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ORIGINAL CONTRIBUTION

Comparison of Four Views to Single-view Ultrasound Protocols to Identify Clinically Significant Pneumothorax

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Abstract

Objective: Ultrasound (US) has been shown to be effective at identifying a pneumothorax (PTX); however, the additional value of adding multiple views has not been studied. Single- and four-view protocols have both been described in the literature. The objective of this study was to compare the diagnostic accuracy of single-view versus four-view lung US to detect clinically significant PTX in trauma patients.

Methods: This was a randomized, prospective trial on trauma patients. Adult patients with acute traumatic injury undergoing computed tomography (CT) scan of the chest were eligible for enrollment. Patients were randomized to a single view or four views of each hemithorax prior to any imaging. USs were performed and interpreted by credentialed physicians using a 7.5-Mhz linear array transducer on a portable US machine with digital clips recorded for later review. Attending radiologist interpretation of the chest CT was reviewed for presence or absence of PTX with descriptions of small foci of air or minimal PTX categorized as clinically insignificant.

Results: A total of 260 patients were enrolled over a 2-year period. A total of 139 patients received a single view of each chest wall and 121 patients received four views. There were a total of 49 patients that had a PTX (19%), and 29 of these were clinically significant (11%). In diagnosis of any PTX, both single-view and four-view techniques showed poor sensitivity (54.2 and 68%) but high specificity (99 and 98%). For clinically significant PTX, single-view US demonstrated a sensitivity of 93% (95% confidence interval [CI] = 64.1% to 99.6%) and a specificity of 99.2% (95% CI = 95.5% to 99.9%), with sensitivity of 93.3% (95% CI = 66% to 99.7%) and specificity of 98% (95% CI = 92.1% to 99.7%) for four views.

Conclusions: Single-view and four-view chest wall USs demonstrate comparable sensitivity and specificity for PTX. The additional time to obtain four views should be weighed against the absence of additional diagnostic yield over a single view when using US to identify a clinically significant PTX.

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Ultrasound (US) has become an integral part of the initial evaluation of trauma patients in the emergency department (ED). The eFAST, or extended focused assessment with sonography in trauma examination, includes US imaging of the lungs to evaluate for the presence of a pneumothorax (PTX). Prior research has shown US to be very effective at identifying a PTX.[1–4] There is no standardized imaging protocol; however, there have been multiple different imaging protocols described in the literature. The two most common are a single view of each hemithorax and four views of each hemithorax.[5–8] Most trauma patients arrive to the ED in the supine position on a backboard. As air is expected to rise to the least dependent portion of the chest,[9] a single view in this area of the chest is commonly used for these patients. Chest wall US using

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four views of each chest wall, with the probe moving down the lateral aspect to more dependent areas, has been advocated as allowing a more comprehensive look at the chest cavity to evaluate for a smaller, trapped, or a loculated PTX.[4] To date, there has been no study that directly compares these two techniques in an attempt to determine the optimal technique to diagnose a PTX. The objective of this study was to compare the diagnostic accuracy of single-view versus four-view lung US techniques for the identification of clinically significant PTX in trauma patients.

METHODS

Study Design

This was a randomized, prospective study on trauma patients meeting state trauma center triage criteria, which is based on method of injury and physiologic and anatomic parameters, who arrived to the trauma resuscitation area of the ED. The University of Massachusetts institutional review board approved our study design. A waiver for consent was given due to the critical and time-sensitive nature of trauma patients and because there was no added risk to the patient by enrollment in the study.

Study Setting and Population

This study was conducted at a single urban academic ED with an annual volume of 130,000 patients and a dedicated Level I trauma service that staffed by trauma surgeons and emergency medicine physicians. There are three levels of trauma patients that arrive to our ED. Level 1 patients are the most severe and unstable patients and require both the ED attending and the trauma surgery attending in the trauma bay on arrival. Level 2 patients have stable vital signs and lower-risk methods of injury and only require the ED attending in the trauma bay; however, the surgery attending is almost always present when available. Level 3 patients are usually walk-in patients who arrive to the main ED and require a trauma team consultation. Adult patients with acute traumatic injury who were undergoing a computed tomography (CT) scan of the chest as part of their clinical care were eligible for enrollment. Physicians performing the US examination were credentialed based on our department policy of having performed 25 FAST and 25 chest wall examinations that were reviewed by experienced US faculty. All residents were credentialed for both protocols prior to their trauma rotation.

