Ultrasound diagnosis of occult pneumothorax*

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Objectives: **Pneumothorax can be missed by bedside radiography, and computed tomography is the current alternative. We asked whether lung ultrasound could be of any help in this situation.**

Design: **Retrospective study.**

Setting: **The medical intensive care unit of a university-affiliated teaching hospital.**

Patients: **All patients admitted to the intensive care unit are routinely scanned with whole-body ultrasound (including screening for pneumothorax) and chest radiography. The study population included 200 consecutive undifferentiated intensive care unit patients who received a chest computed tomography scan in addition to ultrasound and chest radiograph. Forty-seven consecutive cases of radioccult pneumothorax were compared with 310 consecutive hemithoraces free from pneumothorax in the intensive care unit.**

Interventions: **None.**

Measurements and Results: **Three signs were investigated at the anterolateral chest wall in supine patients: lung sliding, the A line sign, and the lung point. A total of 357 hemithoraces were analyzed in this study, 47 with occult pneumothorax and 310 controls. Four of the 47 cases of pneumothorax were excluded from the final analysis (parietal emphysema) as well as eight of the 310 controls (large dressings), leaving a final study population of 345 hemithoraces in 197 patients. Feasibility was 98%. Ultrasound scans in all 43 examinable patients with pneumothorax showed absent lung sliding, 41 of 43 patients had the A line sign, and 34 exhibited a lung point. Among 302 analyzable controls, 65 had absent lung sliding, 16 of them showed an A line sign, and none showed a lung point. For the diagnosis of occult pneumothorax, the abolition of lung sliding alone had a sensitivity of 100% and a specificity of 78%. Absent lung sliding plus the A line sign had a sensitivity of 95% and a specificity of 94%. The lung point had a sensitivity of 79% and a specificity of 100%.**

Conclusions: **For the diagnosis of occult pneumothorax, ultrasound can decrease the need for computed tomography. (Crit Care Med 2005; 33:1231–1238)**

Key Words: pneumothorax; chest ultrasonography; ultrasound diagnosis; lung; ultrasound diagnosis; respiratory failure; intensive care unit

Pneumothorax is a common problem seen in patients with both acute and chronic medical and traumatic conditions. Its frequency in the intensive care unit (ICU) is estimated at 6% (1). Chest radiography, a familiar technique (2), is the primary diagnostic modality used to screen for pneumothorax, but it has imperfect sensitivity for the disease: Misdiagnosis occurs in 30–40% of patients (3–7). Missed pneumothorax can have dramatic consequences in high-risk patients (8, 9). Half of radioccult cases yield tension pneumothorax (4). Even a tension pneumothorax can be radioccult (10), and delay in diagnosis will have deleterious consequences (11). Computed tomography (CT), the current gold standard, solves this problem but introduces major drawbacks (transfer of critically ill patients, delay, irradiation, and cost, among others), whereas the excessive search for pneumothorax has similar drawbacks (12). Hence, an immediately implemented technique at the bedside should be of interest in this setting.

Could ultrasound play such a role? Its potential to examine the lung is classically thought to be limited, since air is considered an insurmountable obstacle. The image is thus exclusively composed of artifacts. However, a growing body of experience has shown that sonographic demonstration of the presence or absence of these artifacts can be used to aid in the diagnosis of a number of pulmonary diseases, including pleural effusion, alveolar consolidation, pulmonary edema, and pneumothorax (13). There is also the potential, based on our own and others' clinical experience, that ultrasound may be more accurate than bedside radiography (14–18).

This study describes the role of ultrasound in the identification of occult pneumothorax.

METHODS

This was a retrospective study extending from 1993 to 2003 (part-time observation) and evaluating 200 consecutive patients from medical and surgical ICUs. All patients underwent routine screening sonography for pneumothorax followed by CT scanning. CT was the gold standard, as it made definite diagnosis or gave definite proof of the absence of pneumothorax.

Our ICUs are equipped with ultrasound devices. All patients are routinely imaged with both chest radiographs and whole-body ultra-

***See also p. 1425.**

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Table 1. Indication of the computed tomography (CT) scans

In the study group
Routine in chest trauma, n = 21
Clinical suspicion in patients with worsening of clinical status, n = 10
Nonspecific radiographic changes, n = 13
Unexpected finding in CT required for other reasons, n = 3
In the control group
Suspicion of pneumothorax, n = 28
Investigation of acute respiratory distress syndrome, search for pulmonary embolism, assessment of pleural effusion, and other, n = 127

sound including the lungs (19). The role of lung ultrasound is to identify life-threatening processes such as alveolar consolidation, interstitial syndrome, and pleural effusion in addition to pneumothorax. A routine thoracic study lasts 1 min per lung.

Patients included in this study were those patients without pneumothorax on chest radiographs, who underwent an ultrasound screening examination in addition to a chest CT showing either occult pneumothorax (pneumothorax group) or absence of pneumothorax (control group). Chest CTs were obtained at the discretion of the treating physician for a wide range of suspected diagnoses regardless of the ultrasound results (Table 1). Patients were eligible if they had a chest ultrasound, supine radiography, and CT scan all obtained within 120 mins.

The pneumothorax group included 47 cases of occult pneumothorax in 45 patients (two bilateral cases). The analysis of the contralateral lung was not considered, as a patient could not be included in both the study and control groups.

Pneumothoraces that were visible on radiography (approximately 300 cases seen during this period) were excluded, as they did not raise diagnostic problems.

The pneumothorax group was compared with a control group of consecutive patients without radiologic pneumothorax, who for various reasons underwent CT that confirmed the absence of pneumothorax. The control group included 310 lungs in 155 ICU patients. Table 1 lists the indications for CT in both groups.

