Basic thoracic ultrasound for the respiratory physician

Bazele echografiei toracice pentru pneumolog

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Abstract

Thoracic ultrasound (TUS) evolved in the last ten years as the method of choice for evaluating pleural abnormalities and for guiding lung procedures. TUS can "see" almost all structures in the chest, including thoracic wall, pleura, pleural space, the heart, the great vessels and the peripheral layers of the lungs. However, there is still a great need to develop TUS services in respiratory departments in Romania. To facilitate this development we reviewed the literature and selected what we considered to be essential practical information for the beginner in TUS, including technique, normal findings, and common abnormalities. Moreover, we describe here a step-by-step scanning technique for chest physicians. Our aim is to raise awareness of TUS. Because TUS is rapid, accurate, noninvasive and can be applied in any ward, we recommend facilitating the training of all junior respiratory doctors in this technique, as it is likely to improve patient experience, clinical effectiveness and to reduce costs with chest radiographs or CT scans in the future.

***Key** words: thoracic ultrasound, diagnosis, training, pleura, lung*

Rezumat

Echografia toracică (ET) s-a dezvoltat în ultimul deceniu ca o metodă de elecție pentru evaluarea anomaliilor pleurale și pentru ghidarea procedurilor toracice. ET poate "vedea" aproape toate structurile din torace, inclusiv peretele toracic, pleura, spațiul pleural, inima, vasele mari și straturile periferice ale plămânului. Se simte, totuși, nevoia dezvoltării ET în departamentele de pneumologie din România. Pentru a ușura acest proces, am revizuit datele de literatură și am selectat informațiile practice pe care le considerăm esențiale pentru începătorul în ET, printre care tehnica, aspectele normale și anomaliile obișnuite. În plus, descriem aici pas cu pas o tehnică de scanare utilă pneumologilor. Scopul nostru este să ridicăm nivelul de atenție asupra ET. ET este rapidă, precisă, neinvazivă și poate fi aplicată în orice serviciu. Prin urmare, recomandăm facilitarea antrenamentului tuturor tinerilor medici pneumologi în această tehnică, fiind așteptat ca ea să îmbunătățească percepția pacientului, eficacitatea clinică și să reducă în viitor costurile cu radiografii și CT toracice.

***Cuvinte** cheie: echografie toracică, diagnostic, antrenament, pleură, plămân*

Introduction

In the last 10 years thoracic ultrasound (TUS) has evolved as the method of choice for investigating the pleura because of two main reasons: the ultrasound machines are now truly portable, they have good image quality, and, in addition, the significance of the chest ultrasound images are better understood[1]. Despite the challenges imposed by the presence of the air in the lungs, it is now clear that TUS can see almost every organ in the chest including: thoracic wall, pleura, pleural space, the heart, the great vessels and the peripheral layers of the lungs[2]. TUS can also guide pleural biopsies, chest drain insertion and lung biopsies[2]. Notwithstanding its benefits TUS is still largely used mainly for pleural procedures in countries such as UK, where ultrasound guided chest drain insertion has become mandatory[3]. However, in Romania, there is very little use of Seldinger chest drains by physicians, no guidelines on TUS, and little experience with chest ultrasound in the respiratory departments. We reviewed the literature and we are presenting what we consider to be the core information on TUS. We hope this work will be of relevance for those interested in starting up a TUS service. Our aim is to encourage the adoption of TUS by all respiratory departments in Romania and to illustrate that TUS is, after all, a simple and a convenient diagnostic test to perform.

What are the advantages of TUS?

TUS have multiple advantages over other radiographic methods (Figure 1)[4]. The most important advantage in our view is the lack of radiation and the possibility of delivering a detailed, real time, image of the pleural structures, which can be interpreted at the patient's bedside. We fully agree with the view that the ultrasound can become as important as the stethoscope for the respiratory physician, as it helps to integrate patient history and the clinical examination with objective findings in most of the respiratory patients at their bedside[1].

Limitations?

