Abstract—A series of 186 patients with blunt chest trauma was studied with transthoracic ultrasonography to diagnose pneumothorax and to evaluate its size and location. The results were compared with bedside chest radiography and spiral CT scan. The prevalence of pneumothorax on CT scan was 56/186 (30.1%). Pneumothorax was proven on radiography in 30/56 cases without false positive results: “radiographic deep sulcus sign” was evident in 3/29 cases, 26/29 cases being occult. The ultrasound study demonstrated the presence of pneumothorax in 55/56 patients: one occult pneumothorax was missed and no false positive results were observed. The CT scan differed of 2.3 cm (range 1–5 cm) from the US study in evaluating size and location of pneumothorax. In conclusion, ultrasound study may detect occult pneumothorax undiagnosed by standard plain radiography. It reflects accurately the extent of pneumothorax if compared with CT scan, outlining the “ultrasonographic deep sulcus sign” on anterior chest wall. (E-mail: testaa@rm.unicatt.it) © 2006 World Federation for Ultrasound in Medicine & Biology.

Key Words: Chest ultrasonography, Transthoracic ultrasonography, Chest trauma, Pneumothorax, Deep sulcus sign.

INTRODUCTION

Traumatic pneumothorax (PNX) is the most common life threatening outcome in blunt chest trauma, occurring in almost 40% of patients with penetrating chest injuries and over 20% of subjects with blunt injuries (Di Bartolomeo et al. 2001; LoCicero and Mattox 1989). Chest tube placement should be considered because even a small PNX can rapidly enlarge and become clinically significant, especially during general anaesthesia, with positive pressure ventilation in the setting of PEEP (Wescott and Cole 1983).

Diagnosis of a PNX on standard chest radiography is based on the identification of a hyperlucent air space between the visceral pleural layer, visible as a thin curvilinear white line marking the boundary of the lung and the parietal pleura layer. The findings of mediastinal shift and diaphragmatic depression are the most important radiographic signs in the detection of tension PNX (Gobien et al. 1982).

In the emergency room (ER), a few PNXs (7 to 30%) may be missed on conventional radiography in the supine patient, being detected only on CT imaging (occult PNXs) (Tocino et al. 1984). Some clues may suggest the presence of a PNX on chest plain radiographs: in a supine patient, air collecting anteriorly within the hemithorax’s lower part causes a hyperlucent focus near the diaphragm and along the juxtacardiac region: this is the “radiographic deep sulcus sign” (Fig. 1) (Gordon 1980). For the same reason, an improved sharpness of the cardiomedistinal border is sometimes visible, but it can be frequently overlooked.

Static and dynamic ultrasound (US) features of PNX have been identified in a number of studies (Lichtenstein and Menu 1995; Rowan et al. 2002; Soldati and Rossi 2000) and recently reviewed by Lichtenstein (2005). The technique involves the identification of the pleural line on conventional 2-D ultrasonography: the observation of its mobility with respiration (“sliding sign”) and/or the presence of vertical artifacts which arise from the pleural line (comet-tails) ruling out the PNX occurrence (Fig. 2), in which a completely horizontal line pattern (“A-line sign”) is shown (Fig. 3). The
demonstration of the lung sliding during respiratory motion may also be shown by M-mode imaging (Soldati 2001) and, finally, enhanced by colour-power-Doppler mode (“power slide”) (Cunningham et al. 2002).

As the air is moving free, the US findings of PNX should be sought in the highest anterior area of the hemithorax’s lower part, near the diaphragm and the cardiomiastinic borders in the supine position. On the other hand, an accurate quick assessment of the PNX extent is mandatory in emergency. Therefore, it is essential to identify the pleural contact reappearance points, the site on the chest wall in which a normal lung US pattern is replaced by a PNX US pattern (Lichtenstein et al. 2000).

The aim of this study was to validate the transthoracic ultrasonography in defining the presence, location and size of traumatic PNX in comparison with anteroposterior supine chest radiography and CT scan (gold standard) in emergency room. Furthermore, we will explain a new US sign (“ultrasonographic deep sulcus sign”), which we believe to be specific for an early and quick detection of PNX in a supine patient.

**MATERIALS AND METHODS**

**Patients**

A series of 186 subjects with blunt chest trauma (69 women and 117 men, mean age 52.4 ± 22.9 y, range 16–89 y), consecutively admitted in the ER of Lucca and

Fig. 1. Anteroposterior supine chest radiograph, revealing the anteromedial and inferior collection of a little amount of air in the antideclivous pleural space on the right side (small PNX) by the hyperlucency of the cardiomiastinal right border (black arrows) and the diaphragmatic dome (white arrows) on the same side. A severe PNX with diaphragmatic depression and lung collapse without mediastinal shift was present on the left side.

