# Not so FAST—Chest ultrasound underdiagnoses traumatic pneumothorax

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**BACKGROUND:** Ultrasonography for trauma is a widely used tool in the initial evaluation of trauma patients with complete ultrasonography of trauma (CUST) demonstrating equivalence to computed tomography (CT) for detecting clinically significant abdominal hemorrhage. Initial reports demonstrated high sensitivity of CUST for the bedside diagnosis of pneumothorax. We hypothesized that the sensitivity of CUST would be greater than initial supine chest radiograph (CXR) for detecting pneumothorax.

**METHODS:** A retrospective analysis of patients diagnosed with pneumothorax from 2018 through 2020 at a Level I trauma center was performed. Patients included had routine supine CXR and CUST performed prior to intervention as well as confirmatory CT imaging. All CUST were performed during the initial evaluation in the trauma bay by a registered sonographer. All imaging was evaluated by an attending radiologist. Subgroup analysis was performed after excluding occult pneumothorax. Immediate tube thoracostomy was defined as tube placement with confirmatory CXR within 8 hours of admission.

**RESULTS:** There were 568 patients screened with a diagnosis of pneumothorax, identifying 362 patients with a confirmed pneumothorax in addition to CXR, CUST, and confirmatory CT imaging. The population was 83% male, had a mean age of 45 years, with 85% presenting due to blunt trauma. Sensitivity of CXR for detecting pneumothorax was 43%, while the sensitivity of CUST was 35%. After removal of occult pneumothorax (n = 171), CXR was 78% sensitive, while CUST was 65% sensitive ($p < 0.01$). In this subgroup, CUST had a false-negative rate of 36% (n = 62). Of those patients with a false-negative CUST, 50% (n = 31) underwent tube thoracostomy, with 85% requiring immediate placement.

**CONCLUSION:** Complete ultrasonography of trauma performed on initial trauma evaluation had lower sensitivity than CXR for identification of pneumothorax including clinically significant pneumothorax requiring tube thoracostomy. Using CUST as the primary imaging modality in the initial evaluation of chest trauma should be considered with caution. (*J Trauma Acute Care Surg.* 2022;92: 44–48. Copyright © 2021 American Association for the Surgery of Trauma.)

**LEVEL OF EVIDENCE:** Diagnostic Test study, Level IV.


**KEY WORDS:** Pneumothorax; ultrasound; lung; thoracic trauma; radiology.

Pneumothorax remains the most common potentially life-threatening injury in blunt thoracic trauma and can be seen in 40% to 50% of patients with thoracic trauma. The criterion standard for diagnosing traumatic pneumothorax remains thoracic computed tomography (CT),[1] but this may potentially delay diagnosis and many trauma patients are too hemodynamically unstable for CT at presentation. The Advanced Trauma Life Support Course (ATLS) indicates supine chest radiographs (CXRs) are the primary diagnostic tool to detect pneumothorax but these have low sensitivity (36–48%).[2] Ultrasonography has been a valuable diagnostic tool in the trauma patient since the 1990s with the formalization of the focused assessment with sonography for trauma (FAST), which largely replaced the need for diagnostic peritoneal lavage in the diagnosis of intraperitoneal hemorrhage.[3]

Submitted: August 28, 2021, Revised: September 27, 2021, Accepted: October 1, 2021, Published online: October 15, 2021.

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This study was presented as an oral quickshot presentation at the 80th Annual Meeting of AAST and Clinical Congress of Acute Care Surgery to be held in Atlanta, GA on September 28 to October 2, 2021.

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DOI: 10.1097/TA.0000000000003429

In recent years, we have implemented the complete ultrasonography of trauma (CUST) which includes thoracic views to rule out traumatic pneumothorax and hemothorax,[4] extended FAST (eFast), as well as complete imaging of the liver and spleen. Ultrasonography provides advantages in rapid assessment and can be performed simultaneously with the initial assessment, resuscitation, and other procedures in the trauma bay. Depending on the trauma center, these ultrasounds may be performed by an emergency medicine physician, sonographer, or trauma surgeon.

While the feasibility of ultrasound to diagnosis pneumothorax has been well described, the use of eFAST for the diagnosis of posttraumatic pneumothorax during the initial resuscitation and its use in decision making for tube thoracostomy is not yet considered standard of care.[1,5–9] While data on direct comparison between the sensitivity and specificity of eFAST and CXR in detecting pneumothorax have been limited, there have been recent, small studies showing ultrasound may be superior to CXR in the diagnosis of pneumothorax.[10–15]

We use a protocol that incorporates a trained, registered sonographer to obtain CUST including eFAST views and provides the opportunity to evaluate high-quality imaging to determine the utility of ultrasound in detecting pneumothorax in the trauma bay. We hypothesized that the sensitivity of CUST would be greater than initial supine CXR for detecting traumatic pneumothorax.

