Traumatic Pneumothorax Detection with Thoracic US: Correlation with Chest Radiography and CT—Initial Experience[1]

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Index terms:
Pneumothorax, 60.732
Thorax, CT, 60.12111, 60.12112, 60.12115
Thorax, radiography, 60.11
Thorax, US, 60.12981, 60.12989

Published online before print
10.1148/radiol.2251011102
Radiology 2002; 225:210–214

Abbreviation:
FAST = focused assessment with sonography in trauma

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PURPOSE: To prospectively compare the accuracy of ultrasonography (US) with that of supine chest radiography in the detection of traumatic pneumothoraces, with computed tomography (CT) as the reference standard.

MATERIALS AND METHODS: Thoracic US, supine chest radiography, and CT were performed to assess for pneumothorax in 27 patients who sustained blunt thoracic trauma. US and radiographic findings were compared with CT findings, the reference standard, for pneumothorax detection. For the purpose of this study, the sonographers were blinded to the radiographic and CT findings.

RESULTS: Eleven of 27 patients had pneumothorax at CT. All 11 of these pneumothoraces were detected at US, and four were seen at supine chest radiography. In the one false-positive US case, the patient was shown to have substantial bullous emphysema at CT. Sensitivity and negative predictive value of US were 100% (11 of 11 and 15 of 15 patients, respectively), specificity was 94% (15 of 16 patients), and positive predictive value was 92% (11 of 12 patients). Chest radiography had 36% (four of 11 patients) sensitivity, 100% (16 of 16 patients) specificity, a 100% (four of four patients) positive predictive value, and a 70% (16 of 23 patients) negative predictive value.

CONCLUSION: In this study, US was more sensitive than supine chest radiography and as sensitive as CT in the detection of traumatic pneumothoraces.

Supplemental material: *radiology.rsnajnls.org/cgi/content/full/2251011102/DC1*.

Patients who sustain trauma (hereafter referred to as trauma patients) to the thorax are at risk of serious morbidity and mortality from several forms of injury. One of the most common—and most easily treated—injuries is pneumothorax. Pneumothoraces often are detected by means of a combination of clinical examination and chest radiography. Although these techniques are reliable for the detection of large pneumothoraces, a subtle pneumothorax may be difficult to detect in a trauma situation for several reasons. Pneumothorax may not be clinically evident if it does not cause substantial respiratory compromise or if it causes only a subtle decrease in air entry, which may not be detectable at auscultation.

In addition, the chest radiographs obtained in trauma settings usually are anteroposterior images obtained with the patient in the supine position, and a pneumothorax may not be evident if it does not produce a deep sulcus sign, sharp delineation of the pericardial silhouette, or large asymmetric area of hyperlucency in one of the hemithoraces (1,2). Radiographs obtained with the patient upright are substantially more sensitive for depicting pneumothoraces, but most trauma patients cannot be positioned upright because of competing concerns, such as cervical spine precautions, hemodynamic instability, immobilization of orthopedic injuries, ongoing resuscitation, and/or decreased level of con-

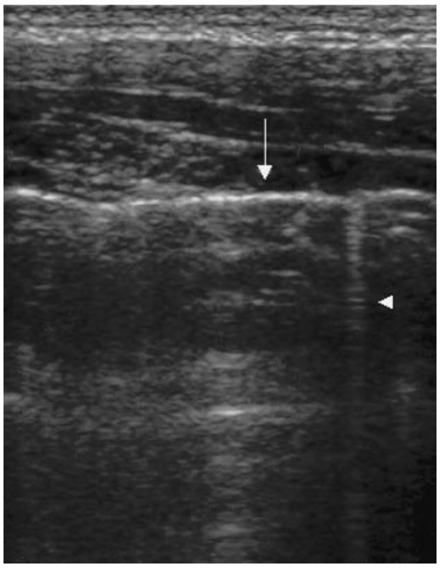

Figure 1. Longitudinal US image of a normal anterior intercostal space in a 25-year-old man, visualized by applying a 7-MHz linear probe. The arrow points to the horizontal hyperechogenic line that represents the pleural–thoracic wall interface, and the arrowhead points to the vertical comet-tail artifact. At real-time US imaging, to-and-fro movement, representing lung sliding, would be seen at this interface. The lung sliding and comet-tail artifacts are synchronized with respiratory movement.

sciousness. Computed tomography (CT) is the reference standard for the detection of pneumothoraces, because it is the most sensitive and specific modality in this clinical setting (3,4). Trauma patients undergo thoracic CT for various indications, including possible aortic, lung parenchymal, or thoracic spinal injuries. Although CT is the reference standard, it is neither practical nor feasible to perform this imaging examination in all trauma patients to rule out pneumothorax.

