
Transthoracic Ultrasound

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Key Words

Chest ultrasound · Thoracic imaging · Pleural mass ·
Pleural effusion · Ultrasound guidance

Abstract

Sonography (US) has inherent limitations for thoracic imaging because sound waves are reflected by bone and air space (such as in lung parenchyma). However, US is less expensive and more convenient than computed tomography (CT) or magnetic resonance imaging (MRI); it provides immediate information with real-time imaging, and can give information not available from a standard radiograph. This review describes the utility and limitations of US and compares US with radiography.

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Introduction

The sonographic diagnostic of the chest is limited by its bony delimitation (ribs, spinal column, sternum, clavicle) and the gas content of the lung [1]. The normal lung cannot be judged. In pleural pathological processes, ultrasound (US) is however surprisingly expressive [2].

Ultrasonic examination of the chest is a rapidly developing application and may be used to evaluate a wide range of peripheral, parenchymal, pleural and chest wall diseases. The technique is particularly suited to bedside use in the intensive care unit, where suboptimal radiogra-

phy may mask or mimic clinically significant abnormalities and where differentiation of pleural from parenchymal changes can be challenging [3]. Furthermore, US is increasingly used to guide interventional procedures of the chest, such as biopsy and placement of intercostal chest drains. Pathological modifications can be detected, if they are situated in the chest wall, the diaphragm or the upper chest aperture [4, 5].

The Ultrasonic Window

US evaluation of chest lesions is difficult per se for two reasons. First, the air-containing lung parenchyma is a poor US transmitter because it reflects most of the US beam. Structures located deep within normal lung cannot be visualized with US; second, the lungs are well concealed by the ribs, scapulae, and spine. The concept of the US window, however, has greatly expanded the applications of US in the diagnosis of chest diseases [1, 2, 6]. The US window is created by consolidation of lung parenchyma or pleural effusion interposed between the lesion and the chest wall, which allows the US beam to penetrate and visualize lesions deep within the lung parenchyma. The range of chest diseases for which US may yield useful diagnostic information has expanded to include not only the chest wall [7]. Only patients with lesions that have a US window, however, are suitable for US-guided transthoracic needle biopsy.

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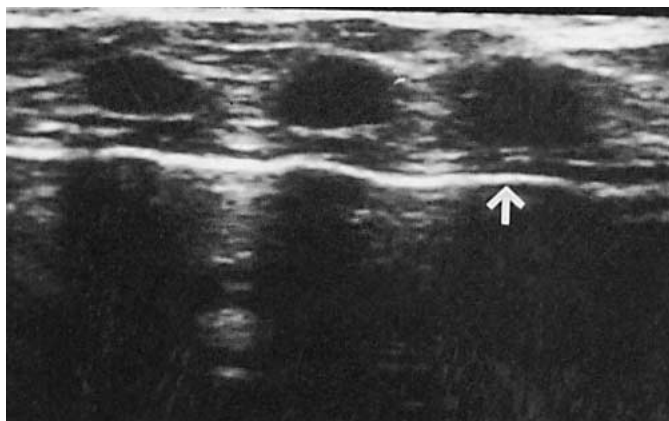


Fig. 1. Normal US appearance of the chest. Below the relatively echogenic subcutaneous tissue, the intercostal muscles appear hypoechoic, but contain multiple echogenic fascia planes. The pleural interface appears as an echogenic line.

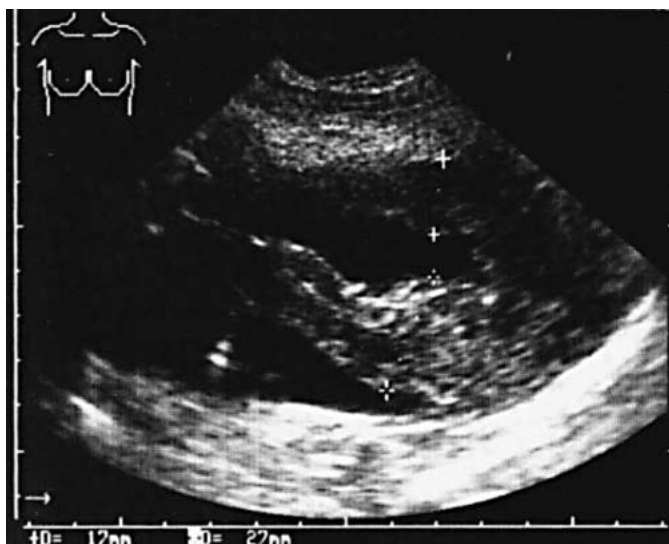


Fig. 2. A large anechoic effusion with passive atelectasis of the underlying lung is seen.

