Occult Traumatic Pneumothorax: Diagnostic Accuracy of Lung Ultrasonography in the Emergency Department

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Occult Traumatic Pneumothorax*

Diagnostic Accuracy of Lung Ultrasonography in the Emergency Department

Gino Soldati, MD; Americo Testa, MD; Sara Sher, MD; Giulia Pignataro, MD; Monica La Sala, MD; and Nicolò Gentiloni Silveri, MD

Background: The role of chest ultrasonography (US) in the diagnosis of pneumothorax (PTX) has been established, but how it compares with lung CT scanning in the diagnosis of radiooccult PTX and in the determination of its topographic extension has not yet been completely evaluated. 

Objective: To determine the diagnostic accuracy of chest US in the emergency department (ED) in the diagnosis of occult PTX in trauma patients and to define its ability to determine PTX extension.

Design: An 18-month prospective study.

Patients: A total of 109 conscious, spontaneously breathing patients who had been admitted to the ED for chest trauma or polytrauma.

Methods: All eligible patients underwent a standard anteroposterior supine chest radiograph (Rx) and a spiral CT lung scan within 1 h of ED admission. Lung US was carried out by an operator who was unaware of the other examination results, both for diagnosis and for the quantitative delimitation of the PTX.

Results: Twenty-five traumatic PTXs were detected in the 218 hemithoraces (109 patients; 2 patients had a bilateral PTX) evaluated by spiral CT scan; of these, only 13 of 25 PTXs (52%) were revealed by chest Rx (sensitivity, 52%; specificity, 100%), while 23 of 25 PTXs (92%) were identified by lung US with one false-positive result (sensitivity, 92%; specificity, 99.4%). In 20 of 25 cases, there was agreement on the extension of the PTX between CT lung scan and lung US with a mean difference of 1.9 cm (range, 0 to 4.5 cm) in the localization of retroparietal air extension; chest Rx was not able to give quantitative results.

Conclusions: Lung US scans carried out in the ED detect occult PTX and its extension with an accuracy that is almost as high as the reference standard (CT scanning).

(CHEST 2008; 133:204–211)

Key words: chest trauma; lung ultrasonography; occult pneumothorax

Abbreviations: ED = emergency department; FAST = focused assessment with sonography of trauma; LR = likelihood ratio; NPV = negative predictive value; PPV = positive predictive value; PTX = pneumothorax; Rx = radiograph, radiography; US = ultrasound, ultrasonography
lung scanning may have some disadvantages, including the need for patient transportation and high doses of radiation.

Among diagnostic imaging, lung ultrasonography (US) has emerged in the past decade as a new and sensitive technique in the evaluation of respiratory diseases. Its advantages include the fact that it can easily and quickly be performed at the bedside by a wide range of “sonographers,” such as trauma, emergency, and critical care physicians.11 Lung US has gained a well-established role in the diagnosis of PTX in critically ill patients6,12 as well as in trauma patients.7,13-15

Some literature15,16 has analyzed the role of lung US in the detection of PTX concentrating on the importance and feasibility of this technique in trauma patients. Lung US could be a solution between a low-sensitivity technique such as chest Rx and the reference standard technique of CT scanning for the study of trauma patients in the ED, but its accuracy in this situation needs further assessment before being able to be used in everyday clinical practice. Furthermore, a challenge exists regarding a possible role played by chest US in revealing the extension of PTX. This could allow the ED physician to take interventional decisions, such as the positioning of a chest tube, without wasting time. However, the accuracy of the chest US in diagnosing the extension of PTX has not yet been evaluated.

**GOALS OF THIS INVESTIGATION**

The aims of this study were to define the accuracy of lung US in the diagnosis of radio occult PTX in trauma patients who were admitted to the ED and to define its ability to delineate PTX extension, comparing this technique with chest Rx and CT scanning.

**MATERIALS AND METHODS**

**Study Design**

This was a multicentric, observational study of consecutive patients who had been admitted to the EDs of Valle del Serchio Hospital, Castelnuovo di Garfagnana, Italy (a small rural hospital with 18,000 ED admissions per year), and of the Policlinico A. Gemelli, Rome, Italy (a large university city hospital with 70,000 ED admissions per year) from June 1, 2005, to November 30, 2006, for chest or major trauma.