Study Protocol

Trauma patients were enrolled as a convenience sample as they arrived to the ED. We included any trauma patient aged 18 and over. We excluded any patient who was too unstable and required clinical care that prevented performing a chest wall US, patients with a chest tube in place prior to arrival, pregnant women, and prisoners. Imaging decisions on trauma patients were made early on in their evaluation. Once it was determined by the treating physicians that the patient was going to receive a chest CT as part of his or her evaluation in the ED, the patient was assigned to one of two imaging protocols, single view versus four views. The patient was assigned using a predetermined randomization scheme to a single view of each hemithorax or four views of each hemithorax prior to any imaging being done. US images were obtained by emergency physicians or the attending trauma surgeon using a 7.5-Mhz (5- to 10-MHz) linear array transducer on a portable Zonare z.one ultra machine (Zonare, A Mindray Company) with digital clips recorded for later review. When obtaining a single view of each hemithorax, the probe was placed in a longitudinal orientation on the midclavicular line in the third intercostal space. When obtaining four views of each hemithorax, the first image location was the same as in the single view and then the probe was moved inferiorly and laterally to obtain the additional three images (Figure 1). Initial US interpretation by the performing physician was blinded to the results of the portable chest x-ray (CXR) if it was completed prior to the US examination. The US examination was always completed prior to, and immediately before, the patient was transported to the CT scanner for a chest CT.

Outcome Measures

Our goal was to determine if the use of a single view of each hemithorax is adequate to identify clinically significant PTX requiring chest tube placement or if four views of each hemithorax are required to identify all clinically significant PTXs. A PTX was considered clinically insignificant if the radiologist, who was blinded to the US interpretation, read the CT scan as a thin collection of air up to 1 cm thick in the greatest slice or seen on fewer than five contiguous slices.[10] The primary study endpoint was the presence of a clinically

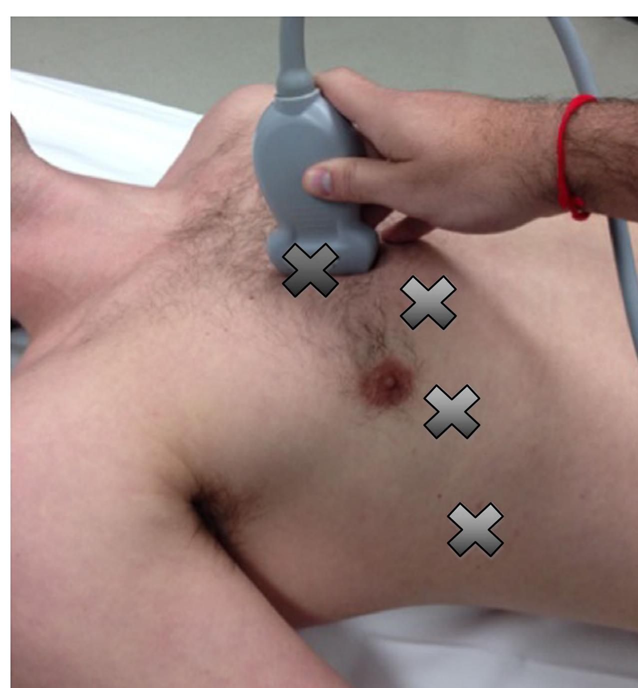

Figure 1. Ultrasound probe placement. The single-view protocol is marked by the probe at the first X. The following X's mark the additional views for the four-view protocol.

significant PTX on US. Each US image was interpreted at the time of presentation as positive or negative for the presence of PTX using the absence of dynamic lung sliding as indicative of a PTX. The reference standard for the diagnosis of PTX was the diagnosis of a PTX on CT scan of the chest. Board-certified attending radiologists interpreted each chest CT for presence or absence of any PTX.

