Chapter 3

Ultrasound Diagnosis of Chest Diseaseses

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1. Introduction

Ultrasound (US) has been proved to be valuable for the evaluation of a wide variety of chest diseases, particularly when the pleural cavity is involved. The advantages of US are that it is a relatively inexpensive, widely available, mobile form of multi-planar imaging free from ionizing. Chest US can supplement other imaging modalities of the chest and guides a variety of diagnostic and therapeutic procedures. Under real-time US guidance the success rates of invasive procedures on pleural diseases increase significantly whereas the risks are greatly reduced. Chest US is a useful tool in the diagnosis of pleural diseases and peripheral pulmonary lesions. Moreover, endobronchial ultrasound (EBUS) is the real advance in recent chest medicine. This chapter will review the application of chest ultrasound and EBUS in chest medicine.

2. Equipment selection and patient position

The suitable probes for chest US are these equipped with 3.5- to 10-MHz linear, convex, and sector transducers. The high-frequency linear probe can exam the detailed signs of pleura and provide assessment of superficial lesions. Commonly a 3.5–5 MHz probe is used which is suitable for imaging adequate depth of penetration of lung. In some expert's opinion, the best probe to use for chest ultrasound in the 5-MHz microconvex probe because it allows access the intercostals space and facilitates to these patients unable to cooperate by sitting. During chest US examinations, patients can be in the seated (Figure 1.1) or supine position (Figure 1.2). The probe is moved along the intercostals space to avoid interference by ribs or sternum. The transducer can be moved longitudinally or horizontally in the chest wall.

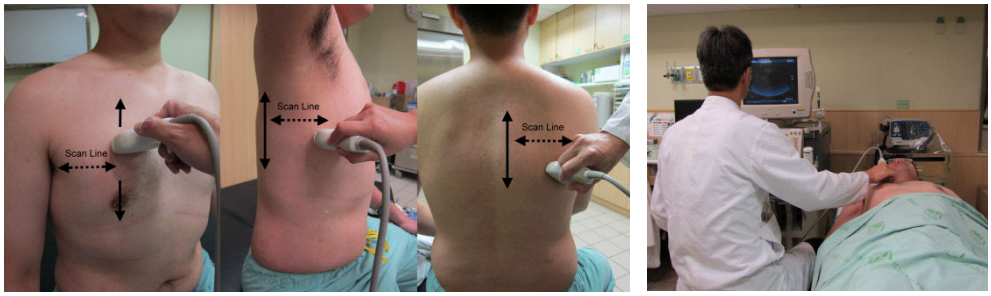

Figure 1. During chest US examinations, patients can be in the seated or supine position (Figure 1.1 on the left; Figure 1.2 on the right).

3. Chest wall: Muscle layers, bone, and pleura

Because air cannot be visualized by US, the normal lung parenchyma cannot be detected by US theoretically. The image of chest US in chest wall including muscle, fascia, bone, and pleura (Figure 2). The soft tissue echogenicity with multiple layers means muscles and fascia. The normal ribs appear hyperechoic surfaces with prominent acoustic shadows beneath the ribs. Approximal 0.5 cm below the ribs shadows, the visceral and parietal pleura appear as an enchogenic bright line. During respiratory movement, the two pleural lines glide with each other which is referred to as the "Gliding sign". Therefore, the "Gliding sign" means normal parietal and visceral pleura slide over each other during respiration and the loss of "Gliding sign" can be seen in pneumothorax or diffuse pleural thickening.