Equipment

US equipment suitable for thoracic imaging includes instruments equipped with 3.5-, 5.0-, 7.5-, and 10-MHz linear, convex and sector transducers. Most series provide color Doppler US. Patients are scanned in the supine or prone position using an intercostal approach. A water-soluble US transmission gel is applied to the skin as a cou-

pling medium. The lesion is first localized using gray scale, real-time US imaging. A high-frequency (i.e., 5 or 7.5 MHz) linear or convex transducer is used to examine lesions in the near field including pleural or chest wall lesions. A lower frequency (i.e. 3.5 MHz) transducer is used for evaluation of deeper lesions. A sector transducer is used for lesions with a small US window or to scan through a narrow intercostal space. The liver and gallbladder are used as intrinsic references for solid and fluid lesions [1, 5, 6, 9]. Scanning should be performed during quiet respiration [6, 7, 9, 10]. Sonographic views of the upper anterior and middle mediastinum can be obtained via a suprasternal approach [11, 12]. This is performed with the patient in the supine position, with shoulders supported with a pillow and head extended backward. Color Doppler US is helpful in distinguishing the great vessels from any mediastinal mass [13].

Sonographic Findings

On US, the normal chest wall appears as multiple layers of soft tissue echogenically representing muscles and fascia. When the transducer is oriented perpendicular to the intercostal space, the normal ribs appear as curvilinear echogenic structures with posterior acoustic shadowing. US can demonstrate replacement of the normal bone by either soft tissue or fluid [9].

The parietal and visceral pleura appear as two thin, bright echogenic lines just beneath the chest wall. On real-time US, the pleural lines can be seen to glide over each other during respiration. The adjacent air-filled lung is a highly reflective interface that blocks transmission of the US beam and appears as a series of bright echoes caused by reverberation artifacts (fig. 1) [1, 9, 10].

Chest Wall

A chest wall tumor usually appears as a hypoechoic mass within the soft tissues of the chest wall. When a chest wall lesion invades the ribs, US can demonstrate the associated bone destruction [7, 9].

Pleural Effusions

Pleural effusions are characterized by the echo-free space between the visceral and parietal pleura whose shape can change with respiration (fig. 2) [14]. There are four sonographic appearances of pleural effusion: anechoic, complex nonseptated, complex septated, and homoge-

neously echogenic [15]. The echogenic material or fibrin strands may float within the pleural effusion (fig. 3).

The ultrasonographic characteristics of a lung abscess include an irregular wall width, a blurred outer margin, an oval or round shape, an acute chest wall angle and a negative pleural separation. If the patient is scanned in the sitting position, an air/fluid level may be seen. The air within the nondependent portion of the abscess appears hyperechoic with posterior acoustic shadowing, while the fluid portion is heterogeneously echogenic. The ultrasonographic characteristics of empyema are a uniform wall width, a sharp outer margin, a lenticular shape, an obtuse chest wall angle and a positive pleural separation [15–17].

In a prospective study, Wu et al. [16] concluded that chest US is a useful tool in the differentiation between lung abscess and empyema and that US alone is often sufficient to make a correct diagnosis.

Pleural Thickening

Pleural thickening is defined as focal echogenic areas greater than 3 mm in thickness with irregular margins arising from the visceral or parietal pleura. A breathing-dependent change in the configuration speaks for effusion, a regular delimitation, for pleural thickening, an irregular delimitation, for a tumor [18, 19] (fig. 4). Abscesses are fixed with the environment and are therefore no longer dependent on breathing.

Previous asbestos exposure is a relatively common cause of pleural thickening and can be confirmed if calcified pleural plaques are evident. These plaques cause focal areas of dense reflectivity with dense posterior acoustic shadowing, often with evidence of adjacent noncalcified pleural thickening.