The main limitations of TUS are due to the presence of air in the lungs[5]. The air limits the transmission of ultrasounds and causes image artefacts. Currently there is no contrast agent to make the aerated lung visible for ultrasounds. In addition, the presence of the ribs can obstruct small underlying abnormalities. TUS is not as good as computed tomography (CT) for the evaluation of lung parenchyma and for the biopsy of lung masses[6].

What equipment do you need for point-of care TUS?

A point-of care ultrasonography service is defined as ultrasonography performed and interpreted by the clinician at the patient's bedside[7]. This kind of service requires a portable machine (Figure 2).

There is a broad range of ultrasound machines that can be used for chest ultrasounds. However, setting up a TUS service does not require the purchase of the most expensive ultrasound machine on the market. For a basic service a basic machine with an abdominal probe and without a

Figure 1. Main advantages of thoracic ultrasound

Doppler is satisfactory. Sometimes older machines or shared machines with a cardiology, or gastroenterology service are practical arrangements that can save money. Nevertheless, a good resolution ultrasound is needed for biopsies and other precise procedures.

Doppler can also be a "nice to have" feature, as it can characterize lesions by highlighting the level of vascularization. In addition, Doppler can help differentiate small effusions from pleural thickening and can help avoid large vessels during a procedure.

We recommend two basic transducers[4]. Most frequently used is the curvilinear transducer, with frequencies between 2-5 MHz. This is identical with the transducer used for abdominal examination. The second most useful transducer is a linear one, with a high frequency between 5-10 MHz; it is helpful for detailed examination of structures closer to the probe (thoracic wall, pleura).

When should you use TUS?

Main indications are related to pleural diseases, however TUS is useful in a number of other situations (Figure 3)[4]:

- Abnormal chest radiographs, with a "white out", "consolidation", or opacity suggestive of a pleural effusion - for the confirmation and assessment of the pleural effusion.
- To exclude a sub-diaphragmatic or chest wall collection.
- To confirm pleural thickening (pachipleuritis), pleural plaques, or pleural malignancies (mesothelioma).
- For bedside detection of a pneumothorax in patients critically ill, or in those who can't have a chest radiograph.
- To diagnose phrenic nerve paresis, or a diaphragmatic pathology (hiatal hernia, diaphragm tumors, diaphragmatic hernias).
- To diagnose and characterize peripheral lung tumors.
- To detect chest wall invasion by pulmonary or pleural tumors.

Figure 2. Portable ultrasound machine and abdominal probe, curvilinear transducer, 2-5 MHz, suitable for thoracic ultrasound

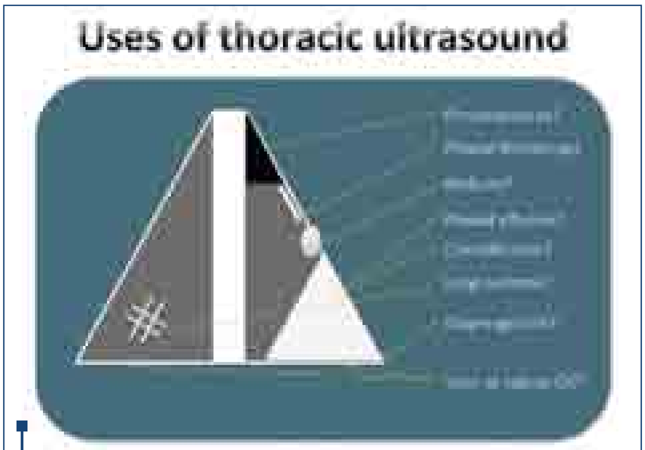

Figure 3. Indications for thoracic ultrasound

- To diagnose sub diaphragmatic collections or abdominal abnormalities responsible for lung damage: hepatomegaly, liver congestion, cirrhosis, ascites, splenomegaly, liver tumors.

In addition, TUS is now the gold standard imaging technique for guiding several minimally invasive interventional pulmonary procedures such as:

- Insertion of Seldinger catheters for draining pleural effusions.
- Percutaneus, targeted pleural, lung or thoracic wall biopsies.
- Drainage (thoracocentesis) of loculated pleural effusions.

