Transthoracic ultrasound for the pulmonologist

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Purpose of review

Transthoracic ultrasound has received increased interest from chest physicians in recent years. Modern ultrasound devices are user friendly, inexpensive, lightweight, and portable, which makes them suited for outpatient settings as well as for bedside investigation of the severely ill. Ultrasound is set to become a practical and essential tool for the pulmonologist in the near future.

Recent findings

An ever-increasing number of articles are aimed at describing and refining how ultrasound can be utilised by chest physicians in daily practice. Only basic ultrasound skills are required to assess pleural effusions and perform ultrasound-guided thoracocentesis. Sonographic assistance with insertion of chest drains as well as identification or biopsy of thoracic masses are more complex, and advanced skills are required for the investigation of pneumothorax and thromboembolic disease.

Summary

The current literature documents the progress in the application of ultrasound for the practicing chest physician. In this article the authors describe the most recent developments and follow up with some simple but essential advice for the novice venturing into chest ultrasound.

Keywords

empyema, pleural disease, pleural effusion, pleural tumors, ultrasound

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Abbreviations

ICU	intensive care unit
US	ultrasound

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Introduction

This article appears only 2 years after a comprehensive review of the principles of ultrasound (US) in the diagnosis and management of chest disease was published in this very journal [1]. A growing proportion of articles in this field is written by physicians and addressed at an audience beyond research or tertiary facilities. This heralds the emergence of US as an essential tool for the practicing pulmonologist. The first part of the current article will provide the seasoned sonographer with an update on the latest available information. On a different note, the second section is aimed at the pulmonary physician less experienced with US. From a more personal perspective, we will share some hands-on advice that we have found useful for our clinical practice with chest US.

Literature review

Sonography is not a new technology. Once a radiologic domain, it was adopted by specialist physicians long ago. It does not come as a surprise that the latest developments in chest US are rather based on its application to chest disorders than on technologic progress. Some excellent current reviews have become available in the print literature [1–3]. Evans and Gleeson [4•] put ultrasonography for pleural disease in perspective with other commonly used radiologic techniques. The review by Koh *et al.* [5], which is accessible free of cost via the Worldwide Web, conveys dynamic information beyond anatomy using animated material and is recommended as a complete guide to sonographic chest morphology.

Pleural effusion

The value of ultrasonography for detection and quantification of pleural effusions is uncontested. In small effusions, US is more sensitive than decubitus expiratory films [6]. Sonographically, a pleural effusion manifests as an anechoic, homogeneous space between parietal and visceral pleura. Transudates are echo-free, unseptated, and free flowing. Exudates can exhibit specific patterns of echogenicity and fibrinous septations of various quality and density, which can serve as diagnostic clues. Echogenic swirling patterns have recently been linked to a malignant nature of an effusion [7]. In parapneumonic effusion and empyema, US has been well established in pediatric patients [8–11] and is gaining ground in adults. Chen *et al.* [12] demonstrated that patients with sonographically septated effusions needed longer chest tube drainage, longer hospital care, and were more likely to require fibrinolytic therapy or surgery compared with those with unseptated effusions. Tu *et al.* [13•] recently confirmed some of these findings in medical intensive care unit (ICU) patients. US ideally integrates with swift decision making in parapneumonic effusion and empyema. At the bedside, extent and quality of the effusion can be determined, a guided aspirate can be obtained, and, if necessary, a thoracostomy tube can be positioned during the same session [14].

Pneumothorax, seropneumothorax

Pneumothorax detection requires more skill than the investigation of pleural fluid. Pneumothorax can be diagnosed with the absence of respiratory movement of the lung surface beneath the chest wall (gliding sign) [15]. Herth *et al.* [16] have recently shown that a pneumothorax following transbronchial biopsy can be reliably excluded with US (sensitivity, 100%; specificity, 83%). This is likely to reduce costs for chest radiographs, increase patient comfort, and offers an excellent opportunity to acquire and practice pneumothorax detection. In a commendable effort to extend the indications of US, Lin *et al.* [17] have recently defined a panel of sonographic features for the differentiation of pyopneumothorax from peripheral lung abscess.

Thoracentesis and drainage

US is particularly well suited for guiding pleural interventions. It increases the success rate and reduces complications of thoracentesis [18–20], and routine use of US assistance in small effusions and in those with abnormal presentations on chest radiograph must be advised. Ultrasonography in the clinician's hands also allows bedside procedures, and the safety and usefulness of US-guided thoracentesis in the critically ill has repeatedly been proved recently [13•,21].