4. Pleural disease

4.1. Pleural effusion

For the purpose of investigation pleural fluid can be divided into three broad categories according to etiology: infective, malignant and miscellaneous. The infective etiologies result in either a para-pneumonic effusion or an empyema. Malignant effusions are due to primary or secondary thoracic disease, which may be pulmonary or pleural. The miscellaneous causes of pleural fluid include sterile benign effusions, haemothoraces and chylothoraces. Pleural effusions are differentiated into transudates or exudates on the basis of biochemical analysis of the aspirated fluid. The erect chest radiograph is the most common first line radiological investigation. Whereas approximately 500 ml of pleural fluid is required before an effusion can be identified clinically, as little 200 ml will blunt the costophrenic angle. US in either a standing or sitting position [1] not only is able to detect smaller volumes of pleural fluid than the erect frontal chest radiograph but it also gives useful information about the nature of the effusion. The pleural effusion images in ultrasound appearances are characterized by an echo-

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free space between the visceral and parietal pleura. The formulae to estimate the volume of pleural effusions are well documented [1-5], but the different variation of actual volume was found in individual condition. The classifications of the volume of pleural effusion known currently are minimal, small, moderate, and massive. The minimal effusion indicate the echo-free space is seen within the costophrenic angle; small effusion indicates the space is greater than costphrenic angle but still within a one-probe range; moderate effusion indicates the space is greater than one-probe range but within a two-probe; and massive effusion indicates the space is bigger than two-probe range.

4.2. Pleural effusion echogenicity

The strength of ultrasound lies in demonstrating characteristics of the pleural fluid itself. Four basic ultrasounds patterns of internal echogenicity of pleural effusion were identified and they can be subclassified as anechoic, complex nonseptated, complex septated, and homogenously echogenic (Figure 3). Anechoic effusion is defined as echo-free spaces between visceral and parietal pleura. Complex nonseptated effusion is defined as heterogenous echogenic materials inside the pleural effusions. Complex septataed effusion is defined as fibrin strands or septa floating inside the pleural effusions. Homogenously enchogenic effusion is defined as echogenic spots density evenly distributed within the effusion [2, 3]. A purely anechoic collection is found in exudates and transudates with equal frequency. However, internal echoes in the form of septations or focal areas of debris are due invariably to exudates. US presentations in transudative pleural effusions are not always in an anechoic pattern. Transudative pleural effusions may have a complex nonseptated pattern or an anechoic pattern [4].

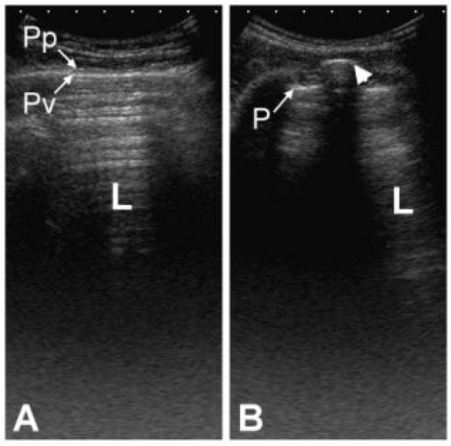

Figure 2. Sonographic images of normal pleura and chest wall using a 5-MHz convex scanner. (A) Transverse image through the intercostal space. The chest wall is visualized as multiple layers of echogenicity representing muscles and fascia. The visceral and parietal pleura appear as echogenic bright lines that glide during respiration (gliding sign). Reverberation echo artifacts beneath the pleural lines imply an underlying air-filled lung. (B) Longitudinal image across the ribs. Normal ribs are seen as hyperechoic chambered surfaces (arrowheads) with prominent acoustic shadows beneath the ribs. Pp, parietal pleura; Pv, visceral pleura; L, lung

There was no transudative pleural effusion with complex septated or homogenously echogenic pattern [5]. The ability of chest US to detect underlying disease was comparable to that of computed tomography (CT) in pleural and parenchymal lesions [6]. The applications of sonographic appearances in effusions of febrile patients in the intensive care unit (ICU) can determine the necessity of thoracentesis in high risk patients with effusion in ICU [7]. This study reported that complex nonseptated and relatively hyperechoic, complex septated and homogenously echogenic pleural effusion patterns might predict the possibility of empyema in febrile patients in the ICU. The sonographic septation in lymphocyte-rich exudative pleural effusions can help us differentiate tuberculosis pleurisy from malignant pleural effusion [8].