Fig. 2. Ultrasound bidimensional (2-D) image of normal chest on longitudinal parasternal scan. The superficial layers are visible at the top of the screen. The ribs are recognised by their curved shape producing posterior acoustic shadow. Below the curved rib line, the pleural line (full arrow) appears as an hyperechoic horizontal line, representing the lung surface-chest wall interface. A bat flying toward us can be imagined (the bat sign). Vertical artifacts (empty arrow) appearing as hyperechoic beams arising from the pleural line and spreading up to the edge of the screen across the lung field (comet-tails) can be produced.

Fig. 3. US bidimensional (2-D) image in case of PNX. Over the abolition of the sliding sign (dynamic sign), valuable just in real time, the static sign of the replacement of the lung US background with an acoustic shadow exclusively containing several horizontal reverberations (empty arrows) can be seen (A-lines sign). Vertical artifacts (comet-tails) arising from pleural line (full arrow) are absent.
Valle del Serchio General Hospitals and A. Gemelli University Hospital of Rome from 1 September 1999 to 31 August 2004, were examined for PNX with chest ultrasonography in a prospective blinded study. The breakdown of injuries was as follows: 114 motor vehicle crashes, 32 cycle and motor cycle crashes, 18 falls and 22 other injuries. Of 204 patients at first included in the study, five cases were unable to give informed consent and 11 cases requiring immediate operative interventions or with chest wall injuries precluding US evaluation (pain, ribs fractures, flail chest) were excluded; subcutaneous emphysema hampered to obtain adequate US imaging in two cases.

**US examination**

The US examination was carried out within 30 min of admission, after primary survey, by emergency physicians (EPs) not directly involving in the patient’s management without hampering or delaying it. Subsequently, all patients underwent a plain chest radiograph and a spiral CT scan, which were all blindly read by radiologists. The PNXs missed on conventional supine chest radiographs were defined “occult”. PNXs were classified on CT images, according to Wolfman et al. (1993), as “anterior” (anterior pleural air not extending to the middle-axillary line dividing the thorax into equal anterior and posterior halves) or “anterolateral” (pleural air extending at least to the middle-axillary line). Patient’s demographic data, examination’s time and findings were recorded on a data sheet for later evaluation, after having obtained the patient’s informed consent.

A Toshiba SSA-250A, an Esaote MEGAS-GP or a Hitachi H21 ultrasound machine, each equipped with a 5 MHz convex array transducer, was used for US examination. The choice of the 5 MHz convex array instead of the higher frequency linear transducer provides a good compromise between resolution and penetration, as previously experienced (Soldati 2001; Soldati and Rossi 2000). The 5 MHz convex transducer is able to afford a complete visualization of the various horizontal and vertical artifacts mostly constituting the normal lung US pattern and a simultaneous good penetration to the deeper layers. Moreover, the curved surface of the convex probe facilitates the scanning through intercostal spaces and it allows rapidly to perform the focused assessment with ultrasonography for trauma (FAST) with the extension to chest for ruling out PNX (E-FAST) without changing the transducer. Trained EPs with over 10 y experience in emergency ultrasonography and at least 1 y in chest ultrasonography have contributed to this study (GS, AT).

All subjects were longitudinally US scanned in the supine position with a two-look approach (Fig. 4). The first look consisted of anterior chest wall examination in the parasternal line on both sides, from the third intercostal space to the diaphragm. When it was possible, the examination was begun in the apparently unaffected lung to determine a baseline. To locate the lung surface, the probe was applied longitudinaly over an intercostal space to identify two contiguous ribs: between these ribs, the pleural line, a hyperechoic horizontal band lying in a deeper plane, displayed the so called “bat sign” (Lichtenstein 2005) (Fig. 2). If PNX US pattern occurred (as described below), a second look was then systematically assessed with transverse scans along the intercostal spaces from sternal to middle-axillary line to evaluate its size and location (Fig. 4) (Lichtenstein and Menu 1995; Rowan et al. 2002; Soldati and Rossi 2000).
The US appearance that was sought to assess PNX diagnosis was the absence of the sliding sign, as well as the detection of the comet-tail artifacts, which was considered enough to rule out PNX. The sliding sign describes the movement of the pleural line that appears as a thin layer of water flowing in rhythm with respiration; its visualization excludes PNX with the exception of massive lung fibrosis, complete atelectasis and pleural symphysis. The comet tail artifacts (or “US B-lines”) (Lichtenstein 2005) are the well-defined rough vertical artifacts arising from the visceral pleura and spreading up to the edge of the screen without fading (Fig. 2). These artifacts are inconstant findings in nondyspnoic patients (up to 60%), sometimes present in small numbers (<8) in a normal chest and even are often seen in injured patients, especially in an expanded lung near a pleural air collection. Comet tail artifacts are absent in PNX because, as they arise from visceral pleura, they are hidden in PNX by the air collected in the pleural space. We did not apply in our study other accessory US criteria of PNX diagnosis, such as M-mode and colour-power-Doppler mode, considering them to be superfluous in our experience and unjustifiable to delay the examination’s execution time in emergency.