Tumors and biopsy procedures

Lesions originating from the pleura, the chest wall, and the anterior mediastinum can be visualised with US. Peripheral lung lesions with pleural contact are also detectable, and US is a proved modality for determining whether and how far a peripheral lung tumor has advanced to or penetrated the pleura and the chest wall [22,23]. Apart from staging of lung cancer, US is a formidable tool to assist with biopsy procedures. Although US-guided needle biopsy requires a certain expertise, the technique is relatively easy to learn and can replace computed tomographic guidance at a much lower cost [24,25]. In a recent study with 91 patients in our own center, US-guided cutting biopsy was 85% sensitive for neoplastic disease and 100% sensitive for mesothelioma [25,26]. Cutting biopsies might not always be necessary for thoracic lesions. In our experience, the yield of fine-needle aspiration cytology in epithelial lung malignancies is comparable with cutting biopsies, whereas the latter performs better in sarcomas, mesotheliomas, and benign lesions [27].

Other indications

Current pioneering work is targeted at improving the diagnostic approach to the severely ill. Lichtenstein *et al.* [28,29] report that lung pathology associated with severe pulmonary illness such as acute respiratory distress syndrome or lung consolidation can be reliably assessed noninvasively and at the bedside with chest US. Pleural effusion and lung consolidation associated with pulmonary embolus are also amenable to US investigation [30], which can also detect other sequelae of thromboembolic disease such as venous thrombosis or right ventricular overload with hepatic congestion. Currently, however, US for these entities is still reserved for experienced physicians with a keen interest in US. A growing number of case reports highlights the broad spectrum of disease accessible to US [31,32].

How to start with thoracic ultrasound

An expert review of all practical aspects of chest sonography is beyond the scope of this article. From a personal perspective, however, we would like to give the novice chest ultrasonographers some practical advice for the initial struggle with gel, sound, and vision. Anyone venturing into chest ultrasonography should start with the evaluation of pleural disease. Determination of a site for a puncture or tube placement comes next, and with growing experience anyone used to performing blind pleural biopsies can proceed to needle aspiration or biopsy of solid lesions.