## PATIENTS AND METHODS

This is a retrospective study of a Level I trauma center registry to identify all patients with a diagnosis of pneumothorax from 2018 through 2020. Patients included had routine supine CXR and CUST performed prior to any intervention as well as confirmatory CT chest imaging. Patients who did not receive routine CUST or had thoracostomy tube placement prior to initial CUST were excluded. The electronic health record was reviewed for diagnosis, procedural interventions, and imaging reports. Imaging was reviewed in Agfa IMPAX for positive and negative findings, and the imaging reports were subsequently verified in the electronic health record. Images were reviewed for pneumothorax on CXR, ultrasound, CT C-spine, and if available chest CT (see Fig. 1).

Complete ultrasonography of trauma examinations were performed during the trauma resuscitation by American Registry of Diagnostic Medical Sonography–registered sonographers with 1 year to 20 years of experience. Probes used were 2.25-MHz, 3.5-MHz, or 5.0-MHz sector transducers or 5.0-MHz curved-array transducers with full-sized US machines (ATL HDI 3000; Advanced Technologies Laboratories, Bothell, WA, or Acuson Model 128-XP; Siemens Medical Solutions USA, Inc., Malvern, PA) using our previously described protocol.[4] Complete ultrasonography of trauma is a more comprehensive examination than eFAST. Seven abdominal regions were examined by the sonographer for fluid, including bilateral upper quadrants, epigastrium, pelvis, both paracolic gutters, and retroperitoneum. Visceral organs including kidneys, liver, and spleen were also evaluated for parenchymal abnormalities. Cardiac views were obtained to evaluate for fluid in the pericardial sac. Complete ultrasonography of trauma scanning time was typically 3 minutes to 5 minutes. All CUST examinations included the eFAST standard four views (right upper quadrant, left upper quadrant, pelvis, and pericardial) as well as four thoracic views in each hemithorax (two anterior views and two lateral views at two different intercostal spaces on each side). The trauma team observes the CUST imaging and notes any concerning findings, including the absence of a "sliding sign" in the thoracic view to suggest a possible pneumothorax. In the case of pneumothorax, we examined for a "barcode" or "stratosphere" sign on M-mode because of the presence of air between the visceral and parietal pleural layers. All CUST images are then uploaded to PACS and reviewed by an attending radiologist for preliminary and final interpretations in real time. All images undergo formal QI review by the Department of Radiology to ensure quality images are obtained and standards are met.

Additional variables obtained included patient demographics; age, sex and body mass index (BMI). The physiologic parameters admission systolic blood pressure and heart rate were obtained. In addition, Injury Severity Score mechanism of injury was categorized as blunt or penetrating were obtained. We defined occult pneumothorax as one visible only on the CT scan and not visible on CXR or CUST.

Statistical analyses were performed using IBM SPSS Statistics Version 27 (IBM Corp). Data are shown as mean ± standard deviation or median [interquartile range). Comparisons of categorical variables were conducted using Pearson's $\chi^2$ test or Fisher's exact test if any expected value was less than five. Continuous variables were compared using the Mann-Whitney $U$ test or independent samples $t$ test to compare false-negative and positive CUST. $p$ Values less than 0.05 were considered statistically significant. A subgroup analysis was performed after removal of occult pneumothorax. Occult pneumothorax was