The focused assessment with sonography in trauma (FAST) examination has gained acceptance as a rapid and accurate tool to screen for free intraperitoneal fluid associated with visceral injury and has almost completely replaced diagnostic peritoneal lavage as the initial screening examination in most major trauma centers (5,6). Ultrasonography (US) is also commonly used to detect pleural or pericardial fluid in trauma patients. Techniques in which US was used to detect pneumothoraces have been described (3,7,8).

US does not enable visualization of the entire lung because of the high acoustic impedance of air (9). However, a high-frequency linear US probe applied to an intercostal space enables visualization of the echogenic interface between the chest wall soft tissues and the aerated lung. To-and-fro movement of the visceral and parietal pleural surfaces at this interface can be seen at US imaging as the patient respires, and this motion is termed *lung sliding* (10). A second US feature of the pleural interface is comet-tail artifacts (3,7), which are hyperechoic reverberation artifacts that extend from the pleural interface to the distal edge of the US image (Fig 1; Movie 1, *radiology.rsnajnls.org/cgi/content/full/2251011102/DC1*). The presence of lung sliding and comet-tail artifacts at the pleural interface indicates apposition of the pleural surfaces. These US features are absent when the pleural surfaces are separated by air within the pleural space. These US findings have been shown to be accurate and sensitive for the diagnosis of non–trauma-induced pneumothorax (8,10,11). This high-frequency-probe US technique was recently described as a rapid and effective technique for trauma patients in Detroit, Mich, although the US findings were not correlated with CT findings in these reports (12). The purpose of this study was to prospectively compare the accuracy of US with that of supine chest radiography in the detection of traumatic pneumothoraces, with CT as the reference standard.

MATERIALS AND METHODS

We performed a prospective blinded study in which patients who had sustained blunt thoracic trauma were examined for pneumothorax at thoracic US and supine chest radiography. Patients were eligible for inclusion in the study if, in the opinion of the attending emergency physician or trauma surgeon (A.W.K.), chest imaging was warranted. Most of the study patients met the criteria for trauma team activation, which at our institution include a respiratory rate of less than 10 or greater than 29 breaths per minute, a systolic blood pressure of less than 90 mm Hg, a Glasgow Coma Scale grade of less than or equal to 13, and anatomic injuries associated with a substantial mechanism or a life-threatening condition (13). Patients in respiratory distress who were clinically suspected of having pneumothorax were treated for such with thoracostomy tube placement, in accordance with current clinical practice guidelines (14). The patients treated with tube thoracostomy prior to imaging were excluded from the study. During 8 months (March to November 2000) of data collection, 70 patients who presented to the emergency department met the study entry criteria. Twenty-seven of these 70 patients also underwent thoracic CT, and they formed our study population.

Thoracic US was performed by either a staff radiologist (S.N.) or a radiology resident (K.R.R., D.L., K.E.F.) who was trained in US pneumothorax detection. All included patients had substantial injuries or a mechanism of injury such that the referring physician requested a FAST examination to rule out the presence of free intraperitoneal fluid. Thoracic US was performed immediately after abdominal US. The 27 patients (25 male patients, two female patients; mean age, 42 years; age range, 17–83 years) included in this study were those who needed to undergo thoracic CT during the course of the study for standard clinical indications, such as suspicion of blunt thoracic aortic disruption, detection or clarification of spinal column injury, discordant findings between chest radiography and clinical examination, work-up of mediastinal hematoma, and thoracic parenchymal injury. Institutional review board approval was obtained prior to commencement of the study. Informed consent was waived as part of the institutional review board approval, because obtaining informed consent is a standard protocol for clinically indicated diagnostic procedures in the trauma setting.