Peripheral Lung Tumors

Peripheral lung tumors appear as homogeneous well-defined hypoechoic or echogenic masses with posterior acoustic enhancement [1, 20, 21]. If the tumor extends to the pleura, the pleural line may be interrupted. The consolidated lung appears as a triangular-shaped isoechoic or hypoechoic area that moves with respiration [9]. Air bronchograms are visualized as branching hyperechoic lines arising from the hilum [9, 20] that move with respiration. A fluid bronchogram appears as a branching hyperechoic tubular structure with an anechoic lumen and no blood flow on Doppler US. Fluid bronchograms are usually observed within a consolidated lung distal to an obstructing central airway lesion.

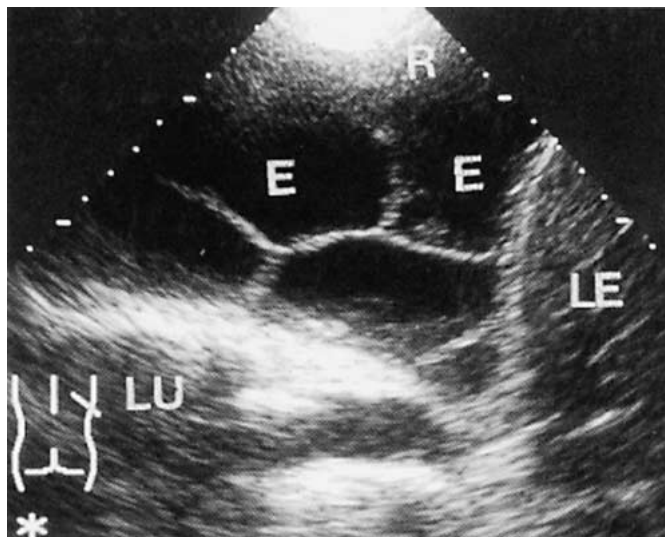


Fig. 3. A large effusion within fibrinoid membranes.

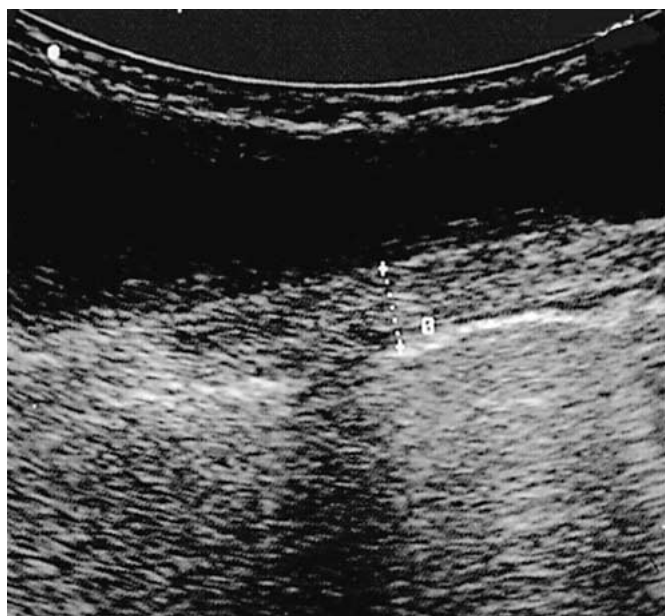


Fig. 4. US demonstrates pleural thickening as a hypoechoic band.

Pleural Masses

Pleural masses present sonographically as an irregular, hypoechoic, knotty or planar widening along the pleura; the probability of a malignant process increases with thickness. A widening of the pleura of more than 1 cm is considered highly suspicious of being a malignant tumor (fig. 5) [19, 22].

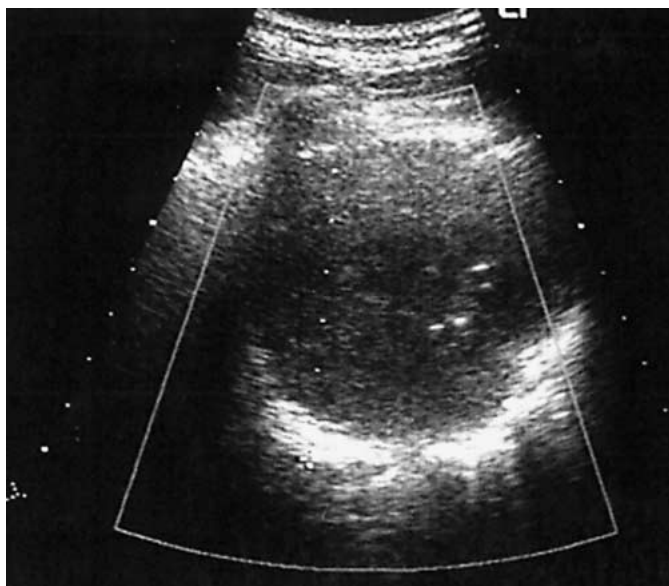


Fig. 5. Malignant mesothelioma.

