Use of chest sonography in acute-care radiology[☆]

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Abstract Diagnosis of acute lung disease is a daily challenge for radiologists working in acute-care areas. It is generally based on the results of chest radiography performed under technically unfavorable conditions. Computed tomography (CT) is undoubtedly more accurate in these cases, but it cannot always be performed on critically ill patients who need continuous care. The use of thoracic ultrasonography (US) has recently been proposed for the study of acute lung disease. It can be carried out rapidly at the bedside and does not require any particularly sophisticated equipment. This report analyzes our experience with chest sonography as a supplement to chest radiography in an Emergency Radiology Unit. We performed chest sonography – as an adjunct to chest radiography – on 168 patients with acute chest pathology. Static and dynamic US signs were analyzed in light of radiographic findings and, when possible, CT. The use of chest US improved the authors' ability to provide confident diagnoses of acute disease of the chest and lungs.

Sommario La patologia polmonare acuta rappresenta una sfida quotidiana per il Radiologo d'Urgenza, al quale è richiesto di porre una diagnosi sulla base di un radiogramma del torace, eseguito spesso in condizioni tecniche precarie.

La Tomografia Computerizzata (TC), pur essendo uno strumento decisivo per ovviare alla scarsa accuratezza del radiogramma del torace, non sempre è eseguibile in questi pazienti che necessitano di assistenza continua. Recentemente è stato proposto l'impiego dell'ecografia toracica per lo studio della patologia acuta. L'esame è eseguito rapidamente al letto del paziente e non necessita di apparecchiature particolari. In 168 pazienti con patologia toracica acuta è stato eseguito uno studio ecografico del torace a completamento dell'esame radiologico. Sono stati valutati i segni statici e dinamici correlandoli ai quadri radiografici e, quando possibile, di TC.

Nell'esperienza riportata l'impiego dell'ecografia del torace ha permesso di migliorare la confidenza diagnostica degli autori nella diagnosi radiologica delle patologie acute del distretto toraco-polmonare.

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Introduction

The diagnosis of acute lung disease is a daily challenge for radiologists working in acute-care areas. It is generally based on the results of chest radiography performed under technically unfavorable conditions. These films are generally obtained with the patient lying on a stretcher in the emergency room (ER) or in a bed in the intensive care unit (ICU). The patient is often uncooperative or his/her position cannot be changed. As a result, the quality of the image is often unsatisfactory [1,2] and the findings are difficult to interpret. In addition to these difficulties, problems can also arise in the interpretation of chest films obtained in various situations, e.g., the presence of an opaque hemithorax that makes it difficult to distinguish pleural or parenchymal lesions; acute dyspnea caused by early-stage interstitial edema that cannot be visualized on the chest radiograph or that develops in a patient with chronic obstructive pulmonary disease (COPD) [3,4]; the presence of a small pneumothorax that cannot be detected on films obtained with the patient in the supine position [5,6].

Computed tomography (CT) is the best solution when the accuracy of the chest film is questionable. But ER and ICU patients need continuous care, and they cannot always be transferred to the CT room. The CT examination itself make take less than a minute, but transport and preparation can take up to an hour [7], and this interruption can have important repercussions on the patient's care [8]. In addition, the decision of whether or not to use an intravenous contrast agent can be complicated in these patients whose renal function is known to be impaired (or simply unknown). Use of CT also exposes the patient to ionizing radiation, a distinct risk in reproductive-aged women, young men, and above all children.

The use of thoracic ultrasonography (US) has recently been proposed for the study of lung disease. It can be carried out rapidly at the bedside and does not require any particularly sophisticated equipment [7–9]. This report analyzes our experience with chest sonography as a supplement to chest radiography in an Emergency Radiology Unit.