What is the best scanning sequence?

The best scanning procedure requires a step-by-step standardized approach (Figure 4). One should always perform the same approach and adapt only if necessary.

Before the actual scanning, we strongly recommend taking a good clinical history, performing a basic respiratory examination and looking at all the images available (chest radiographs, CTs, previous ultrasound scans) to help planning the TUS and to help integrating the findings in clinical thinking.

Consent

A verbal informed consent is required; the patient should be told about the benefits of the procedure and also its lack of significant harm. The gel can give a sensation of cold on the skin, which is sometimes uncomfortable for an anxious patient (you can warm the gel by keeping the flask in warm water). If further invasive procedures are to be performed a specific, separate, written consent is necessary.

Patient positioning

We recommend a standard approach, with the patient sitting on a chair, with arms extended and resting on a table. If the patient cannot sit up, he can be scanned supine, with the head of the bed elevated slightly. Critically ill patients can be scanned in their bed, with the ipsilateral arm held across the chest towards the opposite side.

Acoustic windows and positioning of the probe

A methodical scanning strategy for all patients is essential. This allows a rapid, complete, and a high quality ultrasound examination of the chest. There are multiple acoustic windows available (Figure 5). We recommend starting always on the same scanning windows and lines and then focus on the area of interest. Our preferred windows sequence is described in Figure 4. We like to start with the probe longitudinally, as it helps with orientation, and then transversally, as it offers more details.

- Trans-diaphragmatic windows (trans-hepatic, trans-spleen).
- Intercostal spaces windows posteriorly.
- Intercostal space windows in the axila.
- Supra-clavicular windows anteriorly.

A step-by-step approach to scanning

Start to scan longitudinally, below the diaphragm, on the anterior axillary line on the right, or posterior axillary line on the left. In this way multiple interspaces can be examined in a short time and the reference organs can be quickly identified. Aim to go through the following 5 steps and checks, which ensure the basic technical quality of the examination.

Step 1: the first checkpoint is to identify the reference organs: liver (right) and spleen (left). Adjust the gain and the depth to see these structures clearly, including their inferior margin.

Step 2: identify the lung. Progress with the probe longitudinally, upwards, until the lung movement becomes apparent. Check for the presence of the curtain sign.

Figure 4. *Step-by-step approach to thoracic ultrasound*

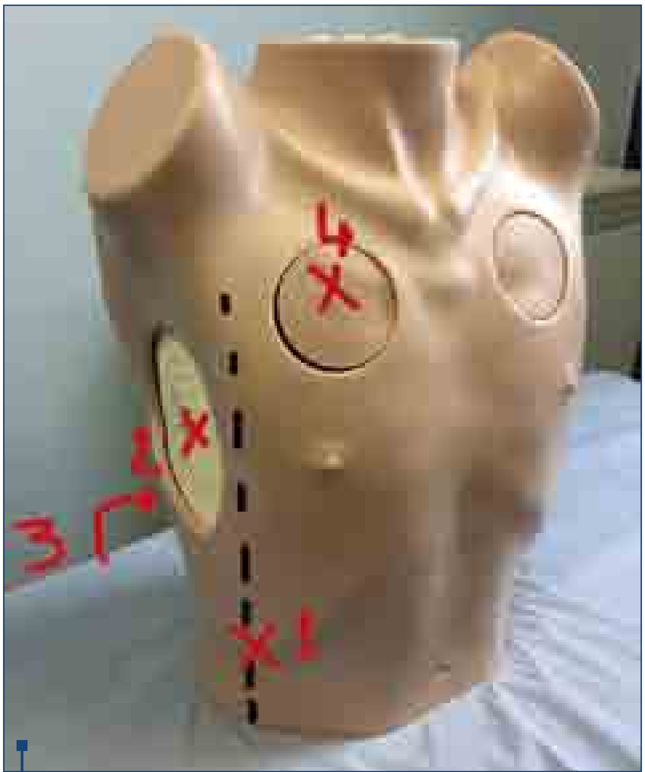

Figure 5. *Acoustic windows of the chest:*
1. *base of the chest anterior axillary line – liver, diaphragm, lung;* ***2.*** *intercostal, mid axillary line – lung, pleural effusions, procedures;* ***3.*** *base of the chest, posterior – small effusions* ***4.*** *second intercostal space – pneumothorax;* ***5.*** *supraclavicular – pneumothorax, lymphnodes (not marked on the picture)*

Step 3: identify pleural line. Check for the presence of pleural sliding. Reduce the depth and focus on the pleural space, or explore further the pleural image/ pathology.