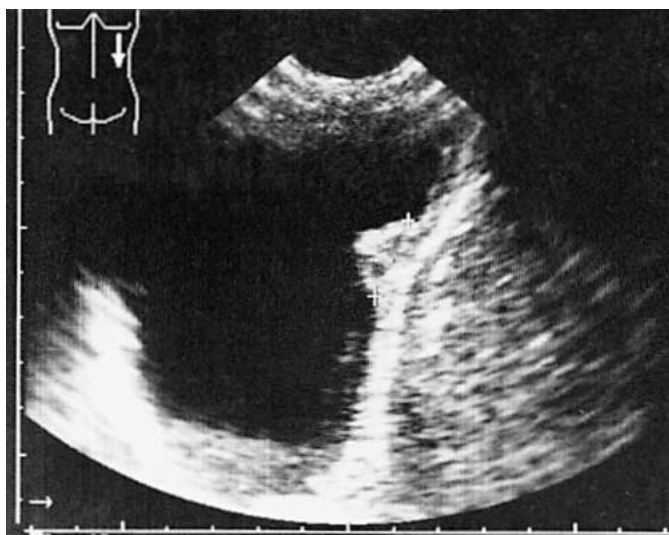


Fig. 6. Pleural metastasis, located on the diaphragm.

Usually, an accompanying pleural effusion is additionally expanded. An effusion is helpful for the visualization of the tumor and favors the sonographic differentiation of the parietal and the visceral pleurae.

The breathing dependency of the lung during the breathing cycle is reduced. Particularly pronounced echo-rich and irregular reflexes are at the transition to a

ventilated lung. They correspond to reinforcement artifacts [23]. In individual cases, distinction may be difficult due to the presence of thickening, coagels, detritus or pseudotumors. However, it is often possible if all relevant clinical factors are known. US should be carried out before attempting invasive methods such as thoracoscopy.

Metastases may also appear as diffuse thickening of the parietal pleura and, to a lesser extent, the visceral pleura. Malignant pleural disease may invade the chest wall, with poor demarcation of the pleural mass and infiltration into the chest wall (fig. 6) [1, 2].

Pneumothorax

Although a pneumothorax can usually be seen on a chest radiograph, a small pneumothorax may be overlooked on a radiograph of a supine patient obtained in the intensive care unit. Absent lung sliding, exaggerated horizontal artifacts, loss of the comet tail artifact and broadening of the pleural line to a band are the key sonographic signs [24, 25].

Bedside US is useful for excluding pneumothorax [26]. Use of a combination of absent lung sliding and loss of the comet tail artifact have a reported sensitivity of 100%, specificity of 96.5%, and a negative predictive value of nearly 100% [27].

Pulmonary Embolism

An area of pulmonary infarction may be recognized at US as a peripheral wedge-shaped hypoechoic region [28–30]. Early infarcts are less well defined, but become more demarcated with time. A central hyperechoic structure, corresponding to a bronchiole, may be visualized (fig. 7). In addition, a congested vessel leading into the infarct may be seen. As in the case of pneumonia, the area of pulmonary infarction demonstrable at US is usually smaller than that seen at angiography or scintigraphy.

Although the technique has been advocated with enthusiasm with a reported sensitivity of 77–98% and a specificity of 66–83% [28, 29], the experience has not been universal. With the increasing use of pulmonary CT angiography, US is unlikely to change current clinical practice in the initial diagnosis of pulmonary embolism.

Lymph Nodes

Lymph nodes, particularly within the axilla and supraclavicular fossa as well as in the mediastinum, are easily examined with US.

Reactive lymph nodes are oval or triangular in shape, demonstrating an echogenic fatty hilum that may become

even more prominent with inflammation. Malignant lymph nodes usually appear plump, rounded, hypoechoic, with loss of the fatty hilum [4–6]. Irregularity in the borders of these lymph nodes suggests extracapsular spread.