Data Analysis

Using a noninferiority power calculation (sealedenvelope.com), and assuming an alpha of 0.05 and a beta of 0.8, we determined that we would need 118 patients in each group, or 236 total patients, to power our study to determine an equivalency or a difference in the detection rate of PTXs of less than 5%. This calculation was based on prior research, which showed a mean of 92% sensitivity for the eight view technique (four views of each hemithorax)[7] and a 95% sensitivity for the two view technique (single view of each hemithorax).[8] Every US was secondarily reviewed for the presence or absence of a PTX by the primary study author. The study author was blinded to all patient and clinical characteristics, as well as all radiology imaging, when performing the secondary review.

RESULTS

A total of 260 patients were enrolled over a 2-year period from February 2012 through November 2013. A total of 139 of those patients received a single view of each hemithorax and 121 received four views of each hemithorax. The patient characteristics for each group are in Table 1, and a flow diagram of the study and results of each protocol are in Figure 4. Overall, the incidence of any PTX as diagnosed by CT imaging was 49/260 (19%) with an incidence of clinically significant PTX of 29/260 (12%). The overall incidence of any PTX on US was 33/260 (13%). A total of 244 of the 260 patients (94%) had a single view, supine CXR done (please see Table 2 for sensitivity and specificity with confidence intervals [CIs] listed for any PTX and clinically significant PTX for each US protocol and CXR). Briefly, for clinically significant PTX, CXR showed a sensitivity of 48.0% and specificity of 100%, a single view US showed a sensitivity of 93.0% and a specificity of 99.2%, and four views showed a sensitivity of 93.3% and specificity of 98.0%. There was no statistically significant difference in either sensitivity or specificity when comparing single view and four-view for clinically significant or any PTX.

There were a total of 44 different physicians who enrolled patients into the study and obtained the US images (please see Figure 2 for a distribution of the results of enrolled patients across all physician operators). The US experience, based on the average number of USs performed prior to involvement with the study, increased as the level of the operator performing the US became more senior. There was 100% agreement between the initial read by the performing provider and the study author, for a Cohen's kappa of 1.

Overall, there were 49/260 patients (19%) diagnosed with any PTX by CT scan. Of those, 30/49 (61%) were on the left side, 14/49 (29%) on the right side, and 5/49 (10%) were bilateral. There were 33/260 patients (13%) diagnosed with any PTX by US during the study. A total of 19/33 of the PTXs were identified following a four view US, with 15 of those were considered clinically significant. All of the clinically significant PTXs and one additional insignificant PTX were seen on the first view of the four views, which is the same probe placement as the single-view group. Of the remaining three positives during the four-view US, two were seen in the second image and one in the third image. All three of these patients had insignificant PTXs and none of them required a chest tube.

Of the 29/49 patients (59% of all PTXs) with a clinically significant PTX, 100% were admitted for observation and 86% required a chest tube. Of the patients who were admitted to the hospital, 93% were discharged with no intervention related to their thorax, but 1 required a chest tube 3 days into their hospitalization and another went to the operating room to have a

Table 1
Patient Characteristics

	All Patients (n = 260)	Single View (n = 139, 53.5%)	Four Views (n = 121, 46.5%)
Age (y), mean (±SD)	45 (±18)	44 (±18)	45 (±19)
Male (%)	186 (72)	100 (72)	86 (71)
Blunt trauma	248 (95)	133 (96)	115 (95)
Admitted	215 (83)	116 (83)	99 (82)
Operative cases	82 (32)	50 (36)	32 (26)
Any PTX	49 (19)	30 (22)	19 (16)
Significant PTX	29 (11)	14 (10)	15 (12)
Chest tube placed	25 (10)	13 (9)	12 (10)
Enrolled by PGY 2 resident	64 (25)	37 (27)	27 (22)
Enrolled by PGY 3 resident	158 (61)	80 (57)	78 (64)
Enrolled by attending	38 (15)	22 (16)	16 (13)

Data are reported as n (%), unless otherwise specified.
PTX = pneumothorax.

