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Original Research

CHEST TRAUMA

Chest Ultrasonography in Lung Contusion*

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Study objective: **Despite the high prevalence of chest trauma and its high morbidity, lung contusion (LC) often remains undiagnosed in the emergency department (ED). The present study investigates the possible clinical applicability of chest ultrasonography for the diagnosis of LC in the ED in comparison to radiography and CT.**

Materials and methods: **One hundred twenty-one patients admitted to the ED for blunt chest trauma were investigated using ultrasonography by stage III longitudinal scanning of the anterolateral chest wall to detect LC. Data were retrospectively collected in an initial series of 109 patients (group 1) and prospectively in the next 12 patients (group 2). All patients who presented with pneumothorax were excluded. After the ultrasound study, all patients were submitted to chest radiography (CXR) and CT. The sonographic patterns indicative of LC included the following: (1) the alveolointerstitial syndrome (AIS) [defined by increase in B-line artifacts]; and (2) peripheral parenchymal lesion (PPL) [defined by the presence of C-lines: hypoechoic subpleural focal images with or without pleural line gap].**

Results: **The diagnosis of LC was established by CT scan in 37 patients. If AIS is considered, the sensitivity of ultrasound study was 94.6%, specificity was 96.1%, positive and negative predictive values were 94.6% and 96.1%, respectively, and accuracy was 95.4%. If PPL is alternatively considered, sensitivity and negative predictive values drop to 18.9% and 63.0%, respectively, but both specificity and positive predictive values increased to 100%, with an accuracy of 65.9%. Radiography had sensitivity of 27% and specificity of 100%.**

Conclusions: **Chest ultrasonography can accurately detect LC in blunt trauma victims, in comparison to CT scan.** ***(CHEST 2006; 130:533–538)***

Key words: chest trauma; chest ultrasound; lung contusion; lung sonography; pulmonary contusion; thoracic ultrasonography

Abbreviations: AIS = alveolointerstitial syndrome; CXR = chest radiography; ED = emergency department; ISS = injury severity score; LC = lung contusion; PPL = peripheral parenchymal lesion

Lung contusion (LC) is a frequent clinical entity. Previous studies[1] have found a 26% rate of lung involvement in blunt chest trauma, with varying severity scores. The need for surgical intervention in chest trauma is not high (10 to 15%),[2] but the diagnosis of LC determines the need of a close physiologic follow-up. This injury is an independent risk factor for the development of ARDS,[3] pneumonia,[4] and long-term respiratory dysfunction, and is associated with a 10 to 25% mortality rate.[5]

Despite its relatively high incidence, LC is a difficult diagnosis to make in the ED. Unless an advanced diagnostic method such as CT is used,

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traditional radiology will underestimate its prevalence. The existing data show that plain chest radiography (CXR) is able to accurately diagnose only major traumatic events. Minor pleural effusions, pneumothoraces, fractures, and LCs, particularly the very recent ones, are missed.[6,7]

Ultrasonography is an optimal diagnostic method in the emergency department (ED) setting, with an extensive and validated usage in the diagnosis of hemoperitoneum,[8,9] as well as of pleural and pericardial effusions. More recently, there is a growing body of evidence supporting the use of ultrasound in the diagnosis of pneumothorax,[10] characterizing a chest-focused or goal-directed approach, instead of the transabdominal or specialty-directed approach. This study was developed with the objective of analyzing the capability of chest sonography to diagnose LCs in comparison to standard radiology and CT, thus expanding the applicability of a tool that is already present in the ED.

Materials and Methods

This study took place in the EDs of three hospitals in Italy: Lucca and Valle del Serchio general hospitals in Lucca, and Policlinico A. Gemelli in Rome. Consecutive patients who presented with isolated blunt chest trauma or polytrauma with chest involvement and an injury severity score (ISS) > 15 were enrolled between April 2001 and December 2003. The population comprised 121 patients (Fig 1) who were classified into two groups. Group 1 consisted of 109 patients who were simultaneously registered for a pneumothorax study (unpublished data). They were blindly analyzed retrospectively by chart review. This analysis was possible because thorax ultrasound at hospital admission in trauma patients is routine in the enrolling hospitals, and a standard form was used for registry, which included signs

