Current role of emergency ultrasound of the chest*

Angelika Reissig, MD; Roberto Copetti, MD; Claus Kroegel, MD, PhD, FCCP

Objective: Chest sonography has gained clinical significance in the diagnosis of various pulmonary, pleural, cardiac, and mediastinal emergency conditions.

Data Source: A systematic literature search of MEDLINE database was performed to identify all studies dealing with transthoracic sonography/chest ultrasound in combination with pulmonary embolism, pneumothorax, pneumonia, pleural effusion, pulmonary edema, and lung contusion. The relevant sonographic studies between 1988 and 2010 were evaluated.

Conclusions: The noninvasive ultrasound-based diagnosis is relatively portable permitting the technique to be performed at any time, in any place, and on any patient, an ideal method for emergency conditions. Sonography allows immediate diagnosis of pulmonary embolism, pneumothorax, pneumonia, pleural effusion as well as rib fracture, and it provides a basis for further diagnostic- and treatment-related decisions. The key sonographic features associated with these most common emergency chest diseases are illustrated herein. (Crit Care Med 2011; 39:000–000)

Key Words: transthoracic sonography; chest ultrasound; pulmonary embolism; pneumothorax; pneumonia; pleural effusion; pulmonary edema; lung contusion

T he role of transthoracic sonography (TS) in the chest has traditionally been limited to evaluation of pleural effusion and as a guidance for thoracocentesis. However, in recent years, TS has become an increasingly valuable diagnostic tool in various pulmonary, pleural, cardiac, and mediastinal diseases (1–12), especially under emergency conditions (13–15). Using TS, some conditions may be immediately diagnosed (e.g., pneumonia, pulmonary embolism, pleural as well as pericardial effusion, pneumothorax [PTX], and atelectasis), or even may be suspected (e.g., diffuse parenchymal lung disease) or may serve as a guide for the next diagnostic or therapeutic steps (e.g., computed tomography [CT], bronchoscopy, or thoracocentesis). In contrast to CT, TS is noninvasive and does not employ radiation and contrast material, the method may be applied on patients, irrespective of their age, during pregnancy, under conditions of renal failure, or in patients with allergy against contrast material. Finally, portable sonographic equipment also allows ultrasound evaluation at any time and in any place. Nevertheless, TS is limited by interobserver variability and requires some time to be learned. Due to the major impact of TS on patient management, any emergency physician and intensivist should be trained.

Emergency Ultrasound Investigation

Each exploration should commence by the acquisition of the patient’s history and a focused, organ and symptom-related clinical investigation. Depending on the information obtained, this should be followed by TS, echocardiography, or ultrasound of the abdomen. Generally, two different approaches are available for performing TS: a systematic investigation or a primary focus on the site of thoracic pain or dyspnea.

Emergency ultrasound favors the last procedure as the method of choice. The focus on investigation for maximum pathologic findings depends on the suspected medical condition. For instance, in pulmonary embolism (PE), peripheral subpleural lesions are predominantly localized in the dorsal and basal regions of the lung, which should be preferentially explored. If PTX is suspected, the presence of air should be assessed at the highest point.

Limitations of Ultrasound Investigation

In general, pulmonary lesions can only be detected by TS under the following conditions: 1) the location of pulmonary lesion is peripheral and extends up to the pleura; 2) there is an absence of air in the pleural space (no PTX); 3) there is an absence of subcutaneous accumulation of air (no subcutaneous emphysema); and 4) the lesion is not hidden behind a bony structure.

It is important to note here that centrally localized processes generally escape sonographic detection, which constitutes a major limitation of TS.

Main Symptoms of Thoracic Diseases

Almost all diseases of the chest, including of the heart, lungs, and mediastinum are accompanied by one or more of the following four cardinal symptoms: thoracic pain, dyspnea, cough, or expectoration. However, in emergency conditions the most frequently accompanied symptoms include dyspnea and thoracic pain.