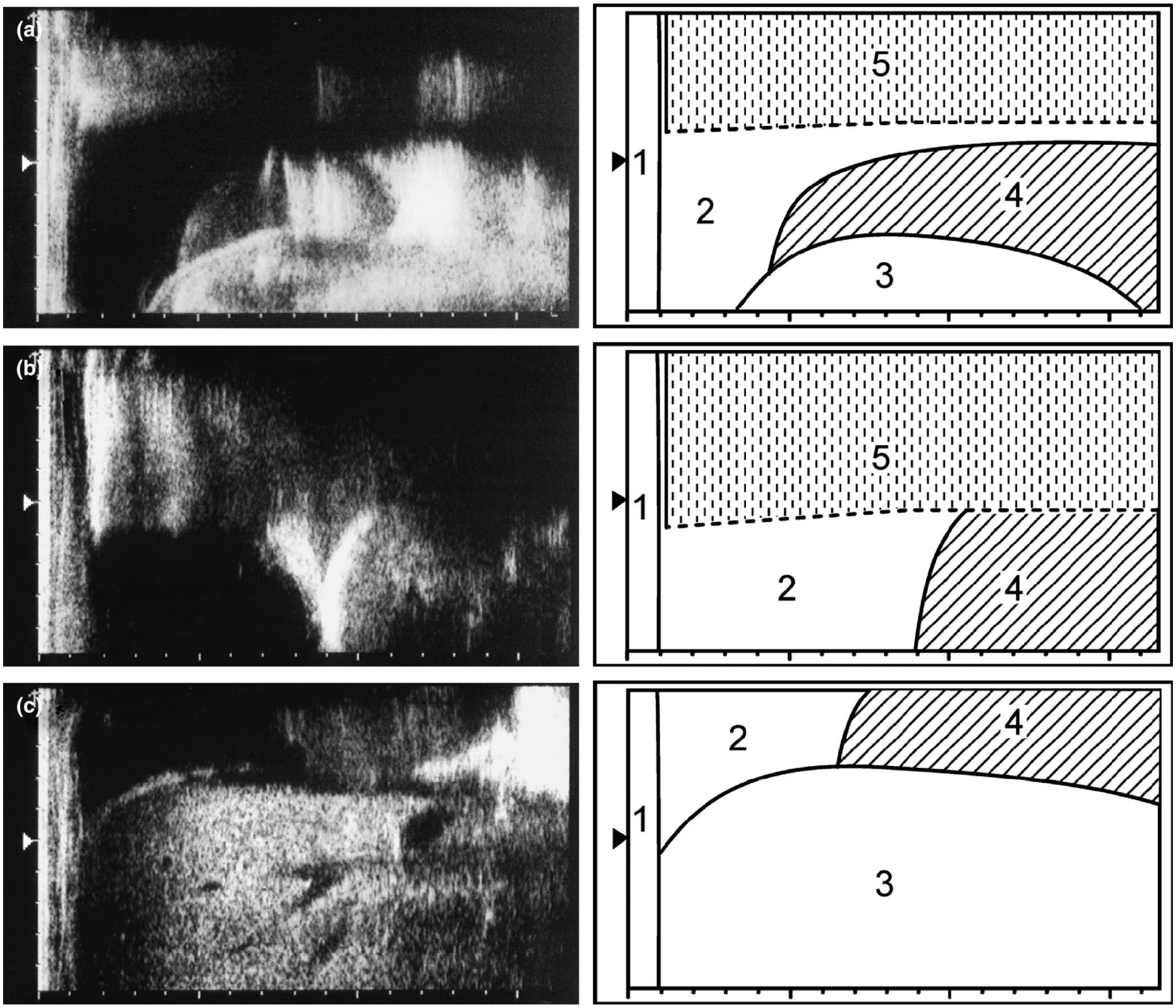
General appraisal of chest ultrasound

The normal lung does not easily lend itself to sonographic examination. The air-filled space beyond the visceral pleura completely reflects US and gives rise to artefacts that might be confused with structural detail by the less experienced. Lesions shielded from the probe by only a tiny portion of air cannot be seen at all, and even air-containing lesions with pleural contact such as lung abscess or seropneumothorax can be difficult to appreciate. As soon as fluid or solid tissue extends to the pleura, however, an acoustic window opens to a variety of lesions of pleural, pulmonary, mediastinal, and chest wall provenance (Fig. 1).

Equipment

Bedside examination is one of the advantages of US, and although there are arguments for advanced technical features such as color screens, Doppler probes for line placement, or advanced digital recording devices, we strongly recommend to go for a basic model that is lightweight, robust, reasonably priced, and transportable. A curvilinear probe at 2 to 5 MHz and a linear probe at 7.5 to 10 MHz are more than sufficient for chest ultrasonography. At no time of the day should there be hesitation to take the machine to the bedside where it is needed. Most occasional sonographers, including us, struggle to memorise the purpose of more than three controls even on a modest keyboard. We advise consulting a radiologist to have the

Figure 1. Sonar pictures (left) with corresponding sketches (right) from the same site varying with respiratory motion



The sonar images are registered with a linear scanner from a lateral position in a sitting patient. A typical moderate-size, free-flowing right-side pleural effusion is shown at normal expiration (a), forced expiration (b), and forced inspiration (c). Note how the respective positions of the intrathoracic organs shift with respiration. The aerated portion of the lung acts like a curtain and effaces the structural detail behind it. 1, chest wall; 2, effusion; 3, liver with liver veins; 4, artefact caused by lower lobe, which is partly collapsed; 5, artefact caused by aerated lung moving in and out of the scanned field.

most basic model-specific functions explained one-on-one. Freezing the image not only generates a still image on the display, but also puts the sonar probe in idling mode. This increases its life span.

Diagnostic scanning

It is common sense that one should avoid trying the most challenging case first. We advise performing sonography routinely on every patient referred for pleural fluid aspiration, no matter how large the effusion and how obvious the puncture site might seem. This strategy allows familiarisation with sonographic anatomy and leads to rapid accumulation of experience.