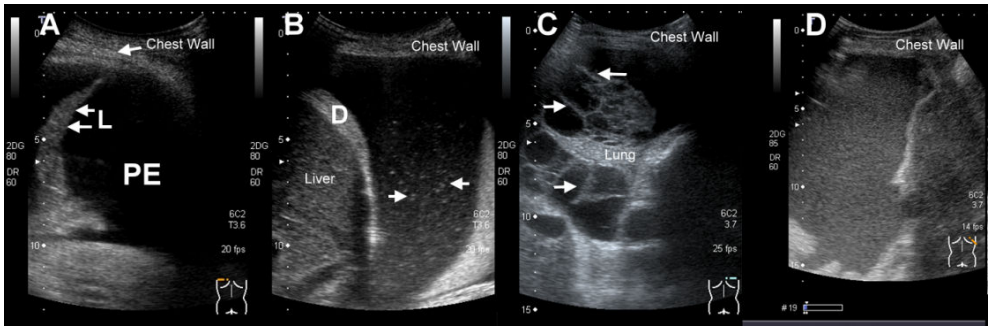

Figure 3. Sonographic appearance of pleural effusion (PE). The effusion can be subclassified as anechoic (A), complex nonseptated with spots(arrows) floating inside effusion. D, diaphragm (B), complex septated (arrows) (C), and homogenously echogenic (D)

5. Pneumothorax

Expiratory erect chest radiographs are the initial examination of choice in suspected pneumothoraces, but the sensitivity of diagnosis was ranging between 50% and 90% [9, 10]. The diagnosis of a pneumothorax on the frontal radiograph is most difficult in critically ill patients where the patient is semi-recumbent and unable to comply with expiratory breath holding. Chest US may be help in the diagnosis of pneumothoraces. Normal parietal and visceral pleura slide over each other during respiration and a pneumothorax is suspected when this 'Gliding sign' is absent in chest US [11]. A recently published systemic review, chest US had a sensitivity of 90.0% and a specificity of 98.2% [12]. The confirmation of lung gliding has a 100% negative predictive value for the absence of pneumothorax [13]. The use of M-mode can also objectify the presence or absence of lung gliding. In the normal lung, the familiar "sea-shore" or "sandy-beach" sign appearance will confirm the presence of lung gliding (Figure 4). In the pneumothorax, the "bar code" or stratosphere sign (Figure 5) is seen [14]. The "curtain sign" describes the variable obscuring of underlying structures by air-containing tissue that movement of air-fluid level denoting a hydropneumothorax (Figure 6).

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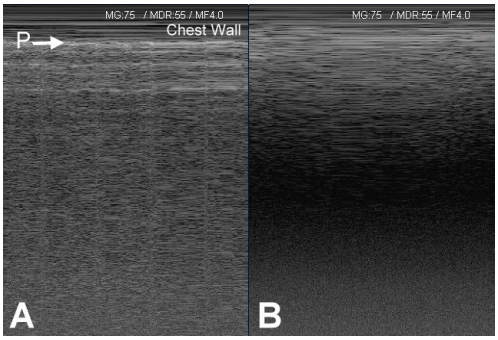

Figure 4. Lung sliding (on M-Mode sonography). P, pleura. Panel (A) shows the granular 'sea-shore' appearance of normal lung sliding. Panel (B) shows the horizontal 'bar-code' appearance that occurs with loss of lung sliding

