Sonographic Detection of Pneumothorax by Radiology Residents as Part of Extended Focused Assessment With Sonography for Trauma

Olga R. Brook, MD, Nira Beck-Razi, MD, Subhi Abadi, MD, Janna Filatov, MD, Anat Ilivitzki, MD, Diana Litmanovich, MD, Diana Gaitini, MD

Objective. The purpose of this study was to assess the accuracy of sonographic pneumothorax detection by radiology residents as a part of extended focused assessment with sonography for trauma (eFAST). ***Methods.*** In a prospective study, a sonographic search for pneumothoraces was performed as part of a standard FAST examination by the on-call resident. Each lung field was scanned at the second to fourth anterior intercostal spaces and the sixth to eighth midaxillary line intercostal spaces. A normal pleural interface was identified by the presence of parietal-over-visceral pleural sliding with "comet tail" artifacts behind. Absence of these normal features indicated a pneumothorax. The sonographic diagnosis was correlated with supine chest radiography and chest computed tomography (CT). ***Results.*** A total of 338 lung fields in 169 patients were included in the study. Patients underwent eFAST, chest radiography, and chest CT when clinically indicated. Chest CT was considered the reference standard examination. Computed tomography identified 43 pneumothoraces (13%): 34 small and 9 moderate. On chest radiography, 7 pneumothoraces (16%) were identified. Extended FAST identified 23 pneumothoraces (53%). Compared with CT, eFAST had sensitivity of 47%, specificity of 99%, a positive predictive value of 87%, and a negative predictive value of 93%. All of the moderate pneumothoraces were identified by eFAST. Twenty small pneumothoraces missed by eFAST did not require drainage during the hospitalization period. ***Conclusions.*** Extended FAST performed by residents is an accurate and efficient tool for early detection of clinically important pneumothoraces. ***Key words:*** focused assessment with sonography for trauma; pneumothorax; residents.

Abbreviations
CT, computed tomography; eFAST, extended focused assessment with sonography for trauma; NPV, negative predictive value; PPV, positive predictive value

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Address correspondence to Olga R. Brook, MD, Department of Diagnostic Imaging, Rambam Health Care Center, Ha'aliya Hashniya 8, 31096 Haifa, Israel.

E-mail: o_brook@rambam.health.gov.il

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Aerated lungs present a challenge for sonographic examination because of the high acoustic impedance of air. Despite this, an echogenic interval between chest wall soft tissues and the lung can be seen. The normal pleura can be identified by the presence of lung sliding, shown as a to-and-fro movement of the visceral and parietal pleura during breathing, and "comet tail" artifacts seen as hyperechoic reverberation artifacts extending from the pleura down to the lung.[1] Absence of these features points to the presence of a pneumothorax. The diagnosis of a pneumothorax can be confirmed further by finding the "lung point," the point where normal sonographic lung features disappear,[2,3] or by clinical correlation.

Pneumothorax is a highly prevalent disease among patients with trauma[4] and can be life threatening if not treated promptly. A large pneumothorax can be detected by clinical examination and chest radiography. Nevertheless, a small pneumothorax is hard to detect. It is still important in patients receiving positive pressure ventilation and those planned to be air transported because the pneumothorax might enlarge due to changes in air pressure.

Standard chest radiography in trauma settings is usually done with the patient in a supine position, where air collects anteriorly, making detection of a pneumothorax difficult. Chest computed tomography (CT) is an excellent tool for the detection of pneumothorax and thus is accepted as the reference standard. It is not practical to perform chest CT in all patients with trauma because of the relatively high radiation dose, elevated costs, and organizational difficulties.

Sonography for the detection of pneumothoraces was first reported in 1986 in the veterinary literature.[5] In this study, we evaluated the accuracy of sonographic pneumothorax detection by radiology residents performing extended focused assessment with sonography for trauma (eFAST) as an extension of the regular FAST examination.

