

EFSUMB – European Course Book

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Chest Sonography

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Technical Requirements

Sonographic examination of the chest wall and axillar/supraclavicular region generally requires a linear array probe using frequencies of 5.0 to 10 MHz. For pleural and peripheral pulmonary lesions, sector scanners are more suitable for intercostals access to the pleura and lung through the narrow intercostal space. Tilting and angulation of the probe provide a good view of most parts of the pleura and underlying pulmonary consolidations. Convex arrays provide better images, giving more overview when the examiner substracts the rib shadows

from the picture. For sonographic examination of pleura and lung, frequencies from 3.5-5 MHz are recommended. For daily clinical use in chest sonography, the best combination is a 3.5-5 MHz sector or curved array probe and a small-parts linear scanner with frequency of 5-8 MHz (10 MHz, if necessary). This combination is used in many other applications, *e.g.*, abdominal, vascular and small-parts US (1).

Examination Technique

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. The examiner is able to visualize the region behind the shoulder blade, if the patient puts his/her hand on the contralateral shoulder. The transducer is moved along the intercostals space from dorsal to ventral in longitudinal and transversal positions. Turning the probe in different positions provides the examiner with a three-dimensional image. During every stage of examination, the user should determine the breath-related moving of the pleura, the so-called sliding sign (Fig 1, 2).

Figure 1 A: Linear probe placed intercostally in an oblique view. The right arm is elevated behind the dead or positioned on the contralateral shoulder. The intercostals spaces are extendend and the scapula is turned. B: Corresponding sonographic view. → = sliding line of the visceral pleura

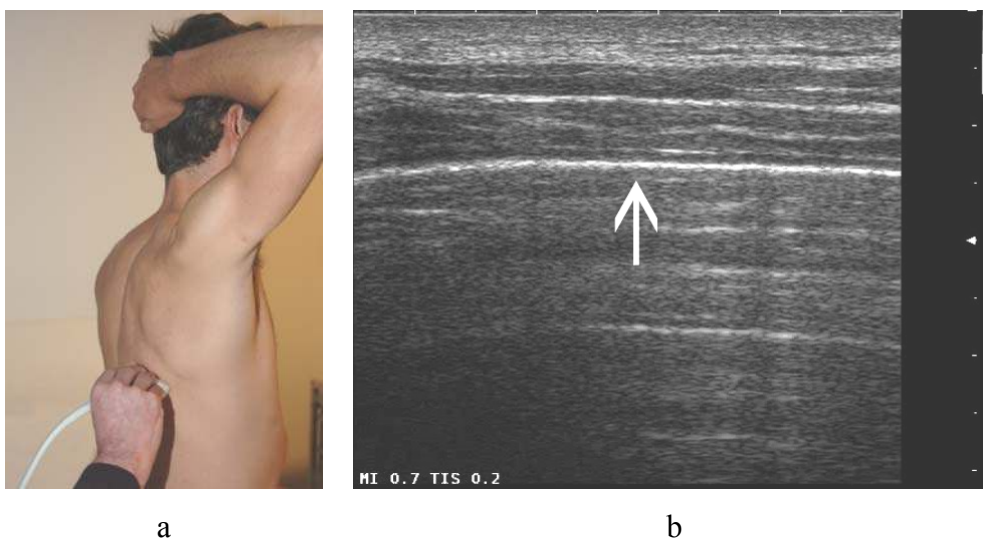
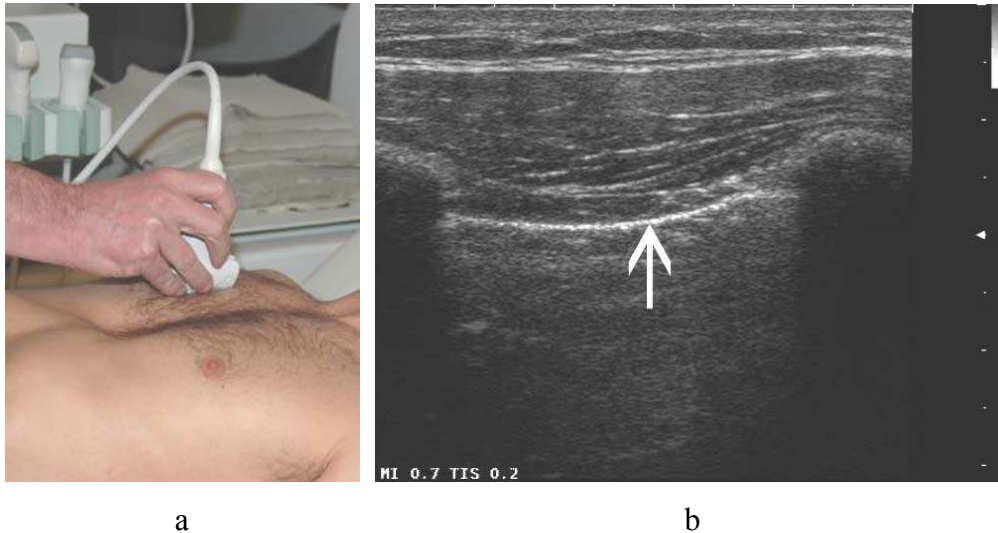


Figure 2 A: Linear probe in an anterior longitudinal scan. B : Corresponding sonographic image, → = sliding line of the visceral pleura



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 (Fig 3). The axilla should be examined in the supine position with the arm abducted over the head. The supraclavicular access allows the investigator to view the region of the brachial plexus, the subclavian vessels and the lung tip (Fig 4). From suprasternal, the anterior upper mediastinum can be viewed.

Bedridden and intensive care patients are examined by turning them to the oblique position in the bed (1).

Figure 3 Transhepatic examination. A: Convex probe placed subcostally from the right. B: Corresponding sonographic image, Lung is indicated as a mirror artefact above the diaphragm

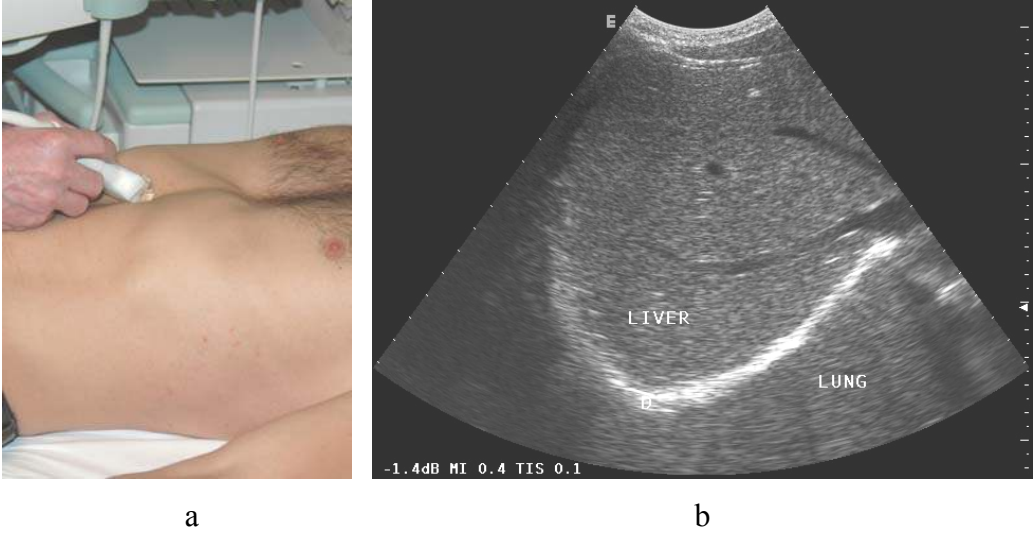
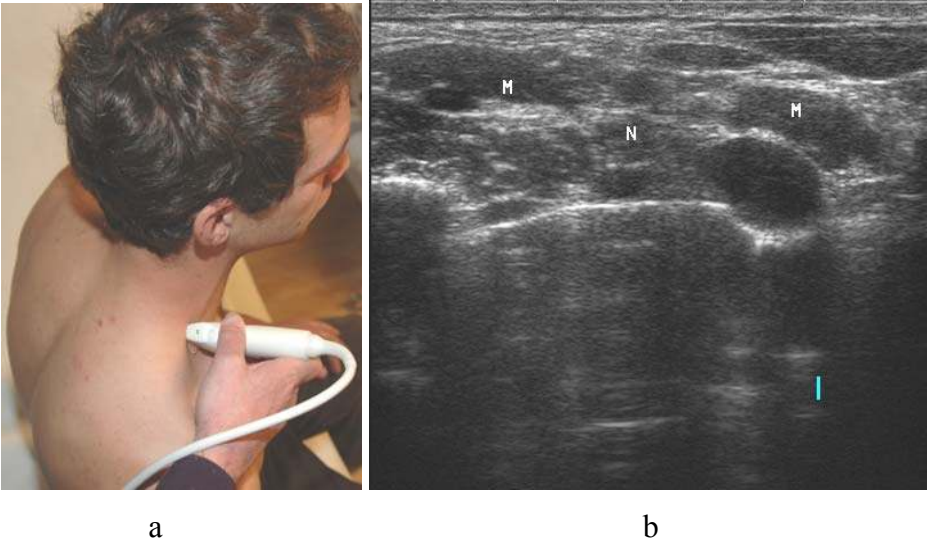


Figure 4 Examination of the supraclavicular region. A: Linear probe placed longitudinally on the lateral base of the neck B: Corresponding sonographic image. N Plexus brachialis. M Scalenus Muscles

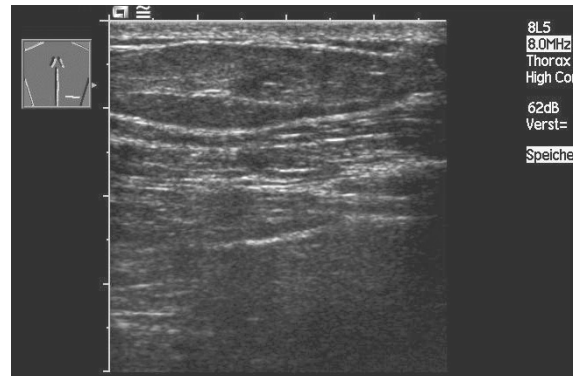


Chest wall

Soft tissue lesions

Suspicious or unclear findings during palpation of the chest wall should be examined first by US. In most cases, the examiner will find lymph nodes, which are the most clinically relevant finding. However, hematomas and lipomas are also visualized by US. Hematomas are echolucent or hypoechoic and show blurred internal echoes. The echogenicity of hematomas depends on the erythrocyte content and the stage of organization. A similar but largely hypoechoic US picture is given by lipomas. Their echogenicity depends on the fat content of cells (Fig 5.). In cases of painful swelling in the region of the axilla, a sweat gland abscess can be differentiated from a lymph node.

