A Prospective Comparison of Supine Chest Radiography and Bedside Ultrasound for the Diagnosis of Traumatic Pneumothorax

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Abstract

Background: Supine anteroposterior (AP) chest radiography may not detect the presence of a small or medium pneumothorax (PTX) in trauma patients. **Objectives:** To compare the sensitivity and specificity of bedside ultrasound (US) in the emergency department (ED) with supine portable AP chest radiography for the detection of PTX in trauma patients, and to determine whether US can grade the size of the PTX. **Methods:** This was a prospective, single-blinded study with convenience sampling, based on researcher availability, of blunt trauma patients at a Level 1 trauma center with an annual census of 75,000 patients. Enrollment criteria were adult trauma patients receiving computed tomography (CT) of the abdomen and pelvis (which includes lung windows at the authors' institution). Patients in whom the examination could not be completed were excluded. During the initial evaluation, attending emergency physicians performed bedside trauma US examinations to determine the presence of a sliding lung sign to rule out PTX. Portable, supine AP chest radiographs were evaluated by an attending trauma physician, blinded to the results of the thoracic US. The CT results (used as the criterion standard), or air release on chest tube placement, were compared with US and chest radiograph findings. Sensitivities and specificities with 95% confidence intervals (95% CIs) were calculated for US and AP chest radiography for the detection of PTX, and Spearman's rank correlation was used to evaluate for the ability of US to predict the size of the PTX on CT. **Results:** A total of 176 patients were enrolled in the study over an eight-month period. Twelve patients had a chest tube placed prior to CT. Pneumothorax was detected in 53 (30%) patients by US, and 40 (23%) by chest radiography. There were 53 (30%) true positives by CT or on chest tube placement. The sensitivity for chest radiography was 75.5% (95% CI = 61.7% to 86.2%) and the specificity was 100% (95% CI = 97.1% to 100%). The sensitivity for US was 98.1% (95% CI = 89.9% to 99.9%) and the specificity was 99.2% (95% CI = 95.6% to 99.9%). The positive likelihood ratio for a PTX was 121. Spearman's rank correlation showed at ρ of 0.82. **Conclusions:** With CT as the criterion standard, US is more sensitive than flat AP chest radiography in the diagnosis of traumatic PTX. Furthermore, US allowed sonologists to differentiate between small, medium, and large PTXs with good agreement with CT results. **Key words:** emergency ultrasound; ultrasound; pneumothorax; trauma; traumatic pneumothorax; emergency medicine. ACADEMIC EMERGENCY MEDICINE 2005; 12:844–849.

Although evaluating trauma patients with ultrasound (US) is not a new concept, the detection of pneumothorax is a novel application of US for many clinicians.[1–4] Patients who have sustained blunt or penetrating thoracic and abdominal trauma are at risk for a wide variety of injuries. Although typically not immediately life-threatening unless a tension pneumothorax is present, early identification of a traumatic pneumothorax is essential.[5] Even a small pneumothorax may progress to cause hemodynamic instability, especially in patients receiving positive-pressure ventilation.[6] Traditional imaging for a potential traumatic pneumothorax initially begins with chest radiography. However, due to the limitations of spinal immobilization in trauma patients, this examination often consists of anteroposterior (AP) supine films, in which radiographic features of pneumothorax may be quite subtle.[7] Recent literature reveals that small penumothoraxes are initially missed on clinical examination, or by admission chest radiography, in 30% to 50% of trauma patients.[7] Computed tomography (CT) is much more sensitive for pneumothorax, but requires the patient to be removed from the emergency department (ED) environment and its resuscitative capability.[8]

Although a more frequent use of US in chest trauma is the evaluation for traumatic pericardial or pleural effusion, research has shown that US of the thorax is highly accurate for the diagnosis of pneumothorax.[1,9,10] Many of these prior studies, however, did

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not use compact US technology, and did not compare chest US with the criterion standard of CT. Further, there are conflicting data, primarily in animal models, on whether this technique can determine the size of the pneumothorax present.[11,12] Our objectives were to compare the sensitivity and specificity of bedside ED US with those for supine portable AP chest radiography and CT for the detection of a pneumothorax in trauma patients, and to evaluate whether US can distinguish between small (10% or less), medium (11% to 40%), and large (over 40%) pneumothoraxes.[13]

METHODS

Study Design. This was a prospective, single-blind study with convenience sampling, based on researcher availability, of blunt trauma patients at a Level 1 trauma center with an annual census of 75,000 patients. The study was approved by the institutional review board with waiver of informed consent, since it is the standard practice in our ED to use US in the evaluation of trauma patients, and contemporaneous collection of data did not require follow-up or identifying information.