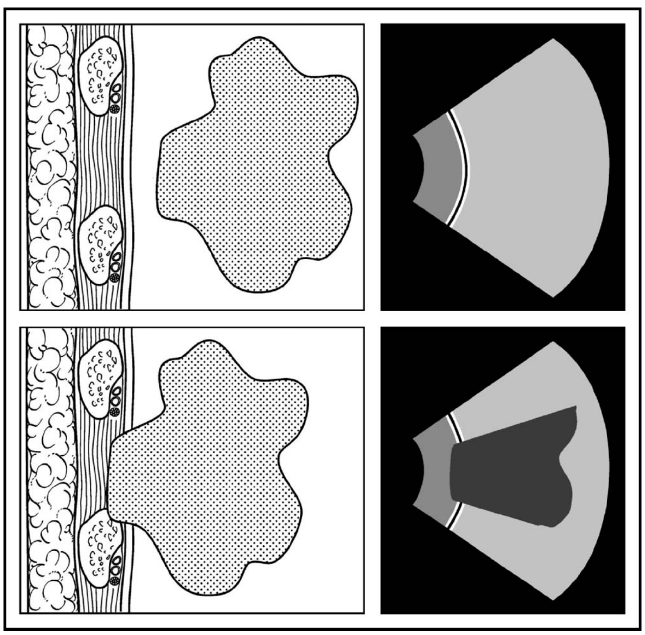
Patient positioning is an underappreciated yet important aspect. There is no standard position suitable for every indication. Patient mobility and the presumed location of the targeted lesion must be considered. Our preferred position is with the patient sitting sideways on a stretcher and both arms resting on a bedside table, which allows shifting the scapula when necessary. Lateral decubitus, supine, or sitting positions are also used. Repositioning a patient or even small postural changes can make a big difference for the sonographic visibility.

For scanning, use enough gel to provide a sound interface between probe and skin. One of the most frequent beginner's mistakes is not to maintain skin contact with the hand holding the probe for scanning. Hands clean of gel are not the objective. As an analogy, one should hold the probe like a pen for writing on paper and not like chalk for writing on a blackboard. Experienced sonographers keep their eyes on the screen while their hand moves the probe across the area of interest and provides the positional information. The probe is moved slowly, preferably along intercostal spaces, which are oblique and not horizontal. The best approach is to identify the area of interest on a radiograph first, and then depart from known anatomic structures to the target area. Liver and spleen have characteristic sonar patterns and indicate the position of the diaphragm. Once identified, the lesion can be assessed for mobility with normal or forced respiration. A typical finding in a patient with a free-flowing effusion of a moderate size is demonstrated in Figure 2.

Thoracentesis and drainage

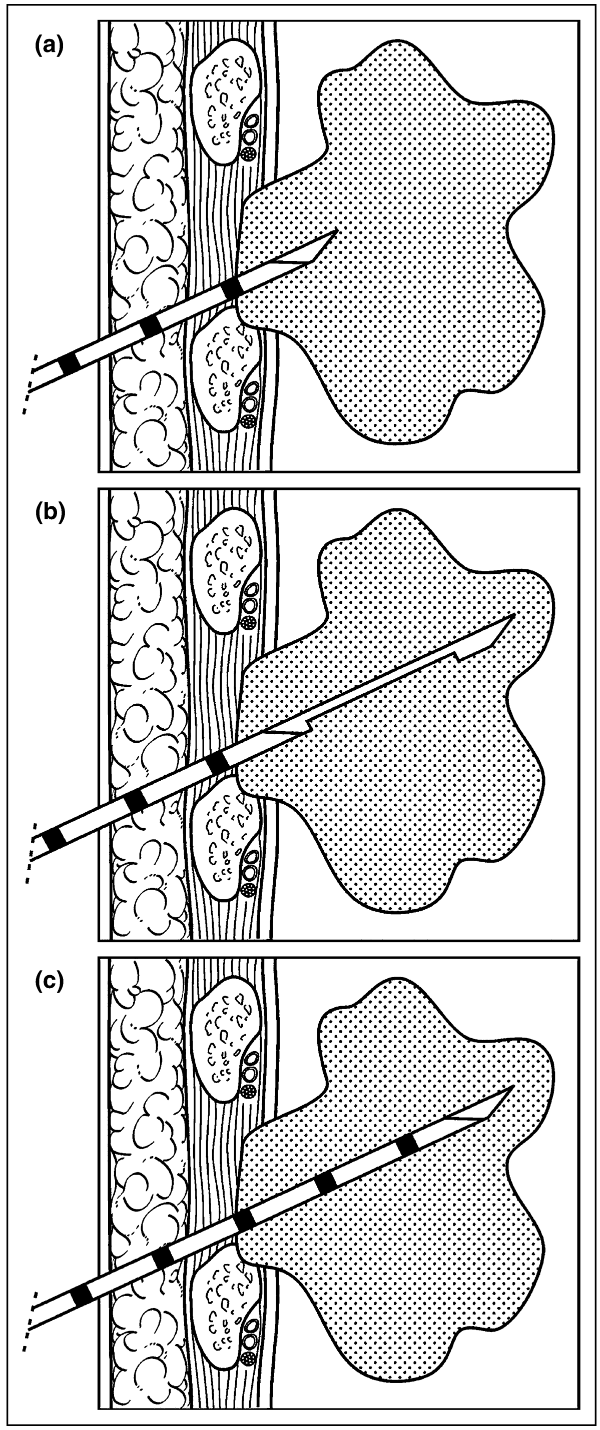
Selection of an entry site for a needle or a chest drain is an easy task in large effusions. In small effusions, however, it is important to monitor the selected site during inspiration and expiration, and it might even be necessary to instruct the patient to hold his breath for the puncture. It has happened with beginners that the liver or spleen was mistaken as fluid collections. It is our policy to identify the upper abdominal organs before a puncture to ensure

