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Clinician-performed Beside Ultrasound for the Diagnosis of Traumatic Pneumothorax

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Introduction: Prior studies have reported conflicting results regarding the utility of ultrasound in the diagnosis of traumatic pneumothorax (PTX) because they have used sonologists with extensive experience. This study evaluates the characteristics of ultrasound for PTX for a large cohort of trauma and emergency physicians.

Methods: This was a prospective, observational study on a convenience sample of patients presenting to a trauma center who had a thoracic ultrasound (TUS) evaluation for PTX performed after the Focused Assessment with Sonography for Trauma exam. Sonologists recorded their findings prior to any other diagnostic studies. The results of TUS were compared to one or more of the following: chest computed tomography, escape of air on chest tube insertion, or supine chest radiography followed by clinical observation.

Results: There were 549 patients enrolled. The median injury severity score of the patients was 5 (inter-quartile range [IQR] 1-14); 36 different sonologists performed TUS. Forty-seven of the 549 patients had traumatic PTX, for an incidence of 9%. TUS correctly identified 27/47 patients with PTX for a sensitivity of 57% (confidence interval [CI] 42-72%). There were 3 false positive cases of TUS for a specificity of 99% (CI 98%-100%). A “wet” chest radiograph reading done in the trauma bay showed a sensitivity of 40% (CI 23-59) and a specificity of 100% (99-100).

Conclusion: In a large heterogenous group of clinicians who typically care for trauma patients, the sonographic evaluation for pneumothorax was as accurate as supine chest radiography. Thoracic ultrasound may be helpful in the initial evaluation of patients with truncal trauma. [West J Emerg Med 2013;14(2):103-108.]

INTRODUCTION

Rapid diagnosis and treatment of traumatic pneumothorax (PTX) is important to prevent tension physiology and circulatory collapse in patients with blunt and penetrating trauma. Supine chest radiograph (CXR) is traditionally employed; however, it misses up to 50% of PTXs.¹ Thoracic ultrasound (TUS) was first described in 1995 for diagnosing PTX in humans when Lichtenstein noted that the absence

of comet-tail artifacts and lung sliding were associated with PTX.² Since then ultrasound has become a validated method of examining the pleura in multiple settings. In 2011 the Eastern Association for the Surgery of Trauma gave a level 2 recommendation for the use of ultrasound to identify PTX in its practice management guidelines.³

In most studies TUS has been found to have favorable results. In Lichtenstein’s study,² TUS had a sensitivity and

negative predictive value of 100% and 96.5%, respectively, for the detection of PTX in the intensive care unit setting.⁴ Dulchavsky⁵ subsequently demonstrated that this modality has a sensitivity of 95% in the detection of PTX in patients at a Level 1 trauma center. These reports used plain radiography as the gold standard: a diagnostic modality known to be inaccurate in the detection of PTX.⁶ In subsequent studies using dedicated chest computed tomography (CCT) as a reference standard, sensitivities of TUS have ranged widely from 49% – 98%, while finding that it is still consistently more accurate than supine CXR.⁷⁻¹³ Studies in which TUS is performed by emergency physicians (EP) for traumatic PTX have reported even higher sensitivities ranging from 86-97% with specificities of > 99%.¹⁴ While these latter numbers are desirable, they have the potential limitation of being less applicable due to a higher skill level of the sonologists involved. The actual performance of TUS for PTX would likely vary based on the sonologist's skill and experience.

The current investigation set out to determine the test characteristics of TUS for traumatic PTX in the hands of a large heterogeneous group of potential sonologists representative of typical clinicians involved in trauma care.

METHODS

This was a prospective non-randomized observational study on a convenience sample of patients with truncal trauma (both blunt and penetrating) who presented to a Level I trauma center with greater than 2,000 trauma patients per year. Patients were enrolled during a 15-month period and the study was approved by the study hospital's institutional review board with a waiver of informed consent and Health Insurance Portability and Accountability Act waiver as authorized by Title 45 Code of Federal Regulations (45 CFR) Part 46.116 (d) and Part 164.512 (i), respectively.