Study Setting and Population. The study was conducted from September 2003 to May 2004. Enrollment criteria were blunt trauma patients more than 17 years of age receiving a focused assessment with sonography for trauma (FAST) examination followed by chest radiography and CT of the chest and/or abdomen and pelvis (which includes lung windows at our institution). Patients in whom the examination could not be completed for any reason were excluded. Patients who had chest tube placement prior to CT scan were included in the analysis, and the presence of pneumothorax was considered to be verified if a rush of air was heard when the chest tube was inserted.

Study Protocol. Patients were classified as trauma patients based on mechanism, loss of consciousness, apparent injury at the scene, and vital signs. During the initial evaluation of patients meeting trauma criteria, attending emergency physicians performed bedside US examinations of the chest using a SonoSite 180PLUS (Bothell, WA) using a 4- to 2-MHz microconvex broadband transducer. Protocol views consisted of four locations of each hemithorax (anterior second intercostal space at the midclavicular line, fourth intercostal space at the anterior axillary line, sixth intercostal space at the midaxillary line, and sixth intercostal space at the posterior axillary line) to assess for the presence of a sliding lung sign to rule out pneumothorax. In the normal lung, the parietal and visceral surfaces can be visualized by US as bright interfaces or echogenic lines. With respiration, these two bright lines slide past each other (Figure 1).[1] This sliding is seen on US deep to the ribs. If air, as in the case of a pneumothorax, were to seep in between the parietal and visceral pleura, the deeper pleural layer would not be visualized due to the inability of medical US to penetrate through air (Figure 2A, B). Thus, since half of the sliding component is invisible, no sliding lung sign is seen.

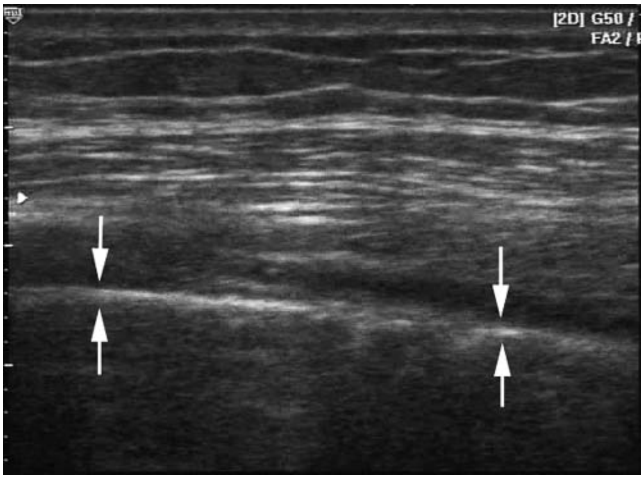

Figure 1. A still image of the pleural interfaces, which are seen as a bright line (*arrows*). With breathing, the pleura slide past each other and two separate lines are seen sliding.

Ultrasound images were obtained parallel to ribs at the rib interspaces. Depth settings were minimized to approximately 5 cm to optimize magnification of the superficial structures being imaged. Power Doppler was utilized to enhance the sonologist's ability to identify pleural sliding whenever the sliding lung sign was not easily detected. Study physicians decided on the presence and size of pneumothorax. When the sliding lung sign was absent at the midclavicular point anteriorly or at the fourth interspace at the anterior axillary line, a small pneumothorax was thought to be present. When it was absent at the midaxillary line, a medium pneumothorax was noted. When sliding lung sign was absent in the posterior axillary line, a large pneumothorax was believed to be present. Pneumothorax sizes were defined as small (10% or less), medium (11% to 40%), and large (over 40%).[13] Portable, supine AP chest radiographs were obtained immediately after US evaluation. CT examination using a multigated scanner was obtained at the discretion of the treating physician, and consisted of using 5-mm thick slices. All examinations (US, CT, radiography) were performed with the patient in the supine position.