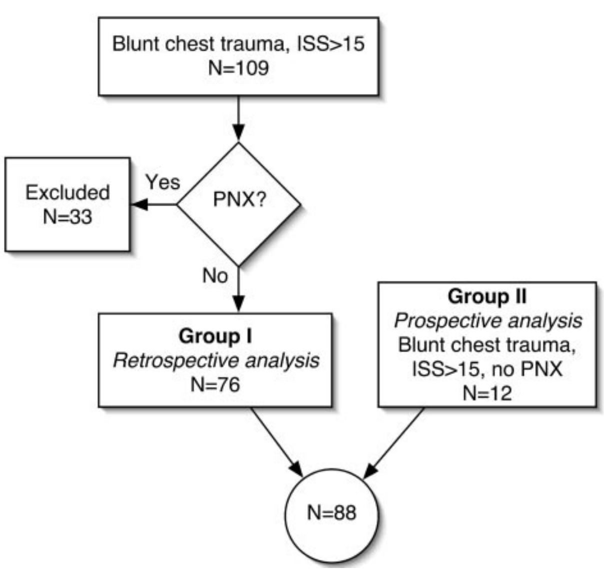

Figure 1. Study flowchart. PNX = pneumothorax.

of extravascular lung water (B-lines), with topographic annotations and thermal prints using video printers (UP-895MD; Sony Corporation; New York, NY) connected to the ultrasound gear. Group 2 was analyzed in a prospective fashion with a population of consecutive patients. Patients who presented with pneumothorax of any size or subcutaneous emphysema large enough to compromise the quality of the examination, in the examiner's opinion, were excluded.

One examiner performed the ultrasound scan (G.S. or A.T.) within 15 min of arrival as the first imaging test (model 220 SSA, convex 3.5-MHz probe; Toshiba; Tokyo, Japan; or convex multifrequency 3.5- to 5-MHz probe; Esaote Megas; Genova, Italy; or model H21, convex multifrequency 2- to 5- MHz probe; Hitachi; Tokyo, Japan). The chest was scanned in search of pneumothorax and signs of LC according to a stage III approach, as described by Lichtenstein[11]: focused scan of the anterior and lateral walls and the most posterior accessible region beyond the posterior axillary line, not compromising patient immobilization in supine position. We suggest the readers to access more details on lung ultrasound technique and findings in the work by Lichtenstein et al.[12] Chest ultrasound was considered a part of the routine initial examination of the patient, being the first imaging test. The ultrasound units are kept in the EDs.

The normal sonographic appearance of the lung is shown in Figure 2: a longitudinal scan of an intercostal space, with the ribs as topographic reference. The gliding sign is usually found, an echogenic line with a to-and-fro movement that is synchronous with the ventilation movements. The gliding sign is present when the visceral pleura slides on the parietal pleura, excluding pneumothorax. Horizontal artifacts—the A-lines—appear cyclically at an interval that reproduces the distance of the transducer to the pleural line. The gliding sign is not always evident, and the pleural contact and lung movement may be shown in the M mode (Fig 2, *right*). This image is called the *seashore sign*, characterized by horizontal lines ("waves") representing the static chest wall and by a scattered region ("sand"), formed by the dynamic artifacts beyond the pleural line, which would be absent in the case of pneumothorax. Eventually, a type of vertical artifact—B-lines—(formerly called *comet tails*) can be found in normal examination. They are generated by ultrasound resonance in a thin structure of soft tissue surrounded by air, as in a thickened interalveolar septum.[11,13–16] B-lines are roughly vertical and well defined (laser-like) and are spread to the edge of the screen without fading, erasing the A-lines and moving synchronically with the lung sliding.

The recognition of a few other artifacts must be mastered when looking for B-lines: Z-line artifacts are lines that arise from the pleural line and fade away vertically, do not reach the edge of the screen, do not erase the A-lines, and do not accompany the lung sliding. This artifact does not seem to have a pathologic meaning.[16] E-lines are generated by subcutaneous emphysema; they are vertical laser-like lines that reach the edge of the screen but do not arise from the pleural line. They arise from the chest wall, usually not allowing the visualization of underlying structures, making the study unfeasible.

