Sensitivity of Bedside Ultrasound and Supine Anteroposterior Chest Radiographs for the Identification of Pneumothorax After Blunt Trauma

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Abstract

Objectives: Supine anteroposterior (AP) chest radiographs in patients with blunt trauma have poor sensitivity for the identification of pneumothorax. Ultrasound (US) has been proposed as an alternative screening test for pneumothorax in this population. The authors conducted an evidence-based review of the medical literature to compare sensitivity of bedside US and AP chest radiographs in identifying pneumothorax after blunt trauma.

Methods: MEDLINE and EMBASE databases were searched for trials from 1965 through June 2009 using a search strategy derived from the following PICO formulation of our clinical question: patients included adult (18 + years) emergency department (ED) patients in whom pneumothorax was suspected after blunt trauma. The intervention was thoracic ultrasonography for the detection of pneumothorax. The comparator was the supine AP chest radiograph during the initial evaluation of the patient. The outcome was the diagnostic performance of US in identifying the presence of pneumothorax in the study population. The criterion standard for the presence or absence of pneumothorax was computed tomography (CT) of the chest or a rush of air during thoracostomy tube placement (in unstable patients). Prospective, observational trials of emergency physician (EP)-performed thoracic US were included. Trials in which the exams were performed by radiologists or surgeons, or trials that investigated patients suffering penetrating trauma or with spontaneous or iatrogenic pneumothoraces, were excluded. The methodologic quality of the studies was assessed. Qualitative methods were used to summarize the study results. Data analysis consisted of test performance (sensitivity and specificity, with 95% confidence intervals [CIs]) of thoracic US and supine AP chest radiography.

Results: Four prospective observational studies were identified, with a total of 606 subjects who met the inclusion and exclusion criteria. The sensitivity and specificity of US for the detection of pneumothorax ranged from 86% to 98% and 97% to 100%, respectively. The sensitivity of supine AP chest radiographs for the detection of pneumothorax ranged from 28% to 75%. The specificity of supine AP chest radiographs was 100% in all included studies.

Conclusions: This evidence-based review suggests that bedside thoracic US is a more sensitive screening test than supine AP chest radiography for the detection of pneumothorax in adult patients with blunt chest trauma.

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Keywords: emergency ultrasound, pneumothorax, traumatic pneumothorax, chest radiography

CLINICAL SCENARIO

You are an attending physician in a Level 2 trauma center. During your shift, paramedics bring in a 22-year-old male who fell from scaffolding and complains of chest pain and dyspnea. He is obese and you do not appreciate asymmetric breath sounds or crepitus on physical examination. You call for a portable chest radiograph but the technician is in the intensive care unit and you anticipate a 10-minute delay. Your colleague explains that she has previously used ultrasound (US) to detect pneumothoraces and after evaluating the patient with US determines that a pneumothorax is present on the right side. The patient is hemodynamically stable and there is no clinical evidence of tension pneumothorax. The chest radiograph confirms your

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colleague's initial impression. After you perform a right tube thoracostomy and admit your patient to the trauma service, you decide to review the evidence on the topic and evaluate whether you should use this diagnostic approach in your future trauma cases. The following evidence-based medicine review seeks an answer to the question prompted by this scenario.

INTRODUCTION

During the initial evaluation of a trauma patient, a supine anteroposterior (AP) chest radiograph is traditionally obtained to evaluate for thoracic injury. Although spine immobilization mandates that patients are kept supine for image acquisition, supine AP chest radiograph has been reported to have very poor sensitivity for the detection of pneumothorax—as low as 36% to 48% in some studies.[1–4] Computed tomography (CT) remains the criterion standard for the diagnosis of pneumothorax. Although patients with small pneumothoraces may be treated conservatively, it is important to know if a pneumothorax of any size exists in a trauma patient. Although recent data suggest that patients with radiooccult pneumothoraces (a pneumothorax detected by CT, but absent on chest radiography) may tolerate positive pressure ventilation, some patients experience progression of their pneumothoraces and/or tension physiology requiring tube thoracostomy.[5] In addition, emergency physicians (EPs) may need to arrange for air transport for victims of blunt trauma with radiooccult pneumothoraces, and tube thoracostomy may be considered prior to transport in these patients.