A total of five emergency physicians participated in study enrollment. All had emergency US credentialing through the hospital in accordance with American College of Emergency Physicians training and credentialing guidelines.[14] The physicians were trained to perform thoracic US for the detection and ruling out of pneumothorax by the emergency ultrasound

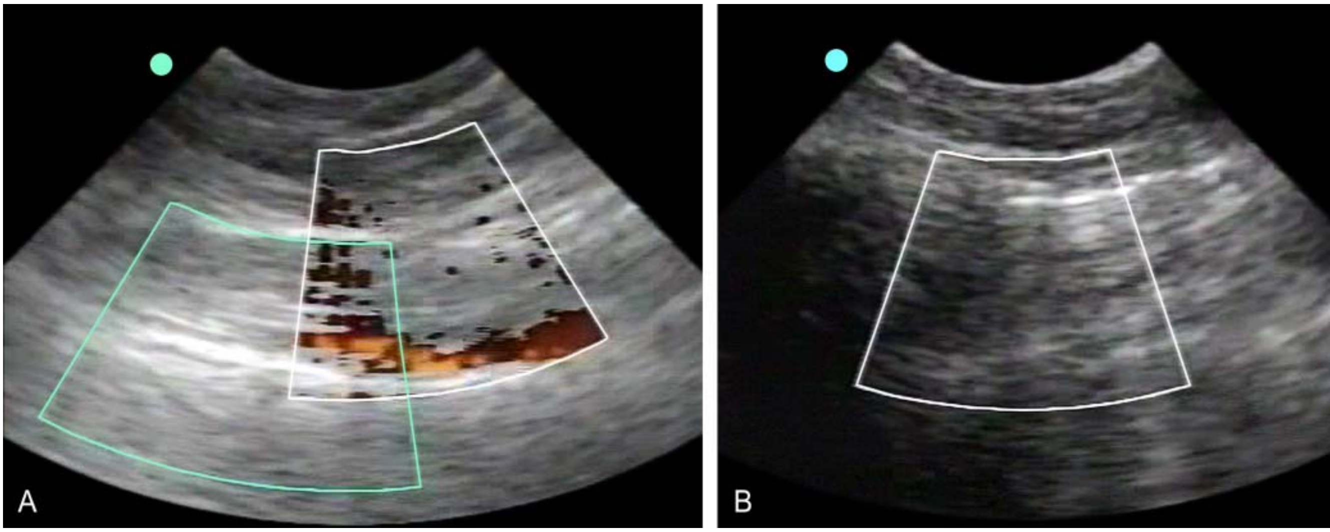

Figure 2. A sliding lung sign is seen on the left side, with the movement of the pleura denoted by a blush of color on the power Doppler setting, **A**. No sliding lung sign is seen on the opposite (*right*) side, with no movement picked up on power Doppler, **B**.

director (MB). All study physicians had performed at least 100 trauma US examinations, and at least ten thoracic US examinations, to evaluate for pneumothorax prior to enrolling patients into the study. The trauma US examination was performed during the secondary survey, and was immediately followed by US of the chest for pneumothorax. Examiners were not aware of physical examination findings, such as breath sounds. However, the presence of obvious chest deformities was not specifically hidden from the study physicians.

Measurements. The study physician filled out a data form asking for his or her determination of the absence or presence of the sliding lung sign in all eight fields of view, the size of pneumothorax if present, chest radiography results per trauma attending, and CT results per radiology interpretation. The US physician was blinded to the chest radiography and CT results until data collection was complete. Recorded US results were compared against both the trauma attending reading of the chest radiography and the radiology reading of the CT. Radiologists were blinded to US results.

Data Analysis. Sensitivity, specificity, likelihood ratio, and positive and negative predictive values with 95% confidence intervals (95% CIs, using the exact binomial method) were calculated for US and AP chest radiography for the detection of pneumothorax. Correlation between pneumothorax size on CT and US findings was performed using a Spearman's rank correlation test to evaluate for US ability to predict the size of the pneumothorax on CT. Agreement statistics for US and CT were calculated using Cohen's weighted method.

RESULTS

A total of 176 patients were enrolled in the study. Seventy-six (43%) of the patients were female. No patient who underwent all three imaging modalities (US, chest radiography, and chest CT) was excluded from data analysis. All US examinations were successfully completed. Twelve patients had a chest tube placed after US and chest radiography, but prior to CT. Twenty-one patients received a dedicated CT of the chest.

The presence of a pneumothorax was detected in 53 (30%) patients by US and 40 (23%) by chest radiography. There were 53 (30%) true positives by CT or on chest tube placement. The sensitivities, specificities, negative predictive values (NPVs), and positive predictive values (PPVs) for US and chest radiography are found in Table 1. The positive likelihood ratio for a pneumothorax diagnosed by US was 121.

The Spearman's rank correlation test yielded a ρ of 0.82, suggesting good correlation between US-assessed sizes and those noted on CT. Cohen's weighted agreement calculation yielded an observed agreement of 94.9% between US and CT for pneumothorax size, with an expected agreement of 73.3%. The kappa was 0.79 (95% CI = 0.6 to 1.0).

