast-enhanced US (CEUS), delayed contrast agent uptake and reduced contrast enhancement can be seen: this indicates predominant bronchial arterial vascularization [13].

US features of pulmonary carcinomas are:

• Hypoechoic inhomogeneous lesions
• Rounded, polycyclic
• Infiltration of chest wall
• Irregular vascularization
**Technique and settings to obtain the best visualization of static and dynamic signs in lung US**

As said above, lung US is based on identification and interpretation of direct and indirect signs or artifacts, by means of different scanning plans (most commonly, longitudinal and paraxial ones). Although indirect signs may be considered with a negative connotation, they are particularly important and informative. As a matter of fact, a great part of lung US semiotics is based on them [2]. So, it is mandatory to choose technical settings that mostly emphasize indirect signs. On these bases, we review the role of transducers, US modality, CEUS, as well as the importance of a proper settings regulation, in order to obtain the best lung US study possible.

**Probes**

Transducers are the key elements of US equipment. The US probe is a complex unit, where fundamental elements are crystals with piezoelectric properties. This means that, in presence of an electric impulse, they undergo a mechanical deformation and consequently generate a potential difference. Two fundamental properties influence clinical application of US probes: geometry and frequency [16].

Thus, several types of probe can be used in lung study, in relation to the structures of interest to be studied, as reported in table 1 [6; 15]. **Figures 19, 20 and 21** show potential applications of linear, convex and sector probes in lung US study.

**US modality**

Three US modalities are available for lung US examination: "B-mode" (Fig. 22), "M-mode" and "D-mode" (Fig. 23 and Fig. 24). Each of them shows several advantages and can be used to obtain specific information about different lung structures, as reported in table 2 [10; 16; 17].

In addition it can be taken advantage of some special US techniques, such as Tissue Harmonic Imaging (THI), Compound Imaging (CI) and CEUS.

THI is based on harmonic frequencies, that originate from non linear US beam propagation through biological tissues. Harmonic frequencies are multiple and submultiples of the fundamental frequency, but they have minor energy [18]. In general, THI increases the overall "B mode" image quality, thanks to its better spatial and contrast resolution. The latter results in a reduction of refraction and reverberation artifacts, as well as of side lobe ones. This means the possibility to better characterize the nature of a pleural effusion or the content of a collection, by minimizing artefactual echoes.

With CI, the structure of interest is studied from several inclination angles, by means of US beam electronic steering [17]. The final US image shows an overall improvement in
quality and definition, thanks to the greater contrast resolution. Moreover, a reduction of speckle, clutter, posterior acoustic shadowing and side lobe artefacts is obtained [16; 17]. However, in presence of a critical number of inclination angles, frame rate decreases, with consequent increase of image persistence and reduction of image definition (so called image blurring). Thus, it is necessary to properly adjust the number of inclination angles in relation to the structures to be studied, in order to obtain the best agreement between rapidity in image representation and artifacts reduction.

Since a large part of lung US semeiotic is based on indirect signs, THI and CI should be not used in the majority of cases [6] (Fig. 25 and Fig. 26). On the contrary, THI and CI must be apply in order to magnify direct signs, e.g. in the identification of septa in the contest of a pleural effusion (Fig. 27).

CEUS provides information about macro- and microvascularization of the structures of interest, thanks to the magnification of the reflected echoes, by means of a contrast medium made of gas microbubbles. In literature, there are only few studies inherent to the use of CEUS in lung assessment. They are focused on CEUS performance in defining vascularization of subpleural lesions to be biopsied [19] (Fig. 28). These studies support the role of CEUS in the differential diagnosis of lung consolidations (inflammatory consolidations vs consolidations due to embolism vs abscesses vs neoplastic consolidations) as well as in the discrimination of the quote of vascularization by bronchial and pulmonary vessels in the context of a lung consolidation [20].