Bedside radiographs along the anteroposterior axis were taken with a VMX portable unit (General Electric, Monza, Italy). Study patients were in the supine position, except four half-sitting patients. CT scans were performed from apex to diaphragm with a CT Twin Flash (Elscint Limited, Haifa, Israel) at a window width of 1600 HU, level of −600 HU, and 10-mm sections. Radiographs and CTs were always interpreted by radiologists unaware of the ultrasound results. The specific radiographic or scanographic sign was displacement by air of visceral pleural from parietal pleura (3). Occult pneumothorax was defined as absence of specific signs like visible pleural line or deep sulcus sign.

Ultrasound Technique. Intensivists specifically trained in general ultrasound and unaware of radiologic or CT findings used a Hitachi Sumi 405 (Hitachi Medical, Tokyo, Japan) with a 5-MHz microconvex probe without Doppler.

The ultrasound technique has recently been detailed (13). The anterior chest wall was delineated by the sternum, the cupola, the anterior axillary line, and the clavicula. The anterior chest wall was divided into four quadrants. The lateral chest wall was delineated by the anterior and posterior axillary lines (Fig. 1). Patients were analyzed at the bedside, in the supine position in 43 cases of pneumothorax and 143 controls and in the half-sitting position in four cases of pneumothorax and 12 controls. The probe was gently applied tangentially to the chest wall and used to scan the intercostal spaces longitudinally. The probe was positioned on each of the four quadrants of the anterior area. The probe was first placed at the most superior aspect of the thorax with respect to gravity, in other words, the lower part of the anterior chest wall in supine patients or the upper part in half-sitting patients.

The stages of the investigation were previously detailed (20). Briefly, stage 1 examined the anterior wall (area 1) in supine patients, and stage 2 examined areas 1 (anterior) and 2 (lateral) in supine patients. Stage 3 included the external part of the posterior wall, an area of clinical relevance and accessible without moving supine patients when using a short probe. Stage 4 was a whole-thorax exploration, including the supraclavicular areas and the posterior chest wall by mobilizing the patient laterally or into a seated position. Investigation of stage 1 (i.e., analysis of lung sliding and A/B lines) took <1 min.

Normal Lung: Basic Terminology. The signs arise at the pleural line, which should be described before dynamic (lung sliding) and static (artifacts) analysis. In a longitudinal view, location of the ribs allows accurate detection of the pleural line (Fig. 2). The succession of the upper rib, pleural line, and lower rib outlines a characteristic pattern, the bat sign. The bat sign must be recognized to correctly identify the pleural line and avoid errors in case of parietal emphysema (discussed subsequently).

Lung sliding (video clip 1) is a to-and-fro movement visible at the pleural line caused by the inspiratory excursion of the lung toward the abdomen and homogeneously displayed below (16, 17). Lung sliding can be objectified using the time-motion mode, which highlights a clear distinction between a wave-like pattern located above the pleural line and a sand-like pattern below, called the seashore sign (Fig. 3 and video clip 2). Lung sliding can be observed in ventilated as well as in healthy subjects, regardless of age or body habitus. At the apex, it may be imperceptible, but the slightest movement is significant (all-or-nothing rule). Dynamic noise filters (often fitted by default) mask lung sliding and must not be used.

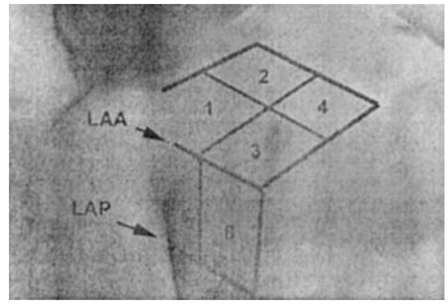

Figure 1. Basic landmarks of the chest wall used in lung ultrasound. The anterior wall, which includes four or five intercostal spaces, can be divided into four quadrants. The anterior axillary line (*LAA*) forms a boundary between the anterior and lateral areas. Stage 2 investigation covers these areas in a supine subject. *LAP*, posterior axillary line.

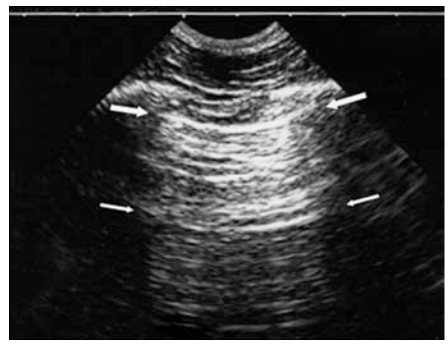

Figure 2. Pleural line. Real-time (two-dimensional) mode. Longitudinal view of an intercostal space of the chest wall. A centimeter scale is shown on the top of the image. On both sides, the upper and lower ribs of the intercostal space are recognized by their acoustic shadow. One must imagine the wings of a flying bat. The bat sign locates the pleural line. A roughly horizontal hyperechoic line is visible 0.5 cm above the rib line: the pleural line (*large arrows*). Several other horizontal lines are again visible in this view. Only one arises at a distance from the pleural line, which is the critical distance between the probe head and the pleural line: This repetition artifact is called A line (*fine arrows*), a basic sign of the normal lung.

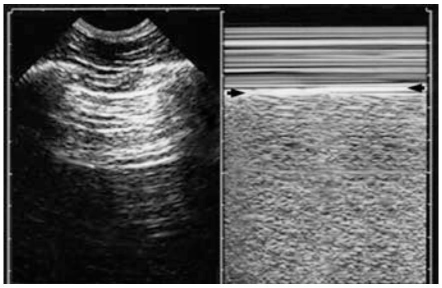

Figure 3. Lung sliding. *Left*, real-time mode. *Right*, time-motion mode. The time-motion mode objectifies lung sliding: Over the pleural line (*arrows*), the motionless parietal tissues yield horizontal lines. Below the pleural line, lung sliding generates a homogeneous granular pattern. This pattern, which is reminiscent of a shore (the seashore sign), rules out pneumothorax.