**Quality Control**

Approval from the institutional review boards at both study centers was obtained, and all patients enrolled in the study gave and signed an informed consent form to participate in the study.

**Selection of Participants**

**Inclusion Criteria:** All patients > 18 years of age who satisfied the criteria for blunt chest trauma or multiple trauma were included in the study. Multiple trauma was defined as the presence of injury occurring simultaneously in more than one organ, considering both the mechanism of injury and the clinical information obtained on arrival at the ED.9,10

**Exclusion Criteria:** Exclusion criteria consisted of at least one of the following conditions: (1) a need for immediate chest decompression for the treatment of tension PTX; (2) hemodynamic instability for any reason; (3) need for mechanical ventilation as treatment either for state of consciousness or for severe respiratory distress; (4) the presence of subcutaneous emphysema; (5) chest wall injuries precluding adequate US evaluation; and (6) an inability to give informed consent.

**Interventions:** Patients enrolled in the study underwent a standard anteroposterior supine chest Rx as well as lung US in the ED within 1 h of ED admission, and underwent spiral CT scanning without contrast medium as soon as it was available, always within the first hour, after US evaluation. CT scans were performed with 5-mm collimation, a pitch of 1.5 mm, and 5-mm imaging spacing. Images were obtained from the pulmonary apices through the lung bases, and were reviewed at the lung and soft-tissue window settings. PTX was considered to be “radio occult” if it was detected by CT scanning but not by chest Rx.

**Methods and Measurements:** Lung US was carried out by emergency physicians (G.S. and A.T.) in each hospital who were experienced operators (at least 1 year experience in chest US) and were unaware of the chest Rx and CT scan results. An echograph (model SSA 250T, Toshiba; Tokyo, Japan) with a 3.5-MHz convex probe or an echograph (model B12; Hitachi; Tokyo, Japan) with a 5.2-MHz convex probe was used. The sonograph was part of our ED equipment and was immediately functional at bedside.

The scanning technique followed that previously described by our group and others,11,17 going through longitudinal, anterior, and lateral scanning along the anatomic lines of the thorax in order to both diagnose and delineate the presence of PTX. The US diagnosis of PTX was based on the disappearance of the pleural “sliding sign” (or gliding sign), the absence of any “comet tail” artifact, the presence of “lung points,”18 and the accentuation of image reinforcements due to air reverberation19 (Fig 1, 2).

In order to define the topography and extension of the PTX on the thoracic surface, the detection of the lung point, a sign that is specific to PTX,17 was systematically assessed through each intercostal space. This is a dynamic sign, always present in cases of nonmassive PTX, representing the regular reappearance of a pleural sliding pattern, replacing the PTX pattern at the point where visceral and parietal pleura regain contact with each breath. The search for the lung points was followed through three intercostal spaces (second or third, fourth or fifth, and sixth or seventh, respectively defined as high, medium, and low sectors), proceeding laterally from the parasternal regions and toward and
over the mediocoronal thoracic line. The succession of lung points through intercostal spaces identifies the lateral limit of the retroparietal air collection in the supine patient (Fig 3, 4). The extent of air collection thus delimited was designated with three pen marks (two pen marks for small PTXs) on the patient’s thorax; PTXs were divided into “anterior,” if the lung points were detected medial to the mid-coronal line (defined as the line that divides the thorax into equal anterior and posterior halves) and “anterolateral,” if they were present beyond this line (Fig 3).

Chest Rx and lung CT spiral scanning were judged by a radiologist who could have been either the same or a different radiologist for each examination according to availability. Radiographic criteria for the diagnosis of PTX were the absence of lung parenchyma and certain indirect signs such as the dishomogeneous appearance of the diaphragm, the incongruency of the pleural line, or the “deep sulcus sign.” No quantitative determination was given, only yes-or-no criteria and whether or not the PTX was hypertensive. PTX seen on CT lung images was classified, according to Wolfman and colleagues19,20 as minuscule, anterior, and anterolateral. A minuscule PTX was defined as a thin collection of air up to 1 cm thick in the greatest slice and seen on no more than four contiguous images. An anterior PTX was categorized as a collection of pleural air > 1 cm thick, located anteriorly, not extending to the mid-coronal line, which may be seen on four or more contiguous images. Anterolateral PTX was defined as pleural air extending at least to the mid-coronal line.