Examination technique

The study population consisted of 168 patients being cared for in the ER or ICU of our hospital who had radiologic examinations for dyspnea, chest pain, fever, or closed-chest trauma between January 1, 2006 and October 31, 2007. Chest radiographs were obtained in the ER or ICU with a portable bedside unit (Visitor AR 30, Burgatti or VMX Collimator, GE Medical System). In some cases, CT (with or without contrast enhancement) was also performed with a Siemens Multistrato Emotion 6 unit.

Chest sonography was also performed on each participant with an ATL 5000 HDI scanner (Philips, Bothel, Washington) equipped with convex- (2–5 MHz) and linear-array (5–12 MHz) transducers. The examination focused on detection of the sonographic signs described by Lichtenstein, which are based on the movements of the pleura during respiratory excursion, ultrasound artifacts generated by the lung parenchyma (the A, B, E, and Z lines), and ultrasound features indicative of consolidation and

effusions [7,8]. Patients were examined in the supine, sitting or lateral decubitus position depending on their clinical conditions and diagnostic needs. For example, patients with suspected pleural effusion were examined – when possible – in the sitting position. The supine position was preferred when pneumothorax was suspected. All trauma patients were examined in the supine position.

Scans were made in the longitudinal plane, parallel and oblique with respect to the ribs. The entire chest was examined, anteriorly, laterally, and posteriorly, along the parasternal, hemiclavicular, anterior and posterior axillary, and paraspinal lines, in a cephalocaudal direction.

In each case, the sonographic and radiographic examinations were performed by the same operator.

Ultrasound semiotics and clinical presentations

Artifacts

The chest wall is composed of various layers: the skin and subcutaneous tissue, the fasciae and muscles, the ribs, and the pleural line. The ribs, which consist primarily of bony tissue, absorb the US beam, producing a characteristic sign known as posterior shadowing. In contrast, the cartilaginous portion of the ribs – unless there is calcification – is anechoic.

The content of the lung – in particular the close rapport between air and water present in the organ – causes artifacts, whose interpretation is the basis of chest sonography. These signs displayed sufficient specificity, constancy, and reproducibility that allowed identification of the clinical picture.

The pleural line is an echogenic line representing the visceral and parietal pleural membranes, which are normally contiguous. Under normal conditions, the pleural line is regular and less than 2 mm thick [10]. This line represents the surface of the lung, its interface with the chest wall. During respiratory movements, the parietal and visceral pleurae membranes glide smoothly over one another. This movement is a reflection of lung mobility and contact between the lung and the chest wall. It is more evident at the apex of the lungs rather than the bases. Recognition of lung sliding or the “gliding sign” is fundamental. It can be demonstrated using the time–motion modality or M-mode, which reveals a characteristic tracing that resembles a sea shore. It is important to recall that the gliding sign can be present even in patients with pulmonary emphysema and in the presence of air bubbles [11].

Another useful artifact is the “lung pulse,” which consists in minute, rhythmic movements of the pleura caused by contractions of the cardiac ventricles. It can best be appreciated in the areas of the lung adjacent to the heart. The presence of the lung pulse automatically excludes a diagnosis of pneumothorax; in the absence of the gliding sign, it is an indication of atelectasis, with pulmonary contact but no respiratory movement.

“Lung points” are those points in the pleural line where the normal gliding movement is suddenly interrupted, and the pleural line appears immobile on the monitor. This sign reflects loss of contact between the lung and chest wall and is indicative of nonmassive pneumothorax.

In addition to these dynamic signs, there are others that constitute the normal appearance of the lung beneath the pleural line. These horizontal artifacts — known as A lines — are constant repetitions at regular intervals of the pleural line. An important artifact that originates from the pleural line is the comet-tail artifact or B lines. It consists in vertically oriented echogenic reverberation, consensual to lung sliding movements, that extend toward the inner part of the lung cancelling the A lines. B lines are rare in normal subjects. Numerous comet-tail artifacts are strongly indicative of interstitial disease (sensitivity and specificity 93%) [3]. Comet-tail artifacts are produced by the marked difference between air and water in terms of their acoustic impedance. Thickening of the interlobular septae and zones with a ground-glass appearance give rise to these artifacts. This is confirmed by reports of correlation between US signs and CT findings in patients with pulmonary edema or lung fibrosis [11,12]. In the presence of fibrosis, the pleural line appears fragmented, irregular, and thickened [13,14]. The E lines also consist of vertical artifacts, but they originate from the subcutaneous layer and are a reflection of subcutaneous emphysema.