Materials and Methods

The study protocol was approved by the Institutional Review Board with a waiver of informed consent.

The study included consecutive patients with trauma treated at the trauma room in the emergency department who underwent chest radiography, eFAST, and chest CT when clinically indicated within 2 hours of admission. Exclusion criteria consisted of patients with known pneumothoraces or previous chest tube insertion.

Extended FAST was performed as part of 24-hour service. Five residents in radiology with at least 6 months of dedicated ultrasound training (O.R.B., S.A., Z.F., A.I., and D.L.) and 2 attending radiologists (N.B.-R. and D.G.) were involved in the study. Before initiation of the study, resident and attending radiologists were trained to detect pneumothoraces on sonography. This training included lectures on the sonographic signs of a pneumothorax and possible pitfalls, followed by a number of practical sessions. Extended FAST was performed by the resident on call during call hours or by the resident or attending radiologist during regular hours. Studies performed by residents were read later by an attending radiologist. On our ultrasound machine, only still images can be recorded. Because the sonographic diagnosis of a pneumothorax demands real-time imaging, the diagnosis was made only by the person performing the examination. Thus, no change in a pneumothorax diagnosis was made at the secondary reading by the attending radiologist.

The regular FAST protocol was performed[6,7] as the first examination, followed by sonographic pneumothorax detection. This scanning sequence, which included FAST followed by sonographic pneumothorax detection, was previously named eFAST.[8] The sonographic examination was performed with an SSD-1400 system (Aloka Co, Ltd, Tokyo, Japan) and a 3.5-MHz sector transducer. The eFAST examination was performed with the same transducer, decreasing the scan depth and approximating the focus level to the pleura. The scans were performed at 2 sites on each lung field: between the second and fourth intercostal spaces at the midclavicular line and the sixth to eighth spaces in the midaxillary line, for a total of 4 views. A normal pleural interface was identified on sonography by 2 main features: (1) "lung sliding," seen as a to-and-fro movement of the visceral and parietal pleura during normal breathing; and (2) "comet tail" artifacts due to hyperechoic reverberations extending from the pleura down to the lung (Figure 1 and Video 1). Absence of both signs was diagnostic of a pneumothorax (Video 2).

Chest radiography was performed with a Mobilette Plus Portable radiography system (Siemens AG, Munich, Germany). Chest CT was performed with an MX 8000 IDT or MX 8000 multislice helical system (Philips Healthcare, Haifa, Israel) after intravenous administration of 130 mL of a nonionic iodinated contrast medium by a mechanical injector. The dose of the intravenous contrast medium for pediatric patients was calculated according to the formula 2 mL/kg. No oral contrast medium was administered. The CT scan was acquired with detector collimation of 16 × 0.75 mm and slice thickness reconstruction of 3 mm. The chest CT studies were evaluated for the presence of a pneumothorax. A small pneumothorax was defined being less than 1 cm in anteroposterior length when measured on the axial CT slice at the pneumothorax-prominent portion. A moderate pneumothorax was defined being greater than 1 cm in anteroposterior length when measured on the axial CT slice at the pneumothorax-prominent portion.

The eFAST evaluation was performed blind to both the bedside supine chest radiography and chest CT. The results of eFAST and chest radiography were compared with the chest CT findings later on.

The sensitivity, specificity, negative predictive value (NPV), positive predictive value (PPV), and accuracy and their 95% confidence intervals for detection of a pneumothorax by eFAST and supine chest radiography were calculated from a 2 × 2 contingency table with chest CT as the reference standard. A comparison between eFAST and supine chest radiography was performed with the McNemar test. The level of statistical significance was set at $P < .05$.

Results

A total of 169 patients with trauma who underwent eFAST, chest radiography, and chest CT within 2 hours or less from October 2004 to April 2007 were included in the study. Records for 338 lung fields were registered.