Differential Diagnosis of Thoracic Pain. The five potentially life-threatening diseases accompanied by thoracic pain comprise rupture of the esophagus, an acute coronary syndrome, PE, PTX, and aortic dissection. The causes of thoracic pain and the importance of ultrasound in diagnosing these conditions are summarized Table 1.
Differential Diagnosis of Dyspnea.
Acute dyspnea may also represent a life-threatening symptom. A differential diagnosis of acute dyspnea and the importance of ultrasound in diagnosing diseases accompanying this symptom are also shown in Table 1. In emergency situations, asthma and chronic obstructive pulmonary disease are diagnosed on the basis of history and clinical investigation indicating bronchial obstruction since no pathologic sonographic features are manifest for these conditions as TS will reveal a normal lung surface (15).

Sonomorphology of Important Emergency Chest Diseases

PE
Diagnosis of PE by TS. In 70% to 80% of cases, central PE is accompanied by peripheral lesions detectable by TS. Lesion configuration reveals mostly wedge-shaped (86%), occasionally rounded (11%), and polygonal (3.3%) areas. The mean lesion number constitutes 2.3–2.6 per patient (range 1–9) (1, 2), and the average size varies between 13.8 × 10.6 mm (1) and 15.5 × 12.4 mm (2). Regular parenchymal lesions are hypoechoic and show unrestricted movement during breathing. Approximately 7% of the patients reveal a single echo localized at the center of the lesions referred to as the central bronchogenic reflex (Fig. 1). Using TS, 43% of the peripheral lesions were localized at the right side, 27% at the left side, and 30% bilateral (17). In addition, the lesions are predominantly located within the lower lobes (80%). Approximately two thirds of the lesions can be detected in the posterior basal segment of the lung (2).

Although PE is a primary disease of the lung parenchymal vasculature, the pleural space can often be secondarily affected. A basal and/or localized pleural effusion is present in 50% to 60% of the patients with PE. The diagnosis of PE is confirmed when two or more typical triangular or rounded pleural-based subpleural lesions are identified. The presence of only one typical lesion with a corresponding pleural effusion points to a probable PE (2). The sensitivity, specificity, and accuracy of TS for diagnosing PE are 70% to 94%, 70% to 95%, and 84% to 91%, respectively (1, 2, 18–20).

In addition, in patients with acute respiratory failure the combination of predominant anterior bilateral A lines (hyperechoic, roughly horizontal lines, arising at regular intervals from the pleural line reflecting a regular lung surface) plus evidence of venous thrombosis showed a sensitivity of 81%, a specificity of 99%, and a positive/negative predictive value of 94%/98%, respectively, for diagnosing PE (15). The evidence of venous thrombosis in cardiopulmonary-compromised patients yields an indirect argument for diagnosing PE. We suggest TS in diagnosing PE as a noninvasive technique applicable any time, any place, and in any patient; although it is not implemented within the current guidelines for the diagnosis and management of PE.

Diagnosis of PE using echocardiography. PE presenting with hypotension or shock is defined as high-risk PE. In a highly unstable patient, the diagnosis of PE may be accepted alone on the basis of echocardiographic findings.

Table 1. Frequent causes of thoracic pain and dyspnea under emergency conditions and significance of sonography and echocardiography in diagnosing these diseases