**Settings regulation**

Frequency, focus, depth and Time Gain Compensation (TGC) regulation is essential in lung US studies, in order to obtain the best US images possible.

Nowadays, US probes show a range of selectable frequencies for the execution of US examination. In general, high frequencies provide high axial and lateral resolution but poor visualization of deep structures [16]. On the contrary, low frequencies guarantee an adequate assessment of deep structures, despite a non-optimal spatial resolution. Thus, high frequencies are recommended for the study of chest wall structures [16], whereas low frequencies are required for evaluation of A- and B-lines, because they induce a reduction in reverberation and ring down artifacts (Fig. 29).

In order to obtain the best spatial resolution, choice of the focal plane is mandatory. It is well known that US beam is affected by progressive divergence. In particular, US beam remains coherent up to a distance equal to the diameter of the piezoelectric element, whereas it diverges in deeper planes. This results in reduction of spatial resolution and in attenuation of US beam. By choosing the focal plane, it is possible to obtain US beam convergence in correspondence to the focal zone, thus providing maximal coherency and intensity of US beam itself [16]. In the study of the lung, several sonographical signs are obtained at the level of the pleural line. Thus, it is necessary to collocate the focal plane in correspondence to the pleural contour, in order to magnify these findings (e.g. A- and B-
lines, lung sliding, focal pleural thickening). Focal plane needs to be more superficial for studying chest wall structures, whereas it should be deeper for analysing pleural effusion, collections, diaphragm contour or lung consolidations (Fig. 30).

Also depth regulation is essential in order to achieve a proper spatial and temporal resolution. As a matter of fact, the field-of-view is optimal when the structure of interest is displayed in the middle or inferior third of the screen. In general, to evaluate superficial structures, depth needs to be reduced (Fig. 31), whereas it should be increased when structures of interest are in deeper planes (Fig. 32).

Reflected echoes are 20-100000 times lower than the original ones; so they must be magnified. It is possible to adjust both, the overall magnification (so called gain) and the one due to the depth (so called TGC), in order to obtain maximal reflection in correspondence to the interfaces, without significantly increasing the noise. Considering TGC magnification, it is extremely useful in presence of a fluid structure, such as pleural effusion. Because fluid structures attenuate US beam lesser than solid structures, there are an excess of reflected echoes from deeper planes that can reduce image quality. This can be avoided by progressively diminishing the amplification from deep planes. On the contrary, in presence of fibrous tissue, US beam is most conspicuously attenuated, thus resulting in the need of a major amplification of reflected echoes from deeper planes. In lung US study, no peculiar TGC arrangements are required, in particular for identification of A and B lines (Fig. 33).

In table 3, principal signs of lung US semeiotic as well as the best US setting adjustment to identify them are summarized.
Fig. 1: Position of US probe for an optimal lung US study: longitudinal scanning plane (a) and paraxial scanning plane (b).

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Fig. 2: Longitudinal US scanning plane, obtained with a linear probe (a; b), in order to represent the bat sign. The two convex hyperechoic lines (yellow lines), with posterior acoustic shadowing (yellow arrows) correspond to the osseous surface of two ribs and the concave line, between them, (light blue line) corresponds to the pleural line. The superficial hyperechoic ribs represent the bat’s wings and the body is made up of the pleural line underneath and between the wings.

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**Fig. 3:** Lung sliding consists of a shimmering of the hyperechoic pleura, during the respiratory cycle. As a matter of fact, as lung expands, visceral pleural surface slides relative to the parietal pleura and chest wall.

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Fig. 4: Absence of lung sliding is due to a lack of propagation of US beam, towards the visceral pleural, in presence of air in the pleural cavity (PNX).

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**Fig. 5:** Representation of lung point on M-mode imaging: lung point is seen as parallel lines in one part of the screen (yellow arrow) with a sudden change to a granular pattern (red arrow).

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Fig. 6: Dynamic representation of lung point: 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 (so called lung point).