Thoracic US was performed by using a US imaging unit (model 128XP; Acuson, Mountain View, Calif) with a 7-MHz linear probe. All patients were in the supine position during the examination. Bilateral pleural interfaces were examined at the second to fourth intercostal spaces anteriorly and at the sixth to eighth spaces in the midaxillary line. The presence of pneumothorax was determined by using accepted US criteria—namely, disappearance of lung sliding and loss of the comet-tail artifact at the pleural interface. A US-based diagnosis was made by the sonographer at the time of the examination, without prior knowledge of the radiographic findings and before CT was performed. The US studies obtained by radiology residents were recorded on videotape and later reviewed by the staff radiologist.

In all cases, chest radiographs were obtained with patients in the supine anteroposterior position. Although both upright and lateral decubitus radiographs are more sensitive for pneumothorax detection than supine radiographs (2), su-

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pine radiographs were obtained for various reasons, including decreased level of consciousness, cervical spine precautions, orthopedic injuries, and hemodynamic instability. The criteria for radiographic pneumothorax detection included visualization of the visceral pleura separated from the chest wall with loss of lung markings laterally, demonstration of a deep sulcus sign, crisp definition of the hemidiaphragm, and demonstration of a continuous diaphragm sign (2). US examinations generally were performed within minutes after the chest radiographic acquisitions, with the longest delay being less than 30 minutes.

CT was performed by using a CT scanning unit (CT HighSpeed Advantage; GE Medical Systems, Milwaukee, Wis) and intravenous (ioversol injection 68% [Optiray 320]; Mallinckrodt Canada, Pointe-Claire, Quebec, Canada) and oral (diatrizoate meglumine 66%, diatrizoate sodium 10% [Gastrografin]; Bracco Diagnostics Canada, Mississauga, Ontario, Canada) contrast materials, when indicated, for evaluation of chest or abdominal trauma. Helical sections were obtained at a pitch of 1.5 and reconstructed to 3-mm-thick sections. CT images were printed on mediastinal and lung windows. The CT criteria for a diagnosis of pneumothorax included any air collections that were displacing the visceral pleura from the chest wall (2). Radiographs and CT images were interpreted by staff radiologists without knowledge of the US findings. Final dictated reports were reviewed by the authors (K.R.R., S.N., D.L.) and compared with the radiographs and CT images for verification.

Estimates of sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy were calculated for US versus CT and for radiography versus CT by using CT as the reference standard for pneumothorax detection. Ninety-five percent CIs based on binomial distribution were calculated for all of the estimates by using a statistical software program (S-Plus 2000; MathSoft, Seattle, Wash). Logistic regression analysis was used to evaluate how well the CT results could be predicted with US and chest radiography. With use of additional statistical software (SPSS 10; SPSS, Chicago, Ill), the CT results were treated as a response variable and US and chest radiography were treated as two independent predictor variables.

RESULTS

The CT, US, and chest radiographic findings in the 27 patients are compared in Table 1. Eleven of the 27 patients had pneumothoraces at CT. US demonstrated the presence of pneumothorax in all 11 of these patients. There were no false-negative US results. A single false-positive US case was reported: The absence of lung sliding in the anterior aspect of one hemithorax suggested pneumothorax. The CT scan did not reveal pneumothorax but rather a substantial bullous emphysema with a large anterior bulla in the area of the US abnormality.

TABLE 1
Pneumothorax Depiction at CT, US, and Chest Radiography

No. of Patients*	CT	US	Chest Radiography
15	Absent	Absent	Absent
1	Absent	Present	Absent
7	Present	Present	Absent
4	Present	Present	Present

* Numbers of patients in whom a pneumothorax was present or absent at the given imaging examination.

A static (ie, non–real-time) thoracic US image obtained in a patient who sustained blunt thoracic trauma is shown in Figure 2. Comet-tail artifact is absent on this image of the left anterior hemithorax. Real-time US imaging depicted loss of lung sliding at this site (Movie 2, *radiology.rsnajnls.org/cgi/content/full/2251011102/DC1*). A supine anteroposterior chest radiograph obtained in the same patient is shown in Figure 3. Although there is a suggestion of increased definition of the left hemidiaphragm on this image, there is no definitive evidence of pneumothorax. The selected thoracic CT image shown in Figure 4, which was obtained in the same patient, shows a moderate left pneumothorax. Mild left subcutaneous emphysema, a mild degree of left lower lobe atelectasis, and a small left pleural effusion also are present.