Outcome Measures: Spiral CT scan findings were the “gold standard” as they made a definitive determination of the presence or absence of PTX. US and chest Rx findings were compared with the results obtained from CT scanning.

The cutaneous projection of the three lung points (ie, the pen marks on the patient’s chest) was visually compared to the cutaneous projection of the lateral limit of the air collection visualized by the

Figure 1. Normal US lung imaging in M-mode (left) and B-mode (right).

Figure 2. US PTX in M-mode (left) and B-mode (right).
CT scan image (Fig 3, 4). The degree of difference between the two assessments was expressed in absolute values (in centimeters) as the mean and range.

**Primary Data Analysis:** Estimates of specificity, sensitivity, overall accuracy, positive predictive value (PPS), negative predictive value (NPV), and likelihood ratios (LRs) were calculated for Rx vs CT scanning and for US vs CT scanning, considering hemithoraxes as the unit of analysis. All data were analyzed with a statistical software package (SPSS for Windows, version 10.0; SPSS; Chicago, IL).

**Data Presentation:** Continuously distributed variables were expressed as the mean ± SD. Categoric variables were presented as counts and percentages. Sensitivity, specificity, PPV, NPV, positive and negative LRs, and accuracy were calculated as appropriate.

**RESULTS**

A total of 116 patients with a diagnosis of chest trauma or multiple trauma was admitted to both EDs during the study period. Among them, seven patients were excluded because of the need of immediate chest decompression (one patient), subcutaneous emphysema (three patients), and the inability to give informed consent (three patients).

The final study population included 109 patients with a mean ± SD age of 41.4 ± 20.5 years, 62.9% were men (total, 73 subjects). Sixty-five evaluated patients were admitted to the ED for chest trauma, and 44 for multiple trauma.

Among patients in the final study population, a spiral CT scan diagnosis of traumatic PTX was made in 23 patients, with 2 patients having bilateral PTX. PTX involved the right side in 10 patients (40%) and the left side in 15 patients (60%). Considering 218 hemithoraxes (i.e., 109 patients × 2), 25 PTXs were found. The evaluation conducted by the three methods is depicted in Table 1.

In the 25 PTXs, an anteroposterior chest Rx performed prior to the CT scan revealed the presence of 13 PTXs (52%). The remaining 12 PTXs (48%) were consequently considered to be radiocult. Five of these PTXs were classified as minuscule at lung CT scan examination. Lung US was able to detect 23 of the 25 PTXs, with two false-negative results. One false-positive result was obtained. The sensitivity and specificity of chest US in detecting PTX were 92% and 99.4%, respectively (Table 2). PPV and NPV were 95.8% and 98.9%, respectively, with an accuracy of 98.6% (positive LR, 153.3; negative LR, 0.08). A supine chest Rx showed a sensitivity of 52% and a specificity of 100%.

Topographic US analyses of PTX through lung point evaluation demonstrated the extension of the retroparietal air collection and in every case defined the correct location with respect to the mediocoronal thoracic line (Table 3), collocating the lateral limit of each PTX for each intercostal level (i.e., high, medium,
and low) at 2.4 ± 0.68, 1.6 ± 0.87, and 1.9 ± 1.01 cm, respectively (range, 0 to 4.5 cm), with respect to those detected by CT scan. Three small (minuscule) PTXs were analyzed through only two lung points.

Lung US identified 100% of nonradio occult PTXs. All radio occult PTXs were either minuscule or anterior, and lung US identified 10 of these (83%). The mean time for US lung evaluation was < 3 min per side.

All anterolateral PTXs were drained, while the anterior and minuscule PTXs were monitored and followed up clinically and echographically. One anterior PTX necessitated draining in view of mechanical ventilation for general anesthesia.