Physicians selected to perform TUS were comprised of trauma attendings and fellows; emergency medicine attendings and residents; and emergency ultrasound fellows. To participate in the study, physicians were required to be competent in the Focused Assessment with Sonography for Trauma (FAST) exam, defined as formal training in this study as mandated by the American College of Emergency Physicians with at least 25 complete proctored examinations.^{15,16} Physicians were then required to participate in a 1.5 hour training session that included a pre-test, a 30-minute lecture on pleural ultrasound, structured review of approximately 15 "unknown" video clips of pleural evaluations, a post-test, and a 30-minute proctored lab session in which participants demonstrated the ability to identify the visceral and parietal lung interface (Figure 1) and obtain dynamic images of the pleura in normal volunteers. Physicians were expected to demonstrate the ability to adjust gain and depth settings appropriate for the pleural evaluation on a machine that had just been used to perform the FAST.

A convenience sample of patients was selected on a consecutive basis when a physician with the aforementioned

training in TUS was present during a trauma evaluation or resuscitation.

Patients were enrolled if they sustained either blunt or penetrating truncal trauma and received a FAST exam in the trauma bay. Patients were excluded if they were less than 18 years of age, pregnant, were prisoners, or if a tube thoracostomy was performed prior to the ultrasound exam. A retrospective chart review was done to record the Injury Severity Score (ISS), age, sex, and mechanism of injury (blunt vs. penetrating).

The TUS examination consisted of the consecutive sonographic interrogation of every intercostal space between the clavicle and the diaphragm on each hemithorax. Scans were performed in the mid-clavicular line. On the left side, if cardiac motion was encountered in the mid-clavicular line, the probe was moved laterally to the left anterior axillary line and the pleura seen in the remaining intercostal spaces was evaluated until the diaphragm/spleen was encountered. To use the ribs to assist in the identification of the rib spaces and the pleura, the probe was placed in a longitudinal plane for the entire exam. Physicians performing the TUS were blinded to the results of any imaging modalities when they recorded the presence or absence of a PTX based upon lung sliding, comet-tail artifacts, and the lung point sign. All examinations were done using the C-15 2-4 Mhz curved array transducer

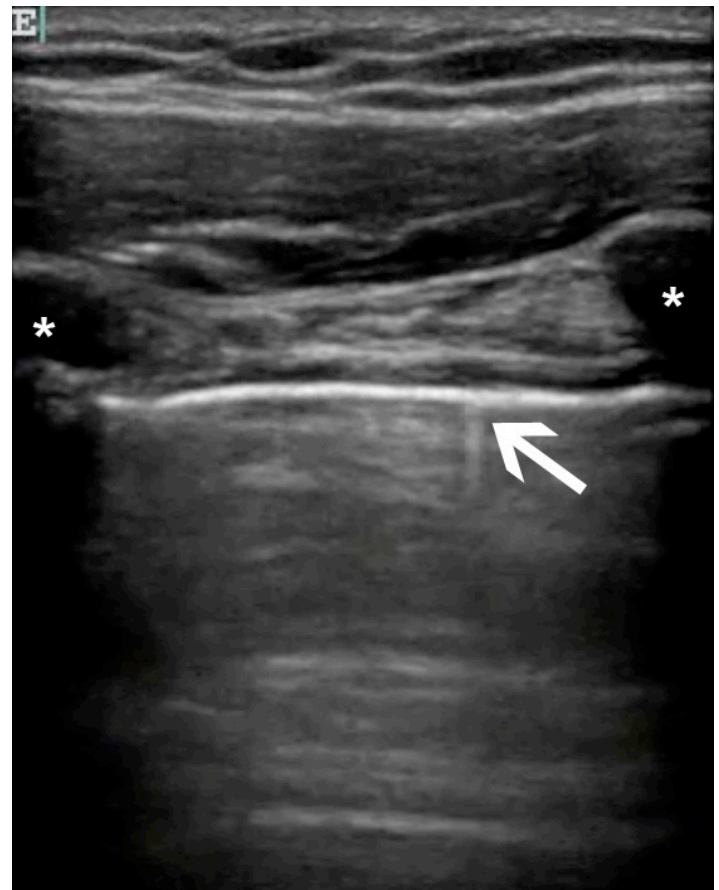


Figure 1. Ultrasound image of a normal lung shows the parietal pleura (arrow) and ribs (asterisks).