The use of US to diagnose pneumothorax was first described in a veterinary medical journal in 1986.[6] The following year, Wernecke et al.[7] described sonographic recognition of pneumothoraces in human subjects on the basis of absence of pleural sliding and comet tail artifacts. A typical US examination for pneumothorax involves the use of transthoracic B-mode (grayscale) imaging and a high- or low-frequency US transducer applied to the patient's anterior and lateral chest wall. The primary goal is to visualize sliding of the lung at the pleural line. Pleural sliding is the to-and-fro movement of the visceral pleura against the parietal pleura during respiration (Video Clip S1, available as supporting information in the online version of this paper) and the presence of pleural sliding excludes the diagnosis of pneumothorax at that location on the chest wall. There are several additional sonographic findings that are relevant to the pneumothorax examination. Comet tail artifacts (also known as B-lines or lung rockets) are vertical hyperechoic lines that arise from the pleural line and extend to the outermost edge of the image, move with respiration, and erase the physiologic horizontal "A-line" artifacts seen in normal lungs. These B-lines may be present in cases of alveolar–interstitial edema (Video Clip S2) or in smaller numbers in normal subjects. The presence of B-lines also excludes the diagnosis of pneumothorax at that location on the chest wall. Additionally, the lung point sign can be encountered. This is the alternating phenomenon of lung sliding and absent lung sliding in the same interspace, representing the movement of the lung at the border of the pneumothorax (Video Clip S3), and confirms the presence of a pneumothorax.[8] Patients are best examined while supine, as the free thoracic air associated with a pneumothorax will rise to the anterior chest wall at the location where the exam is performed. The study is performed at the bedside, without the need to transport the patient and may be repeated as often as clinically indicated.

In formulating this review, we investigated the following question: in emergency department (ED) patients suspected of having pneumothorax after blunt chest trauma, what is the sensitivity and specificity of bedside US compared to supine AP chest radiography in identifying pneumothorax?

Criteria for Considering Studies for the Review

This evidence-based review was confined to prospective observational trials that compared diagnostic performance of bedside transthoracic US by EPs to portable supine AP chest radiographs obtained during the initial evaluation of blunt trauma patients in the ED.

Most centers do not have 24-hour on-call US technicians and/or radiologists who routinely perform transthoracic US examination for the detection of pneumothorax. In addition, the majority of EDs do not have an in-house trauma surgeon trained in thoracic sonography who is available to evaluate trauma victims initially upon arrival. To ensure that included studies remained within the scope of practice of EPs, studies in which US examinations were performed by surgeons or radiologists were excluded.

Participants. We included studies that enrolled adult ED patients in whom pneumothorax was suspected after blunt trauma.

Intervention. Thoracic ultrasonography was performed by EPs for the detection of pneumothorax.

Comparator. Supine AP chest radiography was performed during the initial evaluation of the patient.

Outcome. The primary outcome measure was the diagnostic performance of US in identifying the presence of pneumothorax in the study population. We considered CT of the chest or presence of a rush of air after tube thoracostomy insertion (in unstable patients) as the criterion standard for confirmation of pneumothorax.

Target Study Design. We included trials that were prospective and observational and included US examinations performed by EPs.

METHODS

We searched the MEDLINE database with the OVID interface from 1965 to June 2009 and EMBASE from 1980 to June 2009, using search terms "pneumothorax," "traumatic pneumothorax," "ultrasound," and "sonography." For the detailed search strategy see the Appendix S1 (available as supporting information in the online version of this paper). The MEDLINE search was limited to human studies, but there was no language restriction. We also scanned the databases of the Cochrane Library through 2009, Emergency Medical Abstracts from 1977 through May 2009, and online resources including BestBETS, using the search words "pneumothorax" and "ultrasound." The bibliographies of the eligible trials were reviewed for citations of potentially eligible studies not identified by the search.

These databases yielded a total of 208 citations. The process by which clinical trials were selected or excluded is presented in Figure 1. Each author reviewed the studies to determine whether they met inclusion criteria. After the selection criteria were applied, four studies were included in the final review.[9–12] Two reviews in the BestBETS database[13,14] and one unstructured review[15] were also identified. Only one of the four trials identified by our search (Blaivas et al., 2005[10]) was referenced in these reviews. One BestBET review[13] included surgeon-performed US studies; the other BestBET review[14] included patients with pneumothorax after lung biopsy, as well as patients with posttraumatic pneumothoraces. The unstructured review was conducted in 2003, prior to the four trials identified by our search strategy. These reviews did not provide any additional studies to be included in this review.