**DISCUSSION**

This study demonstrates a high sensitivity and sensibility of lung US as a technique in detecting traumatic PTX. Particularly, lung US has shown a greater ability to detecting PTX in the supine trauma patient when compared to chest Rx. Furthermore, our results indicate the ability of US to define, through the determination of lung points, the extension, and thus the size, of the PTX with an accuracy almost as high as that of a lung CT scan. An evergrowing weight must be given to the necessity of using this technique in the initial evaluation of the trauma patient admitted to the ED.

Air in the pleural space, in the traumatized patient who is forcibly in the supine position, collects in the paracardiac regions and in the anterior costodiaphragmatic sulcuses, making it visible on US examination while being scarcely visible by traditional radiographic signs. It is rare that air does not migrate into this position, as in the case of pleural adherences from previous disease. In our population, we did not encounter this problem.

The diagnostic feasibility and accuracy of lung US for the diagnosis of PTX, especially radio occult PTX,
in trauma patients has so far been suggested in various studies. Blaivas et al found a high specificity for the technique in trauma patients even using a microconvex probe. We used a regular size convex probe, which is the standard probe used in the focused assessment with US for trauma (FAST) examination, and obtained similar results. Although our study included a smaller number of patients, in smaller hospital settings, we believe that this fact is important in showing how the technique may be readily available in every situation and must therefore be implemented.

The determination of the size of the PTX has also been described in previous studies with various degrees of accuracy. By delineating lung points with a pen mark on patients’ chests, we found a great correlation with PTX size as determined by CT scan. It must be noted, indeed, that lung US is a dynamic examination and that the lung point is a dynamic sign (Fig 4), moving with each breath, while CT scan images are static. This accounts for the inevitable variability in measurements seen with lung CT scan comparison and should not be considered to be an imprecise technique.

The determination of the size of a PTX is important in making procedural decisions. In our study, all anterolateral PTXs were drained, while the anterior and minuscule were monitored, and followed up clinically and echographically. Subsequently, it was decided that one of the anterolateral PTXs had to be

### Table 1—Chest CT Scan, Rx, and US Evaluation of the 25 Cases of PTX

<table>
<thead>
<tr>
<th>Case</th>
<th>CT Scan</th>
<th>Rx</th>
<th>US</th>
<th>CT Scan Classification</th>
<th>US Classification</th>
<th>Difference, cm</th>
<th>Side</th>
<th>Drainage</th>
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<td>PTX</td>
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<td>PTX</td>
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<td>26</td>
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<td>Anterior</td>
<td>Anterior</td>
<td>Left</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*H = high intercostal space; M = medium intercostal space; L = low intercostal space. The degree of difference between the CT scan and US assessments is expressed in absolute values (in centimeters).

### Table 2—Total Number of Diagnostic Examinations, False-Positive Results, and False-Negative Results for Each Imaging Modality

<table>
<thead>
<tr>
<th>Variables</th>
<th>Lang US, %</th>
<th>Chest Rx, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>92.00</td>
<td>52.00</td>
</tr>
<tr>
<td>Specificity</td>
<td>99.48</td>
<td>100</td>
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<tr>
<td>PPV</td>
<td>95.83</td>
<td>100</td>
</tr>
<tr>
<td>NPV</td>
<td>98.99</td>
<td>94.15</td>
</tr>
</tbody>
</table>

*ECO = echography.*
PTXs that ultrasonographically were considered to be minimum-anterior PTXs were invisible on chest RXs; in other words, all radiooccult PTXs (48%) were ultrasonographic minimum-anterior PTXs.

Lung US is a relatively new technique that has been proposed as an extension of the FAST examination in the traumatized patient for the diagnosis of traumatic PTX. Its advantages include the feasibility and bedside emergency application, the need of only one trained operator, the brief learning period, and especially its nonphysical or nonbiological invasiveness.

The latter point will never be emphasized enough. As stated in the recently published white paper of the American College of Radiology on the radiation dose in medicine, we have come to a point where “the expanding use of diagnostic imaging modalities that use ionizing radiation may eventually result in an increased incidence of cancer in the exposed population. This problem may be minimized by preventing the inappropriate use of such imaging and by optimizing studies that are performed to obtain the best image quality with the lowest radiation dose.”