Step 4: focus on the lung or pleural pathology and aim to characterize it. Adjust the gain as it is necessary. Adjust the depth. Change the probe position to scan between the ribs, alongside intercostal space, and assess the depth of pleural fluid.

Step 5: scan the remaining chest windows. Check for pleural sliding or for confirmation of pathology.

What are the normal findings on TUS?

It is important to be able to recognize each layer and the echoes produced by skin, subcutaneous tissue, intercostals muscles, fascia, ribs, pleural membranes and the lungs.

Invite the patient to take deep breaths, in order to assess the lung movement and the ultrasound artefacts that are present with a normal lung. Once the lung comes into the echo window no further structures can be visualised beneath the lung (the curtain sign) and the characteristic artefacts described below become visible.

TUS semiology - basic aspects:

A particularity of TUS is that the examining doctor needs to know how to interpret a large number of artefacts, in addition to some real images. The most common artefacts have been simplified in Figure 6.

The pleural line: a hyperechoic, bright-white, thick and horizontal line, corresponding to the parietal pleura.

"Lung sliding": rhythmic movement of the pleural line (along the lung) during respiration. Lung sliding disappears in pneumothorax, pleural effusion, pleural plaques, tumors, pleurodesis and in advanced COPD[8,9].

"A-lines": horizontal hyperechoic lines visible in the lung, which are parallel with the pleural line. "A" lines are repetitive reverberation artefacts of the pleural line. They correspond to the normal lung surface and are an air artifact[1]. The "A" lines are present in patients with COPD, asthma, pulmonary embolism, but in the absence of the lung sliding. The absence of "A" lines means the air is replaced by something that transmits the ultrasound waves and can be observed in the presence of alveolar liquid, blood, increase interstitial cellularity or atelectasis[2].

"B-lines" ("comet tails" or "lung rockets"): hyperechoic (white), vertical, narrow-based laser-like rays extending to the edge of the screen. The width of the comet-tail artifacts increases with the depth, to a value of about 1 cm[10]. They move with respiration and crash the "A" lines. The presence of few thin "B" lines is normal, especially in the last intercostal space, but if the "B" lines are long, multiple, and thick, they may suggest the presence of an abnormality, such as alveolar or interstitial edema, lung contusion, pneumonia, ARDS or interstitial fibrosis[10] (Figure 7). This artefact is the sonographic equivalent of Kerley lines.

"E lines": vertical artefacts produced by areas of subcutaneous emphysema that are seen between the skin and pleural line. Occasionally they can be confused with "B" lines, especially if the operator does not note the characteristic subcutaneous crepitations.

"Z-lines": small, vertical hyperechoic lines that diminish away and do not extend into the entire ultrasound window. They are caused by reverberation of the normal air-fluid interface in the pleural space[1].

"Ground-glass" or **"sandy appearance"** (B mode) or **"seashore sign"** (M mode): is the typically aspect of the normal lung tissue under the pleural line. The seashore image includes several hyperechoic horizontal lines under the pleural line and below them there is a granular aspect (Figure 9).

Figure 6. *Most common signs and artefacts on thoracic ultrasound*

Figure 7. *Long, multiple, thick B lines in the presence of interstitial fibrosis (a), and confirmatory high resolution CT scan from the same patient*

What are the most common abnormalities?

Pleural effusion

Appears as a black shadow with a homogenous, triangular shape between parietal and visceral pleura (Figure 8). The atelectatic lung can be seen floating within the effusion. Ultrasound can detect as little as 20 centimeters cubic of pleural fluid, even if it is loculated, and is more sensitive than decubitus expiratory films[11].