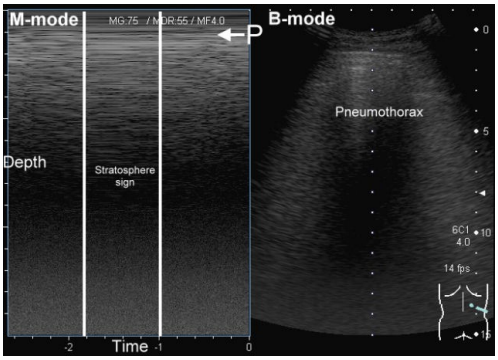

Figure 5. Pneumothorax. Chest US reveals stratosphere sign

5.1. Pulmonary lesions

The normal aerated lung is difficult to image because the dramatic change in acoustic impedance between chest wall and lung results in specular reflection of ultrasound waves at the pleura. However, consolidated lung has a tissue density and echo-texture similar to liver, analogous to pathological hepatisation. This removes the change in acoustic impedance at the pleural interface, and ultrasound waves pass directly into the affected lung. When patient with lobar or segmental pneumonia and the lesion is adjacent to pleura or in the pleural effusion, the pneumonia may be detected by chest US. A marked consolidation with air-bronchogram and treelike ramifications is easily seen (Figure 7). Within the consolidated area, hyperechoic (white) foci may be visible, again representing a change in acoustic impedance, but this time at the tissue interface between solid lung and air-filled bronchi. Subpleural nodule also can be seen in chest US (Figure 8).

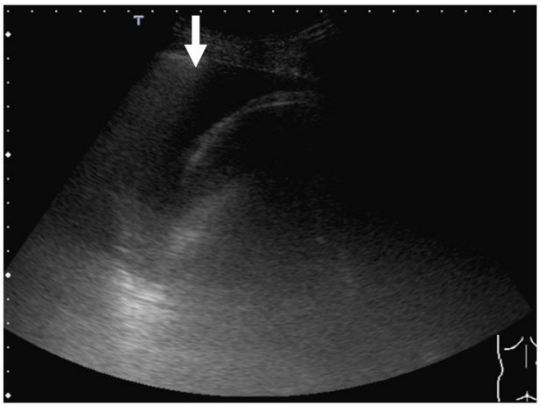

Figure 6. Sonogram of a hydropneumothorax. Notice the gas–fluid and fibrin interface (arrow) between the bright hyperechoic line dorsally representing the pneumothorax and the ventral fluid and fibrin.

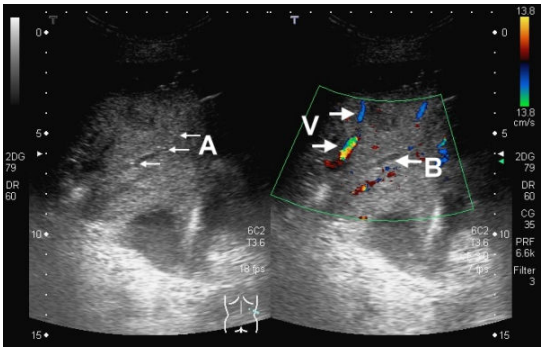

Figure 7. Air bronchogram. Notice the hypoechoic parenchyma and the small hyperechoic areas (A arrows) consistent with residual air in the bronchial tree. Color Doppler can distinguish between vessel and bronchus. V, vessel; B, bronchus.

Chest US with color Doppler is a powerful tool for differentiating the peripheral air-fluid abscess from empyema [15]. The differentiation by chest radiograph alone is difficult when the empyema presents with an air-fluid level. Thoracic CT scanning can prove valuable in differentiating lung abscess from empyema; however, the problems of radiation exposure and contrast induced renal failure sometimes limit its application. The empyema can be detected by chest US with an image of a hypoechoic lesion with complex-septated effusions, passive atelectasis, width uniformity, and smooth luminal and outer margins. Color Doppler ultrasound could not identify vessel signals in pericavitary atelectasis. The lung abscess in the US image reveals hypoechoic lesion with typical pulmonary consolidation, irregular wall width, and irregular luminal and outer margins. Color Doppler ultrasound could identify vessel signals in pericavitary consolidation (Figure 9).