In 80% of all patients [15], faint, poorly defined vertical artifacts known as Z lines are seen. These artifacts are not a pathologic finding. They are easy to recognize because they do not extend to the bottom of the monitor and do not cancel the A lines.

Pleural effusions

Pleural effusions are fairly easy to identify with US and have been diagnosed with this method for some time [16]. The diagnostic accuracy of US in this setting is comparable to that of CT [17] and far superior to that of chest radiography [1]. The effusion appears as an anechoic collection of fluid between the parietal and visceral pleurae. The volume varies. In some cases, the effusion is so small (a few milliliters) that it cannot be detected with chest radiography. The characteristics of the pleural effusion vary: transudates appear anechoic while exudates contain internal echoes. The presence of echoes that move with respiratory excursions (the plankton sign), septation (Fig. 1a,b), or structured echoes are indicative of an exudate, hemothorax, or empyema (Fig. 2a,b).

The M-mode can be used to check for a dynamic artifact known as the sinusoid sign, which is typically associated with low-viscosity effusions. It is caused by displacement of the lung toward the chest wall during inspiration (Fig. 3a,b).

Pneumothorax

Pneumothorax is a fairly common event in critically ill patients. It can be spontaneous or traumatic, iatrogenic or caused by barotrauma. It is not always easy to recognize on chest radiographs. In fact, the sensitivity of this method for diagnosing pneumothorax ranges from 50 to 70%, depending on the magnitude of the lesion and the projection used [5,18].

Computed tomography is regarded as the gold standard for diagnosis of pneumothorax [7,8,18], but it is not used

Fig. 1 Febrile patient with dorsobasal chest pain. a) Posterior axillary ultrasound scan shows area of consolidation with air bronchograms and a pleural effusion with adhesional septation. b) Chest radiography shows a right basal opacity.

routinely for this purpose. For one thing, it is not always available. In addition, transferring a critically ill patient to the CT room can be complicated and risky for the patient.

Ultrasonographic diagnosis of pneumothorax is easy. It is based on the following three signs:

- 1) Absence of the gliding movements of the pleural membranes in the M-mode (Fig. 4a,b). The presence of sliding is associated with high sensitivity (100%) [7] and an excellent negative predictive value (100%) [19], but its specificity is relatively low (60–90%) in the general population or in patients with respiratory distress [19,20], and its predictive value is low (27%) in patients with dyspnea observed in the ER [7]. The gliding sign may be absent in other conditions, including pneumonia, massive atelectasis, pleural adhesions, acute respiratory distress syndrome (ARDS), cardiopulmonary arrest, use of high-frequency assisted ventilation, phrenic nerve paralysis, and simple apnea.

Fig. 2 Eight-year-old girl with several days' history of high fever and chest pain. Chest radiography reveals opacity of the left hemithorax with displacement to the right of the cardiac shadow. a) Ultrasonography: organized pleural effusion (PE). b) Computed tomography: pleural effusion compressing the lung and displacing the heart to the right. Radiologic diagnosis: pleural empyema.

Fig. 3 a) Posterior longitudinal US scan shows an anechoic pleural effusion (white arrow). b) M-mode sonography reveals the "sinusoid sign".