An examination was considered normal in the presence of the gliding sign, the presence of fewer than six B-line artifacts in the entire scanned surface, and the absence of peripheral consolidations. LC was diagnosed in the presence of the following: (1) alveolointerstitial syndrome (AIS), ultrasonographically defined as the presence of multiple B-lines (Fig 3) arising from the pleural line, in a patient with no clinical suspicion of cardiogenic pulmonary edema; or (2) by the presence of a peripheral parenchymal lesion (PPL), defined as the observation of C-lines[11] (Fig 4), confluent consolidations ("hepatization"), or the presence of parenchymal disruption with localized pleural effusion.

Immediately after the ultrasound examination, anteroposterior

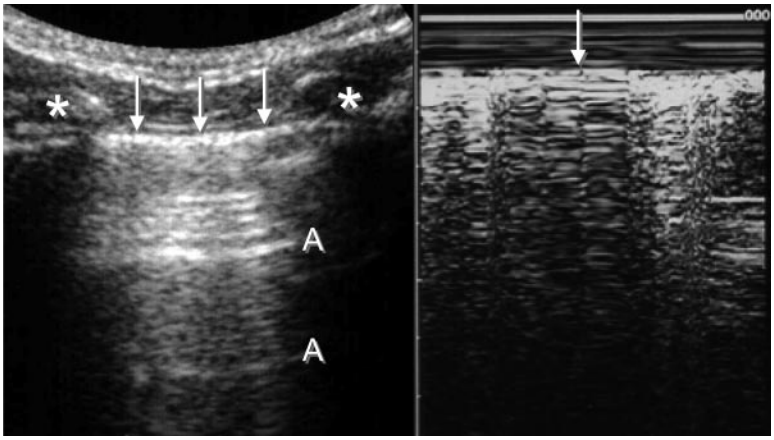

FIGURE 2. *Left*: conventional two-dimensional imaging of the normal lung. The arrows show the pleural line. The asterisks are on the ribs; note their posterior shadow. Normal horizontal artifacts (*A*) are shown (A-lines). *Right*: M-mode imaging of the same normal lung finding (seashore sign; arrow indicates pleural line).

CXR was performed with standard commercially available portable equipment with the patient in a supine position. A staff radiologist who was blinded to the other results analyzed the examinations.

Chest CT scanning was performed at 60 min of arrival in all patients. Available CT devices were multislice with four detectors, or spiral with a single detector. Slice widths of 5 mm and pitch of 1 were used, with lung and mediastinum windows. This examination was assumed to be the "gold standard"[17] to establish the diagnosis of LC by the presence of consolidation or ground-glass areas.

All examinations (ultrasonography, CT, and CXR) were defined as positive or negative for LC. No topographic or quantitative formal analyses were performed. The group and subgroup analyses were performed in a 2×2 table fashion, with evaluation of sensitivity and specificity, positive and negative predictive values, and accuracy.

The study was performed after approval by the scientific and ethics committee of the enrolling hospitals, and written informed consent was obtained from all participants or their families. Patients who were unable to consent on arrival and did so at a later time had their charts reviewed. Chest ultrasound, CT scan, and radiographs are routines for chest trauma in the enrolling institutions.

Pain management is a standard of care in trauma, especially in chest trauma. Additional care is always taken in order not to inflict any pain during examinations over broken ribs, maintaining low probe pressures on all chest examinations in trauma.

RESULTS

After the exclusion of 33 patients who presented with pneumothorax (prevalence, 27.3%), a total of 88 patients were enrolled: 76 patients in group 1 (retrospective; 47 men and 29 women; mean age, 32 years [range, 18 to 89 years]) and 12 patients in group 2 (prospective; 8 men and 4 women; mean age, 41 years [range, 24 to 77 years]). All patients