Table 1. Training level of physician sonologists.

Sonologists	n=36*	Number of scans (n=549)
Trauma fellow	16	258
Trauma attending	4	69
EM resident	9	70
EM fellow	2	38
EM attending	4	113

EM, emergency medicine

*The training level of a sonologist who had performed 1 scan could not be determined.

Table 2. Mechanism of injury.

Mechanism	Number of injuries (%)
Blunt (N=462)	
Motor vehicle injury	202 (37%)
Fall	102 (19%)
Assault	87 (16%)
Pedestrian injury	41 (7%)
Motorcycle injury	30 (5%)
Penetrating (N=87)	
Gunshot wound	59 (11%)
Stabbing	28 (5%)

Table 3. Performance characteristics of thoracic ultrasound (TUS) and supine chest radiograph (CXR) for detection of pneumothorax.

	TUS (N=549)	CXR (N=365)
Sensitivity	57% (42-72)	40% (23-59)
Specificity	99% (98-100)	100% (99-100)
Positive predictive value	90% (73-98)	100% (73-100)
Negative predictive value	96% (94-98)	95% (92-97)

on a portable ultrasound unit (Titan, SonoSite Inc., Bothwell, Washington).

Because it is the usual practice in our trauma resuscitations to make clinical decisions based upon immediate “wet” readings of CXRs, the CXR interpretation from the trauma attending or fellow rather than the radiologist was recorded. The final diagnosis of a PTX used a composite gold standard of CCT, escape of air on chest tube insertion, or supine plain radiography followed by clinical observation.

We calculated performance characteristics, including sensitivity, specificity, positive predictive value, negative predictive value, and positive/negative likelihood ratios along with 95% confidence intervals (CI), using STATA software (version 11, Stata Corporation, College Station, Texas).

Given an estimated 10% incidence of traumatic PTX and a predicted sensitivity of 0.8 for TUS, 500 patients were enrolled in order to achieve a confidence interval width of 0.3.

RESULTS

Thirty-six different physician sonologists performed TUS on 549 trauma patients during the study period and all were included in the analysis. Table 1 shows the varying training levels of the sonologists. The median age of the patients was 38 years (interquartile range [IQR] 25-51). Seventy-five percent (410) of patients were male. ISS data was available for 96% (518) of patients. The median ISS of the patients was 5 (IQR, 1-14), and 7% (37) of patients had an ISS of > 50. Four hundred sixty-two (84%) patients were victims of blunt trauma. Table 2 shows details of the mechanism of injury for the study population.

Figure 2 shows the 3 different methods for obtaining the final diagnosis of the presence or absence of a PTX. CCT was the most frequently used method and there were a small percentage of cases where patients had an immediate tube thoracostomy prior to other imaging modalities.

The incidence of traumatic PTX in the study population was 9%. TUS was performed on all 549 patients and correctly identified a PTX in 27 out of 47 patients. A “wet” CXR reading was recorded by the trauma resuscitation leader in 365 out of 549 (66%) patients. Table 3 compares the characteristics of TUS and CXR versus the composite gold standard.

Table 4 shows characteristics of the 20 out of 47 patients who had a missed PTX. No patients with a PTX had a CXR identifying a PTX, which was not detected by TUS. Nine out of 20 missed PTXs did not require tube thoracostomies.