<table>
<thead>
<tr>
<th>Causes of Acute Thoracic Pain and Dyspnea</th>
<th>Symptom</th>
<th>Role of Sonography#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory diseases</td>
<td>Pleuritis</td>
<td>++</td>
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<tr>
<td></td>
<td>Pleural effusion</td>
<td>++</td>
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<td></td>
<td>Pleural empyema</td>
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<tr>
<td></td>
<td>Pneumothorax</td>
<td>++</td>
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<tr>
<td></td>
<td>Pulmonary embolism</td>
<td>+</td>
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<tr>
<td></td>
<td>Pneumonia</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Atelectasis</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Metastasis of the pleura</td>
<td>+</td>
</tr>
<tr>
<td>Cardiovascular diseases</td>
<td>Dissection of the aorta</td>
<td>+ (+)</td>
</tr>
<tr>
<td></td>
<td>Acute coronary syndrome</td>
<td>+ (#)</td>
</tr>
<tr>
<td></td>
<td>Pericardial effusion/tamponade</td>
<td>+ (+)</td>
</tr>
<tr>
<td></td>
<td>Acute heart failure</td>
<td>+ (+)</td>
</tr>
<tr>
<td></td>
<td>Heart defect</td>
<td>+ (+)</td>
</tr>
<tr>
<td></td>
<td>Pericarditis/myocarditis</td>
<td>+ (#)</td>
</tr>
<tr>
<td>Diseases of the chest wall</td>
<td>Tumor infiltration of the thoracic wall</td>
<td>++</td>
</tr>
<tr>
<td>Muscular-skeletal diseases</td>
<td>Rib fracture</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>Bone tumor, metastasis</td>
<td>++</td>
</tr>
<tr>
<td>Diseases of the gastrointestinal tract</td>
<td>Rupture of esophagus</td>
<td>(+)</td>
</tr>
<tr>
<td></td>
<td>Acute pancreatitis</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Subphrenic abscess</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>Cholecystitis</td>
<td>++</td>
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</tbody>
</table>

#(+), indicative, no clear evidence; +, diagnostic significance, if presentable by sonography; ++, diagnostic confirmation; (#), echocardiography.
Table was modified after reference 16.
and in such conditions thrombolysis or embolectomy would be justified (21). However, a normal echo does rule out PE only in hemodynamically unstable patients.

The typical echocardiographic pattern of hemodynamically significant PE shows the following features (22): 1) right ventricle overload and dysfunction; 2) increased right ventricle/left ventricle ratio caused by interventricular septal bulging into the left ventricle (Fig. 2); 3) dilated proximal pulmonary arteries (Fig. 3); 4) pulmonary hypertension or increased right ventricular afterload as indicated by the increased jet of tricuspid regurgitation (usually in the range of 3–3.5 m/sec); 5) frequent dilation of inferior vena cava and no collapse on inspiration (Fig. 4); 6) McConnell sign (depressed contractility of the right ventricle-free wall compared with its apex); and 7) visualization of right heart thrombi, usually in-transit from systemic veins to pulmonary arteries (Figs. 3 and 5).

Consider: For suspected PE, immediate anticoagulation is necessary. In cardiopulmonary-stable patients (non-massive PE), TS and compression sonography of the leg veins should be considered first. Confirmed diagnosis of PE transpires on detection of two or more typical lesions, which are predominantly located in the dorsobasal region of the lung and in the area of acute (or previous) thoracic pain. In case of inconspicuous TS and compression sonography, a CT is required.

In cardiopulmonary-compromised patients (massive PE), echocardiography should be the diagnostic method of choice. Normal echocardiography rules out massive PE. In very unstable patients with right chamber dilation, thrombolysis should be started, especially if compression sonography is positive.

PTX. Although air-containing lung and air within the pleural space may exhibit the same ultrasound pattern (A-lines), certain signs (Box 1) allow the diagnosis and/or exclusion of a PTX by TS (5–8, 13, 15, 23–29).

If PTX is suspected by clinical exploration, patients should be in a reclined position during investigation, because air collects within the anterior nondependent portions of the pleural space. Thus, examination should focus on the upright areas of the thorax. The most prominent sign demonstrating PTX is the loss of the “gliding sign” or “lung sliding,” referring to the breath-dependent, up and down motion (Fig. 6). Other aspects to be considered are included in Boxes 1 and 2).