Figure 2. Peripheral lung lesion with and without pleural contact



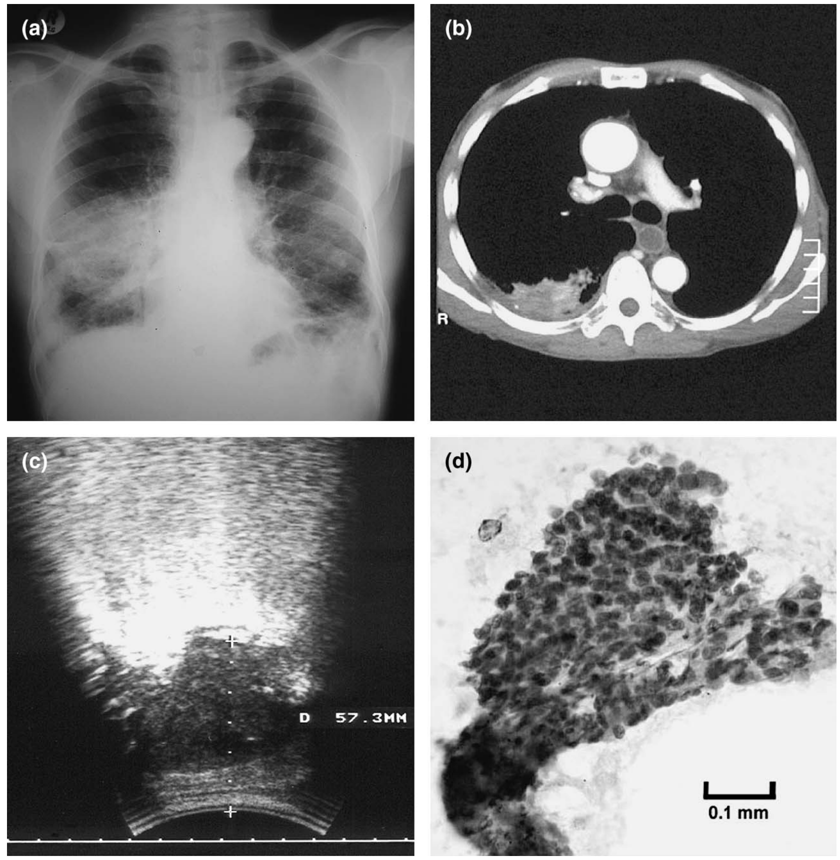
(a–c) A peripheral lung lesion is shown schematically on the left without (top) and with (bottom) pleural contact. The corresponding sonar images recorded with a sector scanner are shown on the right. Only the lesion with pleural contact is visible on ultrasound. Note that the acoustic window is too narrow to demonstrate the whole circumference of the lesion, but it allows determining its full depth.

Figure 3. A schematic view of a cutting biopsy of a peripheral lung lesion



(a) The device is positioned within the lesion, keeping a safe distance from the intercostal neurovascular structures below the ribs. (b) The inner stylet is deployed with the cutting bit pointing away from the neurovascular bundle. (c) The biopsy specimen is harvested by sliding the cutting bit over the inner stylet (not by withdrawing the inner stylet back into the cutting bit). The absence of air between the lung lesion and the chest wall provides both an acoustic window and a pathway for the sampling device through nonaerated tissue, which reduces the risk of pneumothorax. The peripheral nature of the lung lesions makes significant bleeding unlikely.