Figure 5 Palpable mass at back. Oval capsulated lesion – typical lipoma.



Lymph nodes

Reactive and inflammatory lymph nodes are a very common finding in the axilla and supraclavicular fossa. Their typical US appearance is an oval or triangular form; some are long and thin (Fig. 6). The so-called hilus fat sign is found in the center of reactive lymph nodes. This echogenic center becomes larger during the healing process of inflammatory lymph nodes.

Malignant lymphomas also appear echolucent. They are rounded, sharply bordered and expansive, but in most cases they are noninfiltrating. Although we have some sonomorphological criteria to distinguish the etiology of lymph nodes, the pictures could be very similar for different origins. If immediate treatment is required, US-guided needle biopsy may help to make a swift diagnosis. Otherwise, controls can give security according to the clinical course.

The exclusion or proof of lymphatic metastatic disease is a question frequently raised by clinicians. Lymph node metastases appear as round-to-oval inhomogeneous structures with irregular margins, and irregular vascularization. (Fig. 7). However, they typically show extracapsular growth into irregular borders and diffuse infiltrating growth into vessels and the surrounding tissue. Necrosis, calcification or partial lymph node infiltration may produce an inhomogeneous US pattern.

Routine ultrasound evaluation of supraclavicular lymph nodes reveals suspicious lymph nodes in a high number of patients with lung cancer. High-resolution US is superior to CT in the detection of pathological lymph nodes, especially of nonpalpable lymph nodes. Ultrasound-guided biopsy proves malignancy and thereby a N3 or M1 stage. Thus, more invasive and expensive procedures can be avoided. Nonpalpable lymph nodes and metastatic disease in reactive lymph nodes can be detected. (2).

Figure 6 Dolorous swelling in the right axilla: Differential diagnosis: lymph node or abscess of a perspiratory gland? A Echopoor solid structure with hilus sign. B regular vascularization – reactive inflammatory lymph node

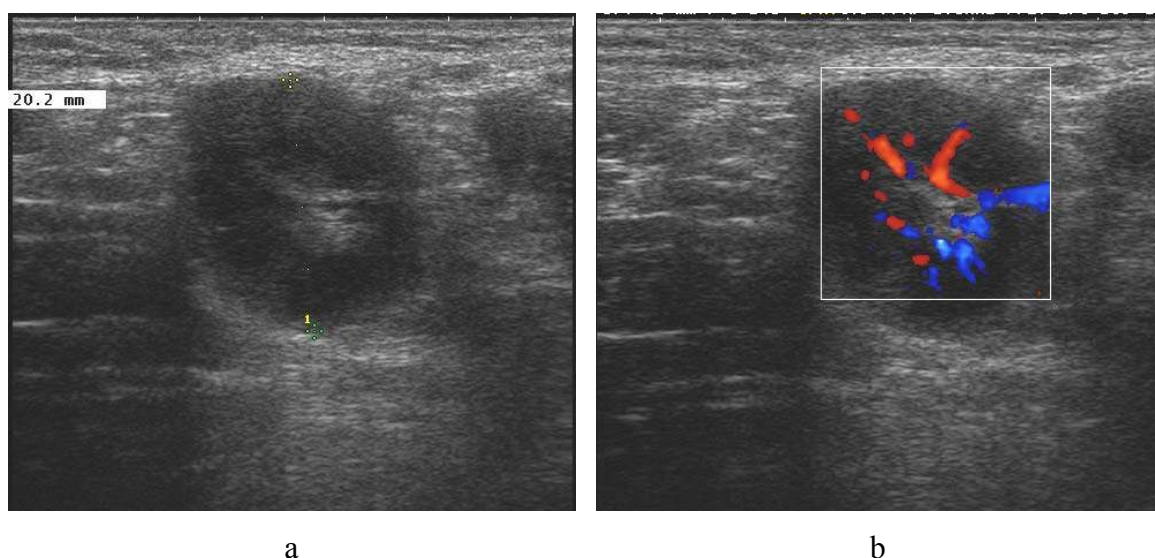
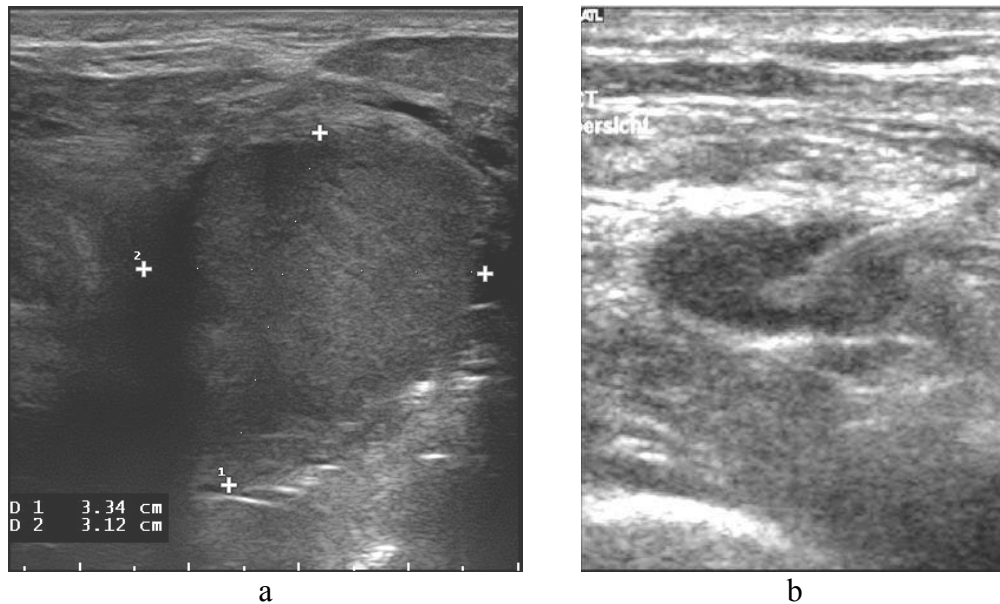


Figure 7 A Neck lymph node metastasis of an epidermoid lung cancer. B: US-guidede lymph node fine needle aspiration biopsy of a supraclavicular lymph node.



Bony lesions

In Chest x-rax nondislocated rib fractures are frequently not seen. At the first sight, it is surprising to note that the diagnosis of rib fractures is made twice as frequently by sonography compared to chest radiography. Typical sonographic findings of rib fractures are gap, step, dislocation, hematoma and minimal concomitant pleural effusion, pneumothorax and lung contusion (Fig. 8, 9). Minute dislocations and fissures are visible by a reverberation artifact at the traumatized point, also known as the so-called chimney phenomenon. (3,4). On US examination, the patient indicates the site of pain and the examiner obtains a cross-sectional image of the region in two planes, with the image closely following the course of the ribs.

Osteolytic metastases in the bony thorax cause disruption of the corticalis reflex with pathologic US transmission. Osteolyses are usually seen as well-demarcated round or oval space-occupying lesions with a partly hypoechoic and partly rough structure. Color-coded

duplex sonography reveals corkscrew-like neovascularization or a vascular inferno, especially in patients suffering from multiple myeloma (Fig 10).

When diagnosing chest wall infiltration in cases of lung cancer, ultrasound is significantly superior to CT. Direct evidence of infiltration of wall structures and rib destruction are reliable criteria. An interruption of the pleural reflex and/or limited respiratory motion of the space-occupying lesion provides an indication but not proof of infiltration of the chest wall. Inflammatory accompanying reactions can also be an indicative of chest wall infiltration (5).

Figure 8 Rib fracture. One mm step in the corticalis reflexion. F= subdermal fat, M = muscle.

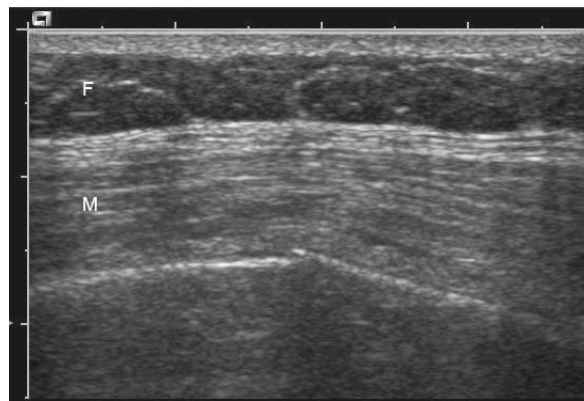
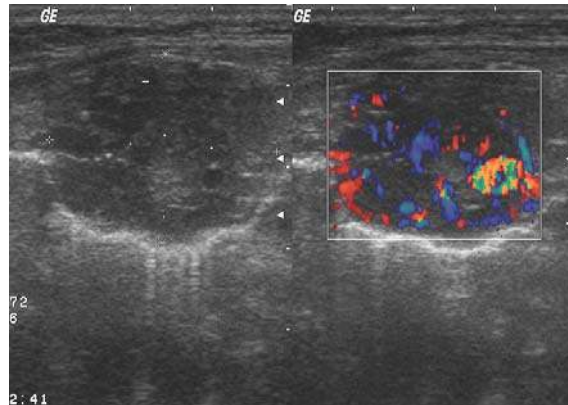


Figure 9 Sternum fracture caused by a car accident. +- Six mm step. H= organized hematoma.