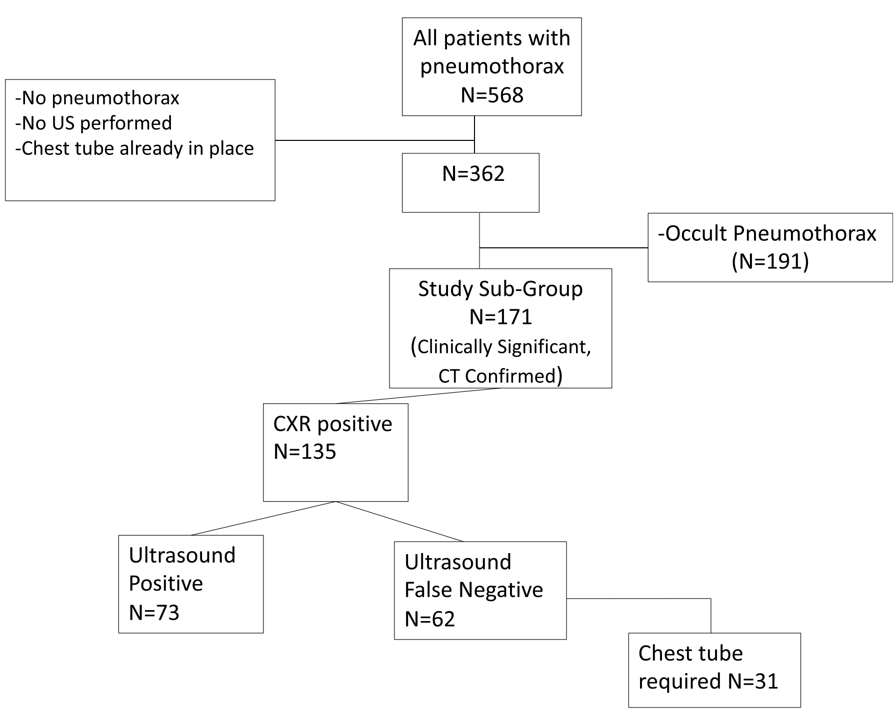


**Figure 1.** Study design and distribution of patients for initial CUST imaging.

**TABLE 1.** Demographic of Patients Screened by CUST

| | |
|---|---|
| N | 362 |
| Age (y) | 46 ± 20 |
| Male sex | 84% |
| BMI | 26 ± 6 |
| SBP (mm Hg) | 129 ± 30 |
| Heart rate (bpm) | 94 ± 22 |
| ISS | 19 ± 14 |
| Mechanism of injury | |
| Blunt | 87% |
| Penetrating | 13% |

ISS, Injury Severity Score; SBP, systolic blood pressure.

**TABLE 3.** Comparison of Patients With False-Negative and Positive CXR Examinations With CT-Confirmed Pneumothorax Including Occult Pneumothorax

| | False-Negative CUST | Positive CUST | *p* |
|---|---|---|---|
| n | 206 | 156 | |
| Age, median (y) | 41 | 41.5 | 0.729 |
| Sex | Male, 160; Female, 46 | Male, 126; Female, 30 | 0.473 |
| BMI | 25.9 | 26.8 | 0.990 |
| SBP, median (mm Hg) | 130 | 130 | 0.795 |
| Heart rate, median (bpm) | 88 | 94 | 0.064 |
| ISS, median | 14 | 14 | 0.239 |
| Mechanism of injury | | | 0.612 |
| Blunt | 178 | 133 | |
| Penetrating | 28 | 23 | |

defined as a small pneumothorax identified only on CT scan and not noted on either CXR or CUST.

In preparation of this article, the STROBE guidelines for observational study were applied.

## RESULTS

There were 568 patients identified with a diagnosis of pneumothorax, of these, we included 362 patients who underwent a CXR, CUST, and confirmatory CT. This study population, seen in Table 1, was 83% male with a mean age of 45 ± 20 years. The distribution of injury types in these patients was 87% with blunt trauma and 13% with penetrating trauma.

Including all patients, the diagnosis of pneumothorax was made using CUST in 126 patients (35%), CXR in 155 patients (43%), and CT in 100% of patients. These findings demonstrated a sensitivity of 35% in CUST with a false-negative rate of 65% and a sensitivity of 43% in CXR with a false negative rate of 57%, which can be seen in Tables 2 and 3. On closer review, 191 of these patients were determined to have an occult pneumothorax the majority of which were small apical pockets of air or blebs and thus were excluded from further analysis, leaving 171 patients.

After removal of occult pneumothorax, the sensitivity of CXR for detecting pneumothorax increased to 78% with a false-negative rate of 22% (see Table 4) and CUST increased to 65% sensitivity ($p < 0.01$). The false-negative rate of CUST was 36% (n = 62). Of those patients with a false negative CUST, 50% (n = 31) underwent tube thoracostomy, with 85% of those patients treated with chest tube placement within 8 hours of admission (see Table 5, Fig. 1). We examined the demographics of patients with false negative CUST vs. positive CUST who had both positive CXR and positive CT. Patients with a false negative CUST were younger compared with patients with positive CUST for pneumothorax. Body mass index and mechanism of injury (blunt vs. penetrating) did not differ between groups (Table 3).