Patients' ages ranged from 6 months to 88 years (mean, 31 years); 144 (85%) were male. On chest CT, 43 pneumothoraces were diagnosed: 34 small (Figure 2) and 9 moderate (Figure 3). On chest radiography, 7 pneumothoraces (16%) were identified. Extended FAST identified 20 of the pneumothoraces (47%; Table 1).

There were 3 false-positive pneumothorax findings on eFAST. A pneumomediastinum was seen in 2 cases, and 1 case showed an extensive lung contusion. In 1 case, on scanning of the right lung, lung sliding was consistently absent, whereas normal comet-tail artifacts were present. This was prospectively interpreted as a lung intubation and later proved by chest radiography.

Extended FAST identified all 9 cases with moderate pneumothoraces (100% sensitivity) and 11 cases (32% sensitivity) with small pneumothoraces. Supine chest radiography identified 2 cases with small pneumothoraces (6%) and 5 (56%) with moderate pneumothoraces. Patients with small pneumothoraces did not require any treatment related to the presence of the pneumothoraces during the hospitalization period. The sensitivity of eFAST was 47%; specificity, 99%; PPV, 87%; and NPV, 93% (Table 2).

The sonographic detection of pneumothoraces was performed by 9 physicians: 6 residents and

Figure 1. Comet tail artifact on eFAST of the normal pleural space. Hyperechoic reverberations (arrows) are shown during breathing, extending from the pleura down to the lung, due to sliding of the visceral over parietal pleura at the anterior midclavicular space.

Figure 2. Small pneumothorax on chest CT. A tiny pocket of air is shown at the mediastinal pleural space in the right hemithorax (arrow). The diagnosis was missed on eFAST.

Figure 3. Moderate pneumothorax on chest CT. Moderate amounts of air (arrow) and fluid in the left pleural space are shown in this patient, who was involved in a motor vehicle collision. Results of eFAST performed by the resident on duty were positive for a pneumothorax (Video 2).

3 attending physicians. The attending physicians performed only 16 examinations (9.5%), identifying 2 cases with small pneumothoraces but missing the diagnosis of small pneumothoraces in 4 cases. A statistical analysis comparing performance by residents versus attending physicians was not feasible because of the small number of cases in the last group.

The McNemar test showed significant differences in the accuracy of eFAST and supine chest radiography for detection of pneumothoraces ($P < .001$ for pneumothoraces of any size; $P = .004$ for small pneumothoraces). A borderline significant difference ($P = .06$) was found for moderate pneumothoraces.

Discussion

Our results showed that eFAST performed by radiology residents in the trauma room can be an excellent tool for detection of moderate pneumothoraces (Table 1). The examination was feasible to perform by residents with limited ultrasound experience in the highly stressful environment of the trauma room. On the other hand, eFAST was found to be insufficient for ruling out small pneumothoraces.

Supine chest radiography is the standard imaging study for the diagnosis of a pneumothorax in the trauma setting. Extended FAST performed at the bedside in the trauma room was a significantly better tool for pneumothorax detection, with sensitivity of 47% versus 16% for overall pneumothoraces ($P < .001$). The superiority of eFAST over chest radiography was seen in cases with both small and moderate pneumothoraces (Table 2).

Our results are in accordance with previously published studies (Table 3). Rowan et al[1] evaluated 27 patients with chest radiography, sonography, and CT. Eleven of the 27 patients had pneumothoraces on CT. All pneumothoraces were detected by sonography, and 4 were seen on supine chest radiography. In the 1 case with false-positive sonographic findings, the patient was shown to have substantial bullous emphysema on CT. The sensitivity and NPV of sonography in their study were 100%; specificity, 94%; and PPV, 92%. Chest radiography had 36% sensitivity, 100% specificity, a 100% PPV, and a 70% NPV. The population size in that study was considerably smaller than in ours.

Knudtson et al[9] compared sonography to chest radiography in 328 patients; in contrast to our study, no correlation with chest CT was performed. The specificity, NPV, and accuracy were 99.7%, 99.7%, and 99.4%, respectively.