The four included trials were read in their entirety and statistical analysis of prevalence, sensitivity, specificity, and likelihood ratios was performed using VassarStats Statistical Calculator (Poughkeepsie, NY). Both authors independently abstracted the data and each author's results were checked for accuracy by the other author.

There are several high-quality studies that did not meet our inclusion and exclusion criteria and thus were not included in our review. The first study, by Rowan et al. in 2002,[1] was a prospective, blinded study of 27 patients with blunt thoracic trauma who received transthoracic US, supine AP chest radiographs, and thoracic CT. The US examinations were performed by either a staff radiologist or a radiology resident, and therefore this study was excluded from our review. The second study by Lichtenstein et al.[16] was a retrospective study of 197 intensive care unit patients who received transthoracic US, supine AP chest radiographs, and thoracic CT. The US was performed by an experienced intensivist and the study was not limited to trauma patients and was therefore excluded from our review. A third study by Kirkpatrick et al.[17] was a prospective, blinded study of 225 patients with acute blunt or penetrating trauma who received transthoracic US, supine AP chest radiographs, and thoracic CT. The US examinations were performed by an attending trauma surgeon, and the study was therefore excluded from our review.

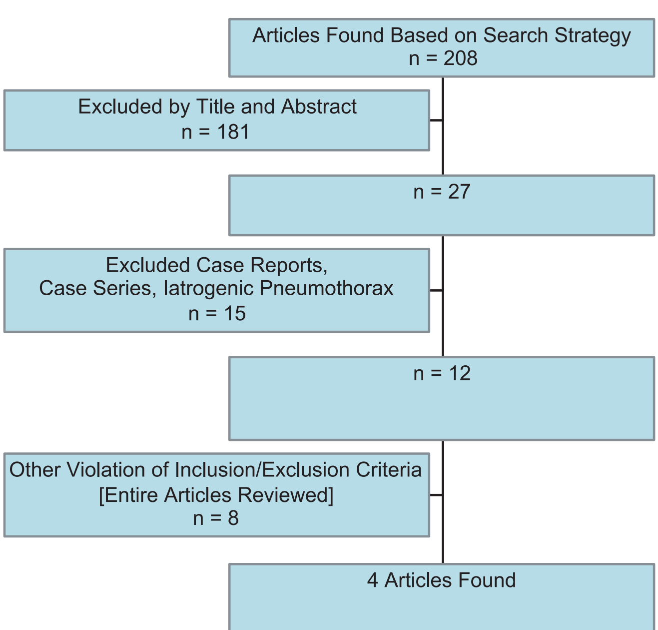

Figure 1. Flow chart illustrating process for selection and exclusion of identified trials.

Quality Assessment of the Included Studies

Methodologic quality assessment of each of the included studies was performed using the Quality Assessment of Studies of Diagnostic Accuracy (QUADAS) guidelines.[18,19] This tool was designed to assess studies for potential for bias, applicability, and quality of reporting. This tool consists of a 14-item checklist, each rated as yes, no, or unclear. Each item is presented in Table 1, and a weighted scoring system was not used.[20] The average number of affirmative items was 13.25 out of a possible 14 (range = 12–14). Noted methodologic concerns include unclear applicability of the study by Blaivas et al.[10] due to lack of reporting of patient characteristics. Another component that was rated negatively was the lack of reporting of the time interval between the index test and the reference standard for both the Blaivas et al.[10] and the earlier Soldati et al.[11] papers.

A second, more complicated system of quality assessment has been previously proposed: the Standards for Reporting of Diagnostic Accuracy (STARD) criteria.[21] In this initiative, a group of researchers and journal editors published a statement with the aims of improving the quality of diagnostic studies. They proposed a system of using a checklist with 25 items and the use of a flow chart in presenting data. We found that the individual items of the STARD criteria allowed too much room for interpretation. An example of this is the following item: "The number, training, and expertise of the persons executing and reading the a) index tests and b) reference standard." All four studies discussed this to varying degrees. In one study, it is only stated that "Trained EPs with over 10 years experience in emergency ultrasonography and at least one year in chest ultrasonography have contributed to this study."[11] It is not clearly stated whether individuals with these qualifications performed all studies. Because of the possibility of poor agreement we chose not to analyze the papers using this quality assessment tool.