There was one false positive finding with US that was due to a large right-sided lung contusion found on CT. One false-negative US was noted in a patient in whom the chest radiograph was also negative, but the CT was read by radiology as having a probable small (about 1%) pneumothorax. There were no adverse events from the false-positive or false-negative US results. Three patients had subcutaneous emphysema, but the US examinations were not affected. There were 23 large pneumothoraxes, 19 small pneumothoraxes, and 11 medium pneumothoraxes on CT, as well as 12 presumed large, based on a rush of air during chest

TABLE 1. Sensitivity, Specificity, and Positive and Negative Predictive Values for Ultrasound and Chest Radiography

	Ultrasound (95% CI)	Chest Radiography (95% CI)
Sensitivity	98.1% (89.9%, 99.9%)	75.5% (61.7%, 86.2%)
Specificity	99.2% (95.6%, 99.9%)	100% (97.1%, 100%)
Positive predictive value	98.1% (89.3%, 99.9%)	100% (91.2%, 100%)
Negative predictive value	99.2% (95.6%, 99.9%)	90.4% (84.2%, 94.8%)

tube placement. All discrepancies between US and CT for pneumothorax size occurred with medium-sized pneumothoraxes, as estimated by US.

DISCUSSION

The use of US in the diagnosis of pneumothorax was first reported in a veterinary journal in 1986.[15] Since that time, multiple case reports and several studies have explored the use of US in the diagnosis of pneumothorax. The primary means used to diagnose the presence of air between the visceral and parietal pleura is the absence of the sliding lung sign. When present, the sliding lung sign has been shown to be a good negative predictor for the presence of a pneumothorax, with Dulchavsky et al. reporting a true-negative rate of 100% for ruling out a pneumothorax when compared with standard radiography.[10] Additionally, the sensitivity of lung US in the detection of pneumothorax is comparable to, or even greater than, routine radiography, with sensitivities in experimental studies ranging from 90% to 100% using CT as the criterion standard.[3,4,6] With the addition of power Doppler, the detection of the pleural sliding as Doppler shift, called the "power slide," may further increase the sensitivity.[16] With Doppler, the US machine detects the movement of the two pleural layers past each other as blood flow in a vessel, and displays it as a color map (Figure 2A). This may be especially helpful when the human eye does not pick up the pleural sliding due to limited resolution or some type of interference.

Several previous studies have evaluated, with varying success, whether the size of a pneumothorax could be estimated when utilizing US. Using archived taped examinations, Sistrom et al. found minimal correlation between US findings and size of pneumothorax.[11] In a porcine model, however, a partial lung sliding sign was seen with as little as 150 mL of air insufflated into the pleural space. This consisted of visualization of lung sliding in a portion of the scanning window with adjacent absence of sliding noted in the same window.[11] As the insufflation volumes increased, there was progressive loss of lung sliding from the anterior to the lateral to the posterior windows. These results suggested that US may allow for distinction between pneumothoraxes of varying sizes.

In a recent study, Kirkpatrick et al. evaluated a hand-carried ultrasound unit for detection of traumatic pneumothoraxes in 225 trauma patients, most of whom were suffering from blunt trauma.[17] The authors utilized a different ultrasound transducer from the one we used in our study. The use of a linear ultrasound transducer should have provided for greater accuracy over the microconvex transducer we utilized. Further, the linear transducer may not be available on many ultrasound units used just for trauma evaluation. Thus, our study was more practical, despite using somewhat inferior technology for visualization of the sliding lung sign. Kirkpatrick et al. noted that 63% of all pneumothoraxes were missed on trauma chest radiography. This was a higher percentage of misses for chest radiography than in our study, but its significance is the same: that trauma chest radiographs are not reliable for detecting pneumothoraxes. However, as in our study, Kirkpatrick noted that occult or small pneumothoraxes were most likely to be missed by chest radiography. The authors reported a sensitivity of 58.9% for ultrasound in comparison with the criterion standard, with a likelihood ratio of a positive test of 69.7 and a specificity of 99.1%. The sensitivity in our study was higher, but the two specificities were comparable.

Despite the promise for high accuracy, a potential for false-positive results on a sliding lung sign search does exist in certain clinical situations. Presence of bullous emphysema has been associated with loss of the sliding lung sign when no pneumothorax is present. Other potential pitfalls are the presence of pleural adhesions and, possibly, extensive subcutaneous emphysema.[7] Knudtson et al. described the absence of a sliding lung sign in the presence of subcutaneous emphysema not associated with a pneumothorax.[1] However, subcutaneous emphysema should be obvious to the experienced sonologist, as image loss from air interference occurs essentially at skin level rather than deep to the ribs. Finally, large lung contusions can lead to false-positive findings due to a change in the pleura. This was seen in one patient in our study with a large unilateral contusion. The patient was believed to have an absence of the sliding lung sign on US. Chest radiography did not show a pneumothorax, and neither did the CT. However, the CT revealed the contusion.