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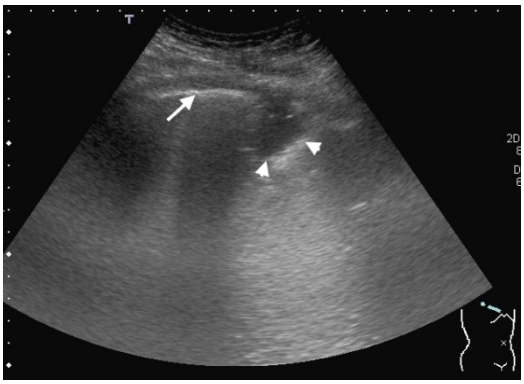

Figure 8. Transverse chest US scan shows a subpleural nodule (arrowheads). The linear hyperechoic area (arrow) represents visceral pleura.

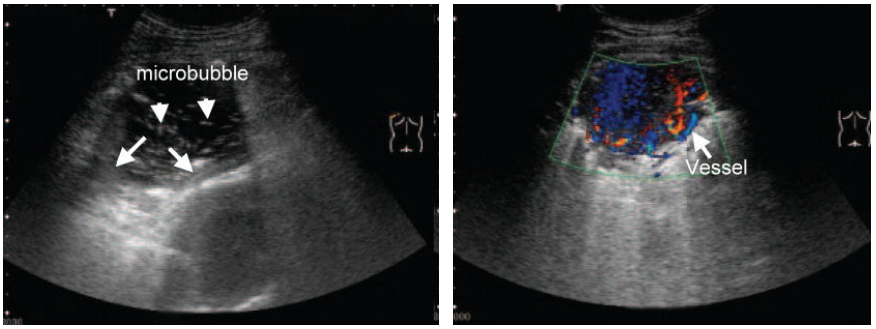

Figure 9. Lung abscess in chest US with Doppler. Chest US examination reveals a hypoechoic lesion with microbubble sign, which is surrounded by whole-lung parenchyma (arrows) (A). Color Doppler ultrasound can identify vessel signals in pericavitary consolidation in a lung abscess (B).

5.2. Alveolar interstitial syndrome

During previous studies, ultrasound imaging is not useful for pulmonary parenchyma imaging. Alveolar interstitial syndrome constitutes a group of diseases that is caused by an increase in lung fluid and/or a reduction in its air content. The result of this thickening of the interlobular septa causes a particular artifact that is seen arising from pleura line. The ultrasound appearance of alveolar interstitial syndrome is a vertical artifact, called B-line. Presence of the comet-tail artifact (Figure 10) allowed diagnosis of alveolar-interstitial syndrome by chest ultrasound [16]. The major causes of alveolar interstitial syndrome include pulmonary edema, acute respiratory distress syndrome (ARDS), and interstitial fibrosis. In the advanced study, application of chest ultrasound in the patients with respiratory failure, chest ultrasounds can help the clinician make a rapid diagnosis in patients with acute respiratory failure according the BLUE protocol [17].

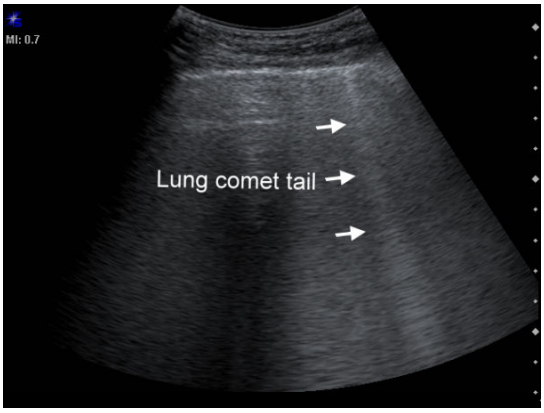

Figure 10. Lung comets. Lung comet tail, also known as 'B lines' (arrows) are indicative an alveolar interstitial syndrome.