Artifacts arising from the lung-wall interface were recently classified (13). Ultrasound lung terminology critically depends on the description of these artifacts. Two main artifacts can be described and were called A and B lines. Only one of these can be observed at one point of the lung. The A line is a roughly horizontal artifact. It refers to a brightly echogenic line between the rib shadows when the probe is positioned longitudinally (Fig. 2). The B line, roughly vertical, is a comet-tail artifact that has five mandatory features: It arises from the pleural line, is well-defined (laser-beam-like), spreads to the edge of the screen without fading (i.e., up to 17 cm with a probe reaching 17 cm), erases A lines, and moves with lung sliding (Fig. 4). Several simultaneously visible B lines are labeled lung rockets (Fig. 4). The significance of ultrasound B lines was recently highlighted. Multiple B lines indicate interstitial syndrome (21). They are generated by pathologic conditions and not by frequency, geometry of the probe, or adjustment of the machine (21). B lines 7 mm apart indicate thickened interlobular septa, an equivalent of Kerley's B lines (22). B lines that are 3 mm apart correlate with ground-glass areas (21). B lines can be isolated and without precise pathologic meaning. As B lines are generated by the visceral and not the parietal pleura, it is expected that they are no longer visible in the case of pneumothorax (17).

Another kind of comet-tail artifact must be described. It arises from the pleural line and is vertical like the B line but has four distinctive features: It is ill-defined, vanishes after a few centimeters (2–5 cm), does not erase the A lines, and is independent of lung sliding. These contrasting details avoid confusion with B lines. Observed in normal subjects as well as in cases of pneumothorax, this artifact, which is called the Z line, in our experience seems devoid of pathologic meaning (Fig. 5).

A last type of comet-tail artifact should be described, as it arises from superficial collections of parietal emphysema, which usually

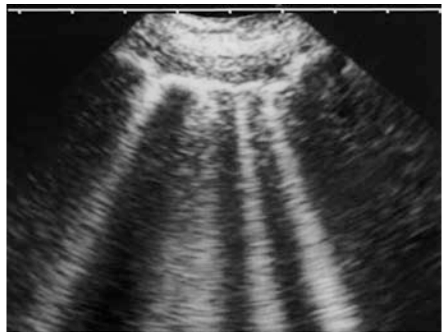

Figure 4. B lines. Four or five comet-tail artifacts are visible fanning out from the pleural line, vertically oriented, well-defined, laser-beam-like, erasing A lines, and spreading up to the edge of the screen without fading, that is, ultrasound B lines. Several B lines visible in a single view are suggestive of a rocket at liftoff, hence the label "lung rockets." B lines rule out pneumothorax at the place they are observed and, at the same time, indicate interstitial syndrome.

prevent visualization of the pleural line. It spreads up without fading to the edge of the screen but rises above the pleural line (17). This comet-tail is called the E line, E for emphysema. In this case, the pleural line is not visible (Fig. 6). Lung ultrasound examination should therefore be considered not feasible when the bat sign is not identified.

Pneumothorax: Ultrasound Terminology. Dynamic (16, 18) and static (17) signs of pneumothorax were considered. A dynamic sign was the abolition of lung sliding (video clip 3), which was objectified in time-motion mode. In time-motion mode, the complete absence of dynamics resulted in superimposing strictly horizontal lines, referred to as the stratosphere sign (Fig. 7, video clip 4). Another dynamic sign was the lung point (Figs. 8 and 9, video clip 5), an inspiratory-synchronized change from lung patterns (lung sliding and/or B lines) to pneumothorax patterns (no lung sliding nor B line) at a critical location on the chest wall (18). The lung point is an all-or-nothing sign.

The A line is an important artifact observed in normal lungs, certain diseased lungs, and also pneumothorax. Both pneumothorax and lung tissue contain air, which acts as a static barrier to ultrasound and is responsible for the generation of A lines. In normal and diseased lungs, A lines can be seen in association with artifacts generated from lung parenchyma, specifically B lines and lung sliding. B lines indicate a diseased lung; they also mean visibility of this lung, that is, absence of interposed air. For the purpose of this study, the presence of A lines alone without the slightest B line was considered pathologic and was referred to as the A line sign.

When neither horizontal nor vertical artifacts were observed, not an unusual situation, the pattern, which was called O lines (or non-A/non-B lines), was by default likened to A

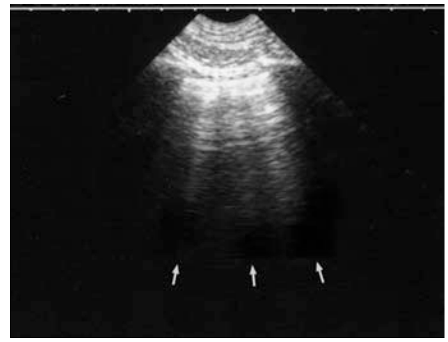

Figure 5. Z lines. Three comet-tail artifacts (*arrows*) arise from the pleural line. Compared with Figure 4, they are ill-defined, they quickly vanish, after <4 cm, and they do not erase the A line. These comet-tails are not B lines. They were labeled Z lines. This patient has pneumothorax. Normal subjects usually exhibit such artifacts.

lines (see Fig. 10). Slight movements of the probe often result in A lines.

Figure 10 classifies these artifacts.

As this study was not invasive or time-consuming, was free from charge, and did not include randomization, and because ultrasound findings did not alter the therapeutic procedures, approval by an institutional committee on human research and informed consent were not required.

RESULTS

Patients Characteristics. The pneumothorax group included 32 men and 13 women. Mean age was 44 yrs, range 17–84 yrs, SD 19. Twenty eight cases occurred during mechanical ventilation. Radiography showed indirect signs in 16 cases (parietal emphysema in four, depressed diaphragm in six, basilar hyperlucency in five, and lung herniation on the contralateral side in one). Radiography was uninformative in 31 cases. Pneumothorax was traumatic in 23 cases, was iatrogenic in ten (venous catheter, thoracentesis, protected brushing, fibroscopy, biopsy), complicated mechanical ventilation in seven, complicated lung disease in three, and was spontaneous in four. Of 47 cases of occult pneumothorax, 16 required a chest tube, and eight had ventilation adaptation (low volume, zero end-expiratory pressure). The control group included 106 men and 49 women. Mean age was 57 yrs, range 20–86 yrs, SD 16; 96 patients were ventilated.