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Fig. 7: US image, obtained with a convex probe, representing lung consolidation (a). On B-mode imaging, lung consolidation from pneumonia appears as a tissue-like pattern of the lung, referred to "hepatization" (yellow arrow). RX projection (b) and CT scan (c) of the same patient confirm the presence of radiological features of pneumonia.

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Fig. 8: US image, obtained with a convex probe, representing air bronchogram in the context of lung consolidation (a). On B-mode imaging, air bronchogram is seen as hyperechoic punctiform or linear scatter artifacts within lung consolidation (yellow arrows). CT scan (b) of the same patient shows air bronchogram within lung consolidation.

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**Fig. 9**: Longitudinal scanning plane, obtained with a linear probe (a; b) and a convex one (c; d) representing A-lines. On B-mode imaging, A-lines are seen as hyperechoic lines (light blue dotted lines), parallel to the pleural line (light blue line) and perpendicular to the US beam, that are depicted at regular intervals below the pleural line.

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**Fig. 10:** US image, obtained with a convex probe, representing B-lines. On B-mode imaging, B-lines are vertical hyperechoic laser like artifacts (yellow arrow), originating from the pleural line (light blue line), that extend to the edge of the screen and erase the A-lines.

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Fig. 11: Longitudinal (a) and paraxial (b) scanning planes, obtained with a linear probe, representing Z-lines. On B-mode imaging, Z-lines are seen as short vertical hyperechoic lines (yellow arrows) that originate from the pleural line and neither reach the edge of the screen nor erase A-lines.

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**Fig. 12:** US image, obtained with a linear probe (a), representing the seashore sign on M-mode imaging. On M-mode imaging, seashore sign indicates that the parietal and visceral pleura are adjacent one to another. Above the pleural line, the motionless chest wall displays a stratified pattern (yellow arrow). Below the pleural line, the dynamics of lung sliding shows the sandy pattern (red arrow). Photo of the seashore (b).

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**Fig. 13:** US image, obtained with a linear probe (a), representing the sinusoid sign on M-mode imaging. On M-mode imaging, sinusoid sign defines the periodic change in pleural effusion. During inspiration, lung (yellow arrow) moves toward the pleural line (light blue line), creating a cyclic apparent reduction of the interpleural distance. Graphical example of sinusoid curve (b).

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Fig. 14: US image, obtained with a linear probe (a), representing the stratosphere or barcode sign on M-mode imaging. On M-mode imaging, stratosphere sign is seen as multiple horizontal parallel lines, generated by total absence of lung parenchyma motion. It substitutes the sandy appearance of the sea-shore sign. Example of barcode (b).

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**Fig. 15:** Paraxial scanning plane, obtained with a linear probe, representing power slide. On D-mode imaging, power slide is seen as a colour signal on the pleural line (light blue line), during respiratory cycle.

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Fig. 16: Longitudinal scanning plane, obtained with a convex probe (a), representing simple pleural effusion, on B-mode imaging. On B-mode imaging, simple pleural effusion appears as an anechoic fluid between visceral and parietal pleura (yellow arrow). CT scan (b) of the same patient confirms the presence of pleural effusion (yellow arrow); in addition, lung atelectasis (red arrow) is seen.

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**Fig. 17:** US images, obtained with a linear probe, representing a subpleural lesion. On B-mode imaging (a), subpleural lesion appears as a round, hypoechoic lesion (yellow arrow), adjacent to the pleural line. On D-mode imaging (b), flow signal within the lesion (green arrow) is demonstrated. CT scan (c) of the same patient confirms the presence of a round solid supleural lesion (yellow arrow).

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**Fig. 18:** Paraxial scanning plane, obtained with a linear probe (a), representing a rib fracture on B-mode imaging. On B-mode imaging, rib fracture is seen as an interruption of osseous contour of the ribs (yellow arrow), accompanied with chimney phenomenon.