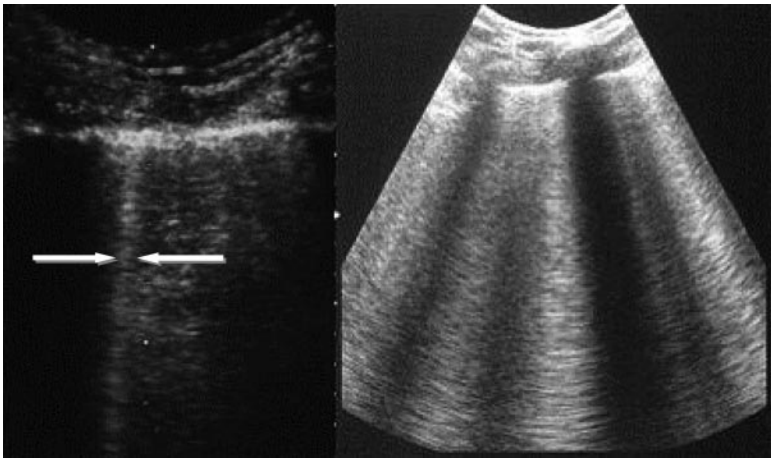

FIGURE 3. *Left*: normal image, with one isolated B-line (*arrows*). *Right*: ultrasonographic pattern of AIS, with several merging B-lines arising from the pleural line; note the absence of A-lines.

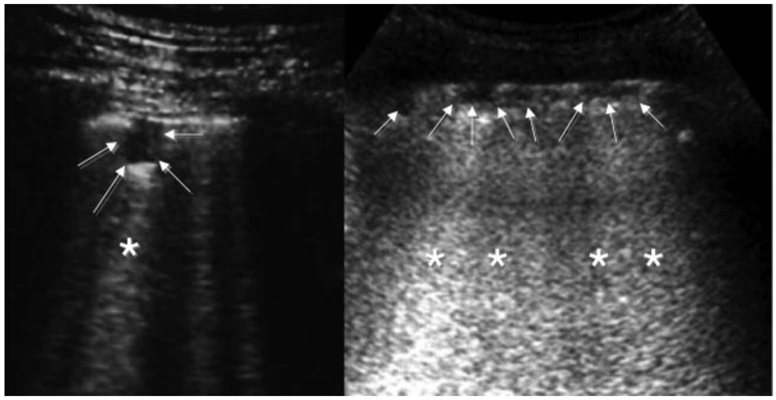

FIGURE 4. Sonographic pattern of parenchymal lung consolidation. PPLs, either isolated (*left panel*) or multiple (*right panel*), [arrows], appear as hypoechoic pleural-based focal images allowing ultrasound transmission, from which B-line-like artifacts arise (asterisks).

who presented with important subcutaneous emphysema had pneumothorax and were excluded. All cases of pneumothorax were found in group 1.

In the enrolled group, 37 patients received a diagnosis of LC using CT (Table 1). Standard CXR documented signs of LC in 10 patients (sensitivity, 27%). No false-positive results were found on CXR. Sonography showed alterations suggesting a diagnosis of LC in 37 patients, with 2 false-positive results (sensitivity, 94.6%; specificity, 96.1%; positive predictive value, 94.6%; negative predictive value, 96.1%; accuracy, 95.4%). The sonographic alveolointerstitial pattern was observed in 35 CT-positive results and in the 2 false-positive results. The PPL pattern was observed in seven patients, all of them also positive for the alveolointerstitial pattern. No false-positive results were found with this lesion pattern (sensitivity, 18.9%; specificity, 100%). In the 37 patients with LC on CT, 7 patients were found to have parenchymal lacerations. Ultrasound found two of these lesions (sensitivity, 28.6%).

A constant topographic correlation between ultrasound findings and the position of lesions on CT was observed, with an informal methodology. With the exception of the two false-positive results, all cases had focal ultrasound findings over the affected area.

Chest examinations were always performed in < 1 min, with < 3 min for the complete—thorax and abdomen—study. An average of 22 min was spent in the transport of the patient and execution of the CT. Patients were transported with accompanying medical personnel without any difficulty.

Discussion

The radiographic diagnosis of LC is based on classic signs: irregular, roughly nodular opacities either isolated or merging, homogenous consolidations, and various combinations of these modalities.[18] These signs may take several hours to appear, most are present in 24 h, and all vanish in a few days.[19] It is agreed that for these reasons, given the low sensitivity of CXR for the diagnosis of LC in the ED,[20,21] several LCs remain undiagnosed. Spiral CT is able to show many CXR occult lesions and affects clinical decisions in one third of cases. It was also stated that for each pathologic finding on CXR, three other findings would be shown on CT.[18] Therefore, CT is the "gold standard" for the evaluation of lung parenchyma and pleural space in trauma. Furthermore, in stable patients, it is the method of choice for

Table 1—*Overview of the Findings*

Tests	CT Findings, No		Sensitivity, %	Specificity, %
	Positive	Negative		
Ultrasound, AIS positive	35	2	94.6	96
Ultrasound, AIS negative	2	49		
Ultrasound, PPL positive	7	0	18.9	100
Ultrasound, PPL negative	30	51		
CXR positive	10	0	27	100
CXR negative	27	51		

diagnosis of pneumothorax,[10,13,14] mediastinal or vascular lesions, and critical modifications of respiratory pattern undiagnosed by CXR.[22] Unfortunately, the access to this examination is not always possible, particularly in the reanimation phase, in cases of hemodynamic instability, or when there are other priorities that would be overrun by the need of transportation to the CT laboratory.