Several ultrasonic findings can help distinguishing a transudate from an exudate:

- Transudates produce anechoic and unseptated/loculated effusions[12].
- Exudates may have an increased echogenicity (due to increased density) with visible sediments or loculations[12].

When trying to differentiate an exudate and a transudate we suggest paying attention to the appearance of the pleura, as a nodular pleura is highly suggestive of a malignant pathology[8].

Pneumothorax

TUS allows rapid identification and monitoring of a pneumothorax in conditions when chest radiographs are not possible, or not sensitive enough as in patients with severe trauma, during surgical intervention, or in ICU, when the patient is in a critical condition[9,13,14]. In a trauma patient there is a high possibility to miss a pneumothorax on a chest radiograph (the sensibility of a chest radiograph for a pneumothorax in these conditions is only 47 – 75%, specificity 100%), while for TUS the sensibility is 98% and the specificity is 99%[13] (Figure 9). TUS can detect even a very small pneumothorax and in ICU can thus prevent further complications of mechanical ventilation[14].

Although rapid scanning for a pneumothorax can begin in the anterior area of the chest, in the second intercostal space (window 2), with the linear probe (7,5-10 MHz) in vertical position, we recommend the standard approach, with the identification of reference organs first. Both M mode and B mode should be used for the assessment of a pneumothorax.

The high specificity and sensitivity of ultrasound examination for a pneumothorax is due to a number of specific sonographic signs[13,14]:

Absence of respiratory movement of the lung - absence of the “sliding/gliding sign” (in B mode)

Absence of ”comet tails” or “B lines” (B-mode).

Presence of the **“transition point”** or “lung-point sign”: the ultimate point where the lung makes contact with the pleura and lung sliding stops.

“Stratosphere sign” or **“barcode sign”** in M-mode: multiple horizontal lines without granular zone and absence of the normal “seashore sign” under the pleural line.

Tumors in the chest wall, pleura or peripheral lung (in contact with the pleura)

Chest wall tumors, mesotheliomas, pleural plaques or peripheral lung tumors can be visualized by TUS if they are in contact with the pleura[4] (Figure 10). For the examination of tumors in the chest we recommend the same standard approach and then a focused examination with a linear high frequency probe. The most frequent ultrasound findings are:

- Disappearance of normal signs and presence of a hypoechoic, nodular, mass linked to the pleura.