Figure 10 Multiple myeloma in a palpable thickened rib. Enhanced Irregular vasculazation. The diagnosis was established by ultrasound-guided biopsy.



Pleura diseases

Normal sonographic appearance

The pleural space is superficial and can be easily examined by ultrasound using either a direct intercostal or an abdominal approach.

The use of high frequency 5-12 MHz linear probes applied directly to an intercostal space provides excellent visualization of the pleural space. The pleural space is located within 1cm of the rib interface. The normal pleura has a thickness of only 0.2-0.4 mm and may be depicted with difficulty even with the new ultrasound equipment.

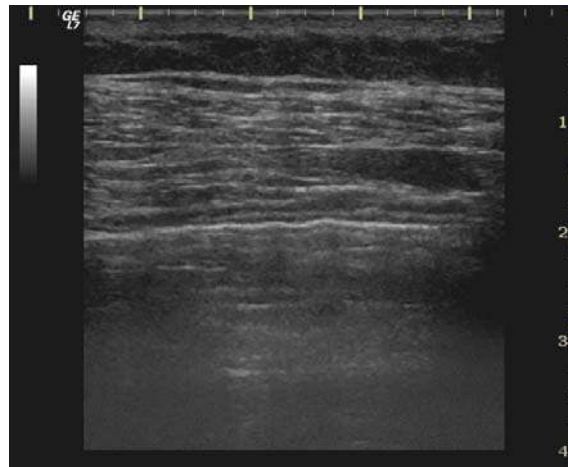
The visceral pleura is a fine echogenic line which is normally included in the thick line of total reflection of ultrasound waves at the air-filled lung. The bright, linear interface produced by the air-filled lung covered by visceral pleura moves with the respiration backwards and forwards, known as “the gliding sign”. Small, uneven irregularities at the visceral pleural surface produce reverberations named comet tail artifacts. Such artifacts, rarely seen in the normal lung are more often and to a greater extent evidenced in cases of interstitial lung disease or when the pleural space is scanned through a normal liver (6,10).

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 (Fig.11). With high resolution transducers the line of

parietal pleura may be divided into 2 layers: the parietal pleura and the external endothoracic fascia (10).

Sometimes the parietal pleura is accompanied by a thin hypoechoic layer and nodular hypoechoic spreading which represents the extrapleural lamella of fat (10).

Figure 11 Pleura. Normal sonographic appearance. A= very thin echogenic line corresponding to the parietal pleura and the endothoracic fascia. B= echopoor pleural space. C= strong total reflexion from the aerated lung, the so-called visceral pleura.



Abdominal approach: When scanned from the abdomen 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 (11).

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.

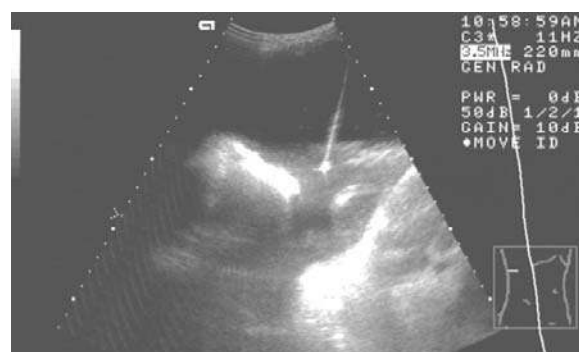
The ultrasonographic hallmark of pleural fluid is an echo-free zone between the parietal and visceral pleura. This may be detected through both intercostal (better) or abdominal approaches. The use of a direct intercostal approach with high resolution linear array transducers allows the detection of even minute amounts of pleural fluid. Other signs of pleural effusion are depicted in Table 1.

Table 1 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 (Fig.12). 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 (6,11). In such cases the use of the above mentioned criteria (2-6) could be very helpful. The “fluid color” sign is a color signal detected by Doppler sonography that appears within a fluid collection in the pleural space during respiratory or cardiac cycles. It has a high sensitivity (89.2 %) and specificity (100%) for detecting minimal or loculated effusions (6).

Figure 12 Large pleural effusion, echo-free. Note the presence of artifacts and a needle for thoracocentesis



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. For

a standard X ray in the same settings, the detection limit is 150ml (6). Moreover, the standard X ray has a low accuracy in patients lying in bed or in effusions accompanied by atelectasis (6).

Due to the anatomical differences and various shapes of the thorax, an exact measurement of volume of the effusion is not possible with any imaging modality. However, a reliable estimation is very desirable in clinical practice to indicate a therapeutic puncture and to ensure a follow up.

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.

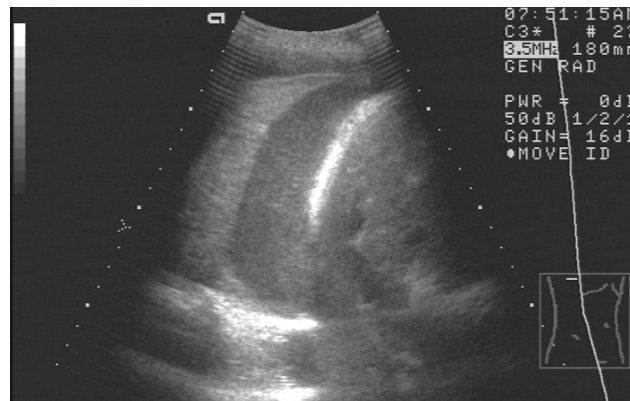
For sitting patients a good method is to calculate the sum of the basal lung to diaphragm distance and the lateral height of the effusion and to multiply the sum by 70. In the supine patients the measurement of the volume is made using the formula $50x-800$, where x is the thickness of the dorsal fluid layer in millimeters measured at a right angle to the chest wall (6).

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 (1).

Types of effusion

The types of pleural effusions are important for the diagnosis. *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. Echoes float or swirl in the liquid and can be easily differentiated from artifacts (1,6,7). The additional findings of pleural nodules or thickening always indicate an exudate.

In prospective studies it has been demonstrated that transudates are always echo-free whereas exudates may be echo-free or echogenic (Fig.13). A definitive diagnosis is made by thoracocentesis. Malignant effusions are more often echogenic than echo-free and are accompanied by solid nodular structures (1).

Figure 13 Echogenic pleural effusion in a patient with metastatic pleural disease

Complicated pleural effusions

Infected parapneumonic effusions, septated or loculated pleural effusions are described as complicated ones. Ultrasonography is a very good method for visualising loculations or septations but cannot diagnose infection which is evidenced only by puncture or aspiration (Fig. 14).

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

In empyema there is gross pus with bacteria or other infectious organisms in the pleural space. The main causes of empyema are infections from pneumonia, trauma, surgery, thoracocentesis, esophageal rupture and others. Three stages of empyema have been described: exudative, fibrinopurulent and organized. In the *exudative stage* multiloculated effusions with large floating echoes with different echogenicity of the contents may be seen. The *fibrinopurulent stage* is characterized by fibrin deposition on the pleura which is moderately thickened in a capsule-like fashion. The fluid may be loculated with limiting membrane formation. In the final *organized stage* a rigid membrane around the lung, called pleural peel is produced (7). Empyema should be differentiated from a subpleural lung abscess.

Hemothorax is seen in patients with underlying lung or pleural malignancy or after chest trauma. The US signs vary regarding the time from the trauma. Fresh blood collection may be echo-poor whereas older ones are echogenic, with both fine echoes and large echogenic structures representing clots (6).

Figure 14 Septated pleural fluid in a patients with infected effusion



Solid pleural lesions

Solid pleural changes encountered in clinical practice are listed in Table 2.

Table 2 Solid pleural lesions

Diffuse pleural thickening (due to fibrosis and/or infiltration)

- Diffuse – fibrothorax, pleural peel, pahypleuritis
- Malignancy

Focal pleural thickening (due to inflammation and/or fibrosis)

- Pleuritis (inflammation)
- Pleural plaque (fibrosis)

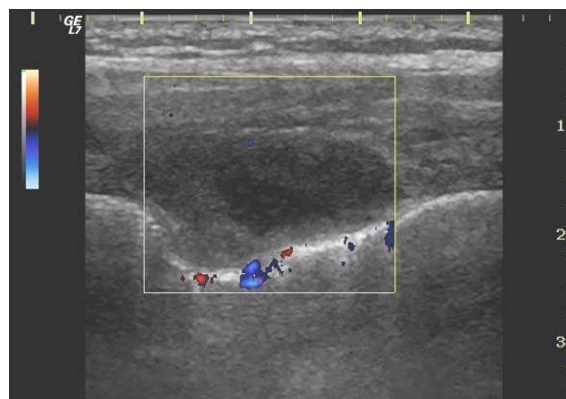
Pleural masses

- benign pleural tumors
- pleural metastases
- pleural mesothelioma
- transpleural growth of tumors

Diffuse pleural thickening

Diffuse pleural thickening is a sign of pleural fibrosis or a pleural malignancy. It involves the visceral pleura, entrapping the lung and causing restriction of ventilation. The main causes are exudative pleural effusion, asbestosis related effusion, hemothorax or empyema (6,7). The US sign of a pleural plaque is a smooth pleural tissue that displaces the lung from the chest wall, is well demarcated against the aerated lung and does not infiltrate the chest wall (Fig.15) (1,6). The diffuse pleural fibrosis observed in malignancy is mainly lobulated, sometimes with multiple discrete pleural masses.