Figure 4. Case demonstration for ultrasound-guided biopsy



A typical case suitable for ultrasound-guided fine-needle aspiration and biopsy. Fiberoptic bronchoscopy had been noncontributory. (a) The chest radiograph shows a lesion in the right mid and lower lung field. (b) On computed tomography, the lesion is located in the apical segment of the lower lobe with abundant pleural contact. (c) The corresponding sonar image shows that good transthoracic access to the tumor is provided. The sonar head is scanning from the bottom of the picture: chest wall, pleura, tumor mass (dark), lung (beyond the mark). The distance from the skin to the full depth of the tumor is 57 mm. (d) Fine-needle aspiration cytology with a 22-gauge spinal needle showed adenocarcinoma (Diff-quick stain, magnification $\times$200). This was confirmed with a histologic specimen provided by cutting biopsy (not shown).

that the targeted structure is indeed above the diaphragm. We discourage marking a puncture site at a remote facility and then transporting the patient elsewhere for thoracentesis. Both the fluid collection and the skin mark might shift considerably with a small change in body position.

Aspiration and biopsy of solid lesions

If a lesion provides a sufficiently large acoustic window throughout the breathing cycle, a puncture can be performed under local anesthesia with little risk of pneumothorax or major bleeding (Figs. 3 and 4). Although dedicated probes are available, we prefer the free-hand technique for its simplicity. The entry site is marked, and the safe range, direction, and depth of the puncture are memorised before the biopsy. The patient must not move between marking and biopsy, because the skin mark can shift away from the targeted deeper structure. Under local anesthesia, we routinely use fine-needle aspiration with a 22-gauge injection-type or spinal needle and a cutting biopsy when the lesion is suitable. A word of caution before using cutting biopsy devices: These are extremely sharp and it is of utmost importance to spare the mammary and intercostal arteries when using them.

Sonographic exclusion of pneumothorax after aspiration or biopsy of a solid lesion is a simple task. If the aspirated lesion is still visible on US in unchanged shape and size, no free air is present between the sampled process and the visceral pleura, and a clinically relevant pneumothorax is unlikely.

Conclusion

The usefulness of US for chest physicians is firmly established. It is an easy-to-learn, low-cost, and elegant method that extends the physicians' diagnostic and interventional potential at the bedside in peripheral lung, pleural, and chest wall disease. In our institution, ultrasonography is routinely used for thoracentesis in the ICU and for chest tube placement. It has replaced computed tomographic guidance for aspiration and sampling of all lesions involving the pleura and also lung masses abutting the pleura. Our experience with ultrasonography is that it adds a new dimension to our anatomic and functional understanding of disease, integrates with our interventional practice, is an excellent training instrument, improves ICU care, and frequently obviates transport of the critically ill. Future research and developments should include formal training programs for chest physicians to ensure a basic standard for chest US and aim at refining the application of chest sonography to problems frequently encountered in the lung physicians' practice.

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References

1 Tsai TH, Yang PC. Ultrasound in the diagnosis and management of pleural disease. Curr Opin Pulm Med 2003; 9:282–290.

2 Herth FJ, Becker HD. Transthoracic ultrasound. Respiration 2003; 70:87–94.

3 Beckh S, Bolcskei PL, Lessnau KD. Real-time chest ultrasonography: a comprehensive review for the pulmonologist. Chest 2002; 122:1759–1773.

4 Evans AL, Gleeson FV. Radiology in pleural disease: state of the art. Respir-
• ology 2004; 9:300–312.
From a radiologic point of view, this article puts transthoracic US into perspective with other radiologic techniques commonly used in chest disease.

5 Koh DM, Burke S, Davies N, *et al*. Transthoracic US of the chest: clinical uses and applications. Radiographics 2002; 22:E1. Available: http://radiographics.rsnajnls.org/cgi/content/full/22/1/e1.

6 Kocijancic I, Kocijancic K, Cufer T. Imaging of pleural fluid in healthy individuals. Clin Radiol 2004; 59:826–829.

7 Chian CF, Su WL, Soh LH, *et al*. Echogenic swirling pattern as a predictor of malignant pleural effusions in patients with malignancies. Chest 2004; 126:129–134.