## DISCUSSION

Our study of enhanced trauma ultrasound is the first to contradict recent work suggesting the superiority of ultrasound to CXRs for the initial assessment of blunt trauma patients. These results demonstrated that supine CXR had higher sensitivity in detecting clinically significant pneumothorax than CUST during the initial trauma evaluation. The high false-negative rate associated with CUST is concerning as we found that many of these missed pneumothoraces required chest tube placement early in their hospital course. These data challenge the idea that CUST or eFAST may replace CXR in the ATLS recommended initial workup of blunt trauma patients.

**TABLE 2.** Comparison of Patients With False-Negative and Positive CUST Examinations With CT-Confirmed Pneumothorax Including Occult Pneumothorax

| | False-Negative CUST | Positive CUST | *p* |
|---|---|---|---|
| n | 235 | 127 | |
| Age, median (y) | 38 | 46 | 0.025 |
| Sex | Male, 179; Female, 56 | Male, 107; Female, 20 | 0.072 |
| BMI | 25.6 | 26.9 | 0.520 |
| SBP, median (mm Hg) | 130 | 126 | 0.457 |
| Heart rate, median (bpm) | 90 | 92 | 0.937 |
| ISS, median | 17 | 14 | 0.031 |
| Mechanism of injury | | | 0.612 |
| Blunt | 209 | 102 | |
| Penetrating | 26 | 25 | |

**TABLE 4.** Comparison of Patients With False-Negative and Positive CXR Examinations With CT-Confirmed Clinically Significant Pneumothorax

| | False-Negative CXR | Positive CXR | *p* |
|---|---|---|---|
| n | 36 | 135 | |
| Age, median (y) | 55 | 43 | 0.382 |
| Sex | Male, 33; Female, 3 | Male, 144; Female, 27 | 0.597 |
| SBP, median (mm Hg) | 124 | 130 | 0.359 |
| Heart rate, median (bpm) | 88 | 92 | 0.21 |
| BMI, median | 25.8 | 25.9 | 0.722 |
| ISS, median | 14 | 14 | 0.258 |
| Mechanism of injury | | | 0.238 |
| Blunt | 29 | 121 | |
| Penetrating | 7 | 13 | |

**TABLE 5.** Comparison of Patients with False-Negative and Positive CUST Examinations With CT-Confirmed Clinically Significant Pneumothorax

| | False-Negative CUST | Positive CUST | *p* |
|---|---|---|---|
| n | 62 | 109 | |
| Age, median (y) | 37 | 46 | 0.02 |
| Sex | Male, 51; Female, 11 | Male, 93; Female, 16 | 0.597 |
| BMI | 24.9 | 26.2 | 0.285 |
| SBP, median (mm Hg) | 129 | 129 | 0.809 |
| Heart rate, median (bpm) | 91 | 89 | 0.279 |
| ISS, median | 17 | 14 | 0.369 |
| Mechanism of injury | | | 0.612 |
| Blunt | 56 | 94 | |
| Penetrating | 6 | 14 | |
| Thoracostomy | 31 (50%) | 85 (78%) | <0.001 |

Ultrasonography is largely recognized as an appropriate screening modality in trauma that can be accomplished with much lower cost and delay in diagnosis compared with routine CT scanning. Complete ultrasonography of trauma has been shown to be equivalent in sensitivity and specificity to routine CT of the abdomen and pelvis in screening for blunt abdominal trauma with 42% less radiation exposure and less cost.[4] Several recent studies support a higher sensitivity of transthoracic ultrasound to supine AP CXR in the diagnosis of pneumothorax. Blaivas et al.[12] found that the sensitivity for ultrasound was 98.1%, while the sensitivity for CXR was 75.5%. In this prospective, single-blinded study of 53 blunt trauma patients with pneumothorax, all ultrasound examinations were performed by attending emergency physicians to determine the presence of a sliding lung sign to rule out pneumothorax. A review article by Alrajab et al.[11] included 13 articles (1,514 patients) with a pooled sensitivity of ultrasound at 78.6% and CXR at 39.8%. They concluded that emergency physicians performed better ultrasounds than nonemergency physicians (sensitivity, 82.3% vs. 72.8%), emphasizing the effect of the operator-dependent nature of ultrasound examinations. Another meta-analysis by Ebrahimi et al. [14]included 28 articles representing 5,314 patients showing a pooled sensitivity of thoracic eFAST of 87% and pooled sensitivity of CXR of 46%. In this study, the nontrauma setting and performing eFAST by emergency physicians were associated with higher sensitivity of ultrasound in diagnosing pneumothorax. The pooled sensitivity of eFAST performed by an emergency physician was 88%. When looking at the studies included more closely, they were performed between the years 1999 and 2014. Of the 28 studies, 9 were not performed on trauma patients. Of the 19 performed on trauma patients, only 10 were performed as consecutive examinations with the remaining being performed with selection bias based on convenience. In the 10 studies with consecutive examinations on trauma patients, no examinations were performed by a trauma team, and all but two studies had less than 50 patients, leading to a concern about the generalizability of these results.