Main Results. Of the 47 cases of pneumothorax in 45 patients, four were excluded from the final analysis because of parietal emphysema. Among 310 lungs in 155 patients in the control group, two

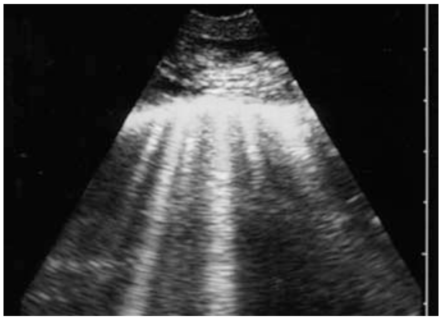

Figure 6. E lines. These comet-tails, which spread up to the edge of the screen without fading, do not arise from the pleural line (the rib shadow, which is part of the bat sign, is not visible). Superficial air layers, coming from a parietal emphysema.

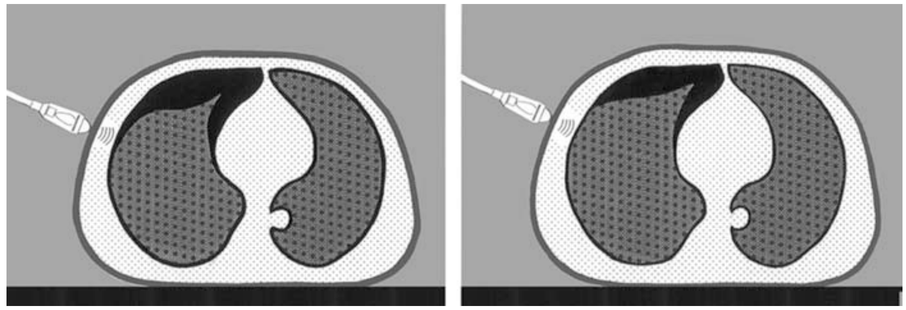

Figure 9. Theoretical explanation of the lung point. *Left*, at expiration, the pneumothorax has a defined volume. A probe placed at a point slightly anterior to the lung level will display a pneumothorax pattern. *Right*, at inspiration, we must imagine that the lung volume slightly increases, therefore increasing the surface of the lung in contact with the wall. The probe remaining at the same location will immediately display fleeting lung patterns.

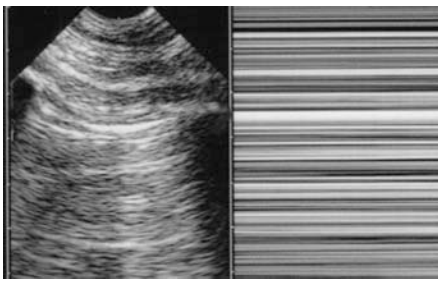

Figure 7. Pneumothorax. *Left*, real-time. There is abolition of lung sliding (which cannot be visualized in this frozen image) associated with exclusive A lines (same pattern as in a normal subject). This static pattern can be called the A line sign. *Right*, time-motion. Below the pleural line, the normal granular pattern (see Figure 3) is replaced by horizontal lines, which objectify abolition of lung sliding. The pattern is reminiscent of squadrons of flying fortresses in the stratosphere, hence the term "stratosphere sign." Note that this pattern is not yet specific to pneumothorax.

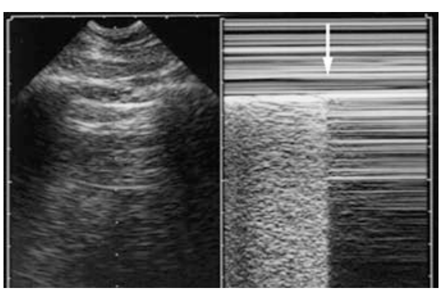

Figure 8. Lung point. Patient with pneumothorax. The time-motion mode (*right*) clearly objectifies the precise moment (*arrow)* when the collapsed lung is (*left of the arrow*) or is not (*at the right*) in contact with the chest wall. The lung point designates this sudden replacement of the normal granular pattern by a horizontal pattern, at a defined location. The lung point is a specific sign of pneumothorax.

cases could not be investigated because of large dressings and six had nonaerated anterior patterns. The final analysis considered 43 analyzable cases of pneumothorax and 302 analyzable hemithoraces in the control group. Ultrasound feasibility was 98%. Each examination lasted $<$2 mins.

The first step was the analysis of lung sliding. All 43 cases of pneumothorax showed no anterior lung sliding. Of 302 controls, anterior lung sliding was present in 237 and absent in 65. For the diagnosis of occult pneumothorax, the absence of lung sliding had a sensitivity of 100%, a specificity of 78%, a negative predictive value of 100%, and a positive predictive value of 40%.

The second step involved looking at whether the presence of the A line sign would further improve the specificity of an absent lung sliding. The A line sign was observed in 41 of 43 cases of pneumothorax and in 114 of 302 controls (this sign alone had a sensitivity of 95%, a specificity of 62%, a negative predictive value of 98%, and a positive predictive value of 26%). In two cases, anterior B lines were observed. The controls were subdivided into four conditions: lung sliding with the A line sign (n = 98), lung sliding without the A line sign (n = 139), no lung sliding without the A line sign (n = 49), and no lung sliding with the A line sign (n = 16). When the condition "no lung sliding with the A line sign" was compared with the three other conditions combined, 41 of 43 cases of occult pneumothorax vs. 16 of 302 controls had this combination, which had a sensitivity of 95%, a specificity of 94%, a negative predictive value of 99%, and a positive predictive value of 71% for the diagnosis of occult pneumothorax.