Table 2
Test Characteristics

	Sensitivity (95% CI)	Specificity (95% CI)
Single view		
Any PTX	54.2 (33.2–73.8)	99.1 (94.5–99.9)
Significant PTX	93.0 (64.1–99.6)	99.2 (95.5–99.9)
Four view		
Any PTX	66.7 (44.7–83.6)	97.9 (91.9–99.6)
Significant PTX	93.3 (66.0–99.7)	98.0 (92.1–99.7)
CXR		
Any PTX	32.6 (19.5–48.0)	100.0 (98.2–100.0)
Significant PTX	48.0 (29.2–67.1)	100.0 (98.0–100.0)

CXR = chest x-ray; PTX = pneumothorax.
Test characteristics of both ultrasound imaging protocols and CXR with the sensitivity and specificity for any PTX and clinically significant PTX with 95% CI of each listed.

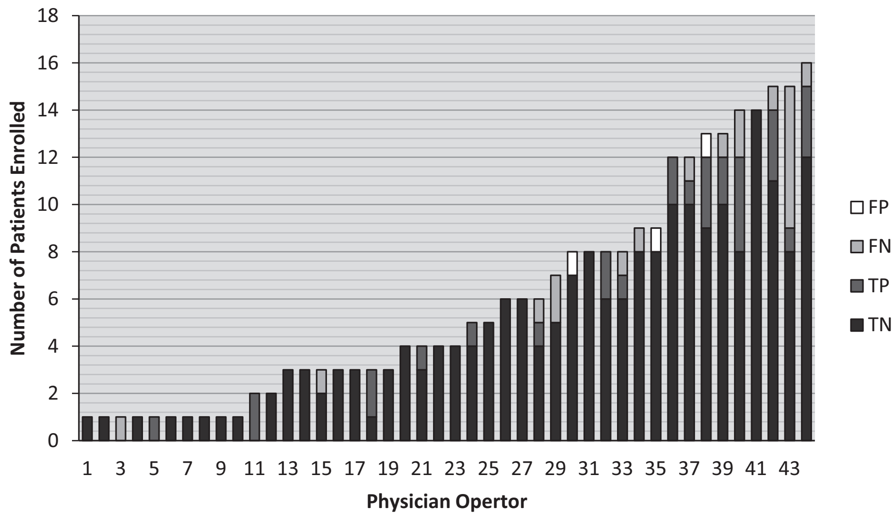

Figure 2. Distribution of results of enrolled patients across all physician operators. FN = false negative; FP = false positive; TN = true negative; TP = true positive.

thoracotomy for an empyema on hospital day 6. Of the 20/49 patients (41%) with a clinically insignificant PTX, 100% were admitted for observation and none of the patients had a chest tube placed during their hospitalization. The overall admission rate for all patients enrolled in the study was 83%.

There were three false-positive USs. Two of these had right mainstem intubations that were seen on CXR and both were interpreted at the bedside as having positive left PTXs. The third patient had a soft tissue defect that limited evaluation of the pleural line and was misread as a positive PTX. There were 19 false-negative USs. Of these, 18 had "small," "tiny," or "apical" PTXs, which categorized them as insignificant and none of these patients required a chest tube during their observation in the hospital. One patient with a false-negative US had a large hemothorax, along with their tiny apical PTX, which required a chest tube inserted in the ED to drain the blood. There were a total of seven patients with a hemo-PTX and three of these, including the one just described, required chest tubes for the hemothorax. There was one patient who had a significant PTX that was missed by US and required a chest tube. This patient received prehospital needle decompression of the chest by paramedics with subsequent randomization to single-view US, which occurred adjacent to the site of the needle decompression and showed lung sliding. The CT images of this patient show the lung near the anterior wall of the chest where the needle decompression occurred, but there was still a large PTX elsewhere (Figure 3).