Four of the 11 CT-confirmed pneumothoraces were detected at supine radiography. The chest radiographs obtained in seven of the 11 patients with CT-confirmed pneumothorax showed no definitive evidence of pneumothorax.

Data on the performance of radiography versus CT and on the performance of US versus CT are summarized in Table 2. Logistic regression analysis revealed a significant correlation between US and CT with regard to diagnostic accuracy, even after chest radiographic findings were taken into account (logistic regression $P < .001$), but not between radiography and CT after US findings were taken into account (logistic regression $P = .35$).

Figure 2. Pneumothorax in a 25-year-old man. Longitudinal US image of the fourth left anterior intercostal space visualized by applying a 7-MHz linear probe. The arrow points to a motionless lung–thoracic wall interface that is devoid of comet-tail artifacts. The absence of lung sliding is apparent only at real-time US imaging.

DISCUSSION

Pneumothorax is a serious potential consequence of blunt thoracic trauma (4) and a potential complication of vascular access procedures (11). In cases in which a pneumothorax is clinically evident or is causing substantial respiratory compromise, treatment is often initiated without performing imaging (14). In many cases, however, pneumothoraces may not be detected at clinical examination. Furthermore, the chest radiographs initially obtained in serious trauma cases are almost invariably anteroposterior supine images, which can be insensitive for detection of subtle pneumothoraces. Although a subtle pneumothorax may not be clinically important initially, in certain situations there can be serious implications if the pneumothorax is not detected. For example, a pneumothorax can increase in size if the patient is exposed to decreased atmospheric pressure during air transport or requires intubation and positive pressure ventilation (15,16).

An accurate, rapid, and practical method to rule out small pneumothoraces that could be used repeatedly throughout the clinical course of a trauma case without additional radiation exposure would have important clinical implications for trauma patient care (17). Several groups of investigators (3,7,8) have found that thoracic US

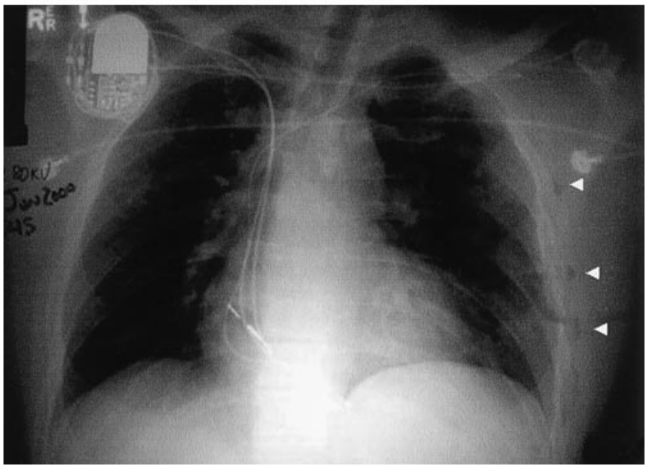

Figure 3. Supine anteroposterior chest radiograph obtained in the same patient as in Figure 2 shows left subcutaneous emphysema (arrowheads). Although no distinct evidence of pneumothorax is visible, there is a suggestion of sharp definition of the left hemidiaphragm, which could lead to the suspicion of pneumothorax. Further imaging is required to make a definitive diagnosis.

Figure 4. Transverse 3-mm contrast material–enhanced spiral thoracic CT image obtained in the same patient as in Figures 2 and 3 shows a moderate-sized left pneumothorax (arrowheads). Left subcutaneous emphysema (arrow), a mild degree of left lower lobe atelectasis, and a small left pleural effusion (*) also are present.