In contrast to many prior studies utilizing the sliding lung sign, all of the subjects in this study were evaluated with the microconvex probe on a true portable US machine, SonoSite 180PLUS. Although a 7.5-MHz linear transducer allows better resolution of

Figure 3. The progression of lung separation from the thoracic wall is shown with increasing volume of pneumothorax (PTX) in frames **A** through **C**. Note that the medium (**B**) PTX tends to extend as far laterally as the large one, **C**. However, the absolute volume of the large PTX in the chest appears significantly larger.

the pleural–pleural interface due to the close proximity to the skin, the 3.5-MHz microconvex transducer is typically used for the FAST examination. Therefore, with the high sensitivity demonstrated in our study for the detection of the sliding lung sign, a microconvex probe has the distinct advantage of being adequate for performing both examinations. Further, the microconvex probe allows for easier imaging through the ribs due to its small-footprint size and pie-shaped image. Therefore, rib shadowing can be minimized by probe maneuvers such as rotation or angling more easily than with a large-footprint linear probe.

We attempted to determine the size of the pneumothorax by evaluating for the sliding lung sign in multiple areas of the chest in supine trauma patients. The areas chosen should reflect an increasing volume of a pneumothorax inside a human hemithorax when the patient is supine. Unless limited by significant adhesion or as part of a bleb, air first moves to the most superior portion of the hemithorax when the patient is supine. As would be expected based on the porcine model, small pneumothoraxes were seen in the anterior portion of the chest only, whereas larger pneumothoraxes were easily seen in much more lateral and even posterior locations. Chest radiography routinely failed to detect pneumothorax in patients for whom US showed an absence of the sliding lung sign only in the anterior position (i.e., a small pneumothorax), and this was also expected. One potential reason for increased difficulty in differentiating between medium and large pneumothoraxes on US was likely due to the pattern of lung collapse, as seen on CT (Figure 3A, B). As the volume of the pneumothorax increases, the lung is pushed away from the chest wall, thus eliminating the sliding lung sign in an increasing arc from the anterior to lateral portion of the chest. As the pneumothorax volume increases from medium to large, the lung volume inside the thorax becomes progressively smaller, but the surface area in which sliding lung sign is absent increases less significantly.

The ability to grade the size of a pneumothorax could be of considerable utility in a number of situations. If a large pneumothorax is noted, a chest tube may need to be placed prior to transfer to a radiography area or another facility. This may be especially useful at disaster scenes with multiple casualties, or on the battlefield, where other imaging modalities may not be available. Further, if a chest tube is not placed, periodic evaluation for increasing pneumothorax size without repeat doses of ionizing radiation is clinically useful. This scenario may occur in an observation setting such as patients admitted with small pneumothoraxes after trauma, or in cases of spontaneous pneumothorax that did not warrant a chest tube on initial diagnosis.

A surprising difficulty occurred with bilateral pneumothoraxes found in two cases involving very thin female patients without a history of significant trauma or mechanism. In both cases, the study physician correctly detected lack of sliding lung sign, but thought that it must have been due to technical error. CT later confirmed small bilateral pneumothoraxes in both patients.

LIMITATIONS

This study has several limitations. It selected patients who were more severely injured than patients who may only receive a chest radiograph without undergoing abdominal CT. However, the criterion standard of CT would not have been available to us for comparison otherwise. Patients were enrolled on a researcher-availability basis. However, this is unlikely to have led to any selection bias, because the researchers worked all shifts and all days in the ED during the study's course. The study researchers were all hospital-credentialed in emergency US, and results may not translate to novice US users. The CTs were often performed more than 10 minutes after initial US, thus giving time for the pneumothorax to enlarge in some cases. We did not use attending radiology readings of chest radiographs, because they were not available at the time of patient care, and the need for prompt clinical decisions was our primary concern. We believe this is a common practice not only in many academic trauma centers, but also in other real-world settings, and more accurately reflects modern practice. Our subjects were all trauma patients, and thus results may not be generalizable to medical patients.

CONCLUSIONS

With CT as the criterion standard, US is more sensitive than plain AP chest radiography in the diagnosis of traumatic pneumothorax. Furthermore, US allowed sonologists to differentiate between small, medium, and large pneumothoraxes with good agreement with CT.

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