DISCUSSION

This study, which compared the two most common number of views to evaluate for a PTX in trauma patients, showed that there is no significant difference between a single view of each hemithorax and four views of each hemithorax in detecting clinically significant PTXs. Although our results show that both techniques are good at diagnosing clinically significant PTXs, both demonstrate decreased sensitivity for smaller, clinically insignificant PTXs. The diagnostic capabilities of either bedside US technique for PTX are significantly better than chest radiograph.

Our sensitivity is at the low end of published studies examining US for PTX in trauma. However, our results are within the range of previously published articles on the accuracy of US in traumatic PTX. A 2012 review article on the diagnostic characteristics of US for PTX found that sensitivities ranging from 48.8% to 100%.[11] In another meta-analysis of 13 studies on US for PTX in trauma, the average sensitivity by study was 78.6% (range = 53% to 100%).[12] Three of the studies in this meta-analysis had similar sensitivities to our study. The study by Brook et al.,[13] for example, which had a sensitivity of 46.5%, included patients with "tiny pockets of air" on their CT scan. Our radiologists read our CT scans in a very similar way, with many of our patients having "tiny apical" PTXs. This less stringent definition of a PTX may be why our studies had lower sensitivities overall. It is possible that operator error contributed to our lower sensitivity, but the relatively high level of experience would argue against this. Other issues, such as our possible selection bias, may have also contributed.

There are a number of different techniques for visualizing the lung using US; we chose the two most common techniques to explore in this study. Techniques examining the thorax for parenchymal disease of the lung generally divide each hemithorax into sections or quadrants. An example is the technique described by Volpicelli et al.[14] that divides each anterior hemithorax into four quadrants using the anterior axillary line and nipple to bisect the chest. The logic of using a single view for diagnosing a PTX in blunt trauma is that patients are transported supine for a period of time prior to arriving at the hospital, theoretically allowing the PTX to collect anteriorly. The counter-argument that not all PTXs are located anteriorly supports the use of multiple views of each hemithorax to maximize sensitivity. The additional views also allow the physician the

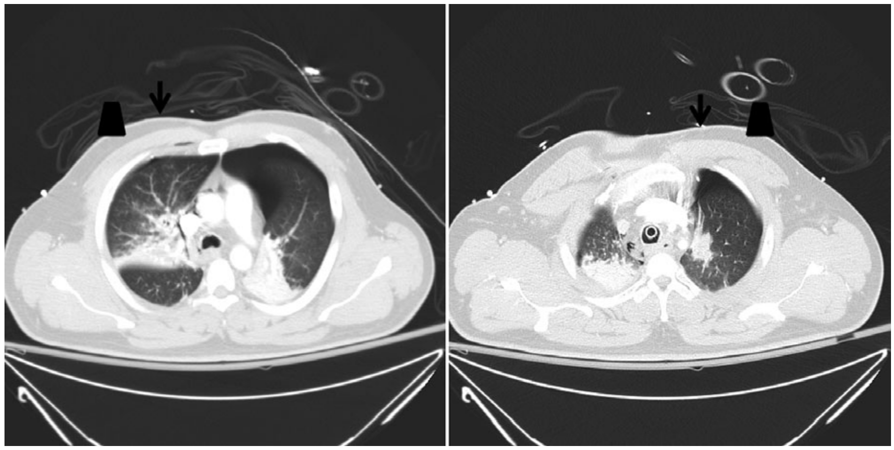

Figure 3. Images of chest CT from the missed significant PTX. The image on the left shows the patient's right lung still adjacent to the anterior chest wall. The PTX on this side was lower. You can see the beginning of it in the image. The image on the right shows the patient's left lung adjacent laterally. Transducer placement in this patient was at this location secondary to the needle decompression in place more medially. The arrow indicates the site of the needle decompression on each side of the chest and the trapezoid indicates the site where the ultrasound was performed. CT = computed tomography; PTX = pneumothorax.