The third step involved searching for a lung point. Of 43 cases of occult pneumothorax, a lung point was present in 34 and absent in nine. Of 302 controls, especially in the 16 cases with absent lung sliding associated with the A line sign (i.e., a profile suggestive of pneumothorax), none displayed a lung point. For the diagnosis of occult pneumothorax, the lung point had a sensitivity of 79%, a specificity of 100%, a negative predictive value of 97%, and a positive predictive value of 100%.

Tables 2 and 3 detail these results. Table 4 shows that ultrasound accuracy is a function of the number of signs considered.

Additional Results. Findings consistent with pneumothorax were most often seen in the anterior chest wall (41 of 43 patients) with variable extension superiorly and inferiorly. Among 39 patients with pneumothorax studied in the supine position, the area involved was the entire anterior wall in 23 cases and the lower half in 15. In one posterior location, there were anterior B lines with abolished lung sliding. In one case of apical pneumothorax, B lines were present at the anterior area, with abolished lung sliding.

A correlation was made between the lung point location and the need for chest tube insertion, suggesting substantial volume. Among 34 cases exhibiting a lung point, two of 24 patients showing anterior locations (8%) required tube insertion vs. nine of ten patients showing lateral locations (90%).

Z lines were observed in the pathologic area in 36 of 43 cases of pneumothorax and in 242 of 302 controls (i.e., 84% and 80%, respectively). This result seems to confirm that Z lines are parasite

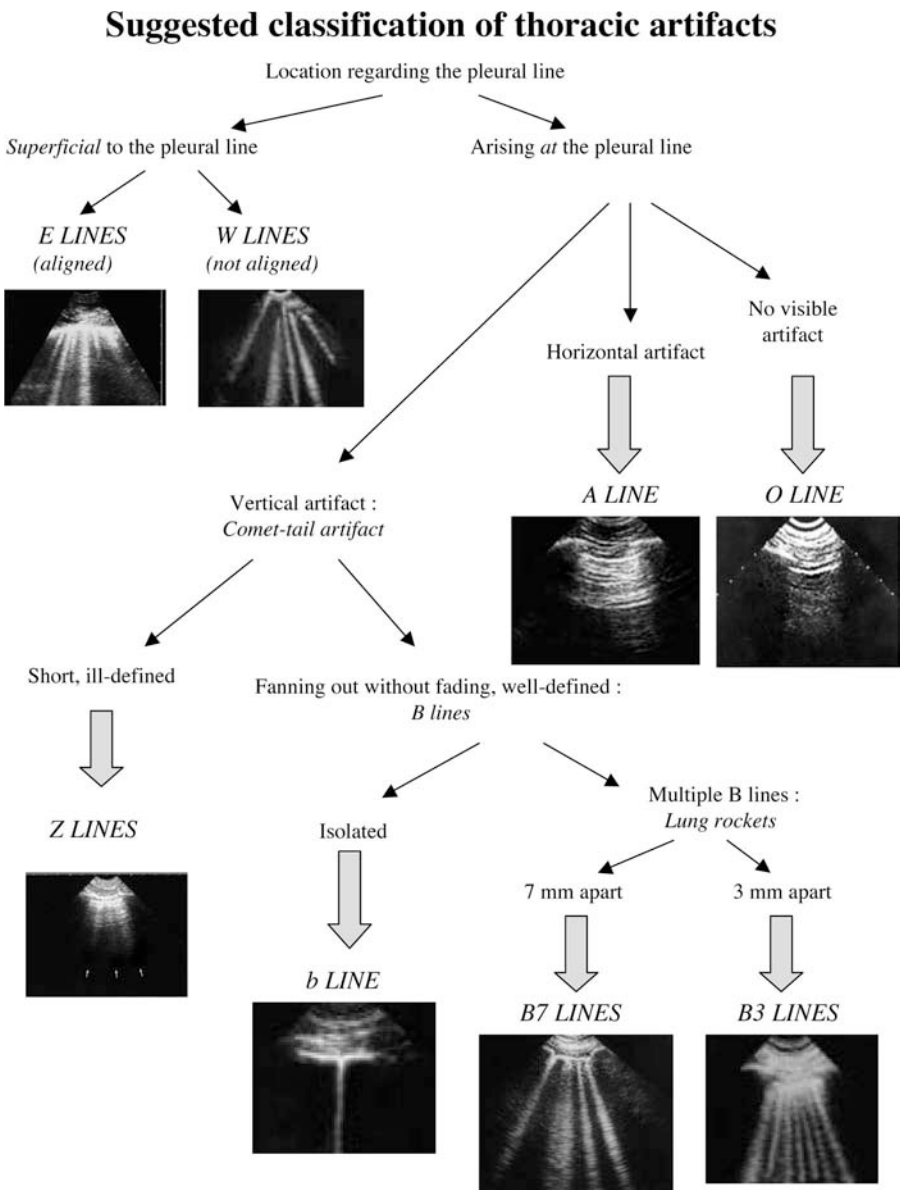

Figure 10. Suggested classification of thoracic artifacts.

Table 2. Overall results

	Occult Pneumothorax Group	Pneumothorax-Free Group
Step 1—abolished lung sliding	43 of 43	65 of 302
Step 2—abolished lung sliding + the A line sign	41 of 43	16 of 302
Step 3—no lung sliding + the A line sign + lung point	34 of 43	0 of 302

Table 3. Absent lung sliding plus A line sign

	Occult Pneumothorax Group		Pneumothorax-Free Group	
	A Line Sign	B Lines	A Line Sign	B Lines
Lung sliding present	0	0	98	139
Lung sliding absent	41	2	16	49

artifacts that do not provide diagnostic information.

DISCUSSION

As an air-filled structure, the lung is an organ for which ultrasound traditionally had a limited diagnostic value. In fact, lung ultrasound is hardly supposed to exist (23). Yet the use of basic signs makes immediate management of life-threatening conditions possible (13). Accessible with simple units, lung ultrasound could have been developed from the advent of real-time ultrasound. Our first observations were made using 1978 technology (ADR-4000). In addition, the small size of these devices made them fully suitable for the ICU and the emergency department.