Tension PTX. The diagnosis of tension PTX is a clinical diagnosis. In an unstable patient, tension PTX may be suspected on absence of a lung point or if the lung point is below the anterior axillary line. The integrated data obtained from an ultrasound examination of the lung, heart, and inferior vena cava are often crucial because tension PTX reveals small and hyperkinetic heart chambers and a large inferior vena cava without respiratory variation. However, in traumatic severely hypovolemic patients, the inferior vena cava may also be small. Sensitivity and specificity for diagnosing postinterventional and traumatic PTX vary between 80% and 100% and between 83% and 100%, respectively (5–8, 32). In contrast, an ex-
tended and focused sonographic assessment for trauma attained a sensitivity of 58.9% and a specificity of 99.1%, respectively (13). The somewhat reduced sensitivity probably reflects the emergency setting under nonstandardized conditions. In cardiopulmonary-compromised patients, the absent anterior lung sliding, absent anterior B-lines, and the presence of a lung point achieved a sensitivity of 88% and a specificity of 100% for diagnosing PTX (15).

Consider: Based on the diagnostic accuracy, the amount of time required, the availability, and the costs, TS is the diagnostic modality of choice, in particular, if a tension PTX is suspected. The sonographic diagnosis of PTX relies mainly on the loss of respiratory motion of the pleura and B-lines as well as evidence of horizontal artifacts (A-lines). However, because these criteria are nonspecific, a comparison with the contralateral lung is strongly recommended as well as the detection of the "lung point," which confirms the diagnosis of PTX. Although TS may give an idea of the size of PTX, the decision for placing a chest tube under emergency conditions is preferentially based on clinical symptoms and integrated data from pleura, heart, and inferior vena cava ultrasound. TS is also useful in confirming lung re-expansion following drainage.

A radiograph of the chest or even the gold standard CT may be performed to estimate the volume of the PTX, if sonographic examination is limited (for instance subcutaneous emphysema), or in case of discrepancy between TS and clinical symptoms.

Pneumonia. The clinical diagnosis of pneumonia may be difficult to establish. Nevertheless, the history of productive cough, fever, and auscultation should raise a suspicion of pneumonia. In such cases of doubt, TS is helpful in yielding a definitive diagnosis. The ultrasonic features of pneumonia enclose a hypoechoic area of varying size and shape with irregular and serrated margins together with a heterogeneous echotexture (Fig. 7). In addition, pneumonia typically reveals an air bronchogram (multiple lentil-sized echoes within the lesion) and free breath-dependent motion of the lesion. Occasionally, a positive fluid bronchogram (echo-poor/echo-free tubular structures without any perfusion signals) may be detectable. In more than two thirds of the cases, pneumonia is accompanied by a pleural effusion (3, 4, 12, 34, 35).

Consider: Bedside chest radiography is often of limited value in diagnosing pneumonia. Although current guidelines still suggest radiograph as first diagnostic...
Absolute limitations

- Depth of pulmonary collapse can not be determined precisely, although the lung point gives an idea of the size of PLX.
- In cases of subcutaneous emphysema, no investigation is possible

Relative limitations

1. Extreme obesity
2. Adhesive pleural diseases
3. Encapsulated pneumothorax, bullous emphysema
4. Mainstem intubation

Figure 8. Limitations of TS in diagnosing pneumothorax and serothorax.

Figure 9. Pneumonia sonogram. A 57-yr-old woman with fever, cough, and purulent sputum. A, The sonogram depicts an area with irregular and serrated margins and an inhomogeneous echotexture, caused by an air bronchogram. B, Corresponding computed tomography reveals lobar pneumonia in the left lower lobe.

Figure 10. Empyema sonogram. A 38-yr-old patient with fever, cough, and expectoration for 4 wks. Despite antibiotic therapy, there was no improvement. The patient developed progressive dyspnea and chest pain. The sonogram demonstrates an echo-rich effusion with multiple echogenic structures within the effusion.

Figure 11. Pulmonary edema sonogram. A 73-yr-old man suffering from acute coronary syndrome with development of pulmonary edema. The sonogram shows multiple comet tail artifacts.

The sonographic diagnosis relies on the detection of an air bronchogram within an irregular hypoechoic lesion. In adult patients showing no air bronchogram, pneumonia is unlikely to be present. These patients need further diagnostic investigations such as radiograph in two planes or CT.

Pleural Effusion, Hematothorax, and Empyema.