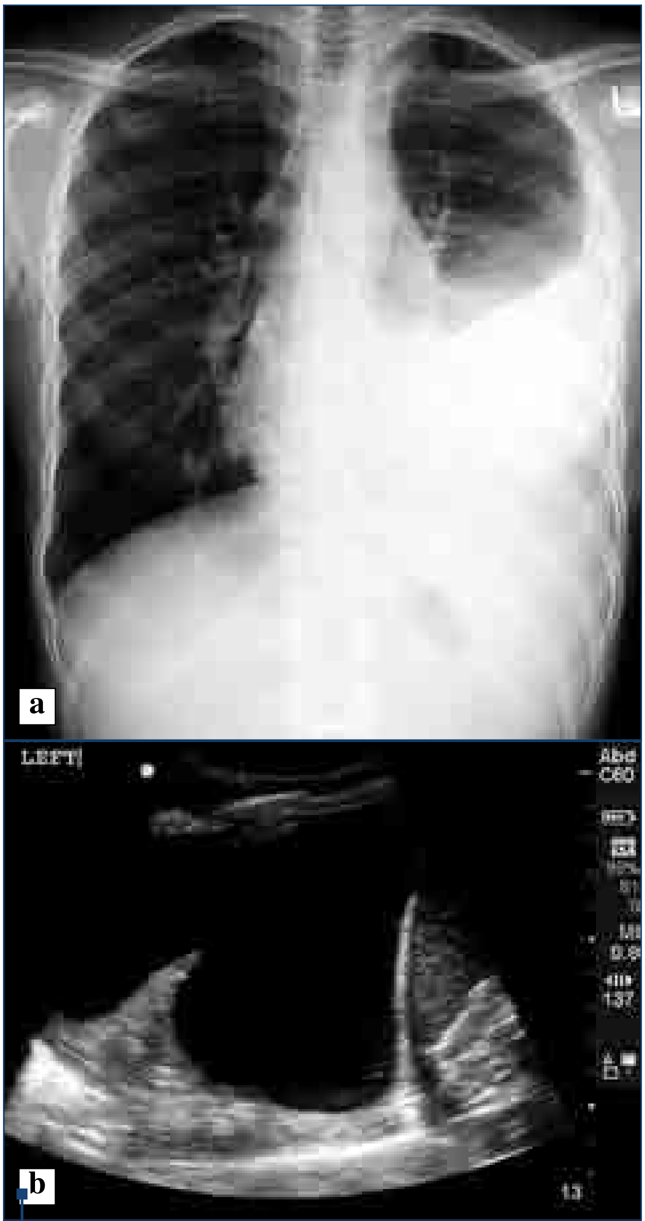

Figure 8.** Pleural effusion. Chest radiograph **(a)** and pleural ultrasound **(b)

- Doppler mode can show hypervascularisation in a malignant tumor.

TUS can guide a percutaneous needle aspiration/biopsy of peripheral masses[15]. In a recent study with 91 patients, US-guided cutting biopsy was 85% sensitive for neoplastic disease and 100% sensitive for mesothelioma[16,17]. TUS can also guide the pleural fluid aspiration and cytological evaluation of an effusion potentially associated with a lung tumor[18,19].

In addition, TUS may assist with tumor staging in certain conditions[20]:

- If there is invasion of the visceral pleura - then the stage is T2.
- Invasion of the parietal pleura and the chest wall is equivalent with T3.
- A non complicated Pancoast tumor is staged T3 (IIIA)
- Pleural effusion or pericardial effusion is equivalent with stage IV M1 metastasis.

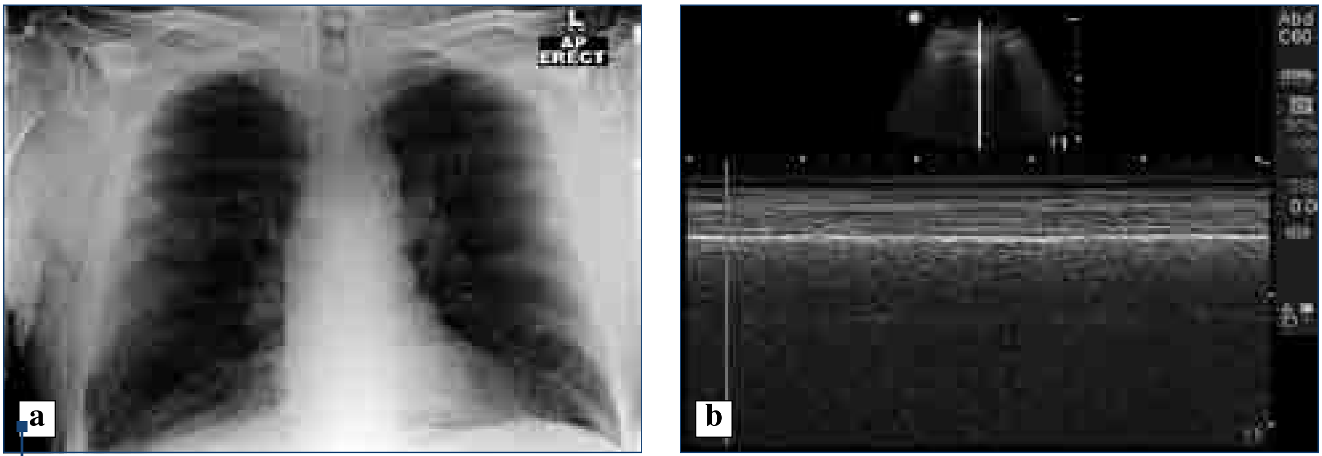

Figure 9. *Pneumothorax. Chest radiograph with a small pneumothorax and chest drain in situ* ***(a)*** *and image in B and M mode* ***(b)*** *with the sea shore sign*