TABLE 2
CIs for Chest Radiography versus CT and for US versus CT for Detection of Pneumothorax

Parameter	Chest Radiography		US	
	Estimate	95% CI	Estimate	95% CI
Sensitivity (%)	36 (4/11)	15, 65	100 (11/11)	74, 100
Specificity (%)	100 (16/16)	81, 100	94 (15/16)	72, 99
False-positive rate (%)	0 (0/16)	0, 19	6 (1/16)	1, 28
False-negative rate (%)	64 (7/11)	35, 85	0 (0/11)	0, 24
Positive predictive value (%)	100 (4/4)	51, 100	92 (11/12)	65, 99
Negative predictive value (%)	70 (16/23)	49, 84	100 (15/15)	80, 100
Accuracy (%)	74 (20/27)	55, 87	96 (26/27)	82, 99
Prevalence (%)	41 (11/27)	25, 59	41 (11/27)	25, 59

Note.—Data in parentheses are numbers of patients.

can be used to reliably detect pneumothoraces, which are diagnosed on the basis of loss of lung sliding and absence of comet-tail artifacts at the hyperechoic pleural interface.

In this small study of 27 trauma patients, US was more sensitive and accurate than supine chest radiography and as sensitive as thoracic CT in the detection of pneumothoraces. Comparison of CIs indicated a significant difference ($P <$ .05) in sensitivities and false-negative ratios between US and chest radiography. Although the CIs for negative predictive value and overall accuracy overlap, the mean value for these parameters indicates that US had a greater than 20% superiority. This suggests a clinically relevant difference between US and chest radiography.

Although both the estimated sensitivity and the estimated negative predictive value of US were 100% in the study group, the specificity was 94%. These results were due to one false-positive US case, in which a patient with bullous emphysema showed absence of lung sliding in the area of a large anterior bulla. This finding is one of several possible pitfalls that sonographers should be aware of when performing US to diagnose pneumothorax. Another potential pitfall is the presence of pleural adhesions or any condition in which the pleural surfaces do not slide against each other at respiration. Additionally, extensive subcutaneous emphysema can interfere with US visualization of the pleural surfaces. Several of our study patients had small areas of subcutaneous emphysema; however, we did not experience difficulty in avoiding the emphysematous collections and visualizing the pleural surfaces in these cases.

The sample size in this study was small, and our inclusion criteria may have introduced bias to the study in two ways: First, CT was performed in patients for various clinical indications, such as abnormal mediastinal contour on chest radiographs that raised suspicion of aortic injury and assessment of lung parenchymal injury. It could be argued that the patients who required CT, on average, had more serious injuries than the patients who did not require CT. The second source of bias was that patients were excluded if they were treated with chest tube thoracostomy prior to imaging. This bias, however, possibly lent further credibility to the technique, because patients with large, clinically important pneumothoraces were excluded, and, therefore, the pneumothoraces detected at US in this study were subtle and clinically "silent" at the time of diagnosis. We did not attempt to estimate the size of the pneumothoraces ultrasonographically, because previous research has shown that although US is highly sensitive for pneumothorax detection, it does not enable a reliable estimation of the volume of a pneumothorax (9). Our study results demonstrate that US is highly sensitive and has a high negative predictive value for the detection of traumatic pneumothorax and therefore can be an effective diagnostic tool to definitively exclude pneumothoraces in trauma patients.

The diagnosis of traumatic pneumothorax, especially life-threatening tension pneumothorax, is usually made on clinical grounds. There are occasional cases, how-

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ever, in which the diagnosis is delayed or even missed by well-trained residents, emergency physicians, or trauma specialists (18). Additionally, in settings with less-trained personnel, limited equipment, or logistic limitations, even more pneumothoraces will be missed. Newly developed US equipment includes high-quality portable units that are easily transported by hand. The use of these units can enable the assessment of thoracic trauma in many diverse environments, especially situations in which CT and chest radiography may not be readily available. Such environments may include patient transport vehicles, conflict or battle zones, commercial airlines, ocean-going vessels, or manned space flights. The international space station has already been equipped with an advanced modified US machine (HDI 5000; Advanced Technology Laboratory, Bothell, Wash). One of the many potential applications of this unit is the diagnosis of pneumothoraces, because recent research suggests that the techniques used to detect pneumothorax can also be applied in microgravity conditions (19).

The results of this study suggest that thoracic US, when performed by trained individuals, can enable definitive exclusion of pneumothorax. As a corollary, we believe that thoracic US should be added to the currently performed FAST examination in trauma cases and be labeled as the expanded FAST examination. With this new protocol, US would be used to exclude both intraperitoneal free fluid and pneumothorax in one focused rapid assessment of the trauma patient.

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