8 Hilliard TN, Henderson AJ, Langton Hewer SC. Management of parapneumonic effusion and empyema. Arch Dis Child 2003; 88:915–917.

9 King S, Thomson A. Radiological perspectives in empyema. Br Med Bull 2002; 61:203–214.

10 Gates RL, Hogan M, Weinstein S, *et al*. Drainage, fibrinolytics, or surgery: a comparison of treatment options in pediatric empyema. J Pediatr Surg 2004; 39:1638–1642.

11 Yao CT, Wu JM, Liu CC, *et al*. Treatment of complicated parapneumonic pleural effusion with intrapleural streptokinase in children. Chest 2004; 125:566–571.

12 Chen KY, Liaw YS, Wang HC, *et al*. Sonographic septation: a useful prognostic indicator of acute thoracic empyema. J Ultrasound Med 2000; 19:837–843.

13 Tu CY, Hsu WH, Hsia TC, *et al*. Pleural effusions in febrile medical ICU pa-
• tients: chest ultrasound study. Chest 2004; 126:1274–1280.
This article shows in an exemplary fashion how US in a physician's hands can be used to improve bedside patient care.

14 Diacon AH, Theron J, Schuurmans MM, *et al*. Intrapleural streptokinase for empyema and complicated parapneumonic effusions. Am J Respir Crit Care Med 2004; 170:49–53.

15 Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung sliding. Chest 1995; 108:1345–1348.

16 Herth FJ, Eberhardt R, Ernst A, *et al*. Diagnosis of pneumothorax by means of transthoracic ultrasound: a prospective trial. Eur Respir J 2004; 24:S491.

17 Lin FC, Chou CW, Chang SC. Differentiating pyopneumothorax and peripheral lung abscess: chest ultrasonography. Am J Med Sci 2004; 327:330–335.

18 Diacon AH, Brutsche MH, Soler M. Accuracy of pleural puncture sites: a prospective comparison of clinical examination with ultrasound. Chest 2003; 123:436–441.

19 Jones PW, Moyers JP, Rogers JT, *et al*. Ultrasound-guided thoracentesis: is it a safer method? Chest 2003; 123:418–423.

20 Doelken P, Strange C. Chest ultrasound for 'dummies.' Chest 2003; 123:332–333.

21 Mayo PH, Goltz HR, Tafreshi M, *et al*. Safety of ultrasound-guided thoracentesis in patients receiving mechanical ventilation. Chest 2004; 125:1059–1062.

22 Sugama Y, Tamaki S, Kitamura S, *et al*. Ultrasonographic evaluation of pleural and chest wall invasion of lung cancer. Chest 1988; 93:275–279.

23 Suzuki N, Saitoh T, Kitamura S. Tumor invasion of the chest wall in lung cancer: diagnosis with US. Radiology 1993; 187:39–42.

24 Yang PC, Chang DB, Yu CJ, *et al*. Ultrasound guided core biopsy of thoracic tumors. Am Rev Respir Dis 1992; 146:763–767.

25 Diacon AH, Schuurmans MM, Theron J, *et al*. Safety and yield of ultrasound-assisted transthoracic biopsy performed by pulmonologists. Respiration 2004; 71:519–522.

26 Scarsbrook A, Gleeson FV. Progress through sound and vision. Respiration 2004; 71:448–449.

27 Maskell NA, Gleeson FA, Davies RJO. Standard pleural biopsy versus CT-guided cutting-needle biopsy for diagnosis or malignant disease in pleural effusions: a randomised controlled trial. Lancet 2003; 361:1326–1331.

28 Lichtenstein D, Goldstein I, Mourgeon E, *et al*. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. Anesthesiology 2004; 100:9–15.

29 Lichtenstein DA, Lascols N, Meziere G, *et al*. Ultrasound diagnosis of alveolar consolidation in the critically ill. Intensive Care Med 2004; 30:276–281.

30 Reissig A, Kroegel C. Transthoracic ultrasound of lung and pleura in the diagnosis of pulmonary embolism: a novel non-invasive bedside approach. Respiration 2003; 70:441–452.

31 Kumar RV, Ramana DV, Gopal PR. Giant Morgagnian hernia masquerading as pleural effusion. J Indian Med Assoc 2004; 102:98–99.

32 Groves AM, See TC, Appleton DS, *et al*. Transpleural ultrasound diagnosis of a pulmonary arteriovenous malformation. Br J Radiol 2004; 77:620–622.