In a study of 134 consecutive patients, Kirkpatrick et al[8] compared the results of eFAST with chest radiography and CT. Extended FAST detected 21 of 43 pneumothoraces and falsely showed 3 pneumothoraces that were not detected on CT. The sensitivity of eFAST was 58.9%, and the specificity was 99.1% when compared with a composite standard that included chest radiography, chest and abdominal CT, the clinical course, and invasive interventions. The sensitivity decreased to 48.8% when compared with chest CT as the reference standard. In that study, the sensitivity of chest radiography for detection of pneumothoraces was 20.9%.

Blaivas et al[10] reported 98.1% sensitivity for sonography in 176 patients. The sensitivity of supine chest radiography for pneumothorax detection in that study was 75.5%. The prevalence of pneumothoraces in that population, which were detected on chest CT or air release on chest tube placement, was 30%. This patient group had a higher prevalence of pneumothoraces than our group (13%), and the average pneumothorax size was probably larger than in our study.

Lichtenstein et al[3] evaluated 200 intensive care patients with no pneumothoraces on radiography who were evaluated by CT within 120 minutes of sonography. Forty-seven pneumothoraces were identified; 16 of them required a chest tube. For the diagnosis of occult pneumothoraces, the abolition of lung sliding alone had sensitivity of 100% and specificity of 78%. Absent lung sliding plus the "A-line" sign had sensitivity of 95% and specificity of 94%. The lung point had sensitivity of 79% and specificity of 100%.

Another recent study by Soldati et al[11] evaluated sonographic pneumothorax detection in 109 patients. The sensitivity of sonography in that study was 92% versus 52% for supine chest radiography. Most of the pneumothoraces in that group of patients were also larger than in ours. Of 12 radiologically occult pneumothoraces (either anterior or small), sonography identified 10 cases (83%). Larger anterolateral pneumothoraces were all drained, whereas small ones were followed clinically.

The sensitivity for sonographic pneumothorax detection in the above studies varied between 58.9% and 100%; the lowest sensitivity was found when CT was the reference standard. This was suggested in a review by Jaffer and McAuley[12] to be most probably due to small clinically unimportant pneumothoraces picked up by CT but not detected by sonography.

Our study, compared with those reviewed above, comprised a relatively large cohort of prospectively evaluated consecutive patients without knowledge of the results of subsequent chest radiography and CT. It is a standard practice in our department for all sonographic examinations to be read at a later time by an attending radiologist. Sonographic detection of a pneumothorax is truly a real-time diagnosis, thus making it nearly impossible to achieve the diagnosis with still images. Thus, the diagnosis of a pneumothorax is based on radiology resident interpretation alone at the time of the examination. In our country, trauma sonography is performed by radiologists. The radiology department in our hospital is located next door to the emergency department, and a small portable ultrasound machine is located in the trauma room of the emergency department, allowing nearly immediate performance of trauma sonography (a matter of a couple minutes from the request); thus, delays are minimal. Our results proved that sonographic detection of pneumothoraces is feasible for radiology residents.

Table 1. Detection of Pneumothoraces by CT as the Reference Standard Versus Supine Chest Radiography and eFAST

Pneumothoraces	CT, n	Supine Chest Radiography, n (%)	eFAST, n (%)	*P*
Total	43	7 (16)	20 (47)	<.001
Small	34	2 (6)	11 (32)	.004
Moderate	9	5 (56)	9 (100)	.06

The eFAST results were correlated with chest CT as the reference standard in all cases. This could have misleadingly lowered the sensitivity of eFAST detection of pneumothoraces because most pneumothoraces detected on CT were small, with little clinical relevance.