To evaluate the PNX extent, we looked for the “lung point sign”: this is a dynamic sign that represents the fleeting appearance of pleural sliding (with or without comet tail artifacts) replacing a PNX 2-D US pattern on the left side (absent lung sliding and comet-tail artifacts replaced by horizontal reverberation lines) (empty arrows).

**US appearances**

The US appearance that was sought to assess PNX diagnosis was the absence of the sliding sign, as well as the detection of the comet-tail artifacts, which was considered enough to rule out PNX. The sliding sign describes the movement of the pleural line that appears as a thin layer of water flowing in rhythm with respiration; its visualization excludes PNX with the exception of massive lung fibrosis, complete atelectasis and pleural symphysis. The comet tail artifacts (or “US B-lines”) (Lichtenstein 2005) are the well-defined rough vertical artifacts arising from the visceral pleura and spreading up to the edge of the screen without fading (Fig. 2). These artifacts are inconstant findings in nondyspnoic patients (up to 60%), sometimes present in small numbers (<8) in a normal chest and even are often seen in injured patients, especially in an expanded lung near a pleural air collection. Comet tail artifacts are absent in PNX because, as they arise from visceral pleura, they are hidden in PNX by the air collected in the pleural space. We did not apply in our study other accessory US criteria of PNX diagnosis, such as M-mode and colour-power-Doppler mode, considering them to be superfluous in our experience and unjustifiable to delay the examination’s execution time in emergency.

To evaluate the PNX extent, we looked for the “lung point sign”: this is a dynamic sign that represents the fleeting appearance of pleural sliding (with or without comet tail artifacts) replacing a PNX US pattern (exclusive horizontal lines of reverberation in place of sliding sign and comet tails: the “A-line sign”) (Fig. 5). Therefore, our experience suggests that the lung point efficiently marks the periphery of the pleural air collection in the point where the visceral pleural layer restores its contact with the parietal pleural layer.

The sonographic findings of PNX in the “deep sulcus sign” area are what we have defined as the “ultrasonographic deep sulcus sign”. The “deep sulcus area” is the anterior thoracic area corresponding to the projection of the cardimediastinal borders and anterior costophrenic sulcus, bounded superiorly by the second rib, inferiorly by the diaphragm and laterally by the mammary lines above and the anterior axillary lines below (Fig. 4). The definitions of the various transthoracic ultrasonographic findings are summarized in Table 1 (Lichtenstein 2005; Lichtenstein and Menu 1995; Rowan et al. 2002; Soldati and Rossi 2000).

**Statistics**

Continuously distributed variables were expressed by mean values with SDs and categorised variables in contingency tables. Estimates of specificity, sensitivity and overall accuracy were calculated for radiography versus CT (assumed as reference standard for PNX detection), US versus CT and US versus radiography on 372 lung fields (= 186 × two patients). All data were analyzed with SPSS for Windows, version 10.0 (Chicago, IL, USA) software.

**RESULTS**

The feasibility of ultrasound in first time eligible patients was 98.9% (186/188) and 91.2% in all patients admitted with blunt thoracic trauma (186/204 patients).

The prevalence of PNX revealed by CT scan (gold standard) in the studied population was of 56/186 (30.1%), of which 29 were anterior and 27 anterolateral. PNX was confirmed by anteroposterior supine chest radiograph in 30/56 cases (53.6%), without false positive radiographic results (specificity 100%). Despite the excellent specificity, the plain chest radiographs presented false negative results in 26/56 cases (46.4%) (occult PNX), showing sensitivity of 53.6% (95% CI: 39.8 to 67.0) and specificity of 100%, a 100% positive predictive value and a 83.3% (95% CI: 76.6 to 88.8%) negative predictive value (LR: 70.2). All PNXs missed by standard supine chest radiograph were anterior; 12 of these were very small (up to 1 cm thick and seen in no more than four contiguous images) (Wolfman et al. 1993). Supine chest radiograph correctly identified three PNXs classified as anterior by recognition of radiographic deep sulcus sign, while it identified all the anterolateral PNXs.