6. Ultrasound-guided intervention

6.1. Diagnostic thoracentasis

The aim of the initial assessment of pleural fluid is to identify malignancy or infection and starts with a visual inspection of the aspirate prior to laboratory analysis. Therefore diagnostic thoracentesis is mandatory. When performed with image guidance thoracentesis provides clinically useful information in more than 90% of cases. If the pleural effusion spans three intercostal spaces and its presence can be confirmed clinically by percussion then aspiration can be performed safely at the bedside without the aid of image guidance. When the effusion is small, loculated or associated with underlying pulmonary collapse this becomes more difficult and hazardous. In all these situations US examination is required to confirm the presence of fluid and to guide thoracentesis. Moreover, bed-side procedures are sometimes necessary due to patient debilitation and can be performed satisfactorily with a portable US machine. By performing the aspiration at the time of the US examination success rates will be optimized and complication rates kept to a minimum. The most commonly reported complication for non-guided thoracentesis is that of pneumothorax with published rates varying from 11 to 12%. When US-guidance diagnostic thoracentesis is performed the complication rates fall to between 0.2% and 2.7% [18].

6.2. Ultrasound-guided small-bore chest tube insertion

Chest US also can be used guidance for small-bore catheter (pigtail tube) insertion and also provide a safe and effective method of draining various pleural diseases which includes pneumothorax, malignant pleural effusion, para-pneumonic effusion/empyema, and massive transudate effusions [19]. In primary spontaneous pneumothorax patients, ultrasound-guided

pigtail catheter drainage is effective and had a shorter hospital stay than patients treated by chest tube drainage [20]. Moreover, US-guided pigtail catheter for secondary spontaneous pneumothorax (SSP) is also effective and has low complication rate. A higher treatment failure rate was noted in infectious related SSP patients [21, 22]. In mechanically ventilated patients, US-guided pigtail catheter drainage is also effective in treating iatrogenic pneumothorax [23].

6.3. Ultrasound-guided biopsy

Transthoracic needle biopsy with fluoroscopic or computed tomographic (CT) guidance is a well-established and safe method for diagnosing malignant and benign thoracic lesions. However, radiation exposure is considerable and the cost is relatively high, as compared with US guidance. US is as effective as CT for guidance of transthoracic biopsies of peripheral pulmonary lesions and mediastinal tumors and offers a number of advantages. Real-time US imaging allows for dynamic evaluation of vessels and localization of target lesions that move during respiration. In US-guided transthoracic biopsy, the tip of the needle can be monitored throughout the procedure and fine adjustments can be made quickly and precisely; this is especially beneficial for biopsy of small thoracic lesions [24, 25]. Pleural biopsy is required for unexplained pleural effusions, pleural thickening (whether focal or diffuse) and pleural masses. The advances in imaging of the pleura provided by US and CT have meant that radiologists now play an important role in pleural biopsy either directly or indirectly. In most instances biopsies are performed to establish whether or not pleural disease is due to malignancy or to evaluate a suspected inflammatory process such as tuberculosis. Because focal pleural thickening or pleural tumors can be easily identified by US, US-guided pleural biopsy is related to possible focal pleural involvement in various diseases such as pleural tumor, thickening pleura, and small amounts of pleural effusion [26]. Besides, in critically ill patients, chest US is helpful in diagnosis and is a useful diagnostic tool for critically ill patients with chest disease [27].

6.4. Endobronchial Ultrasound (EBUS)

Endobronchial ultrasound (EBUS) technology is a relatively new bronchoscopic method of visualizing the tracheobronchial tree, the surrounding pulmonary parenchyma, and the mediastinal structures, with a particular role in lung cancer diagnosis, staging, and treatment [28]. There are 2 types of probes used in EBUS: the peripheral or radial probe (RP) and the linear or convex probe (CP) EBUS, which have technical differences and distinct diagnostic abilities. Both are used for EBUS-guided biopsies and transbronchial needle aspirations (TBNA), which increases the diagnostic yield over conventional bronchoscopic techniques, thus providing advanced information on staging, diagnosis, and treatment. The 20-MHz RP-EBUS (Figure 11) is positioned inside a water-inflatable balloon and is inserted through the working channel of the bronchoscope. The RP-EBUS was first introduced to evaluate the central airway structure. With advances in technology, the small radial probes can now visualize and assist transbronchial biopsies of peripheral lung nodules without exposure to radiation. Kurimoto and colleagues [29] showed that using a guide sheath with radial probe EBUS and leaving it there to pass the forceps catheter through it could improve the diagnostic