- 2) Absence of B lines (comet-tail artifacts). In the presence of a pneumothorax, these artifacts are masked by the air present between the visceral and parietal pleurae. In the absence of lung sliding, the presence of even one B line excludes the presence of a pneumothorax.
- 3) Presence of lung points. This is a specific sign of non-massive pneumothorax, which reflects points in which contact between the two pleural membranes is restored and lung gliding recurs (Fig. 5). This sign has a specificity of 100% and sensitivity of 66% [21]. In cases of pneumothorax that cannot be detected with portable chest radiography, its sensitivity is 76% [21]. Anterior lung points indicate a small pneumothorax. Those located in the extreme posterior regions (or the complete absence of lung points) are indicative of massive pneumothorax.

The interstitial syndrome and the alveolar-interstitial syndrome

An increase in extravascular water is the cause of the interstitial syndrome, which is manifested on ultrasonography by the presence of multiple B lines or comet-tail artifacts. B lines separated by a distance of at least 7 mm are associated with mild forms of the syndrome; with more extensive involvement of the pulmonary interstitium, the number of B lines increases. They may even become confluent and conceal the A lines. The interstitial syndrome may be restricted to one sector of the lung or characterized by diffuse involvement. The diffuse presence of multiple B lines is diagnostic of pulmonary edema (Fig. 6a,b) with sensitivity of 100% and specificity of 93% [4]. This sign can be detected even in the early stages before the edema is evident on the chest radiograph, i.e., when the extravascular water compartment has expanded by 30%.

B lines can also be observed in the presence of lesional forms of edema, diffuse interstitial disease, pulmonary fibrosis (Fig. 7a,b) and in full-blown cases of ARDS.

Fig. 4 Patient with closed-chest trauma after chest tube placement. a) M-mode US of the left side of the chest reveals no "lung sliding". b) Comparison with the right chest scan, which reveals "lung sliding" with the "sea-shore" effect.

They also appear in patients with interstitial pneumonia. They can be observed in early-stage foci of pneumonia, areas of contusion, and in the peripheral regions of consolidative lesions (associated with contusion, laceration–contusion injury, pneumonia).

These sonographic signs obviously have to be interpreted in light of the clinical context in which they appear.

It is important to recall that in cases of flare-ups of COPD, bronchial asthma, and acute pulmonary embolism, sonographic findings are unremarkable with normal A lines and few or no B lines. This finding is of immediate value in the differential diagnosis of certain forms of acute dyspnea [4].

Alveolar consolidation

Areas of alveolar consolidation contain mainly water and little air. In 98.5% of all cases, they extend all the way to the pleura [22] and can thus be detected easily with US. They appear as structured areas with an appearance similar to that of liver tissue (hepatization). The surface contour may be regular when it is formed by the pleural line or by

Fig. 5 Patient with closed-chest trauma. US – longitudinal scan along the hemiclavicular line in the M-mode: alternating pathologic (left) and normal (right) patterns with breathing movements, "lung points".

the borders of a pleural effusion; unless the entire lobe is involved, the deeper borders of the consolidated area are irregular since they are in contact with normal, aerated lung tissue. Involvement may be lobar, segmental, or casual; the affected area may appear swollen/bulging, normal, or retracted with multiple comet-tail artifacts (or B lines) in the periphery (similar to the pattern associated with pneumonia, ARDS-related consolidation, and organized pulmonary contusions [11,23] (Fig. 8a,b) or present a normal pulmonary pattern with A lines only. In the presence of pulmonary infarction (Fig. 9a–c) and consolidative forms of ARDS, the pleural lines may appear irregular and fragmented with a convex profile [9].

In aspiration pneumonia, B lines are typically absent since alveolar filling precedes the interstitial changes. There may be some degree of pleural effusion. The sensitivity of US in detecting these conditions (compared with CT as a gold standard) is 90% with a specificity of 98% [22].

The consolidated area is immobile; lung sliding is reduced or absent, and there is no sinusoidal movement on M-mode studies. This latter finding distinguishes these cases from those characterized by corpuscular effusions, which are affected by changes in respiratory activity.