In the literature, we discover, surprisingly, that horses have already benefited from ultrasound—because the movement of the lung toward the chest wall is visible (24). Human studies followed, but their impact was minimal. In fact, to our knowledge, studies have suffered from various shortcomings.

Sistrom et al. (25) looked at the sensitivity of lung sliding and comet-tails in 13 patients with radiologic pneumothorax occurring after chest biopsy, using 7-MHz linear probes in units handled by sonologists (i.e., nonphysicians) subsequently supervised by radiologists. This study demonstrated moderate accuracy of ultrasound with 73% sensitivity, 68% specificity, 89% negative predictive value, and 40% positive predictive value. How can such results be explained? First, ultrasound gives its best, in our opinion, when used by only one and same operator. If the operator is the physician in charge to the patient, the results will be obviously optimized. No description is made of A lines, seashore sign, stratosphere sign, and lung point, and the comet-tail terminology is not specified (no distinction B/Z lines). The linear probes render transversal scans mandatory, which is not logical: Lung sliding is a craniocaudal movement. The 7-MHz probes usually explore ≤5–6 cm. Consequently, distinction of B/Z lines as well as detection of deep disorders (pleural effusion, consolidation) is hazardous, whereas our 5-MHz probe explores not only the lung surface but also the whole body (26). The use of dynamic noise filter is not specified (see Methods). Last, CT was not used, an oversight when searching for occult pneumothorax; studies that

Table 4. Accuracy of ultrasound as a function of the number of signs used

	Pneumothorax	Control Group
Lung sliding (LS) abolished	43 of 43	65 of 302
LS abolished + A line sign	41 of 43	16 of 302
LS abolished + A line sign + lung point	34 of 43	0 of 302
	Sensitivity, %	**Specificity, %**
LS abolished	100	78
LS abolished + A line sign	95	94
LS abolished + A line sign + lung point	79	100

fail to use CT as a gold standard should be interpreted cautiously. These flaws are also seen in other studies (27, 28).

The study by Rowan et al. (14) is more interesting, because CT was used. This is a wise attitude as outlined long ago (16). In this study including 11 cases of pneumothorax with seven occult cases, in which the authors investigated lung sliding and comet-tail artifacts with a 7-MHz linear probe, the sensitivity and negative predictive value were 100%, specificity was 94%, and positive predictive value was 92%. These data are encouraging, even if limitations of the previous studies are found: small sample, non-ICU patients, operators not clinicians, incomplete description of the comet-tails (making confusion possible between B and Z lines), time-motion-mode signs and lung point not used, suboptimal probe, and filter use not specified. On the other hand, this study could assess the value of bedside radiography, which had a sensitivity of 36%.

If signs such as A/B/Z lines, seashore, stratosphere, and lung point are considered, linear high-frequency probes are avoided, dynamic noise filters are rejected, ultrasound is handled by the physicians in charge of the patients, and CT is used as a gold standard, the performance of ultrasound cannot be but be optimized. When all these points were taken into consideration, sensitivity and negative predictive value of abolished lung sliding for every analyzable kind of pneumothorax were 100%, specificity was 91%, and positive predictive value was 87% (16). The A line sign had a sensitivity and negative predictive value of 100%, a specificity of 60%, and a positive predictive value of 42% for complete pneumothorax (17). The lung point had a sensitivity of 66% and a specificity of 100% for every kind of pneumothorax (18).

The limitations of lung ultrasound should be considered. It may be of limited use in those critically ill patients with parietal emphysema or pleural calcifications, because acoustic artifacts resulting from these conditions may limit visualization of the pleural interface. Emphysematous bullae are not a limitation, because they do not alter lung sliding (study in progress). Septated pneumothoraces are rare and usually of little clinical relevance. Note that this implies pleural adhesions, a condition that abolishes lung sliding (study in progress). Posterior or apical pneumothorax can give anterior B lines. Cases of pneumothorax with anterior B lines perfectly illustrate the fact that B lines rule out pneumothorax at the location where they are observed. Obviously, the sensitivity rate of 95% in this study would have been improved if the supraclavicular area had been included, but mastery of this area requires particular skill.

Statistical issues can be highlighted. Most patients admitted to our ICU do not undergo CT. If lung ultrasound is normal, pneumothoraces may be missed. These potential cases are assumed to be rare: 3 days of follow-up did not reveal signs at least on serial radiographs, a logical finding considering the excellent negative predictive value of ultrasound. On the other hand, positive lung ultrasound in patients without pneumothorax means false-positive cases. If we consider the group of patients scheduled for CT in this study as representative of standard ICU patients, it is noteworthy that in these patients without pneumothorax, no false-positive results were found. This group is certainly biased, as severe lung disorders are conditions at high risk for pneumothorax, but this bias impairs ultrasound performance: Abolition of lung sliding without pneumothorax is frequently observed in severe lung disorders.

Is the need to refer to several signs a limitation? Ultrasound must not amount to abolition of lung sliding alone. In critically ill patients, lung sliding is impaired in 21% (in this study) to 40% of cases (if only acute respiratory distress syndrome or extensive pneumonia is considered, study in progress). Not taking these notions into account may have deleterious consequences. Failure to see lung sliding may be the result of technical deficiencies: inappropriate technique or probe frequency, dynamic noise filters, and so on. The loss of lung compliance, a disorder seen in atelectasis, pleural symphysis, or fibrosis, yields abolition of lung sliding. This explains why other signs are warranted (the A line sign and the lung point). Critically ill patients without pneumothorax but with abolished lung sliding usually display B lines.

In this new field, potentially important in the ICU in mechanically ventilated patients and pneumothorax risk, where decisions are usually based on clinical and simple radiologic grounds, more research is advocated by some (29, 30). Chan (30) considers that the mention of comet-tail artifacts in the academic literature is confusing. Standardization of the various kinds of artifacts should obviously solve the problem.