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<table>
<thead>
<tr>
<th>Probes type</th>
<th>Characteristics</th>
<th>Application field</th>
<th>Lung US</th>
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<tbody>
<tr>
<td>Linear</td>
<td>- Set of crystals, linearly arranged on a single plane&lt;br&gt;- High frequency (5-17)</td>
<td>- Study of superficial structures</td>
<td>- Study of chest wall&lt;br&gt;- Evaluation of lung sliding&lt;br&gt;- Guide for interventional procedures</td>
</tr>
<tr>
<td>Convex</td>
<td>- Set of crystals, arranged on a convex matrix&lt;br&gt;- Low frequency (2-5)</td>
<td>- Study of deep structures</td>
<td>- Identification of &quot;A&quot; and &quot;B&quot; lines (High SnT)&lt;br&gt;- Evaluation of pleural effusion and diaphragm contour</td>
</tr>
<tr>
<td>Sector</td>
<td>- Set of crystals, arranged on a small area&lt;br&gt;- Narrow US beam near the transducer vs wide US beam away from the probe&lt;br&gt;- Low frequency (2.5-3.0)&lt;br&gt;- Easy to handle&lt;br&gt;- Low resolution for superficial planes</td>
<td>- Study of deep structures through limited accesses</td>
<td>- Evaluation of pleural effusion</td>
</tr>
<tr>
<td>Micro-convex</td>
<td>- Set of crystals arranged on a convex matrix with a greater curvature than the one of the convex probe&lt;br&gt;- High and intermediate frequency crystals (1-10)&lt;br&gt;- Easy to handle&lt;br&gt;- Panoramic</td>
<td>- Study of deep and superficial structures</td>
<td>- Evaluation of pleural contour through intercostal space</td>
</tr>
</tbody>
</table>

**Table 1:** Probes type and their applications in lung US.

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**Fig. 19:** Linear probe (a) and its possible application in lung US study (b: identification of chest wall lesion (yellow arrow); c: representation of bat sign).

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Fig. 20: Convex probe (a) and its possible applications in lung US study (e.g.: representation of A-lines (light blue dotted lines) (b) and B-lines (yellow arrow) (c).

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**Fig. 21:** Sector probe (a) and its possible applications in lung US study (b: identification of pleural effusion (yellow arrow); c: representation of B-lines (red arrow)).

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**Fig. 22:** Longitudinal scanning plane, obtained with a convex probe, representing B-lines on B-mode imaging (yellow arrow).

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Fig. 23: Longitudinal scanning plane, obtained with a linear probe (a), representing colour signal in the jugular-subclavian confluence on D-mode imaging. Longitudinal scanning plane, obtained with a convex probe (b), representing colour signal in heart chambers.

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Fig. 24: US images, obtained with a linear probe, representing a chest wall lesion (yellow arrow) on B-mode imaging (a) and D-mode imaging (b). Colour signal within the lesion is seen in D-mode imaging (green arrow). T1 weighted (c) and T2 weighted (d) MR sequences confirm the presence of solid tissue around the rib (yellow rib).

