Title: A bedside ultrasound sign ruling out pneumothorax in the critically ill: lung sliding
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Study objective: To describe and evaluate an ultrasound pattern useful in the diagnosis of pneumothorax.

Design: Ultrasound examination of "lung sliding," a respiratory movement visible when investigating the chest wall.

Setting: The medical ICU of a university-affiliated hospital.

Patients: The study group included 43 proved pneumothoraces, either by chest radiograph (n=40) or by CT (n=3). The control group included 68 hemithoraces in which the absence of pneumothorax was proved by CT.

Intervention: Analysis of anterior chest was in supine patients.

Measurements and results: Feasibility was 98.1%. Disappearance of "lung sliding" was observed in 100% of 41 analyzable cases of pneumothorax vs 8.8% of the hemithorax without pneumothorax (6 of 68). In this series, sensitivity was 95.3%, specificity 91.1%, and negative predictive value 100% p<0.001).

Conclusion: Ultrasound was a sensitive test for detection of pneumothorax, although false-positive cases were noted. The principal value of this test was that it could immediately exclude anterior pneumothorax.

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Key words: intensive care unit; pneumothorax ultrasound diagnosis; US studies, lung

Pneumothorax is a longstanding problem in the ICU. Its requency has been estimated as 6%,[1] and the intensivist must daily exclude this diagnosis: in acute dyspnea in a ventilated patient, after insertion of central venous fines, or routinely in a ventilated patient. Its diagnosis is radiologic; however, the reliability of the supine anteroposterior chest radiograph is not absolute[2] and misdiagnosis may occur in up to 30% of all pneumothoraces[3] Chest radiographs taken on expiration or in the lateral decubitus position[4] have been proposed, but are not yet routinely performed. Consequently, CT is the gold standard, but necessitates transfer of a critically ill patient out of the ICU. Besides, CT cannot always be performed promptly. Pneumothorax can quickly become life threatening in a ventilated patient. In some instances, any delay in provision of radiologic evidence may be deleterious.[5]

Can ultrasound, paradoxically, partly resolve these numerous problems?

When an ultrasound transducer is laid on a normal chest wall, a respiratory movement can indeed be observed at the lung surface. The disappearance of this movement, in the case of pneumothorax, was first noted in 1986,[6] but little practical use has been made of this discovery.[7,8]

To our knowledge, no studies have dealt with critically ill, ventilated patients. Nor, it seems, has ultrasound been compared with CT, the gold standard. Furthermore, the predictive value of ultrasound does not appear to have been evaluated.

The movement of the lung toward the chest wall is characteristic. The ribs are identifiable by their acoustic shadow. Between two ribs, a hyperechogenic line, behind which only airy artifacts are present, is always visible (Fig 1). This line is the interface between the soft tissues of the chest wall and the aerated lung. In a normal subject, one can identify at this "lung-wall interface," (which we may call "pleural line") a kind of to-and-fro movement synchronized with respiration. This movement is striking because the surrounding structures are motionless. We may call it "pleural sliding" or perhaps a better term would be "lung sliding."

We observed "lung sliding" in ventilated patients and in healthy subjects, regardless of their age or corpulence. Its amplitude is greater at the base than at the apex, where it may be imperceptible. Even the slightest movement should therefore be carefully investigated. The aim of this study was to analyze "lung sliding" in the case of pneumothorax.

Methods

We have studied 43 pneumothoraces in 42 consecutive, critically ill patients: idiopathic (n=15), iatrogenic (n=11), complicated thoracic trauma (n=2), adult respiratory distress syndrome (ARDS) (n=10), or chronic lung disease (n=4). Average age was 42 years (range, 21 to 75 years). Seventeen patients (40.4%) developed pneumothorax while receiving mechanical ventilation.

We considered as a specific sign of pneumothorax a displacement of the visceral pleura from the parietal pleura by air within the pleural space,[2] visible either on bedside chest radiograph or on CT. Care was taken to distinguish pneumothorax from skinfolds on chest radiographs.

The diagnosis was confirmed in 40 of 43 cases using radiographs. The pleural displacement was apico-lateral in 39 cases, and subpulmonic in I case. In three patients, only CT revealed the pneumothorax, which was anterior in each case. Of these 43 pneumothoraces, 36 required a chest tube.

The control group included 68 hemithoraces in 34 consecutive, critically ill patients. Pneumothorax was shown to be absent by means of CT. Average age was 53 years. Twenty-one patients (61.7%) were receiving mechanical ventilation. All CTs were clinically necessary: screening for pneumothorax (n=10), including 6 patients receiving mechanical ventilation); analysis of ARDS or extensive pneumonia (n=10);other acute thoracicconcems (n=7);and miscellaneous reasons (n=7).

A portable unit (ADR-4000) was used with a 3.0-Mhz cardiac probe. The same investigator, not informed of the radiographic or CT results during his examination, performed longitudinal scans in supine patients. The anterior chest wall was explored up to the clavicles. The apex and the posterior chest wall were not investigated.

The item under study was the presence or the disappearance of the anterior "lung sliding" at the lung/wall interface (Fig 2). The [X.sup.2] test was used.

RESULTS

Investigation of the anterior lung/wall interface was possible in 109 of 111 hemithoraces: in two patients, pneumothorax was associated with parietal emphysema, and the lung/wall interface was not analyzable.