There are a number of potential pitfalls that can lead to false-positive and -negative ultrasound diagnoses. In addition to a pneumomediastinum and an extensive lung contusion, as seen in our study, subcutaneous emphysema,[9] lung emphysema, and pleural adhesions are potential sources of false-positive results. A pneumomediastinum may extend over the left hemithorax, thus causing disappearance of both the comet tail artifact and lung sliding at the midclavicular line. An extensive lung contusion diminishes both comet tail artifacts, because there is a decrease in the impedance change over the pleural interface, and lung sliding, because of impeded movement of the contused lung. Subcutaneous emphysema extends a curtain of air that degrades the whole image. It may mimic a pneumothorax if unrecognized promptly clin-

Table 2. Statistical Analysis of Sonographic Versus Radiographic Pneumothorax Detection Compared With CT as the Reference Standard

Parameter	Supine Chest Radiography	eFAST
Sensitivity, %	16.3 (8.1–29.8)	46.5 (32.5–61)
Specificity, %	100 (98.7–100)	99 (97.1–99.7)
PPV, %	100 (64.6–100)	86.9 (67.9–95.5)
NPV, %	89.1 (85.1–92.2)	92.6 (89.3–95.1)
Accuracy, %	89.3 (85.6–92.2)	92.3 (89–94.7)

Values in parentheses are 95% confidence intervals.

Table 3. Sonographic Detection of Pneumothoraces in the Various Studies Compared With This Study

Study	Year	Pneumothoraces/ Patients	eFAST Sensitivity, %	Reference Standard
Rowan et al[1]	2002	11/27	100	Chest CT
Knudtson et al[9]	2004	12/328	92.3	Chest radiography
Kirkpatrick et al[8]	2004	65/208	58.9	Composite standard[a]
Blaivas et al[10]	2005	53/176	98.1	Chest CT/air release on chest tube insertion
Lichtenstein et al[3]	2005	43/200	79	Chest CT
Soldati et al[11]	2007	25/109	92	Chest CT
This study	2008	43/169	53	Chest CT

[a]Included chest radiography, chest and abdominal CT, clinical course, and invasive interventions.

ically and sonographically because the diagnosis of a pneumothorax on sonography is based on the disappearance of normal features. An emphysematous lung and lung adhesions both diminish normal lung movement, decreasing lung sliding. False-negative results are mainly due to the size of the pneumothorax, as in a small pneumothorax, in which there is still some contact between pleural leaves. A loculated pneumothorax is another possible cause of false-negative results. Again, none of the small pneumothoraces missed by eFAST in our study required treatment on follow-up. This is accordant with previously reported studies, in which most small pneumothoraces could be managed successfully with close observation alone.[13]

In addition to the diagnosis of pneumothoraces by sonographic evaluation of the pleura in the emergency department, we were also able to diagnose a lung intubation by eFAST performed on a recently intubated patient. One lung intubation was diagnosed by the absence of lung sliding despite the presence of comet tail artifacts in the right lung. A recently published study validated this method for evaluation of endotracheal tube placement.[14] We did not assess the "lung pulse,"[15] which constitutes perception of heart activity at the pleural line, because the radiologist performing the study was not aware of it at the time of the examination.

There were a number of potential limitations of our study. First, the sonographic examination for pneumothoraces was performed with a sector transducer because the examination was an extension of the FAST examination. Even though this saved time, which is important in emergency treatment, the use of a linear transducer could have produced better results. Second, the delay between admission and CT was up to 2 hours. During this time, a slowly leaking pneumothorax may go from an undetectable size to being recognizable on CT. In most patients, the delay was less than 40 minutes, which was needed to complete initial emergency care, thus minimizing this potential pitfall to the lowest possible level under the circumstances. Third, we did not assess the lung point,[2] which is known to be a more specific sign of a pneumothorax, because of the lack of time. We might have eliminated the false-positive finding if we had used that sign.

In conclusion, sonographic detection of pneumothoraces is a feasible examination that can be performed by radiology residents on call. It is highly accurate for moderate pneumothoraces but may miss up to 50% of subtle pneumothoraces, which are of limited clinical importance.

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