Figure 15 Localized pleural thickening in a patient with postinflammatory pleural fibrosis.



Fibrosis has different echogenicities, usually hypoechoic, but the older ones tend to be more echogenic. A new developed fibrosis may be very hypoechoic being sometimes misinterpreted as effusion. In such cases the use of “color-Doppler” sign may be helpful in the differential diagnosis. Sometimes calcifications are present in the thickened pleura, more often in tuberculosis or empyema (7,8). As all these sonographic features are also seen in pleural carcinoma and mesothelioma, a sonographic differentiation between them is rarely possible.

Focal pleural thickening

Pleuritis is usually diagnosed clinically, being rarely accompanied by laboratory or imaging findings. The US findings in pleuritis are: a) hypoechoic thickening of pleura often with rough appearance and interruption of the normally, smooth pleura ; b) small subpleural consolidations between 2- 20 mm in size, round or wedge shaped ; c) localized pleural

effusions ; d) fibrinous echogenic bands at the lung surface, towards the parietal pleura or dividing an accompanying pleural effusions (6).

The presence of large pleural effusion with subpleural infiltrates favors the diagnosis of tuberculosis (1).

Pleural plaques are found in pneumonia, asbestos exposure, pulmonary infarction, trauma, chemical pleurodesis and drug-related pleural disease. On sonography pleural plaques appear as smooth, elliptical, hypoechoic pleural thickenings, sometimes with calcifications. In asbestosis the pleural plaques are located mainly in the dorsolateral portion of the costal region of the parietal pleura and contain calcifications in 10% of cases (6,7).

Pleural tumors

Benign pleural tumors (fibrolipomas, chondromas, neurinomas and benign pleural mesotheliomas) are rare, accounting for less than 5% of the pleural tumors. They are round, well demarcated, encapsulated (usually by a fine capsule), hypoechoic or moderately echogenic lesions in the pleural space (Fig.16). Depending on their size they can displace the surrounding structures but do not invade them. Additional findings are small effusions around the tumor and calcifications (6).

Figure 16 Benign well demarcated pleural tumor. Histology: fibrous solitary pleural tumor



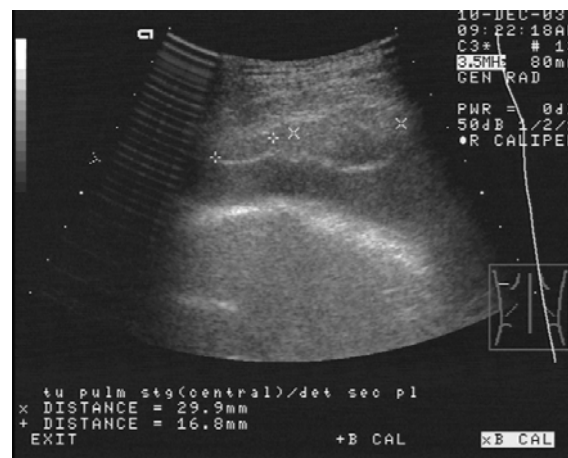
Pleural metastasis are found more often in breast and lung cancers. Their occurrence and visibility are closely related to pleural effusions and they are usually overlooked by sonography due to their small size (< 5mm). If metastases grow larger, they become very

visible on the parietal and diaphragmatic pleura. The metastatic nodules are hypoechogenic to moderately hyperechogenic, may be round or polypoid, sometimes with a broad base and are well-demarcated against the surrounding tissue or pleural fluid. Large metastases may invade the lung or the chest wall, the invasion being recognized on US as interrupted or absent delimitation between the lesion and the surrounding tissue.

The combination of pleural effusion and nodules or sheet like pleural thickening in a patient with a known malignancy, is very suggestive of metastatic disease (8, Fig.17).

The main diagnosis challenges in tumoral pleural disease are: a) to ascertain if a single pleural lesion is a metastatic nodule, a benign tumor or primary pleural tumor; b) to differentiate between a metastasis located on the visceral pleura and a subpleural pulmonary tumor; c) to differentiate an extensive or sheet-like infiltration of the pleura in metastatic carcinomatosis from a inflammatory thickening or a tapestry-like mesothelioma (6). All these tasks may be solved by a needle biopsy.

Figure 17 Pleural metastases (2) from lung cancer.



Pleural mesothelioma is a rare fatal pleural tumor, usually associated with asbestos exposure. The sonographic signs of mesothelioma are: a) diffuse pleural thickening, often nodular and irregular; b) calcifications in the pleura; c) pleural effusion and d) focal pleural masses (Fig.18) (7). It is a very aggressive tumor that invades the chest wall or diaphragm and spreads to the contralateral pleura or pericardium. The invasion of the chest wall appears as striped, hypoechoic ramifications (6).

Figure 18 Malignant mesothelioma. Large pleural tumor invading the lung.



Interventions in the pleural space

Materials and techniques

The transducers used in US guided chest interventions in the pleural space vary according to the distance to the target lesion. High frequency linear probes are generally used. In cases of larger pleural masses 3.5 MHz convex transducers may be needed. Due to the presence of narrow spaces between the ribs, small (micro) convex probes are the choice.

Ultrasound (US) offers a number of advantages over other imaging methods (CT or fluoroscopy): a) the capability to monitor continuously the interventional procedures; b) the possibility to perform the procedures with the patients in an upright position (providing an optimal access to gravity-layered pleural fluid) and even in sick dyspneic patients; c) its multiplanar capability which permits even oblique, angled approaches useful in cases of “difficult” located thoracic lesions; d) shorter procedure time; e) portability; f) lower cost. Needle and catheter placement can be monitored under direct and constant sonographic visualization, assuring maximum safety and benefit. (7,9).

Diagnostic thoracocentesis

Ultrasound guidance of this procedure should be done whenever clinically guided thoracocentesis is unsuccessful or judged to be difficult. An ultrasound scan is performed to confirm the presence of fluid and to select and mark the puncture site. Usually after choosing the punctured site with US, the probe is removed and the puncture made with careful attention paid to the depth of the collection and the localization and depth of the lung. If the fluid

collection is small, the puncture and aspiration can be done under continuous US monitoring. A 22G needle attached to a 10 ml syringe is generally used for diagnostic aspiration. Occasionally, the pleural fluid may be too viscous to aspirate through a 22 G needle. In such cases, after a recheck of the correct needle's position an aspiration with larger needles (20 or 18G) should be tried.

US guidance adds accuracy and safety to the procedure, the incidence of pneumothorax being decreased from 18% for clinically guided thoracentesis to 1-3% (1,7,9).

Pleural biopsy

Biopsy of pleural masses can be performed using standard biopsy needles (16-20G). Fine needle aspiration has less value in the diagnosis of tumoral pleural disease, especially for primary pleural tumors such as mesothelioma (9). For nonmesothelial malignancy the sensitivity of FNA for malignancy is higher (up to 78%) but typing is seldom possible by means of cytology (10). Core biopsy using 14-18 G cutting needles is more accurate than FNA in the diagnosis of both focal pleural tumors and diffuse pleural thickening (9,10). The overall sensitivity in diagnosing pleural malignancy varies between 70-90%. In the detection of pleural mesothelioma sensitivity and specificity are 77-88%, respectively 88-100% (10). The presence of pleural effusion does not influence significantly the sensitivity of core biopsy (88% for malignancy, 93% for pleural mesothelioma) but reduces the risk of complications (10).

A wide variety of complications can occur after pleural biopsy: vasovagal reactions, chest wall hematoma, subcutaneous emphysema, infection, hemothorax, air embolism, lung laceration, and injury to liver, spleen and stomach (3,11). The complications rate of echo guided pleural biopsy varies between 2-5%, being decreased in the presence of pleural effusion (10). The most encountered complication is pneumothorax with reported frequency in published series between 0% and 9% (9). Most pneumothoraces are small, self-limiting, and produce minimal symptoms.

Therapeutic drainage of symptomatic pleural effusions.

Drainage of large pleural effusions can generally be performed in one step, without leaving an indwelling catheter, provided that the pleural is not infected. If a large amount of fluid is to be withdrawn, the aspiration needle is replaced with a catheter to decrease the possibility of trauma to the lung. Short soft and flexible catheters (7F), designed for intravenous use may be introduced into the pleural space, mostly by the trocar method (7,11). The use of small

indwelling pleural catheters in management of large plural effusions is a safe, efficacious and cost-effective procedure.

US can be used to optimize positioning of the drainage catheter (including further manipulation into additional pockets of fluid) and to monitor the amount of fluid remaining.

Catheter drainage of pleural collections

External drainage of infected pleural fluid collection through an image-guided inserted catheter is a well-accepted treatment option of empyema and complicated parapneumonic effusions. A drainage through an US guided inserted catheter is indicated in patients with a short duration of symptoms, free-flowing or unilocular effusions, absence of thick pleural peel on CT scans and fluid that can be aspirated easily by needle (11).

In thoracic empyema the success rate ranges between 72-92%, being influenced by the aspect of fluid prior to drainage. Thus, the success rate in anechoic and complex nonseptated collections (92, 3% and 81, 5% respectively) is significantly higher than in complex septated collection (success rate of 62, 5%) (12). Transcatheter instillation of urokinase or streptokinase may be useful to facilitate drainage of such collections but more recent studies have failed to show any improvement with regard to the primary endpoints, namely surgery or death (6). Despite these maneuvers, some authors advocate the use of US guided catheter drainage for early unilocular pleural effusions or empyema thoracis, but not for multiloculated effusions.

Pleural sclerotherapy

Traditionally, the most common treatment for a persistent, recurrent malignant effusion has been large-bore chest tube (>30F) drainage followed with instillation of a sclerosing agent (tetracycline, doxycycline, bleomycine, sterile talc) (7,9). Large bore chest tubes, however, limit patient mobility and are uncomfortable.