There is no doubt that diagnostic imaging has immense benefits, but we must always keep in mind the risks of such modalities and respect the criteria of appropriateness when requesting these examinations, as this has been demonstrated to result in a strong positive impact on the cost of imaging and on the radiation dose received by patients in the setting of trauma. It is in this setting that lung US should be implemented as it has an immense potential to abate the long-term risks of an excess number of CT scan requests in the ED.

This study has certain limitations. First, it is an operator-dependent examination, which makes the comparison with other more objective diagnostic tools difficult. Second, it was conducted, in each center, by experienced operators, and this makes comment on the reproducibility of the technique unfeasible. In this regard, however, we must say that US findings of pleural disease are relatively simple and that the acquisition of the lung US technique needs only a short period of training, as was recently demonstrated with respect to the US evaluation of extravascular lung water. For this reason, in order to implement the use of this technique in trauma patients we must extend the teaching and learning of the method to every emergency physician. A third point deserves to be underlined. Our population was represented by spontaneously breathing patients, and so results regarding the semi-quantification of PTX extension may not be extrapolated to mechanically ventilated patients. PTX in mechanically ventilated trauma patients in the first hour of care is often more extensive and clinically significant; however, while we purposely aimed at a population in whom the US lung echography did not detect 2 of the 25 PTXs that were present. Both of these cases were minuscule PTXs that were located in the left paracardiac region. In this point, in fact, i.e., physiologic lung points were represented by the pulmonary curtain covering the heart with each breath. A thorough examination of the dynamic pleuropericardiac relation in this difficult-to-explore paracardiac window must always be undertaken.

One false-positive PTX US diagnosis was made on a left hemithorax. It was an erroneous diagnosis in which the search for lung points as a confirmation criterion was ambiguous for the presence of the above-mentioned physiologic pleural sliding on the heart, which we retain, thus making us able to induce both false-negative and false-positive diagnoses. In addition, this was the case of a patient with globally reduced pleural sliding, possibly for low lung compliance, which underlines the necessity of enlarging the US image, regulating the US gain, and focusing on the pleural line in order to increase accuracy in detecting pleural movement. For this purpose, a linear (high-frequency) probe may be used when there is enough time. In this study, we did not use a high-frequency probe in order not to lose time, but further studies could evaluate the advantages of changing probes to obtain a higher accuracy for pleural sliding visualization vs time loss. All of our lung US examinations in the ED took <3 min per side and were used only to search for the presence or exclusion of PTX; a thorough examination, in fact, was not carried out.

In our study, CT scan, chest Rx, and lung US evaluations have been quantitatively compared. One interesting aspect of the study was the fact that all

<table>
<thead>
<tr>
<th>PTX Extension</th>
<th>CT Scan</th>
<th>Chest Rx</th>
<th>Lung US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>10</td>
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<td></td>
</tr>
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<td>Minuscule</td>
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<td>Anterior</td>
<td>5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Anterolateral</td>
<td>13</td>
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</table>

PTXs that were located in the left paracardiac region. Both of these cases were identified, it may be followed in its evolution by US revealing in these situations in which, once a PTX is drained due to mechanical ventilation for general anesthesia. No decisions were made only on the basis of a lung US evaluation, but in the future we believe that we will have enough experience and enough confidence in this type of diagnostic technique to be able to make procedural decisions without necessitating the support of CT scanning, and especially without a chest Rx. The utility of lung US is especially able to make procedural decisions without necessitating the support of CT scanning, and especially without a chest Rx. The utility of lung US is especially

with the Three Different Techniques
which radiooccult PTX would presumably be more frequent. In fact, it is exactly in these patients in whom early knowledge of radiooccult PTX, before intubation, may have a significant impact on management.

CONCLUSION

Our study demonstrates the accuracy of lung US in the ED diagnosis of traumatic PTX not shown by traditional chest Rx and in the definition of its extension, whether radiooccult or not. We thus propose the use of lung US as a tool for the diagnosis and semi-quantification of traumatic PTX in the ED.

We believe that echographic evaluation of the thorax should be performed during the primary survey as an extension of the FAST examination in every trauma patient. This could help to identify a significant number of radiooccult PTXs and give therapeutic indications as to the follow-up and treatment of this category of patients, avoiding patient transport and a large amount of ionizing radiation.

REFERENCES