Transthoracic ultrasonography detected a PNX in 55/56 patients (98.2%). The sliding sign was visualized...
in all patients without a PNX (130 subjects) while the presence alone of comet tail artifacts ruled out PNX in 69 patients (53.1%). One occult PNX (very small) was missed by US, but false positive US results were never observed. We found the US sensitivity and specificity in diagnosing PNX to be 98.2% (95% CI: 90.4 to 99.9%) and 100%, respectively, the positive predictive value being 100% and the negative predictive value 99.2% (95% CI: 95.8 to 99.8%) (LR 128.7). The negative predictive value of the comet tail artifacts (B-line sign) was 100%. The lung point was recognised in each of the 28 patients with anterior PNX; at this level, comet tail artifacts were shown in 25 cases (89.3%). The evaluation of anterior PNX extension by using the lung point agreed enough with CT scan evaluation in all 27 cases, resulting in a ±2.3 cm difference (range 1–5 cm), with US overestimation in 14 cases and US underestimation in seven cases. Finally, in each US detected anterior PNX, the location of PNX involved the lower anteromedial zone of chest wall as expected, always showing an ultrasonographic deep sulcus sign. The average time to complete the chest US examination was ±2 min.

**DISCUSSION**

PNX may be the result of preexisting lung disease, the complication of diagnostic and therapeutic procedures or the outcome of trauma. Chest trauma accounts for 25–33% of all trauma-related deaths and PNX represents the second most common injury, after rib fracture, in blunt chest trauma (Di Bartolomeo et al. 2001; LoCicero and Mattox 1989). The diagnosis of traumatic PNX is suggested by clinical signs and is generally confirmed by standard chest radiography. However, up to 30% of cases are missed (occult) by the initial bedside anteroposterior supine chest radiograph (Tocino et al. 1984). Previous studies of cadaver have identified the supine position as the least sensitive in the detection of PNX and shown that readers of the supine radiographs were not confident in their diagnosis until 200 up to 400 mL of air had been introduced (Rhea et al. 1989). An excellent method for an anteroposterior projection with carryable device requires, in fact, a patient position at least partially upright, an exposition at the end of the inspiration, a patient/tube distance of 1.5 to 2 m and correct tension values (80–100 kV) associate with limited exposition times (≤0.1 s.) (American College of Radiology 1995).

On the other hand, the detection of an occult PNX is important, because the progression of small PNX can have a significant deleterious effect on respiratory function and the development of tension PNX can occur up to in half of these cases, particularly in the setting of general anaesthesia or PEEP (Tocino et al. 1984; Wescott and Cole 1983). When a precise recognition is needed, a referral to CT is mandatory (Wollman et al. 1993). Despite its excellent diagnostic accuracy, CT has some drawbacks, mainly because it involves the removal of critically-ill patients, resulting in increased delay, costs and exposure to irradiation.

<table>
<thead>
<tr>
<th>Sign</th>
<th>Type</th>
<th>Definition</th>
<th>Anatomical structure</th>
<th>Normal</th>
<th>PNX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleural line</td>
<td>Static</td>
<td>Horizontal hyperechoic band lying between and below the curved rib lines</td>
<td>Lung surface-chest wall interface</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bat sign</td>
<td>Static</td>
<td>Image showing a bat on the wing obtained by applying the probe longitudinally over an intercostal space</td>
<td>The pleural line between two contiguous ribs</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sliding sign</td>
<td>Dynamic</td>
<td>Movement of the pleural line synchronised with respiration</td>
<td>Visceral on parietal pleural layer gliding</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Comet tail</td>
<td>Static</td>
<td>Vertical hyperechoic artifact arising from pleural line and spreading at the bottom without fading</td>
<td>Bubbles with gas/fluid interfaces from visceral pleural layer</td>
<td>Yes, incostant</td>
<td>No</td>
</tr>
<tr>
<td>A-line sign</td>
<td>Static</td>
<td>Exclusive horizontal lines visible at regular intervals below the pleural line, typical of the PNX US pattern</td>
<td>Reverberation artifact arising from the pleural line</td>
<td>Yes, incostant</td>
<td>Yes</td>
</tr>
<tr>
<td>B-line sign</td>
<td>Static</td>
<td>Ultrasound finding looked for to rule out PNX and corresponding to the comet tail artifacts</td>
<td>Bubbles with gas/fluid interfaces from visceral pleural layer</td>
<td>Yes, incostant</td>
<td>No</td>
</tr>
<tr>
<td>Lung point</td>
<td>Dynamic</td>
<td>Fleeting appearance of sliding sign</td>
<td>Reinstatement of contact between visceral and parietal pleural layers</td>
<td>No</td>
<td>Yes, occult</td>
</tr>
<tr>
<td>Deep sulcus sign</td>
<td>Static</td>
<td>The anterior thoracic area corresponding to cardio-mediastinic borders and anterior costophrenic angles</td>
<td>Air collecting in antideclive pleural space</td>
<td>No</td>
<td>Yes, occult</td>
</tr>
</tbody>
</table>
Because of its simplicity, security and portability, ultrasonography could be especially useful in emergency diagnosis, in which no radiographic equipment is readily available. Furthermore, for physical reasons, the detection of the absence of sliding sign in the supine patient with PNX is more successful anteriorly in the parasternal line and near the diaphragm (“deep sulcus sign” area) (American College of Surgeon 1997). In fact, when the patient is in the supine position, air in the pleural space collects anteriorly and inferiorly within the anteromedial and costophrenic regions of the pleural spaces. When the patient is upright, the air collects in the apicolateral location.