More recently, small-bore catheters (7-24F) have been placed with US guidance with no difference in response rates; the catheters were well tolerated and accompanied with minimal complications (13).

US guidance is used to ensure accurate catheter placement for thoracocentesis and instillation of the chemical agents, to assess adequacy of drainage and reaccumulation of fluid, to locate loculated fluid collections and to check for reaccumulation of fluid at 24 hours (7,9).

Pneumothorax

The benefit of thoracic ultrasound for pneumothorax is striking, because it is highly accurate (14), extremely quick to be performed at bedside and much more sensitive than chest radiography (15) or physical examination. The ultrasound technique is based on a combination of 4 sonographic signs: the lung sliding, the B lines, the lung point and the lung pulse (Fig 19) (16). The examination should be performed on the supine patient. It is enough to place the probe in a single site on both sides of the upper chest, where air should be collected for reasons of gravity (Fig 20). Once visualized the parietal pleura as an echogenic horizontal line below the ribs, the first two signs to be sought are a to-and-fro movement of the pleural line synchronous with respiration, the *lung sliding*, and some echogenic vertical artifacts, the *B lines* (Fig 21). Their visualization immediately rules out pneumothorax. When a sonographic pattern suggestive of pneumothorax is found on the anterior chest (absent sliding and B lines), the probe should be moved to the lateral areas looking for sudden visualization of a respiratory pattern, detected as appearance of sliding and B lines (Fig 22). 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. This phenomenon, the *lung pulse*, rules-out the diagnosis of pneumothorax thus suggesting other conditions that have in common absence of lung sliding.

Bedside ultrasound diagnosis of pneumothorax is particularly important in two different scenarios. In cases where patients are unstable or in cardiac arrest, it is reasonable to immediately decompress the lung by chest tube placement when lung sliding, B lines and lung pulse are absent on the anterior chest. The second setting where ultrasound shows its great usefulness is the diagnosis of radio occult pneumothoraces (15). In this case, the lung point should be used to confirm the diagnosis and evaluate the percentage of lung collapse.

Figure 19 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.

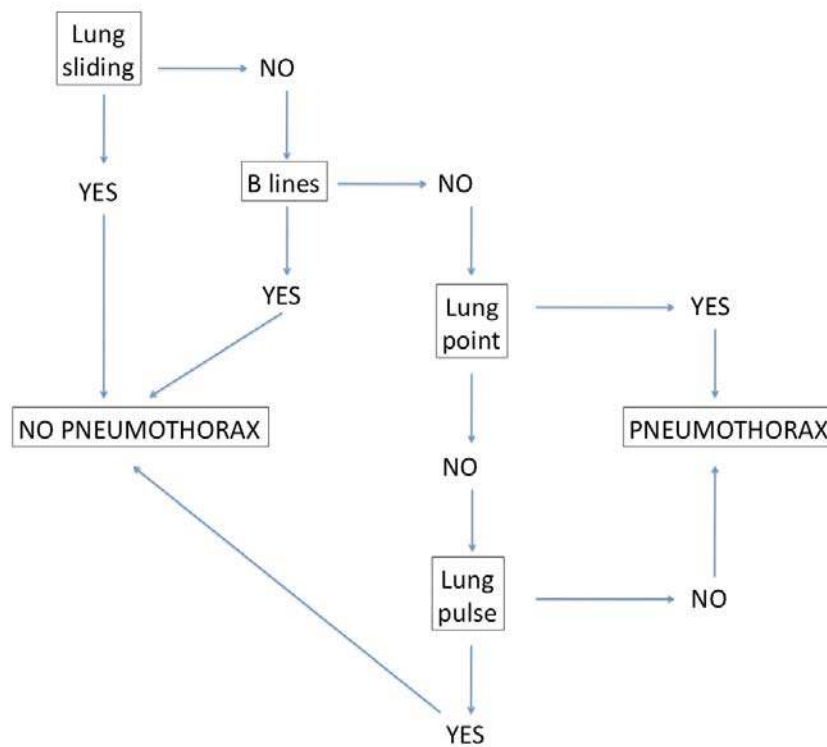


Figure 20 The ultrasound examination for pneumothorax should be performed on a single site on both sides of the upper chest (white crosses), where air should be collected for reasons of gravity.



Figure 21 Lung ultrasound scan showing the pleural line (grey arrow) between and below two ribs (white arrows). We can also distinguish some vertical echogenic lines arising from the pleural line, that spread-up without fading to the edge of the screen: the B lines.

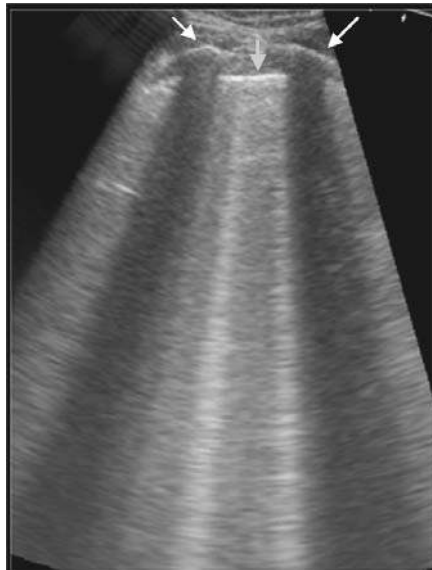
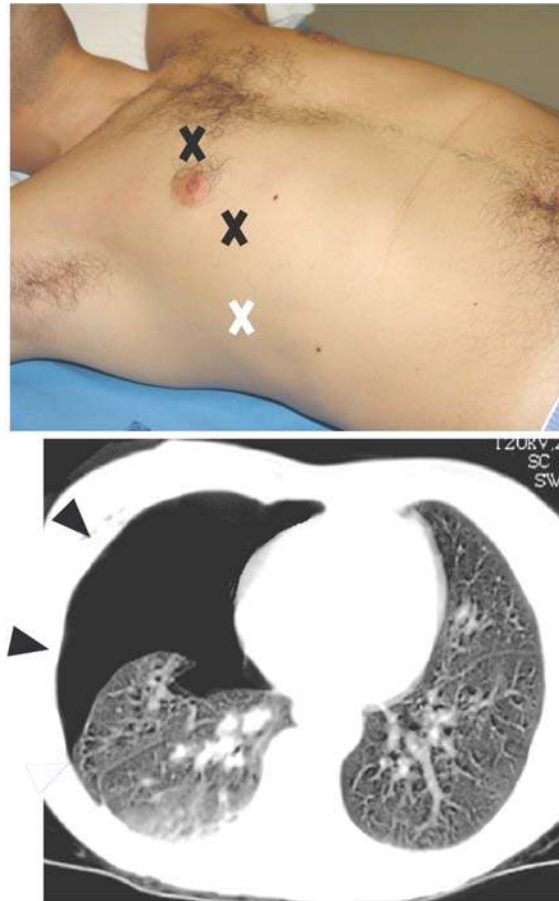


Figure 22 Upper panel: in case of lack of sliding and B lines in the anterior chest (black crosses), the probe is moved to the lateral areas looking for sudden visualization of a respiratory pattern (appearance of sliding and B lines), the lung point (white cross). Lower panel: corresponding CT scan 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.



Lung consolidations

In healthy persons, ultrasound imaging of the lung is not possible because the ultrasound beam is reflected totally at the surface. Pulmonary processes can 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 and therefore cannot be ruled out with this technique.

Pneumonia

In early congestive stage of pneumonia, the echo texture of the consolidated lung is similar to the liver. However, a marked tree-shaped bronchoaerogram, and a large number of lens shaped echo reflections measuring a few millimeters in size are frequently observed up to the pleura (Fig 23). In a densely subpleural location, one finds a broad and highly hypoechoic strip: superficial fluid alveologram. 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/hypoechoic branched tubular structures in the course of the bronchial tree. It does not have a perfusion signal. A persistent fluid bronchogram arouses suspicion of poststenotic pneumonitis and requires suitable bronchoscopic investigation (17). On colour-coded duplex sonography, pneumonia has a typical appearance: circulation is uniformly increased and branched, vessels have a normal course (Fig. 24). Corresponding to findings in color Doppler sonography, the contrast enhanced US has a short wash-in period und an intensive enhancement (17,18,19,20, Tab 3).

Bacterial pneumonias tend to fuse and form abscesses: round or oval and largely anechoic foci (Fig 25). Depending on the formation of a capsule, the margin is smooth and echodense. 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. Such air gives rise to reflection and reverberation artefacts. The pneumonia recedes on the ultrasound image and appears smaller than on chest radiograph, according better to the clinical course (Fig 26).

Table 3 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

Figure 23 Pneumonia in the left upper lung lobe: large liver-like lung consolidation with intensive reflexes of the aerated brochial tree, the bronchoaerogram.

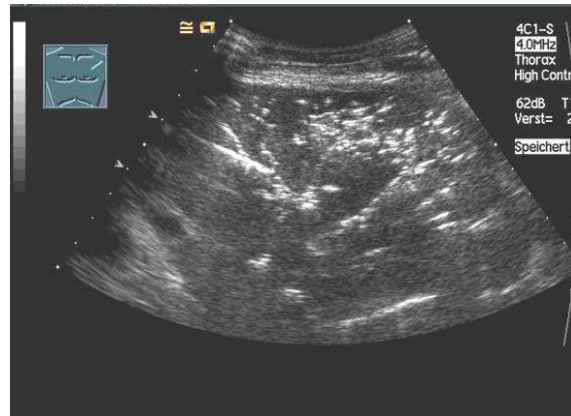


Figure 24 On color-coded duplex ultrasound pneumonia is seen as an accentuated, regular pattern of vascularization.