Within the consolidated area, there may be patches of hypoechoic or anechoic tissue that sometimes contain gas artifacts. These areas represent abscesses or areas of necrosis. There may also be hyperechoic lines or punctate images that represent air bronchograms (Fig. 10a,b). Their dynamic or static nature distinguishes nonretractile (pneumonia) (Fig. 11a,b) from retractile (atelectasis) forms of consolidation with a specificity of 100% [7,24].

In the presence of complete atelectasis, the lung pulse is observed but lung sliding is absent. The presence of the lung pulse is a sensitive indicator (90%) of atelectasis of the left lower lobe caused by incorrect positioning of an endotracheal tube [25].

Diminished or absent lung sliding and the appearance of a lung pulse are also expression of severe forms of ARDS,

Fig. 6 Patient with acute dyspnea. a) US longitudinal scan of the anterior chest shows multiple comet-tail artifacts (or B lines). b) Chest radiography performed with the patient lying on a stretcher: congestion of the hilar and perihilar regions with early signs of interstitial edema.

and they reflect markedly reduced lung compliance [7–9]. Fluid bronchograms may also be present (post-obstructive pneumonia, diseases caused by bronchial obstruction). They appear as anechoic tubular structures with hyper-echoic walls and no signal on color Doppler studies. Within the consolidated area, vascular structures can also be identified as anechoic tubular structures without walls. Arteries and veins can be distinguished on the basis of their dynamic indices on color Doppler.

It is also important to identify changes involving adjacent organs, the width of the intercostal spaces, and the position and movements of the diaphragm.

Lesions of the chest wall, costal cartilages, ribs, and diaphragm

In trauma patients, ultrasonography can be useful for detecting pneumothorax and lesions of the chest wall, rib fractures, and above all lesions of the costal cartilages,

Fig. 7 Patient with severe dyspnea. a) US: B lines that cancel the A lines and irregularity of the pleural line. b) Chest radiography reveals pulmonary fibrosis.

which cannot be visualized with radiography (Fig. 12). It can also reveal lung contusions, lacerative/contusive lesions, and interruptions of the diaphragm, which may be missed on chest radiographs and also on CT (Figs. 13a,b and 14).

Discussion

Chest radiography is still the first-line study to order when acute chest disease is suspected, but, as noted, the quality of films obtained under emergency conditions is often unsatisfactory. In most cases, the patients' clinical condition is poor; their positions cannot be significantly modified, and their ability to cooperate is markedly reduced. As a result, the quality of the film is poor and the findings are difficult to interpret.

In a polytrauma patient or a patient who has just had a chest tube inserted, US evidence of pleural movement (consisting of lung sliding and/or the lung pulse) together with comet-tail artifacts or B lines allow the emergency

Fig. 8 Patient with closed-chest trauma after chest tube placement (case shown in Fig. 4). a) US – posterior axillary scan reveals a small consolidated area with air bronchograms (white arrow) and peripheral B lines. b) CT reveals residual pneumothorax in the anterior chest and an area of lung contusion (black arrow).

radiologist to rapidly diagnose a small pneumothorax that might have been missed on the chest radiograph.

Sonographers have long been aware of the value of ultrasound in the detection of pleural effusions, but this imaging modality has also proved to be superior to CT in revealing the characteristics of the effusion. A completely anechoic pattern is indicative of simple transudates, while exudates are characterized by mobile internal echoes (the plankton sign) or adhesional septae. In cases of severe empyema or hemothorax, the pleural fluid is characterized by intensely structured echoes.

The demonstration of diffusely distributed comet-tail artifacts (or B lines) has proved to be useful for differentiating early-stage interstitial edema in which the extravascular water content of the lungs is too small to be detected with chest X-ray from flare-ups of COPD.

In cases of opaque hemithorax, US rapidly provides useful information on the presence of atelectasis or

Fig. 9 Patient with several days' history of progressive dyspnea and intense posterior thoracic pain treated for bronchopneumonia with no improvement. a) US – right posterior longitudinal scan shows an area of consolidation containing several hyperechoic air artifacts (white arrow). b) CT-angiography shows evidence of pulmonary embolism (white arrow); pulmonary infarction in the dorsal base of the lung (white arrow). c) The small translucent area represents a minute area of normally aerated parenchyma.