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<table>
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<tr>
<th>US modality</th>
<th>Physical bases</th>
<th>Lung US</th>
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<tbody>
<tr>
<td>“B” mode</td>
<td>- Reflected echoes displayed as points at different luminosity, on a grey scale &lt;br&gt;- Luminosity proportional to the amplitude of reflected echoes &lt;br&gt;- Position of the reflected echoes related to the depth of the structure, from which they are created &lt;br&gt;- Morphological, 2D images; real time</td>
<td>- Evaluation of direct sign (lung sliding, lung hepatization, pleural effusion) and indirect sign (A, B, Z and E lines)</td>
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<tr>
<td>(Brightness mode)</td>
<td></td>
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<tr>
<td>M” mode</td>
<td>- Evaluation of US beam on a line &lt;br&gt;- Graphical representation of the depth of the structure of interest vs time &lt;br&gt;- High temporal resolution</td>
<td>- Representation of pleural profile movement (sea-shore; stratosphere sign; bar-code sign; sinusoid sign)</td>
</tr>
<tr>
<td>(Motion mode)</td>
<td></td>
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<tr>
<td>“D” mode</td>
<td>- Evaluation of vascular flow (fast and slow) on the basis of Doppler effect &lt;br&gt;- Graphical representation of the frequency variation of US beam versus time, by means of a colour code map &lt;br&gt;- Colour code assigned on the basis of flow velocity</td>
<td>- Evaluation of heart and lung venous and arterial vascular structures &lt;br&gt;- Evaluation of the vascularisation of chest wall, pleural and sub-pleural masses &lt;br&gt;- Visualisation of the pleural profile movement (Power slide)</td>
</tr>
<tr>
<td>(Doppler Mode)</td>
<td></td>
<td></td>
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**Table 2:** US imaging modality and their application in lung US.

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Fig. 25: Representation of B-lines with (a) and without (b) THI. Using THI, B-lines are attenuated and less evident (yellow arrow). On the contrary, without using THI, B-lines are clearly displayed (red arrow).

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Fig. 26: Representation of A-lines (light blue dotted lines) with (a) and without (b) THI. Using THI, A-lines are attenuated. Without using THI, A-lines are better recognized.

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Fig. 27: Representation of pleural effusion with (a) and without (b) CI. Using CI, pleural effusion appears anechoic (yellow arrow), thanks to artifactual echoes reduction. Without CI, a simple pleural effusion looks like corpusculated (red arrow).

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**Fig. 28:** Role of CEUS in lung US study: evaluation of subpleural lesion. On B-mode imaging (a), subpleural lesion appears as a round hypoechoic lesion, adjacent to the pleural line (yellow arrow). After administration of contrast medium (b) subpleural lesion shows contrast enhancement (red arrow). CT scan (c) of the same patient confirms the presence of a round, contrast enhanced subpleural lesion (yellow arrow).

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**Fig. 29:** US images, obtained with a convex probe (a) and a linear one (b; c), using different frequencies. Low frequencies (a: 2.5 Mhz) are useful in evaluation of indirect signs or artifact (e.g.: A-lines). High frequencies (b: 8.4 MHz; c: 15 Mhz) are used for better representing chest wall and lung sliding.

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Fig. 30: US images, obtained with a convex probe, representing different focus position. When focus is located at the level of the pleural line (a), B-lines (yellow arrow) are well defined and are displayed in a great number. On the contrary, with focus located in deeper planes (b; c), B-lines are less defined, until when they become invisible (d).

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Fig. 31: Longitudinal scanning planes, obtained with a linear probe, representing evaluation of superficial structures with different depth (a; b). For the study of chest wall, depth should be set as superficially as possible (a) in order to obtain the best anatomical detail.

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Fig. 32: US image, obtained with a convex probe, representing evaluation of pleural effusion with correctly set depth (red arrow).

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Fig. 33: TGC settings: US image, obtained with a convex probe (b) in which there is no particular TGC adjustment. For the study of lung disease, it is mandatory to maintain a neutral TGC setting. Amplification is not necessary neither for superficial nor for deep echos (a; c).

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Table 3: Main signs of US semeiotic and proper US settings.

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Conclusion

Lung US is becoming increasingly important in the diagnostic workout of the lung.

As well as in the examination of other organs, even in the study of the lung, knowledge of findings to be identified is mandatory in order to adequately choose the best sonographical settings.

Lung US evaluation is easier with respect to that of other organs, because in the majority of cases, only few centimetres from the transducer are assessed and high resolutions are generally not required. At the same time, it is a sophisticated study, because it is based on the capability to evoke artifacts. For this reason, proper technical settings and execution are crucial to obtain high quality examination and reliable representation of main normal and pathological findings.
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References