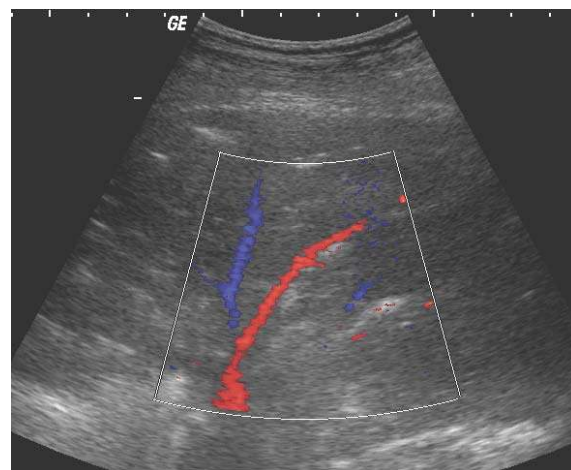
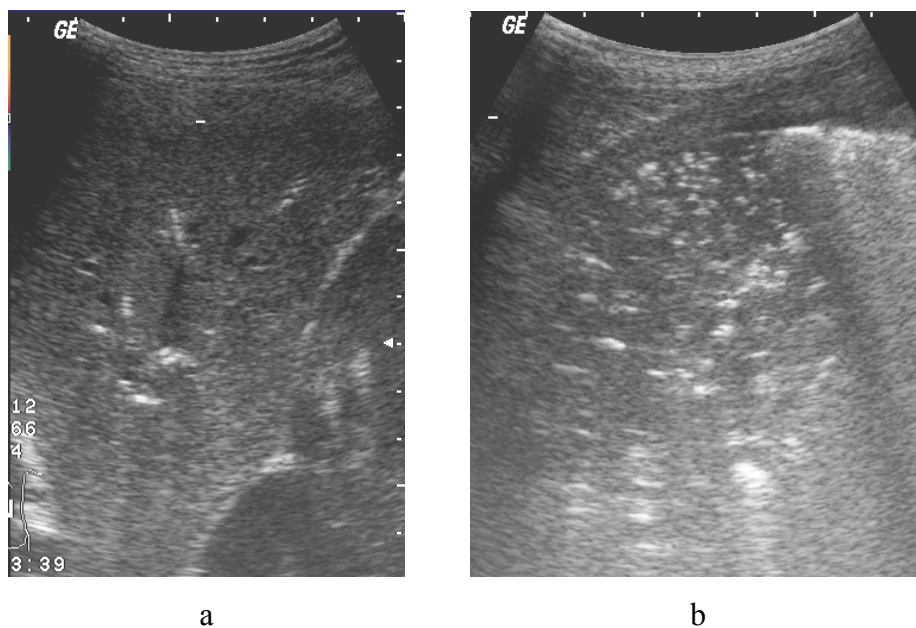


Figure 25 Colligated abszess with persistent fever. Ultrasound-guided aspiration showed surprisingly tubercle bacilli.



Figure 26 Changing of pneumonia in ultrasound corresponding to the clinical course. A: Day 1, B Day 5



Tuberculosis

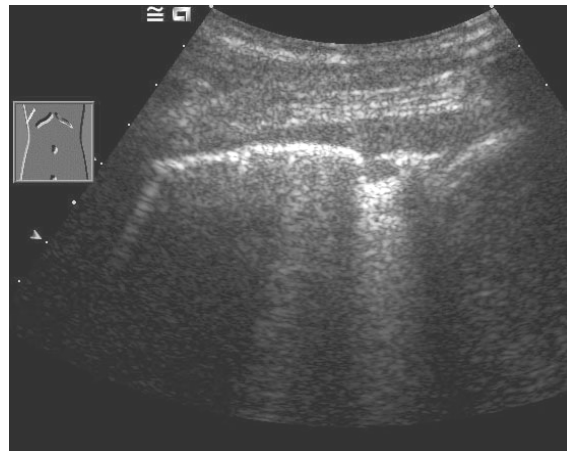
Pulmonary tuberculosis is polymorphic on x-ray as well as on chest sonography. In sonography tuberculosis lung lesions can be round or irregular shaped and of a relatively homogeneous texture. (Fig 27). The imaging of these lesions may be facilitated by the

presence of a pleural effusion. Miliary tuberculosis is characterized by a nodular dissemination in terms of multiple subpleural nodules measuring several millimetres in size. However, the presence of air in the tuberculous cavern may prove disturbing and limit visualization. The patient's response to tuberculostatic treatment can be evaluated by sonography, especially in cases of pleural effusion and subpleural tuberculosis (Tab. 4).

Table 4 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

Figure 27 Tuberculosis. Lymphocytic pleural effusion, a subpleural nodule – Diagnosis by ultrasound guided biopsy



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 thickened, irregular/fragmented pleural line indicate the presence of interstitial

changes. In this setting, sonography is nearly meaningless as a primary diagnostic tool. Here, the value of sonography lies in the detection of minimal pleural effusions and subpleural infiltrations in follow up.

Pulmonary embolism

Several minutes after occlusion of a pulmonary subartery, the surfactant collapses. Interstitial fluid and erythrocytes flow into the alveolar space. This hemorrhagic congestion offers ideal conditions for ultrasound imaging. These consolidations are open at the periphery along with their base, which creates good conditions for transthoracic sonography. The frequency of hemorrhagic reperfusionable pulmonary infarction is much higher than reported, proven by new imaging procedures (Fig 28). Sonomorphologic criteria of peripheral pulmonary embolism are listed in Tab. 5.

Figure 28 Pulmonary embolism. A 1.2 – 1.5 mm triangular subpleural lung consolidation. B. Vascular sign at the margin, not central

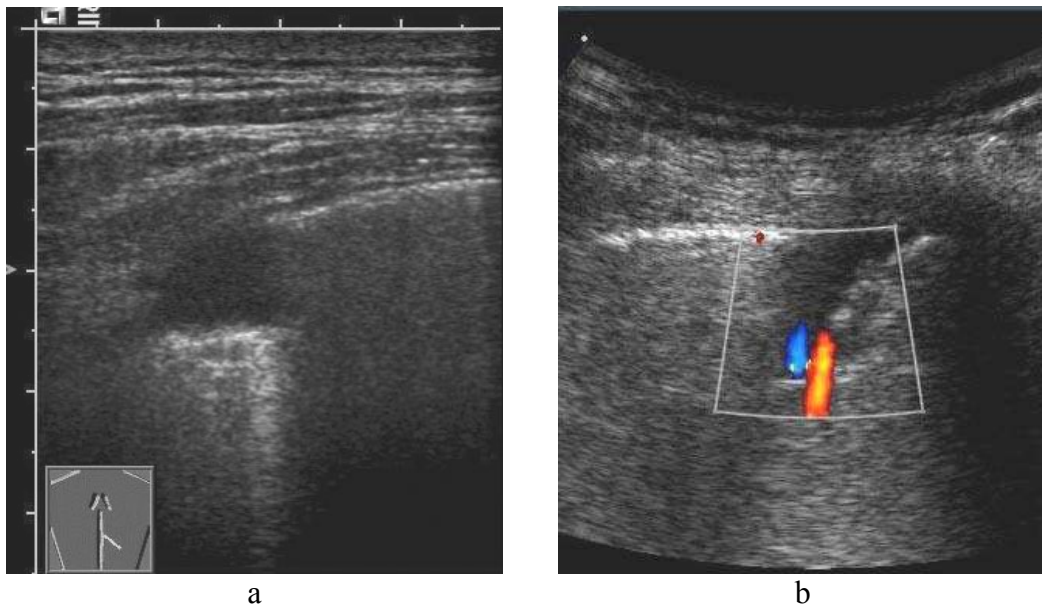


Table 5 Sonomorphology of peripheral pulmonary embolism (21)

- 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

In color Doppler sonography pulmonary embolism-based subpleural lung consolidations do not show flow signals in center of the lesions, sometimes the stop of blood flow at top of the wedge (19,20). In contrast agent-enhanced ultrasound very slow and minimal enhancement has been described. Infectious pleuritis or pleuropneumonia can be differentiated by early enhancement and intensive saturation (21).

The overall sensitivity of chest sonography in pulmonary embolism is 80%, the specificity 94%. In dynamic process of thromboembolism chest sonography should be performed in context to echocardiography und leg vein sonography. With one system, using US one can “kill three birds with one stone”: source, way and outcome of pulmonary embolism (22, 23). Combination of these three applications enhances the sensitivity of sonography to 92%, while this accuracy can not be reached with any other imaging method.

Pulmonary carcinomas and metastases

Lung carcinomas and metastases are sonographically visualized as hypoechoic or moderately echogenic inhomogeneous structures. Mostly they are round, oval or polycyclic. Pulmonary malignancies may have a variable echotexture sometimes with echopoor necrotic areas. They frequently have sharp margins and fringed or finger-shaped ramifications into the ventilated lung (Tab.6, Fig 29).

T-staging: In dynamic US-examination, malignant invasion of the chest wall or subclavian vessels can better depicted by US than in CT (89%-10% vs 42%-68%). The following are reliable criteria for infiltration of the thorax wall: direct evidence of infiltration of the wall structures and rib destruction. An interruption of the pleural reflex and/or limited respiratory motion of the subpleural consolidation provides an indication but not proof of infiltration of the chest wall. Inflammatory accompanying reactions can also cause these signs. Malignant

invasion of the chest wall frequently causes local pain. Targeted US-investigation of the region will help to diagnose the condition immediately (5, 24).

N-staging: US of the supraclavicular and lower cervical lymph nodes has a special role in the staging of bronchial carcinoma since lymph node metastases are identified in 16-26% of all patients. For malignancy criteria for lymph nodes see Chap... Routine ultrasound evaluation of supraclavicular lymph nodes reveals suspicious lymph nodes three times more than by palpation, 18%-36% more than in CT.