DISCUSSION

The current investigation found that thoracic ultrasonography was as sensitive as supine radiography in the detection of traumatic PTX, but still misses more than 40% of PTXs identified on CCT. These findings concur with a large retrospective study which has shown that the supine CXR misses over half of the PTXs identified on CCT.¹⁷ Similar

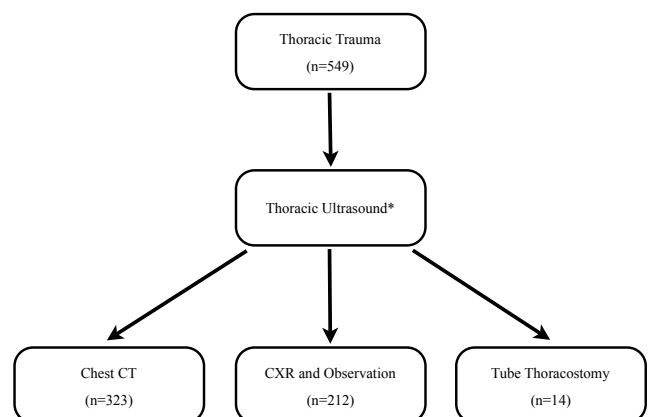


Figure 2. Method of final diagnosis of the presence or absence of pneumothorax in patients with truncal trauma.

*Physician sonologists performed thoracic ultrasound prior to other imaging modalities.

Table 4. Pneumothoraces missed by both thoracic ultrasound and chest radiography.

Patient	Method of final diagnosis	Tube thoracostomy performed?
1	Chest CT	Yes
2	Chest CT	Yes
3	Chest CT	Yes
4	Chest CT	Yes
5	Chest CT	Yes
6	Chest CT	Yes
7	Chest CT	Yes
8	Chest CT	No
9	Chest CT	No
10	Chest CT	No
11	Chest CT	No
12	Chest CT	No
13	Chest CT	No
14	Chest CT	No
15	Chest CT	No
16	Chest CT	No
17	Chest CT	Yes
18	Clinical judgement	Yes
19	Clinical judgement	Yes
20	Clinical judgement	Yes

CT, computed tomography

to the current study, Kirkpatrick et al⁸ found that thoracic ultrasound had a greater sensitivity for ruling out a PTX than supine radiography (48.8% vs 20.9%, respectively).

The sensitivity of ultrasound in the current study was much lower than reported in most of the previous studies (Table 5).⁸⁻¹³ The difference in sensitivities of these studies may be associated with the number and training level of enrolling physician sonologists. Four similar studies have resulted in 95-100% sensitivity^{9,10,12,13}; 1 study showed an 86% sensitivity¹¹, and another similarly found a sensitivity of 59%.⁸ These studies are either performed by a small number of highly trained sonologists or do not report the number, background, and training of sonologists performing TUS examination, making it difficult to apply the results to a typical cohort of physicians. The 36 physicians involved in the current study came from varied backgrounds (ranging from residents to attending physicians in both trauma surgery and emergency medicine) and had not performed TUS of the pleura prior to a brief training course at the initiation of this study. It is possible that such a group reflects the gamut of clinicians in the United States whose evaluation of acute trauma includes use of the FAST examination.

We performed TUS on a cohort of patients inclusive of blunt and penetrating trauma after a FAST exam but did not limit the study population to only those who received a CTT

(although more than half of the patients in our sample did). Since CCT is the gold standard for the detection of PTX it is possible that a small number were missed in patients after they were discharged from the trauma bay or intensive care unit. However, with the monetary and manpower costs involved in CCT, as well as its exposure of patients to ionizing radiation, it is unlikely that the standard practice of managing many trauma patients who are at low risk for PTX solely with CXR is likely to change. Thus, the protocol followed in the current study reflects clinical practice, and our results suggest that management of low-risk patients with TUS alone, or in addition to CXR, would most likely identify more PTXs than CXR alone. To prevent selection bias we designed the study to include both stable and unstable trauma patients. As a result, 14 patients underwent immediate tube thoracostomy prior to any imaging. TUS correctly identified a PTX in 11 of these 14 cases. If these patients were not included in our study population, then nearly all of the traumatic PTX cases would have involved patients who were stable enough to either wait for a portable CXR or be transported to the CT suite.