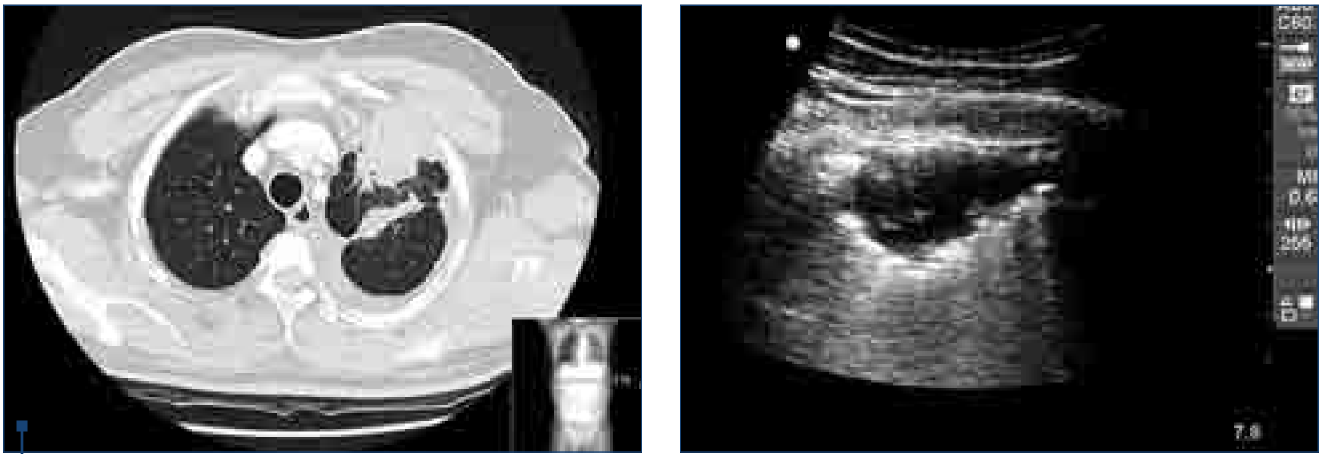

Figure 10. *Peripheral lung tumor (adenocarcinoma). Computer tomographic image* ***(a)*** *and thoracic ultrasound* ***(b)***

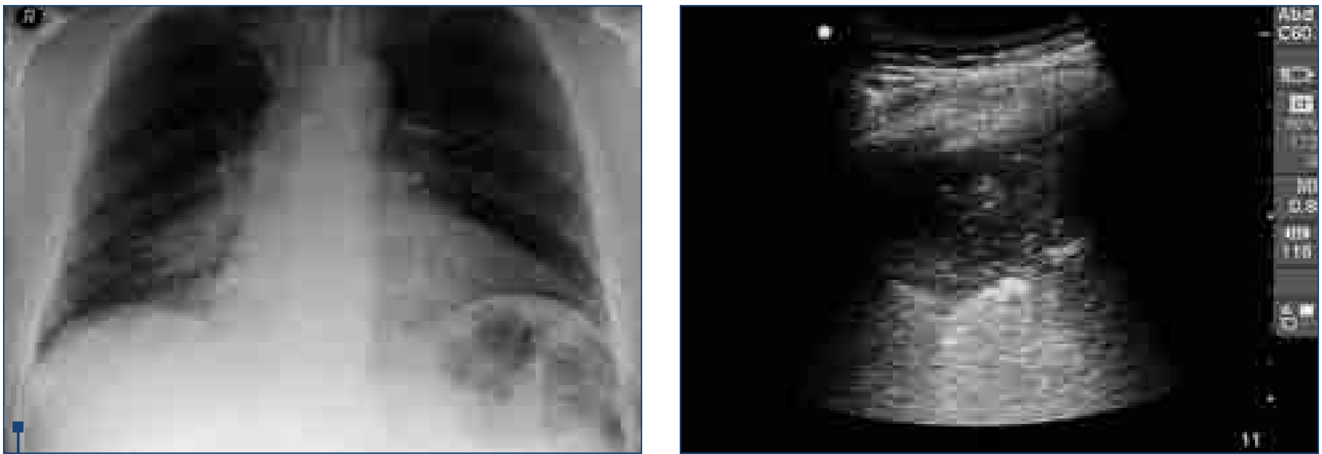

Figure 11. *Pneumonic consolidation at the right lower lobe. Chest radiographic appearance* ***(a)*** *and thoracic ultrasound* ***(b)***