Although it is still a “young” technique in trauma and intensive care, the use of US to detect the presence of PNX has an established scientific basis. The first report of ultrasonographic findings about PNX appeared in 1986 in a veterinary journal (Ratanen 1986), while Wernecke et al. (1987) reported the first evaluation of PNX by US in humans. The technique has been examined in traumatic, spontaneous and iatrogenic PNX (Rowan et al. 2002; Sistrom et al. 1996; Targhetta et al. 1992; Wescott and Cole 1983). Despite the experience of Sistrom et al. (1996) (sensitivity for PNX 73%, specificity 68% and high interobserver variability) and, recently, of Kirkpatrick et al. (2004) (sensitivity 58.9% but specificity 99.1%), sensitivities greater than 90% have been reported in patients with PNX by other authors (Dulchavsky et al. 2001; Lichtenstein et al. 1999; Targhetta et al. 1993). Our previous research (Soldati and Rossi 2000) and recent unpublished observations confirmed that US is more sensitive than plain radiography and as sensitive as CT for PNX detection. The prevalence of occult PNXs seen among all PNXs was 46.5%, higher than recent literature data (Kirkpatrick et al. 2004) and than the ones in our unpublished observations, but it was in agreement with the recent data of Neff et al. (2000).

The difference among the various studies around the sensibility of the US can mainly be imputed to the different experience of the operators and the different criteria adopted for the US diagnosis of PNX, while the difference in the prevalence of the occult PNXs can depend on the different patient inclusion and exclusion criteria adopted in the single studies.

In our study, chest ultrasonography, performed by EPs, focused on evaluating the sliding sign: US was more sensitive and accurate than plain radiography performed by radiologists (98.2 versus 53.5%) and it was nearly as accurate as CT. However, the fact that the radiologists did not know the research project, as well as they did not have any direct knowledge of the severity of the patients’ condition, could have penalised the estimate of diagnostic accuracy in favour of ultrasonography. Comet-tail artifacts (US B-line sign), inconstant findings in the deep sulcus area in normal subjects, were a useful adjunct to the sliding sign in a subset of patients (53.1%), because of their absolute negative predictive values. On the other hand, comet-tail artifacts were more evident as a sign associated with the lung point (89.3%) and represented a useful finding for its quick recognition.

Our study has several limitations. First, all US examinations were performed by EPs who are experienced in US imaging; therefore, we could not assess sonographer operator dependence. Second, our studied population includes only patients with blunt chest trauma who underwent a comprehensive (including CT) chest imaging. It could be argued that the patients who required a CT, on average, had more serious injuries. Third, the sample size in this study is relatively small and our inclusion criteria may have introduced bias to it. Fourth, the technique requires further investigation in patients with preexistent disease affecting the pleura.

In conclusion, US has to be considered as an elective examination for the PNX diagnosis. The extended focused assessment with sonography for trauma (E-FAST), as recently proposed (Kirkpatrick et al. 2004), should be investigated as a clinically attractive modality that every physician can readily learn. The finding of an immobile pleural line in the “deep sulcus sign” area allows the diagnosis of PNX, whereas the systematic research of the lung points permits the evaluation of its extent and consequently the hypothesis of its radiographic visibility. Anyway, an US PNX diagnosis, independently from its clinical or radiographic expression, imposes an accurate observation because of the risk of progression toward more serious conditions.

Acknowledgments—We are indebted to Dr. Monica La Sala for technical assistance during the preparation of manuscript.

REFERENCES