Puncture Techniques

No diagnostic criterion is known, by which pleural masses could be differentiated of a pleural tumor of other genesis (carcinomatosis of pleura, nonspecific pleuritis). A histological confirmation of the diagnosis is therefore essential [1, 7, 8].

Depending on the findings, the puncture can be done by means of a fine needle, a hand-guided or an automated puncture needle (fig. 8, 9). The process, which can be delineated by a dotted line, should be clearly identified and localized before the puncture.

The most important contraindications for this diagnostic method are lacking cooperation, severe coagulation disturbances and advanced lung illness with an FEV₁ <1.0 liter. Furthermore the patient must be informed of the risks and the methodology, and taught the breathing technique because the puncture is best performed in the supine position. There are three different puncture techniques [31–33].

Pleural Process

US can be used to guide biopsy of the pleura, either with a standard Tru-cut needle or an automated cutting needle device (18 or 20 gauge). The biopsy may be performed with either a needle guide with the US probe or by freehand insertion of the needle. The passage of the tip of the needle can be seen in real time, confirming sampling of the lesion. US has a reported sensitivity of 97% and an accuracy of 98% in the diagnosis of peripheral lung cancer [2, 34, 35]. In tumors exhibiting central necrosis, US is particularly helpful in directing biopsy to the solid viable portions of the tumor with improved sensitivity [36]. Biopsy with a cutting needle is preferred to fine-needle aspiration because of its higher diagnostic yield, and as it allows identification of histological subtypes, it has a higher specificity for benign lesions.

The complications in the context of punctures involve bleedings, infections, violation of the visceral pleura with pneumothorax, hemoptysis, tumor cell kidnapping in the container system as well as local tumor cell propagation along the passage of the transthoracic puncture [31, 37].

The complication rate in punctures of pleural lesions by means of US or computer tomography is comparable

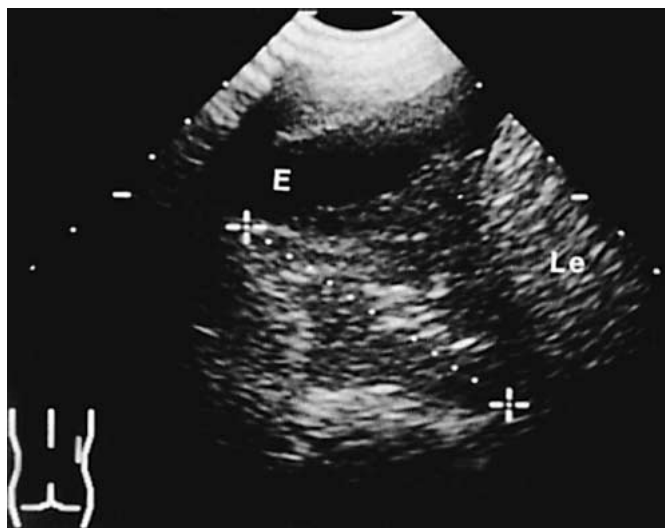


Fig. 7. Early sonographic finding in pulmonary infarction.

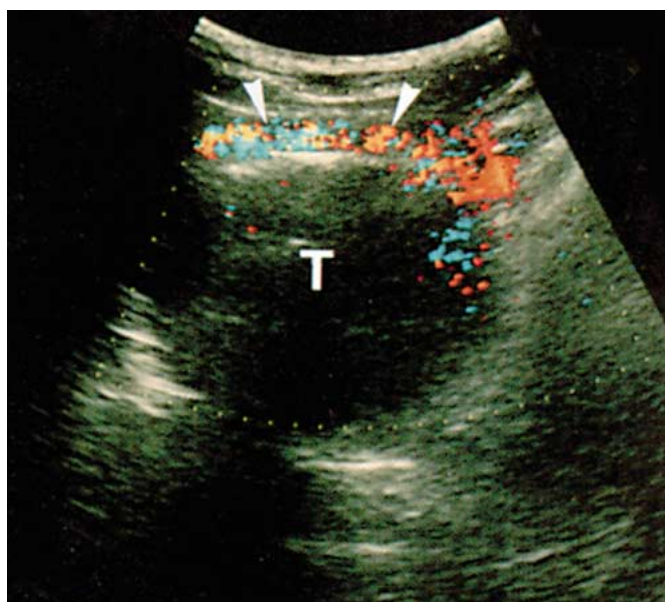


Fig. 8. Pulmonary tumor with an artery overlying the tumor (T).

and amounts to about 3–5% when performed by experienced examiners [2, 31].