Pneumonia

Pneumonic consolidations appear smaller on the ultrasound than on chest radiograph[21] (Figure 11). In a patient with pneumonia TUS can reveal the following abnormalities[4]:

- Consolidation - loss of air in lobular spaces allows transmission of the ultrasound and the visualization of the lung tissue with air bronchograms. Air bronchograms are hyperechoic lines within a hypoechoic mass, which increase in inspiration. In advanced lung consolidation the ultrasonographic image is similar to the liver ("hepatization" of the lung).
- Atelectasis - appears like a consolidation that does not have the associated air bronchogram.

Peripheral lung abscesses

They appear as a hypoechoic, inhomogeneous masses, without the normal lung ultrasound signal and well circumscribed by a hyperechoic wall.

Pulmonary edema

TUS can be helpful in differentiating cardiogenic pulmonary oedema from decompensated COPD. Patients with pulmonary oedema will have bilateral, diffuse, excessive, B-lines[22].

Therapeutic procedures guided by TUS

TUS is useful in guiding several procedures, such pleural aspiration, pleural biopsy, insertion of a Seldinger pleural catheter, sampling of lung or chest wall abnormalities and samplting of lymph nodes. The precise protocols for these procedures will be discussed elsewhere.

A holistic approach

Because the managing clinician (who knows the patient very well) is also the ultrasonographer, any additional ultrasound abnormalities observed during the procedure will help the differential diagnosis. For this reason we found that it is useful to the respiratory clinician to know elements of abdominal and cardiac ultrasonography, but it is not essential to be fully competent in these procedures. When in doubt, always ask a radiologist to clarify the findings.

Abdominal US can add important information about a thoracic pathology. A look at the liver can offer a first impression regarding the staging of lung tumors, or can suggest pathology under the diaphragm to explain a pleural effusion (cirrhosis, abdominal tumors, and concomitant ascites).

Heart US (echo) can give important, clarifying, information on a respiratory diagnosis (transudate vs. exudate, etc).

In addition, TUS may be associated with bronchoscopic techniques such as endobronchial ultrasound. However this requires dedicated and expensive equipment and additional training.

How much training do I need?

Ultrasonography is a user-dependent tool and is only as good as the ultrasonographer is. There is a need to have a standardised training programme and to define competency. Achieving competence through a recognised training programme in TUS is strongly recommended by the international respiratory and medical societies[23]. TUS can be easily learned by a large number of specialists and residents from different backgrounds who are involved in the care of acute and chronic respiratory patients. The European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) recommends for Level 1 competence (basic) that the trainee should observe 25 examinations and perform under supervision at least 100 examinations on normal patients, 50 on patients with pleural effusions and 25 thoracocenteses[24]. All trainees should keep a log book and record all procedures.

In Romania there are no guidelines or programmes for achieving competence in TUS. However, a pleural pathology working party has been created within the Romanian Society of Pneumology and we hope that further guidance will follow soon.

Conclusions

TUS is a rapid, accurate, noninvasive procedure that can be applied at the bedside. TUS is likely to improve patient experience, clinical effectiveness and to reduce the costs for chest radiographs, or more complex and expensive CT scans. It is a simple technique that is easy to learn if the training is structured and focused on practical elements. Further research is needed to define the cost effectiveness of various ultrasound training programs. Collaboration in a network rather than individual examples, with colleagues interested in chest ultrasounds openly sharing their experiences might quickly lead to new applications and new high quality studies in this field. In conclusion, we strongly recommend and support training Romanian physicians in TUS and engaging colleagues in active networking, nationally and internationally. ■

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