Fig. 10 Patient with acute dyspnea and chest pain. a) Left posterior axillary scan shows an area of consolidation (white arrows) with scarce air bronchograms and an adjacent B line. b) Computed tomography: acute pulmonary edema with alveolar-interstitial involvement on the left.

Fig. 11 Febrile patient with abdominal pain. a) Left posterior longitudinal paraspinal sonogram: small consolidated area with air bronchograms. b) Chest radiograph taken with the patient supine: mild parenchymal consolidation can be seen in the retrocardiac region (black arrow). Radiologic diagnosis: early-stage focus of bronchopneumonia.

massive pleural effusions. In the latter case, it can also be used to guide placement of a chest tube.

On post-intubation studies, the presence of a lung pulse without lung sliding at the level of the left anterior chest wall allowed immediate diagnosis of left lower lobe atelectasis caused by incorrect placement of the tube, which was not yet evident on the chest radiograph.

In a patient with chest pain and fever, US demonstration of a consolidated area with dynamic air bronchograms in the posterobasal region of the left lung can allow early diagnosis of pneumonia, especially when the consolidation is in the retrocardiac zone, which is sometimes hard to explore on a radiograph obtained with the patient supine. In addition, in patients with foci of pneumonia, US can also reveal small pleural effusions that may not be evident on the chest film.

Chest sonography plays an important role in monitoring patients in ICUs, and it should be more widely used on

pediatric patients. In these cases, daily chest X-rays are often necessary and the patient is thus exposed to a substantial dose of ionizing radiation during his/her

Fig. 12 Rib trauma. Ultrasonography shows fracture of the costal cartilage with overlap of the stumps.

Fig. 13 Polytrauma patient. a) Left posterior axillary scan reveals small post-traumatic interruptions in the left hemidiaphragm, homolateral pleural effusion, and a consolidated area at the base of the lung caused by contusive injuries. b) Small area of irregularity in the dorsal margin of the spleen.

hospital stay. We believe that the information that can be obtained with chest sonography can markedly reduce the need for radiographs in reproductive-aged women, young patients, and children.

Our use of ultrasonography has allowed us to overcome the difficulties involved in radiological examination of small children, who are likely to be uncooperative, because it is based on a real-time approach with no time limits.

Finally, it is important to note that with the use of newer, more advanced ultrasound scanners, evaluation of the artifact-based signs described by Lichtenstein may be difficult since these units are based on sophisticated technological solutions that tend to eliminate the artifacts themselves.

Fig. 14 The polytrauma patient shown in Fig. 13. Contrast-enhanced computed tomography shows thickening of the posterior margin of the left hemidiaphragm (black arrow) and a small laceration in the dorsal margin of the spleen.

Conclusions

In our experience, the main advantages of lung sonography were

- The rapidity of the examination, which can be done in the ER or at the bedside of the patient;
- Fewer technical limitations compared with emergency chest radiography, which is often performed on uncooperative, supine patients;
- Reduced need for CT with decreased exposure to ionizing radiation and contrast agents and cost reductions;
- Portability that allows bedside examinations and eliminates the need to transfer unstable patients to the CT room, which involves interruption of care;
- Unquestionable safety benefits that are especially important in pediatric patients, young subjects, and above all reproductive-aged women and those who are pregnant.

In the past, radiologists were the last to stress the importance of ultrasonography in this field because they could always use high-performance methods like CT, which continues to be the "gold standard." It still plays a dominant role in the work-up of critically ill patients, providing panoramic pictures of the situation and visualization of lesions that are difficult to diagnose with other methods. Considering the advantages of ultrasound, however, we feel that this position needs to be reexamined and an integrated approach adopted, which makes full use of all the modalities at our disposal and minimizes the patients' exposure to radiation.

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