Anterior "lung sliding" was absent in 100% of the other 41 proved pneumothoraces, each time over an anterior area larger than three intercostal spaces. Anterior "lung sliding" was present in 91.1% of the hemithoraces in the control group, ie, 62 of 68. In six cases, it was absent without pneumothorax on CT. Four patients had ARDS or extensive pneumonia (one bilateral form). One patient had pleural sequelae.

Table 1 summarizes our results. There was a significant difference between the two groups $p<0.001$). In this series, feasibility of ultrasound examination was 98.1% (109 of 111 hemithoraces). If the patients with parietal emphysema are considered as having nondiagnosed conditions, sensitivity was 95.3% (41 of 43), specificity was 91.1% (62 of 68!, negative predictive value was 100% (62 of 62), and positive predictive value was 87% (41 of 47).

[TABULAR DATA OMITTED]

DISCUSSION

The lung is usually considered poorly accessible to ultrasound. Indeed, the ultrasound image is herein exclusively composed of artifacts, because air stops the progression of the ultrasound beam (Fig 1). The lung is, however, a vital organ. In our

study, ultrasound was able to detect at least one elementary sign, probably due to the movement of the lung toward the abdomen during inspiration and vice versa.

The first description of the role of ultrasound in the diagnosis of pneumothorax was given by a veterinarian in a study of horses.[6] Curiously, very few studies have subsequently dealt with the same subject. Wernecke et al[7] reported similar findings in eight patients presenting with pneumothorax. Targhetta et al[8] also noted the disappearance of the respiratory movement in 11 cases of hydropneumothorax.

However, these studies seem to be relatively unknown in the radiologic and intensive care fields. It was only after having "discovered" this possibility of ultrasound in 1991 that our literature search revealed the first previous reports; we fully agree with their conclusions. In our opinion, this application, which opens the way to lung ultrasound, deserves wide recognition.

In addition, our study provides further information: first, for the first time, to our knowledge, critically ill patients, many receiving mechanical ventilation, are studied. Second, also for the first time, ultrasound results are compared with CT. Third, we describe a simple protocol, limited to a precise area: analysis of the anterior chest wall in a supine patient. Lastly, our study reveals the possibility of false-positives. This essential problem has not been highlighted in previous studies.

Let us detail the performances of ultrasound. First and foremost, feasibility was 98. 1%. It is generally admitted that a free pneumothorax always collects at least in the anterior and low area, in a supine patient. In our medical ICU population, this area was highly accessible to ultrasound. The airy interpositions, usually considered a hindrance, were herein turned to our advantage. However, parietal emphysema will constitute a major obstacle to ultrasound investigation.

The sensitivity of ultrasound was high (95.3%): "lung sliding" was absent in all 41 analyzable pneumothoraces, and always over a large area, even in the case of a small anterior pneumothorax that was undetectable using chest radiography. Thus, ultrasound may allow detection of incipient pneumothorax, while chest radiograph is still normal. However, posterior, mediastinal, and apical locations will be hard to detect if there is not the slightest anterior involvement in supine patients.

The negative predictive value of ultrasound was even better (100%): in the 62 CT scans in which anterior "lung sliding" was present, there was no pneumothorax. The basic consequence of this is that anterior or complete pneumothorax can be immediately ruled out at the bedside. Similarly, recognition of a normal "lung sliding" may avoid referral of the patient to radiography - or CT - when the crucial question is detection of pneumothorax.

These performances are not surprising. Through "lung sliding," ultrasound just detects the lung itself, as it slides against the chest wall. "Lung sliding" actually represents lung ultrasonography.

The specificity of ultrasound was only 91. 1%. False-positive cases may be explained by acute pleural symphysis (in one patient, this was confirmed at autopsy), chronic symphysis (one case), or acute lung fibrosis, with loss of lung expansion. For ethical reasons, our control group included only patients scheduled for mandatory CT. This may lead to a selection bias, resulting in reduced specificity, as false-positives were seen above all in ARDS or extensive pneumonia. However, these patients are precisely those at high risk for pneumothorax. Nearly half of them gave false-positive results (four of ten), and the notion of false-positives should be stressed as a critical problem in intensive care medicine: the absence of "lung sliding" alone could not, in itself, allow diagnosis of pneumothorax. Other signs are under investigation to improve ultrasound specificity. When this sign alone is observed, the diagnosis must be confirmed by the usual methods: radiography or, except in extreme emergencies, CT.

One decisive advantage of ultrasound is its simplicity. A light unit was suitable. "Lung sliding" was successfully investigated with our 3.0-MHz probe. Higher frequencies will certainly display an even better view. However, we rarely detected it with the 2.25-MHz probes of echocardiography units. Lastly, the learning curve for those grounded in the use of ultrasound is short. With little experience, "lung sliding" can be recognized instantaneously, which may be crucial in extreme emergencies.

Pneumothorax ultrasound will definitely be of the greatest value in critically ill patients. In this field, ultrasound should ideally be used routinely as a visual stethoscope.[9]

CONCLUSIONS

Ultrasound visualization of "lung sliding" was always correlated with the absence of pneumothorax. From this elementary sign alone, it was possible to exclude at least anterior pneumothorax, promptly and at the bedside of a mechanically ventilated patient. This was the major finding of this study.

The absence of "lung sliding" was suggestive, but not sufficient to affirm pneumothorax. Life-threatening pneumothorax in patients in the ICU is often extensive, with at least anterior involvement. In this particular situation, ultrasound may acquire a new role in emergency, and, what is more, in an unexpected field: the lung.

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