The FAST exam is used internationally by both traumatologists and EPs for the detection of traumatic hemoperitoneum.¹⁶ It has largely replaced diagnostic peritoneal lavage, and has proven to be accurate, easily learned, and rapidly deployed.¹⁸⁻²⁰ Some authorities have advocated that TUS be added as a component of the FAST.⁸ Others, based on a study that was retrospective and limited by a small sample size, have argued against this approach on the grounds that the rate of occult PTX is as low as 2.1%.²¹ To our knowledge, this report involves the largest sample size of any prospective study of TUS for the diagnosis of PTX in the literature. Our PTX rate was significantly higher, at 9%, although this is much lower than that reported in most series.^{7,9,12} Based on this study, we advocate that TUS should be incorporated as an extension of the FAST exam because it can identify cases of PTX that would be missed on supine CXR alone, and thereby allow earlier tube thoracostomy. This might be especially important in patients going to the CT suite or for emergent laparotomy where general anesthesia with positive pressure ventilation with undetected PTX might be particularly dangerous.

LIMITATIONS

Limitations to the current study include the possibility of selection bias from enrolling a convenience sample of trauma patients with thoracic injuries. Unstable patients may have been excluded if no one from the resuscitative team was able to enroll the patient due to other resuscitative duties. The potential exclusion of the highly unstable patients may explain the low prevalence of PTX found in our study. TUS may be less relevant in this cohort as algorithms often call for empiric needle decompression in unstable trauma patients.

Not all subjects underwent CCT and instead just had CXR and clinical observation. It is possible that some patients in this latter group had radio-occult PTX that may have been

Table 5. Characteristics of previous studies reporting test characteristics of thoracic ultrasound (TUS) in various patient populations.

Study	N	Type	Sensitivity	Enrolling physicians and training
Dulchavsky (2001)	382	B, P	95%	Unreported number of surgical residents and attendings “familiar with ultrasound for abdominal trauma.” Residents also had hands-on demonstration of normal lung model and viewed one pre-recorded exam.
Rowan (2002)	27	B	97%	Exams performed by 4 different sonographers (1 staff radiologist, 3 radiology residents) “trained in ultrasound pneumothorax detection.”
Kirkpatrick (2004)	225	B, P	59%	Unreported number of attending trauma surgeons who trained in TUS “through the use of an animal laboratory, review of video-taped images, and proctoring by the most experienced investigator.”
Lichtenstein (2005)	195	I	100%	Unreported number of “intensivists specifically trained in general ultrasound.”
Blavais (2005)	176	B	98%	Five emergency physicians who had completed the ACEP EUS guidelines, were “trained” in TUS by the director, performed “at least 100 trauma US examinations, and at least ten TUS examinations.”
Soldati (2006)	186	B	98%	Two EPs “with over 10 year experience in emergency ultrasonography and at least 1 y in chest ultrasound.”
Zhang (2006)	135	B, P	86%	Three EPs with previous “formal training on emergency bedside ultrasound.” Training in TUS not reported.
Soldati (2008)	109	B, M	92%	Two EPs with “at least 1 year experience in chest ultrasound.”

B, blunt trauma; P, penetrating trauma; I, intensive care unit patients; M, mixed trauma patients; EP, emergency physician

visualized on CCT leading to misclassification bias. Such a bias could result in a lower sensitivity rate for both TUS and CXR, however would likely not affect the accuracy of these tests for determining clinically significant PTX.

A Hawthorne effect may have occurred since sonologists knew they were being studied. Blinding was attempted to prevent bias. However, it is possible that clinical factors existed (e.g. a stab wound to the chest) that biased the sonologist’s TUS interpretation. The test characteristics of CXR for PTX may have been subject to selection bias as only 66% of the patients had an interpretation of the CXR recorded for analysis.

CONCLUSION

TUS is as accurate as portable supine CXR in the diagnosis of traumatic PTX. Because ultrasound can be used by a diverse group of trauma providers and can be done rapidly, it should be considered as part of the routine evaluation of patients with thoracic trauma.

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Conflicts of Interest: By the WestJEM article submission agreement, all authors are required to disclose all affiliations, funding sources and financial or management relationships that could be perceived as potential sources of bias. The authors disclosed none.

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