One reason our results differ from other published studies may be because of the unique infrastructure at our trauma center. A dedicated sonographer performs a CUST examination on all patients and images are reviewed in real time by the trauma attending and also sent to the radiology department for immediate evaluation. Another explanation for our results may be that in a nonstudy environment, such as ours, the pleural views were not universally performed with the same rigor as in a prospective study designed specifically to detect pneumothorax. However, the CUST examinations were performed by an experienced group of registered sonographers in an academic setting with a history of ultrasound trials, so we think the CUST examinations were technically proficient. Given the expertise of the registered sonographer, the real-time radiologist interpretation, and the regularity that we perform this examination, we think that our study has given true evaluation on the sensitivity of chest ultrasound what it would mean to replace CXR in the ATLS algorithm as the routine screening examination. In addition, we think it would be difficult to replicate the quality of these CUST examinations in a system without access to trained sonographers and radiologic interpretation.

Our study represents the largest study to compare CXR and ultrasound during the initial evaluation in patients with traumatic pneumothorax. In an attempt to explain our findings, we closely examined the positive and negative CUST groups. Previous reports do not describe patient BMI, and we postulated that perhaps elevated BMI could contribute to increased rate of false-negative CUST. We found no difference in the performance of CUST to detect pneumothorax based on BMI. We did find that younger patients were more likely to have a false negative CUST examination. To our knowledge, this has not been previously reported and represents an interesting finding for future exploration.

It is important to emphasize that both CXR and ultrasound failed to identify many clinically significant pneumothoraces. We found that in the patients who had a false-negative chest ultrasound (35%), many still required an intervention. A possible explanation may be because of the variation in location of the pneumothorax or expansion of an occult pneumothorax after the CUST is performed. To ensure chest tubes were being placed for appropriate reason and in a standardized fashion, we reviewed all of the images individually. Using the methods described by Eddine et al.[16] we measured all of the pneumothoraces on CT scan in the axial view requiring chest tube placement. We found that the average pneumothorax requiring chest tube in the occult pneumothorax group was 24.5 mm. In our subgroup of clinically significant pneumothoraces, the average size in the false-negative CXR group as measured on CT was 38.8 mm and was 38.3 mm in the false-negative CUST group. Looking closely at all three groups many of these tubes were placed following a repeat interval CXR (typically 1–6 hours after initial examination) where there was significant expansion noted. This finding demonstrates the importance of maintaining a high level of clinical suspicion for an underlying pneumothorax even in patients with negative screening examinations.

Our study has several limitations. It is a single-center retrospective study, and all imaging reports and procedural findings were obtained from the electronic medical record. This study includes all patients who were admitted to the trauma service; however, some patients were initially evaluated in the emergency department rather than in our trauma center and received slightly delayed ultrasound imaging. Because of the retrospective nature of this study, many of the imaging reports did not comment on the presence or absence of pneumothorax and were not included in this study. Patients who did not have confirmatory CT scan were also removed from the study, ultimately limiting our study sample size and possibly creating a selection bias. Lastly, our initial population for this retrospective study was obtained by identifying patients diagnosed with pneumothorax, therefore, there were no false-positive examinations, and thus we were unable to calculate a specificity.

Since the implementation of the eFAST with thoracic views, recent literature supports the use of thoracic ultrasound in diagnosing traumatic pneumothorax. These data question the reliability of thoracic ultrasound to replace CXR at the time of initial trauma survey. The sensitivity of CXR was 78% compared with 65% with CUST in CT-confirmed cases of traumatic pneumothorax with 50% of the pneumothorax missed on CUST requiring tube thoracostomy. The use of chest ultrasound as the sole primary imaging modality in the initial evaluation of thoracic trauma should be evaluated with caution.

## AUTHORSHIP

J.E.S. contributed in the literature search, study design, data analysis, data interpretation, and writing. H.C. contributed in the literature search, data collection, data analysis, and writing. L.G. contributed in study design and critical revision. G.C. contributed in the study design and data analysis. J.J. D. contributed in the study design, data collection, data analysis, and critical revision. T.W.C. contributed in the literature search, study design, data collection, data analysis, data interpretation, writing, and critical revision.

## DISCLOSURE

The authors declare no conflicts of interest.

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