The anatomopathologic evolution of the LC has three phases[23–26]: (1) the trauma itself, which determines a hemorrhagic or lacerated core by direct energy transfer to the lung parenchyma; (2) an edematous phase, with a progressive infiltrate of the interstice within 1 to 2 h after the primary injury; and (3) flooding of air spaces with blood, inflammatory cells, and tissue debris. This consolidation is maximal at 24 to 48 h after the primary injury,[27] yet is worsened by a secondary surfactant deficiency.[28,29] The conventional CXR can only detect contusion in the third phase, when a confluent consolidation is established.

The clinical respiratory worsening and eventual progression to ARDS tend to accompany the radiologic evolution; therefore, the diagnosis of LC might be delayed. Yet, it is known that the size of the contusion, in comparison to the total lung volume, clearly correlates to the risk of ARDS.[30] These data reinforce the need of a more sensitive method to diagnose early LCs, allowing the emergency physician to more accurately preview the clinical course and, eventually, modify intervention (*eg*, fluid restriction, prehospital triage, early admission to the ICU).

Ultrasonography is an accurate method for detecting interstitial edema.[11,16] Based on this statement, we can assume that chest ultrasound may be able to find pulmonary contusions at an earlier stage than CXR, therefore reaching a higher sensitivity in the ED. The present study suggests this assumption is true, by finding an overall sensitivity of 94.6% for ultrasound and 27% for initial CXR. If we consider the ultrasound finding of consolidation, a specificity of 100% could be achieved in the selected trauma population. Of course, these data cannot be extended to a clinical population, since there are other diseases that show the same consolidative pattern, such as pneumonia.[11] The interstitial sonographic pattern achieved a very high sensitivity in our study, with good specificity. Again, there are several other diseases that present interstitial syndromes (ARDS, cardiogenic pulmonary edema[11,16,28]) and, naturally, this specificity can only be considered for this selected population. One difference to be noticed is the focal pattern of the B-lines in LC found in our study. Although not methodologically analyzed, the topographic correlation of CT and ultrasound could be noticed, confirming the finding that LC is a focal process. This localized pattern differs from the diffuse bilateral B-lines pattern found in cardiogenic pulmonary edema, thus increasing the specificity of ultrasound in the diagnosis of pulmonary traumatic contusions.

One must keep in mind that ultrasound imaging is based on tissue density and resonance; therefore, diseases that present with similar anatomic densities will produce similar images. Aspiration or atelectasis will produce images generated by the structural alteration they inflict, appearing as B-line artifacts for interstitial syndromes and consolidations—or C-lines—for larger densities. There were two false-positive ultrasound results. Pulmonary fibrosis was later diagnosed in both patients, a diffuse disease that shows the same interstitial pattern (unpublished data). All other patients with positive results did not have diffuse patterns, but focal. In spite of this, we believe that a cautious correlation with the clinical picture must always be made. Furthermore, in chest trauma the diagnosis of cardiogenic pulmonary edema after a myocardial contusion or tamponade must be considered. We also emphasize that a clear distinction between the B-lines and other artifacts (Z-lines and E-lines[11,12]) is of extreme importance, particularly in the trauma setting, where subcutaneous emphysemas are very prevalent.

Conclusion

This study reinforces the applicability of the sonographic study of the lung in the emergency setting. In addition to the well-established role of ultrasound in the diagnosis of pneumothorax, hemothorax, and hemoperitoneum, the diagnosis of LC may also be accessed. The given data may support a more selective use of CT. Further studies are being performed to investigate the correlation of a B-line score and the LC volume as measured by CT. This could restrict even further the need of CT scans on chest trauma, bringing the management of the chest trauma victim to an even more point-of-care approach.

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