Although US-guided fine-needle aspiration with 19- to 22-gauge needles is safe and provides a high diagnostic yield for lung cancer, this technique has several limitations. Some investigators have suggested that whereas the small tissue fragments obtained by fine needle aspiration

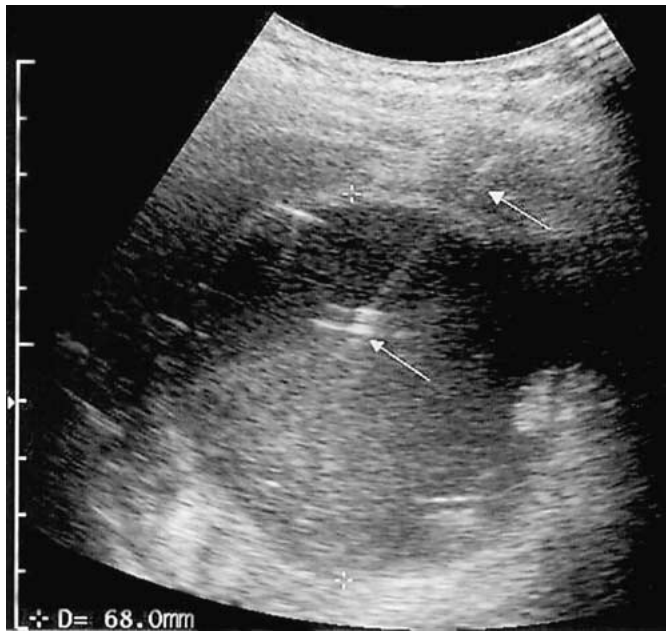


Fig. 9. Needle puncture of a pleural mass.

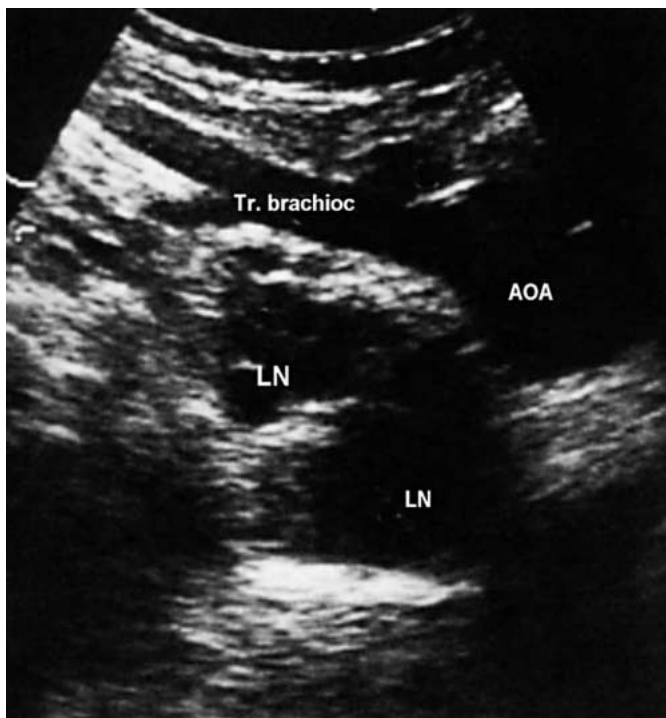


Fig. 10. Suprasternal view to paratracheal lymph nodes (LN). Tr. brachioc. = Truncus brachiocephalicus; AOA = descending aorta.

are adequate for both cytological and histological examinations, these specimens are often insufficient for detailed histological studies. This is important since the accurate identification of cancer cell type by fine-needle aspiration is not always possible. Another concern is the reliability of a nonspecific benign or 'negative' result. Although multiple passes may increase the diagnostic yield for malignant lesions by 35–45%, a negative but non-specific result does not confidently exclude malignancy [38, 39]. In a study comparing US-guided large-bore cutting-needle and fine-needle aspiration biopsy of thoracic tumors, Yang [38] has shown that a 16-gauge large-bore Tru-cut biopsy is as safe as fine-needle aspiration. More importantly, the diagnostic accuracy of large-bore Tru-cut biopsies was found to be significantly greater than that of fine-needle aspiration. Large-bore Tru-cut biopsy is particularly useful in the histological diagnosis of benign lesions. While the sensitivity of fine-needle aspiration for benign lesions is only 33% [34], the yield may reach 85% with large-bore Tru-cut needle biopsies [39].