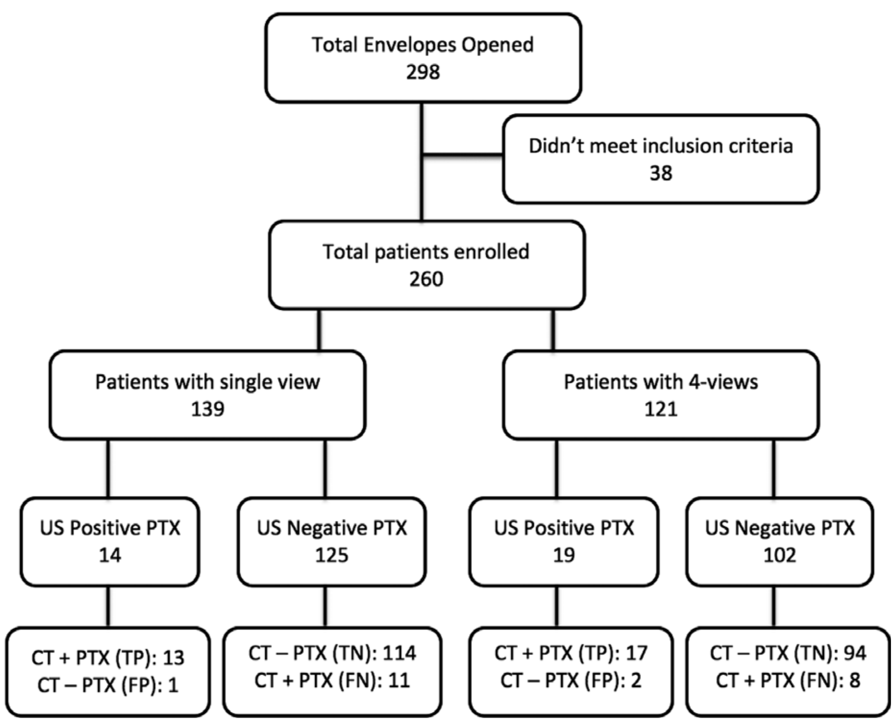

Figure 4. STARD diagram. FN = false negative; FP = false positive; PTX = pneumothorax; TN = true negative; TP = true positive.

additional advantage of being able to attempt to quantify the size of the PTX. The potential negative of performing eight views instead of two views during the eFAST is one of timing, in that it takes longer to get the additional views while adding no diagnostic value.

In this study we noted that needle decompression may cause focal approximation of the parietal and visceral pleura, resulting in a false negative, as discussed in the results. This patient was not excluded because it is not our practice to assume that patients who have received this procedure prehospital have, or ever had, a PTX. In a study examining prehospital needle thoracostomy (NT), two NTs were found to have not penetrated into the thorax, with the catheter tip still in the soft tissue. Two patients received NTs despite the absence of any chest injuries found upon operative intervention, resulting in two iatrogenic PTXs.[15] Therefore, patients who have undergone needle decompression prior to presenting to the ED may benefit from additional views of the chest wall for further evaluation.

LIMITATIONS

This study was conducted at a single center with a standard prehospital approach to spinal immobilization that results in placement of patients supine on a long board.

In areas where this approach may differ (e.g., patients arrive semirecumbent or upright), the positioning of a PTX in the chest may be altered, rendering a single view of the anterior chest wall less accurate than was found in this study. As this study was a convenience sample that required the treating physician to remember to enroll the patient and randomize them prior to performing the US, there is a possibility of selection bias. There were large number of CT scans that were read as "tiny pockets of air" resulting in a large number of insignificant PTXs that were not detected by US. As such, our data resulted in a wide CI for the sensitivities of the single- and four-view USs in the detection of a PTX.

CONCLUSIONS

The sensitivities are equivalent for both a single view and four views of each hemithorax when using point-of-care ultrasound to evaluate for a clinically significant pneumothorax in the trauma population. The additional time required for additional views should be weighed against the lack of additional diagnostic accuracy when evaluating critically ill and time-sensitive trauma patients in the ED.

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