A number of attractive advantages of ultrasound are highlighted in this study.

High Feasibility. Unlike other organs, the lung can almost always be visualized.

High Sensitivity. Ultrasound proved to be more sensitive than radiography. The lung point was easy to detect especially in the case of minimal pneumothorax. Note that bedside radiography, recently assessed in acute respiratory distress syndrome patients for other disorders (pleural effusion, consolidation, interstitial syndrome), cannot be considered a reliable tool (31).

Rapidity. Lung sliding or its absence, A lines, B lines, or lung point can be recognized immediately, a critical advantage in extreme emergencies.

Ability to Predict the Extent of Pneumothorax. This potential is reputed to be unreliable (14, 25, 29, 30). In this study, a lateral lung point location was correlated with the need to insert chest tubes (study in progress).

Simple Technique. A protocol limited to the anterolateral chest wall is sufficient. This highly accessible area is involved in all complete pneumothoraces

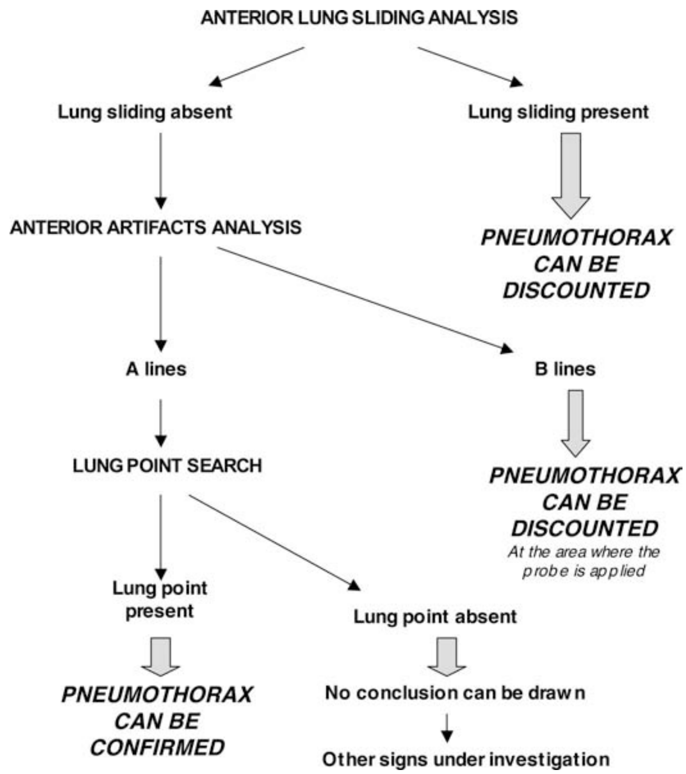

Figure 11. Decision tree.

For the diagnosis of occult pneumothorax, ultrasound can decrease the need for computed tomography.

(16–18). CT analysis of occult pneumothorax in supine patients shows that the anterior area is involved in almost all cases (32).

Short Learning Curve. Correctly trained physicians quickly master the signs (33). A training program in emergency ultrasound is available in our institution—www.ceurf.net. Teams begin to use this potential in emergency (34) and routine situations (35). For the time being, ultrasound should not suddenly replace radiography or CT. These basic tools must be used until full mastery of ultrasound is acquired.

Simple Logistics. Unsophisticated devices without Doppler are suitable, and 1978 technology is sufficient. The use of several probes increases costs and generates problems of asepsis. Note that bulky echocardiographic units and probe frequencies <3 MHz will not be adequate. See also our comments regarding linear 7-MHz probes.

Wide-Ranging Applications. B lines distinguish interstitial from noninterstitial disorders, a finding of clinical relevance in dyspneic patients (36, 37). Whole-body analysis can be achieved in the ICU, the emergency room, and, using ultraportable units, prehospital medicine (38).

Noninvasive Method. Ultrasound will limit irradiation and costs. Ultrasound will be used in routine practice (insertion of subclavian venous catheter, draining of pneumothorax) or when irradiation must be avoided (in pregnant women and infants).

Our decision tree (Fig. 11) prompts us to search for lung sliding. Pneumothorax is immediately suspected in stage 1. If the A line sign is present, the next step is to search laterally for a lung point (stage 1 or 2). A lung point calls for immediate drainage if clinically requested. If the lung point is absent, no conclusion should be drawn and a traditional approach (i.e., bedside radiography or transfer to CT, time permitting) should be used. No lung sliding with the A line sign is highly suggestive of but not specific to pneumothorax (sensitivity 95%, specificity 94%). Additional signs will be dealt with in future reports.

CONCLUSIONS

Lung sliding rules out pneumothorax, lung rockets rule out pneumothorax, and lung point rules in pneumothorax. Although usually considered a hindrance, the ultrasound artifacts generated by the lung can lead to an accurate interpretation. The possibility of immediately obtaining basic information, at the bedside, on this vital organ can make ultrasound a genuine visual stethoscope (39). Lung ultrasound can reduce the need for CT in diagnosing occult pneumothorax.