US in Critically Ill Patients

US is particularly useful in the evaluation of critically ill patients with chest disease. Portable chest x-ray devices often fail to depict parenchymal and pleural lesions and the adjunctive use of US in the intensive care unit is helpful in the detection of pleural and peripheral lung disease [3]. Since US can be performed at the patient's bedside, transportation of monitored patients or those on life-support systems to the radiology department is not necessary. An additional advantage is that patients can be examined in any position. Invasive diagnostic procedures including thoracentesis, drainage of pleural effusion, empyema or abscess, and transthoracic needle biopsy can all be performed accurately and safely at the bedside.

Mediastinal Diagnosis

Considering the potential difficulties, a surprisingly large number of mediastinal compartments are very well visualized with US when 3.5-MHz sector or curved-array transducers are applied to the proper windows. Color Doppler imaging helps in the identification (fig. 10) and avoidance of the major vessels within the mediastinum. Bruggemann et al. [40] performed real-time scanning of 100 healthy adults to determine which structures were reliably visible. They found that the aortic arch arteries

and trachea were seen from the suprasternal approach in all cases; the brachiocephalic veins and superior vena cava were visible in 98%, and the pulmonary artery and the aortopulmonary window were seen in 92% of the subjects. The parasternal windows were scanned with the patient in the decubitus position. The left side gave the best results, with the heart and great vessels seen 91 and 59% of the time, as opposed to 32 and 28% for the right side.

These results were further refined in larger series that compared chest radiographs with CT and US [12]. There were 182 patients, of whom 134 had mediastinal masses of various origins, including lymphoma, lung cancer, primary mediastinal tumors, and metastases from distant sites. The supra-aortic, paratracheal, prevascular, and pericardial tumors were detected with an average sensitivity of 95%. Subcarinal and aortopulmonary window lesions were somewhat more difficult to see, with the sensitivity of US being 69 and 81%, respectively. The posterior mediastinum and paravertebral regions were poorly seen, with 6 and 11% sensitivities. In all regions, the specificity of US was 99 or 100%. In all but the paravertebral compartment, US was far superior to radiography, with CT as the 'gold standard'.

Adenopathy is the most common abnormality that will be encountered during US scanning of the mediastinum. Diseased nodes are mostly hypoechoic, whether they are due to lymphoma, metastatic cancer, or inflammatory processes. Calcification is characterized by bright-shadowing foci, as in other locations. Normal lymph nodes are virtually invisible because they are isoechoic with respect to relatively bright mediastinal fat [41, 42]. After specific treatment, abnormal lymph nodes shrink and become more hyperechoic until they become invisible [41, 43].

Advantages and Limitations

There are several advantages to using US. US is relatively inexpensive, does not entail exposure to radiation, does not restrict image direction, is easy to handle, and can be performed at the bedside in critically ill patients. Most importantly, US can provide real-time dynamic images even during transthoracic biopsy, and enables the operator to be sure of exactly what the needle is targeting or has passed through. The flexibility and short examination time also make repeated examination possible. Chest US examination is easily mastered, and the equipment required is similar to that used for evaluating hepatobilia-

ry, renal, or gynecologic diseases. The facilities are available to most physicians and can be shared between different departments.

US also has some disadvantages. First, because the US wave is easily hindered by air, as in an aerated lung or pneumothorax, an US window is a prerequisite for chest US examination. In addition, US achieves only poor visualization of the mediastinum as compared with CT scan, cannot visualize the airways, has a restricted field of vision, and is operator dependent.

Conclusion

US of the thorax offers an important contribution to the diagnostic procedures of the chest. It performs nearly as well as CT in the costal and diaphragmatic portions of the pleura.

US is the simplest and most sensitive technique to image and measure pleural fluid. Sonographic evidence of pleural nodules is a specific finding in patients with malignant effusions. Peripheral pulmonary consolidations are visible by US if they extend up to the pleura. Pleuritis, pneumonia, lung cancers, pulmonary infarction, and atelectasis with typical sonomorphology can be visualized by US, but with limited specificity. US-guided transthoracic puncture is minimally stressful to the patient, is accurate, has a low rate of complications and is also cost effective.

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