Ultrasound guided biopsy proves malignancy and thereby a N3 or M1 stage (5).

In color Doppler sonography, tumor-vessels are irregular and corkscrew like.

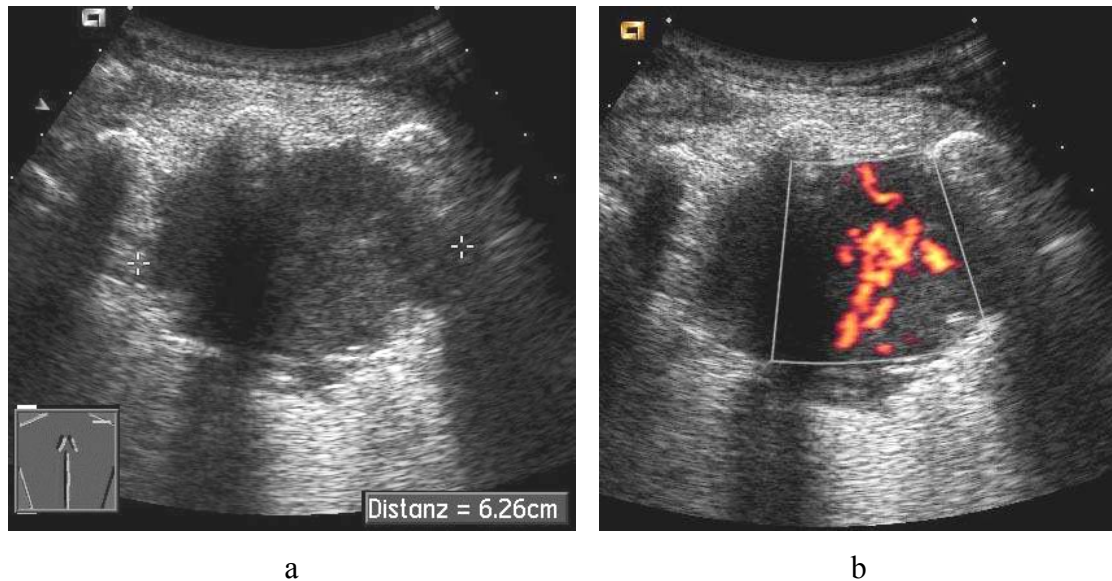
Reduced vessel visualization is observed in epidermoid and small cell cancers, supplied by bronchoarterial Neovascularization. Flow signals can be derived from pulmonary arteries in several tumor tissues, particularly in the case of adenocarcinoma and bronchioloalveolar carcinomas.

Contrast agent-enhanced ultrasound shows a delayed start of contrast agent uptake and reduced contrast enhancement. This is an indication of predominant bronchial arterial vascularization (21).

Table 6 Sonomorphology of pulmonary carcinomas

- Hypoechoic, inhomogeneous
- Rounded, polycyclic
- Sharp, serrated margins
- Ramifications and fringes
- Infiltration of chest wall
- Irregular vascularization

Figure 29 Lung cancer. A rounded, tumoral fringes, central echopoor necrotic lesion with B irregular neovascularization



The advantages of ultrasound-guided biopsy are manifold: fast availability, low complication rate, the absence of radiation, and low costs.

Atelectasis

Lung atelectases are characterized by partial or complete absence of ventilation.

Compression atelectasis is caused by voluminous pleural effusion. It is largely apneumatic and liver-like. The patient may develop triangular, hypoechoic consolidations shaped like a wedge or a pointed cap and show blurred margins to ventilated lung parenchyma (Fig. 30). The compression atelectasis is floating in the effusion like a waving hand (17, 19). These are partial reventilated during inspiration and after puncture of effusion. In color Doppler sonography atelectasis shows increased branch-like vessel visualization (20).

The sonographic image of **Obstructive atelectasis** is marked by a largely homogeneous, hypoechoic presentation of lung tissue in terms of hepatisation. Effusion is absent or small. Depending on the duration of atelectasis, intraparenchymatous structures may also be seen: hypoechoic vascular lines and echogenic bronchial reflexes. Secretory congestion of bronchi presents a fluid bronchogram. The image is similar to that of pneumonia but with significantly less air bronchograms. Obstructive atelectasis has a variable shape. In the case of lobar atelectasis, the border to the ventilated lung is clear and smooth. Sometimes it is also possible to detect an underlying central tumor (19). On color Doppler sonography, regular vessels along the bronchi are seen. Contrast enhanced ultrasound is very similar to pneumonia, but seldom necessary (23).

In cases of blunt chest trauma, especially serial rib fractures, **pulmonary contusions** are seen better on sonography than on radiographs in up to 18%. Alveolar edema and alveolar hemorrhage caused by trauma are visualized as hypoechoic, plate-like lesions bordered partially clearly and partially unclearly with respect to the ventilated lung (Fig. 31). These are more pronounced in the presence of concomitant pleural effusion (25).

Figure 30 Compression atelectasis: cap-like hypoechoic transformation of lung parenchyma

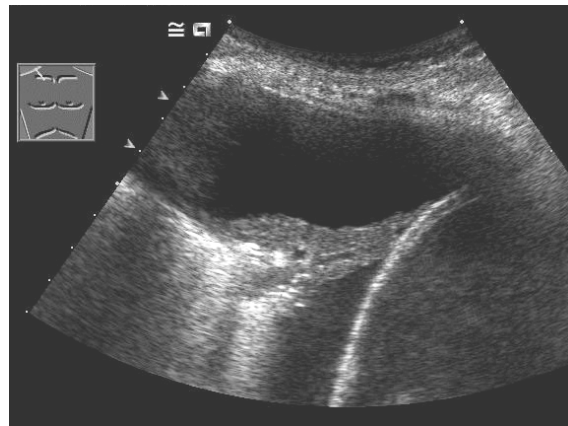
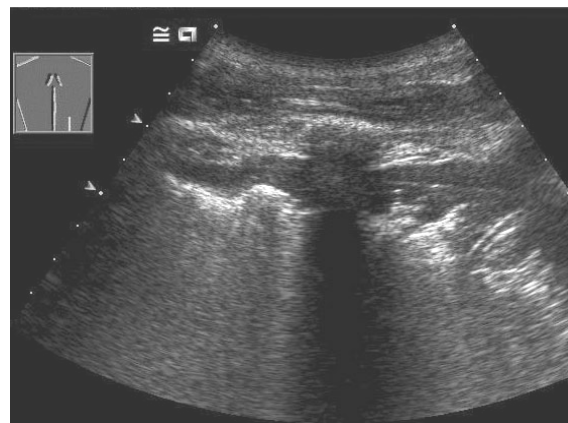


Figure 31 Lung contusion: plate formed subpleural lung consolidation.



Interstitial syndrome

Using thoracic ultrasound for diagnosing the interstitial syndrome is one of the easiest ultrasound skills to learn. The interstitial lung involvement in heart failure, ARDS, pulmonary

fibrosis and interstitial lung infections share a similar sonographic pattern, extremely easy to be detected by bedside thoracic ultrasound in critically ill and emergency medicine patients (26, 27). Although poorly specific, the sonographic diagnosis of interstitial syndrome is highly useful in many clinical scenarios, such as in the differentiation between pulmonary edema and exacerbation of COPD during acute respiratory failure (28). The technique is based on the recognition of lung sliding and some vertical artifacts, the *B lines*, generated by multiple reflections of the sonographic beam trapped between the air alveolar content and water-rich structures. 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 (Fig 32). Once visualized the pleural line, between and below two adjacent ribs by a longitudinal scan, the probe should be slightly turned to obtain an oblique scan (Fig 33). The diagnosis of the diffuse interstitial syndrome is based on 3 basic steps. i) 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 (Fig 33, right panel). ii) Diagnosis of a positive single scan (Fig 33, right panel), 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 (Fig 34). iii) Diagnosis of a positive examination, defined as at least two positive scans per side (Fig 35) (27). Isolated positive scans identify the focal interstitial syndrome, which has a different meaning and can be visualized in the area surrounding alveolar consolidations or even in normal lungs.

In addition to the differential diagnosis of a cardiac cause of acute respiratory failure, lung ultrasound for B lines has been shown to be useful also to monitor pulmonary congestion in heart failure and hemodialysis, to assess the extravascular lung water in cardiac patients, to stratify the prognostic risk in chest pain and dyspnea.

Figure 32 The areas of thoracic ultrasonography. Areas 1 and 2 upper anterior and lower anterior. Areas 3 and 4 upper lateral and basal lateral. Each area is the same on both sides. AAL: anterior axillary line, PAL: posterior axillary line.

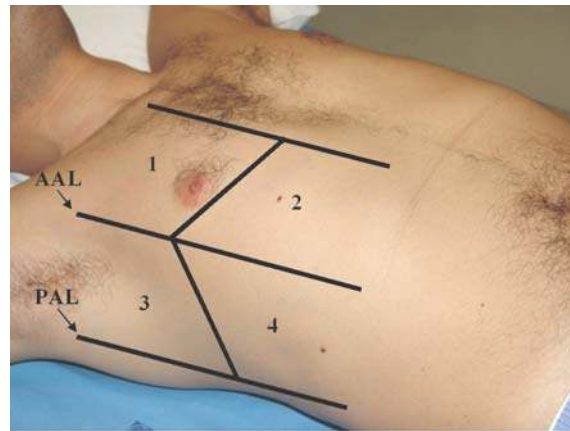


Figure 33 Left panel: sonographic oblique lung scan obtained by positioning the probe along the intercostal space, showing no vertical artifacts below the echogenic pleural line. Right panel: lung scan showing multiple and close echogenic vertical artifacts arising from the pleural line and spreading up without fading to the edge of the screen: this is a positive scan for B lines.