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REFERENCES

1. Kollef MH: Risk factors for the misdiagnosis of pneumothorax in the intensive care unit. *Crit Care Med* 1991; 19:906–910
2. Williams FH: The Rœntgen Rays in Medicine and Surgery. New York, Macmillan, 1901
3. Chiles C, Ravin CE: Radiographic recognition of pneumothorax in the intensive care unit. *Crit Care Med* 1986; 14:677–680
4. Tocino IM, Miller MH, Fairfax WR: Distribution of pneumothorax in the supine and semirecumbent critically ill adult. *Am J Roentgenol* 1985; 144:901–905
5. Kurdziel JC, Dondelinger RF, Hemmer M: Radiological management of blunt polytrauma with CT and angiography: an integrated approach. *Ann Radiol* 1987; 30:121–124
6. Hill SL, Edmisten T, Holtzman G, et al: The occult pneumothorax: an increasing diagnostic entity in trauma. *Am Surg* 1999; 65:254–258
7. McGonigal MD, Schwab CW, Kauder DR, et al: Supplemented emergent chest CT in the management of blunt torso trauma. *J Trauma* 1990; 30:1431–1435
8. Pingleton SK, Hall JB, Schmidt GA: Prevention and early detection of complications of critical care. *In:* Principles of Critical Care. Second Edition. Hall JB, Schmidt GA, Wood

LDH, eds. New York, McGraw-Hill, 1998, p 183
9. Sahn SA, Heffner JE: Spontaneous pneumothorax. *New Engl J Med* 2000; 342:868–874
10. Gobien RP, Reines HD, Schabel SI: Localized tension pneumothorax: unrecognized form of barotrauma in ARDS. Radiology 1982;142: 15–19
11. Steier M, Ching N, Roberts EB, Nealon TF. Pneumothorax complicating ventilatory support. *J Thorac Cardiovasc Surg* 1974; 67: 17–23
12. Brenner DJ, Elliston CD, Hall EJ, et al: Estimated risks of radiation-induced fatal cancer from pediatric CT. *Am J Rœntgenol* 2001; 176:289–296
13. Lichtenstein D: Lung ultrasound in the critically ill. *In:* Yearbook of Intensive Care and Emergency Medicine. New York, Springer-Verlag, 2004, pp 625-644
14. Rowan KR, Kirkpatrick AW, Liu D, et al: Traumatic pneumothorax. Detection with thoracic US: Correlation with chest radiography and CT. *Radiology* 2002; 225:210–214
15. Kirkpatrick AW, Ng AK, Dulchavsky SA, et al: Sonographic diagnosis of a pneumothorax inapparent on plain radiography: confirmation by CT. *J Trauma* 2001; 50:750–752
16. Lichtenstein D, Menu Y: A bedside ultrasound sign ruling out pneumothorax in the critically ill: lung sliding. *Chest* 1995; 108: 1345–1348
17. Lichtenstein D, Mezière G, Biderman P, et al: The comet-tail artifact, an ultrasound sign ruling out pneumothorax. *Intensive Care Med* 1999; 25:383–388
18. Lichtenstein D, Mezière G, Biderman P, et al: The lung point: An ultrasound sign specific to pneumothorax. *Intensive Care Med* 2000; 26:1434–1440
19. Lichtenstein D, Axler O: Intensive use of general ultrasound in the intensive care unit, a prospective study of 150 consecutive patients. *Intensive Care Med* 1993; 19:353–355
20. Lichtenstein D, Lascols N, Mezière G, et al: Ultrasound diagnosis of alveolar consolidation in the critically ill. *Intensive Care Med* 2004; 30:276–281
21. Lichtenstein D, Mezière G, Biderman P, et al: The comet-tail artifact: An ultrasound sign of alveolar-interstitial syndrome. *Am J Respir Crit Care Med* 1997; 156:1640–1646
22. Kerley P. Radiology in heart disease. *Br Med J* 1933; 2:594
23. Weinberger SE, Drazen JM: Diagnostic procedures in respiratory diseases. *In:* Harrison's Principles of Internal Medicine. 16th Edition. New York, McGraw-Hill, 2005, pp 1505–1508
24. Rantanen NW: Diseases of the thorax. *Vet Clin North Am* 1986; 2:49–66
25. Sistrom CL, Reiheld CT, Gay SB, et al: Detection and estimation of the volume of pneumothorax using real-time sonography. *Am J Roentgenol* 1996; 166:317–321
26. Lichtenstein D: General Ultrasound in the Critically Ill. New York, Springer-Verlag, 2005, pp 3–200
27. Wernecke K, Galanski M, Peters PE, et al: Sonographic diagnosis of pneumothorax. *Rofo* 1989; 150:84–85
28. Targhetta R, Bourgeois JM, Balmes P: Ultrasonographic approach to diagnosing hydropneumothorax. *Chest* 1992; 101:931–934
29. Sistrom C. US in the detection of pneumothorax. *Radiology* 2003; 227:305–306
30. Chan SS: Pneumothorax detection with thoracic US: More research is needed. *Radiology* 2003; 227:905-906
31. Lichtenstein D, Goldstein I, Mourgeon E, et al: Comparative diagnostic performances of auscultation, chest radiography and lung ultrasonography in acute respiratory distress syndrome. *Anesthesiology* 2004; 100:9-15
32. Lichtenstein D, Holzapfel L, Frija J: Projection cutanée des pneumothorax et impact sur leur diagnostic échographique. *Rean Urg* 2000; 9(Suppl 2): 138s
33. Lichtenstein D, Mezière G: Apprentissage de l'échographie générale d'urgence par le réanimateur. *Rean Urg* 1998; 7(Suppl 1):108s
34. Dulchavsky SA, Hamilton DR, Diebel LN, et al: Thoracic ultrasound diagnosis of pneumothorax. *J Trauma* 1999; 47:970–971
35. Maury E, Guglielminotti J, Alzieu M, et al: Ultrasonic examination: an alternative to chest radiography after central venous catheter insertion? *Am J Respir Crit Care Med* 2001; 164:403–405
36. Lichtenstein D, Mezière G: A lung ultrasound sign allowing bedside distinction between pulmonary edema and COPD: The comet-tail artifact. *Intensive Care Med* 1998; 24: 1331–1334
37. Lichtenstein D, Mezière G: Ultrasound diagnosis of an acute dyspnea. *Crit Care* 2003; 7(Suppl 2):S93
38. Lichtenstein D, Courret JP: Feasibility of ultrasound in the helicopter. *Intensive Care Med* 1998; 24:1119
39. Dénier A: Les ultrasons, leur application au diagnostic. *Presse Méd* 1946; 22:307–308