yield of specimens from peripheral pulmonary lesions/nodules, including those too small to be visualized by fluoroscopy. Nowadays, the evaluation of mediastinal lesions has been facilitated by the use of CP-EBUS probe. This type of probe incorporates a 7.5-MHz ultrasound transducer at the tip of a flexible bronchoscope. Real-time biopsies of the lymph nodes can be carried out with a 22-gauge needle inserted through the working channel. EBUS-TBNA is most commonly used for staging non-small cell lung cancer (NSCLC), but is also used for diagnosis of unexplained mediastinal lymphadenopathy (Figure 12) of other causes. The safety of this technique is well established and few serious complications have been reported, including pneumothorax, pneumomediastinum, and hemomediastinum [30, 31].

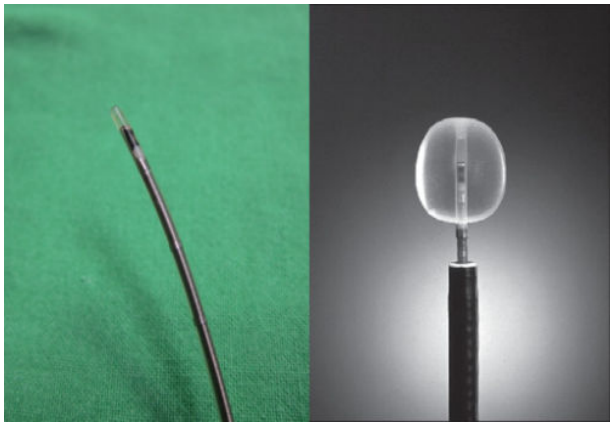

Figure 11. Radial Probe Endobronchial Ultrasound. Left, probe and deflated balloon. Right, probe within a bronchoscope with balloon inflated.

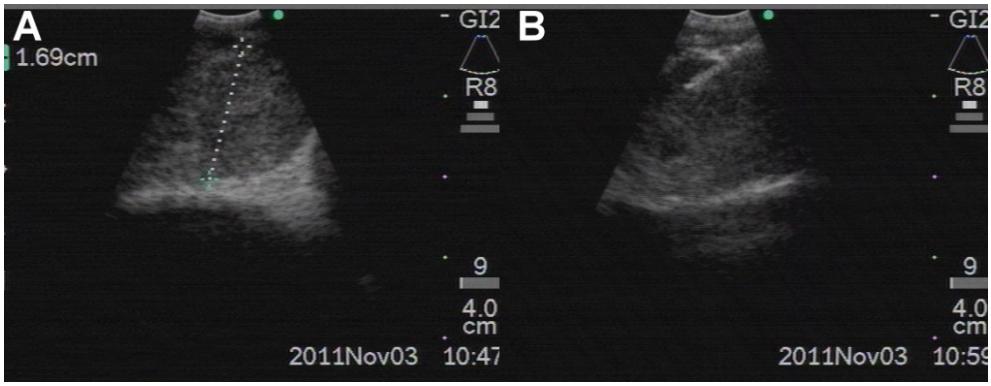

Figure 12. Image of a lymph node biopsy under endobronchial ultrasound guidance. Real-time EBUS-TBNA revealed a lymph node of 1.69 cm (A). The needle (arrows) is clearly visible in the lymph node (B).

7. Conclusions

Pleural US has a proven role in improving the safety of pleural procedures and should be offered as standard of care in this setting. US also offers advantages over conventional radiography in the detection, quantification and characterisation of pleural effusions. Lung US has excellent test characteristics for the diagnosis of consolidation, interstitial syndrome and subpleural pulmonary nodules. EBUS based technology may be used in the diagnosis of a lung or mediastinal lesion, staging of lung cancer, and treatment of an endobronchial abnormality.

In the future, chest sonography is likely to be an essential skill for the physician, and training requirements are likely to evolve with advances in the field.

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