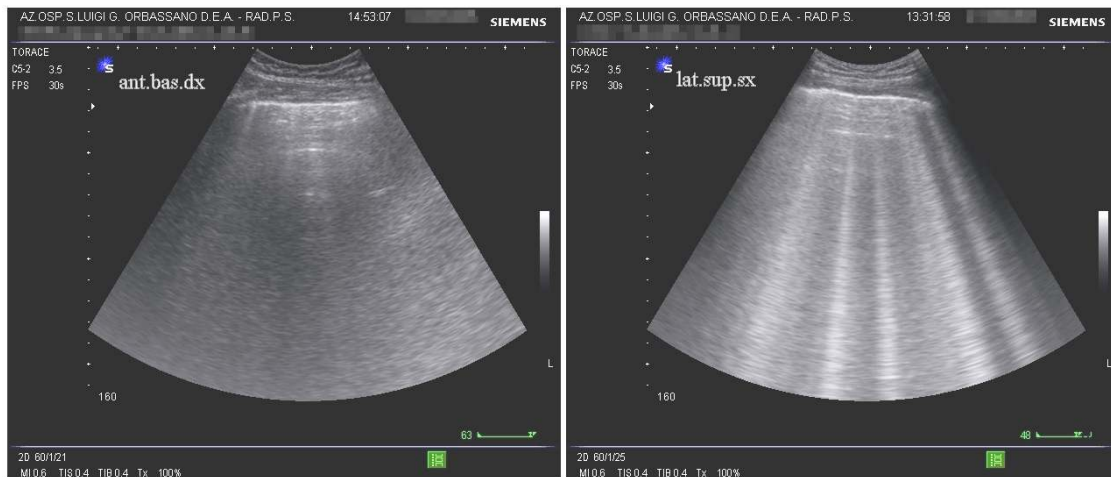


Figure 34 Oblique sonographic lung scans showing only one isolated b line (left panel) or multiple B lines far from each other (right panel). These patterns are still not significant of interstitial syndrome. White arrows: pleural line; asterisks: B lines.

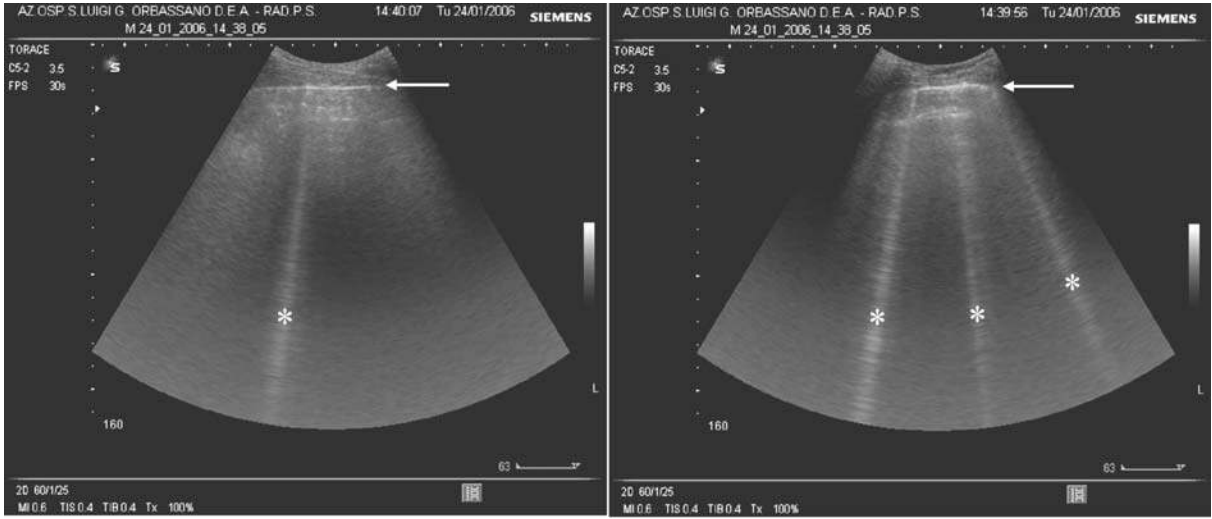
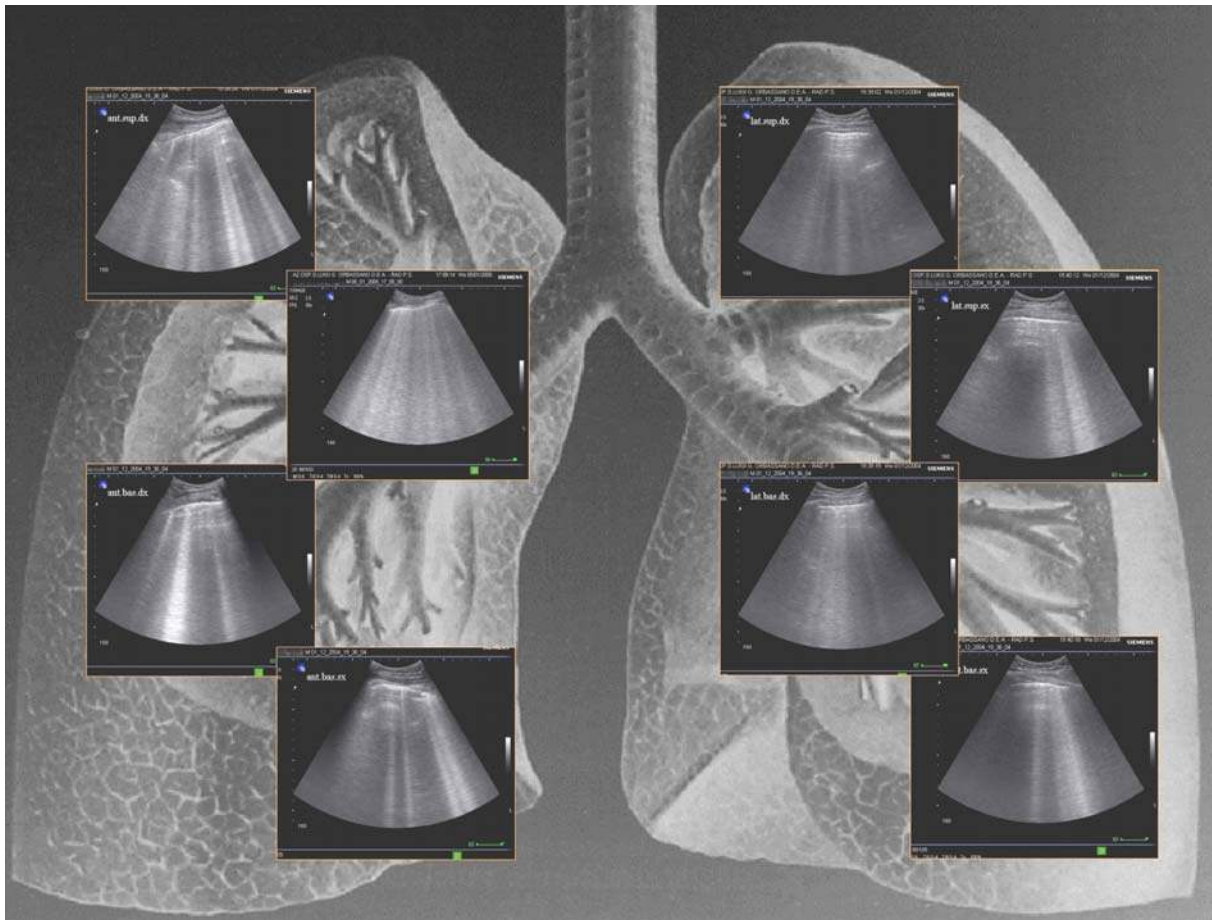


Figure 35 Thoracic ultrasound examination is considered positive for interstitial syndrome when at least two scans per side show multiple B lines: in this case (cardiogenic pulmonary edema), positive scans are detected all over the anterolateral chest.

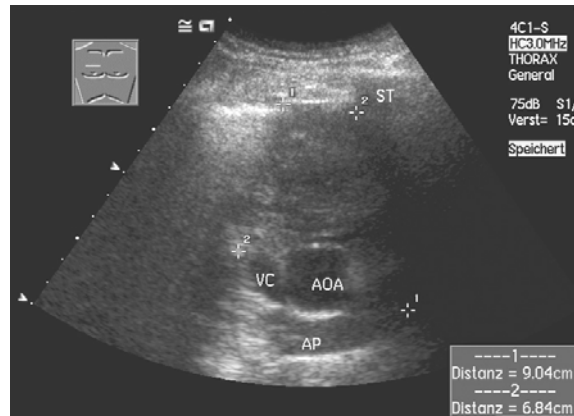


Mediastinum

Most of clinically relevant space-occupying masses in the adult mediastinum are located in the anterior and mid mediastinum and therefore readily accessible for sonographic assessment. Sonographic access of the mediastinum is obtained by a suprasternal or parasternal approach; the infrasternal path is chosen occasionally. Profound knowledge of anatomy is absolutely essential. Lesions of the anterior superior mediastinum may be identified clearly as solid or cystic. Tumors that appear at the margin of the sternum are easily localized and biopsied. Ultrasound examination may demonstrate regression after the treatment of mediastinal lymphoma or metastases (Fig 36). Inflow congestion, respectively, superior vena cava syndrome can be cleared by sonography. Color Doppler may detect

collateral vessels (29, 30). The development of endoscopic ultrasound (endobrochial and transesophageal) has opened up new diagnostic possibilities for detection and analysis of mediastinal lymph nodes.

Figure 36 Malignant Non-Hodgkin-Lymphoma in the upper anterior mediastinum. AOA= Aorta ascendens, AP= pulmonal artery, ST= sternum, VC= vena cava



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