A pleural effusion exhibiting as an echo-poor or echo-free space between the pleura visceralis and parietalis is best visible above the diaphragm in sitting patients (34–37).

However, the amount of fluid collected in the pleural space is estimated (assessed in supine position with a mild trunk elevation at 15 degrees) by means of a simplified rule of thumb as follows (38):

Estimated amount of effusion (in mL):

\[
\text{Maximal distance}^* (\text{mm}) \times 20
\]

* Cranio-caudal distance between parietal and visceral pleura at the lung base in posterior axillary line.

In the case of a large pleural effusion, the nonventilated lung parenchyma presents as compressive atelectasis within the effusion in a “waving hand” motion. Typically, a transudate appears as anechoic area, whereas an exudate often depicts varying degrees of increased echogenicity. A hematothorax is usually characterized by multiple echoes that appear to dance within the effusion as in a “snow flurry.” Empyema may also present as a snow flurry but generally depicts echo-rich traces comparable to a “Swiss cheese” (Fig. 8). However, for a definitive differential diagnosis of exudate, transudate, hematothorax, and empyema, thoracocentesis is required.

TS had a diagnostic accuracy of 93% for pleural effusion whereas bedside chest radiography showed a diagnostic accuracy of 47% compared with CT in patients with acute respiratory distress syndrome (ARDS) (39).

Consider: TS is the diagnostic modality of choice in case of suspected pleural effusion.
Pulmonary Edema, Acute Lung Injury, and ARDS. Pulmonary edema (Fig. 9) typically manifests with B-lines that initially prefer the lung bases but with increasing capillary venous pressure extend to the medium and superior fields. These findings are usually bilaterally and symmetrically. Furthermore, pleural line abnormalities are rarely observed in cardiogenic pulmonary edema. In contrast, patients with acute lung injury (ALI)/ARDS, B-lines have a nonhomogeneous distribution with evidence of spared areas and are constantly associated with important pleural line abnormalities (Table 2) (14, 15, 40, 41). Radiographically, the findings of ALI/ARDS are often indistinguishable from those of pulmonary edema. CT scanning is useful in the initial characterization of patients with ALI/ARDS. However, the method has some disadvantages. First, CT exposes patients to high dose of ionizing radiation. Second, it is a costly resource and not readily available in all hospitals. Finally, it requires patient transport to the CT. Thus, and considering the high sensitivity and specificity, TS is the first modality for distinguishing pulmonary edema from ALI/ARDS.

Consider: B-lines are characteristic signs of both pulmonary edema and ALI/ARDS. TS is the first modality in diagnosing interstitial syndrome and follow-up during the course of the disease. Whereas TS apprehends only pulmonary and subpleural changes, CT allows a comprehensive visualization of the lung.

Lung Contusion. Chest trauma may be associated with a lung contusion, rib fractures, pleural effusion/hematoma, atelectasis, PTX, and hematoma of the chest wall. Approximately one fifth of the patients with blunt chest trauma suffer from lung contusion, localized within the traumatic thoracic region.

Figure 12. Rib fracture sonogram. A 47-yr-old patient with chest pain after a bicycle accident. The sonogram depicts a discontinuity of the fractured rib with dislocation of the endings.
(40). Whereas radiograph of the lung may be inconclusive, sonographic detection of these signs strongly indicates lung contusion.

Lung contusion may be suspected on finding one of the following features: Subpleural, echo-poor, irregular bony or step within the bony reflex may be seen, which may be better visible if the affected region is carefully pushed down with the scanner (Fig. 10). However, this technique may not always be applicable because of the pain associated with rib fracture.

Consider: TS is the diagnostic modality of choice for diagnosing pleural effusion, fractures, and subpleural lung lesions following contusion. In contrast, CT may encompass deeper lesions of the affected region is carefully pushed down with the scanner.

Table 3 summarizes the most important differential diagnoses based on the most relevant sonographic signs in patients with severe dyspnea and/or thoracic pain.

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REFERENCES