RESULTS

Table 2 contains a summary of study characteristics for each of the trials. All studies included blunt trauma patients. In all studies, patients in whom US examinations could not be performed for any reason were excluded. Sample size was relatively uniform, preventing one study from overpowering the others in analysis. The smallest of the studies (Soldati et al., 2008[12]) enrolled 109 patients, and the largest (Soldati et al.,

Table 1
Reporting of Individual Items of the Quality Assessment of Studies of Diagnostic Accuracy (QUADAS)

Item	Blaivas et al., 2005[10]	Zhang et al., 2006[9]	Soldati et al., 2006[11]	Soldati et al., 2008[12]
1. Was the spectrum of patients representative of the patients who will receive the test in practice?	Unclear*	Yes	Yes	Yes
2. Were the selection criteria clearly described?	Yes	Yes	Yes	Yes
3. Is the reference standard likely to classify the target condition?	Yes	Yes	Yes	Yes
4. Is the time period between the reference standard and the index test short enough to be reasonably sure that the target condition did not change between the two tests?	No	Yes†	No‡	Yes§
5. Did the whole sample or a random selection of the sample receive verification using a reference standard of diagnosis?	Yes	Yes	Yes	Yes
6. Did patients receive the same reference standard regardless of the index test result?	Yes	Yes	Yes	Yes
7. Was the reference standard independent of the index test?	Yes	Yes	Yes	Yes
8. Was the execution of the index test described in sufficient detail to permit its replication?	Yes	Yes	Yes	Yes
9. Was the execution of the reference standard described in sufficient detail to permit its replication?	Yes	Yes	Yes	Yes
10. Were the index test results interpreted without knowledge of the results of the reference standard?	Yes	Yes	Yes	Yes
11. Were the reference standard results interpreted without knowledge of the results of the index test?	Yes	Yes	Yes	Yes
12. Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?	Yes	Yes	Yes	Yes
13. Were uninterpretable or intermediate test results reported?	Yes	Yes	Yes	Yes
14. Were withdrawals from the study explained?	Yes	Yes	Yes	Yes

CT = computed tomography of the chest; CXR = supine anteroposterior chest radiograph; US = thoracic lung ultrasound.
*Sex percentage stated, no description of age, presenting symptoms, or mechanism.
†US, CXR, and CT were performed in no particular order all within 3 hours of presentation.
‡All US examinations were performed within 30 minutes of admission. No discussion regarding the time interval to CXR or CT.
§US and CXR were done within 1 hour of presentation. CT was performed less than 1 hour after CXR and US exams were completed.

2006[11]) enrolled 186 patients. Males made up 66.6% of the overall study population, ranging from 57% to 84%. The prevalence of pneumothorax had moderate heterogeneity as determined by visual inspection of data plots, ranging from 11.5% to 30.1%. The two studies performed by Soldati and colleagues[11,12] were conducted during different time periods and therefore do not contain overlapping patient populations.

Transducer selection varied among the studies. Blaivas et al.[10] used a 4–2 MHz microconvex broadband transducer. Zhang et al.[9] primarily used a 3.5 MHz curvilinear probe and occasionally a 7.5 MHz linear probe. In the study by Soldati et al.[11] from 2006, a 5 MHz curvilinear probe was used. In their 2008 study, they utilized both 3.5 and 5.2 MHz curvilinear probes.[12] The superiority of one probe over another has not been established.

In all studies, EPs performing the US examinations were blinded to the results of chest radiographs and CT scans. In all studies, the radiologists interpreting the chest radiographs and CT scans were blinded to the results of the US examinations. Not all of the studies specified whether the radiologist who interpreted the chest radiograph was blinded to the CT scan results or vice versa. Two of the studies, Blaivas et al.[10] and Zhang et al.,[9] used a rush of air or bubbling in the chest drain, respectively, as surrogate criterion standards for pneumothorax in patients who were too unstable to receive a CT scan before tube thoracostomy was performed.

Table 3 compares the diagnostic performance of US for the detection of pneumothorax between the reviewed trials. The prevalence of pneumothorax showed moderate heterogeneity, and the diagnostic performance was similar among the trials. Table 4 compares the diagnostic performance of supine AP chest radiography for the detection of pneumothorax between the reviewed trials. Figures 2 and 3 are the forest plots that compare the diagnostic performance of US and supine AP chest radiography, respectively, among the included trials.

Applying the Evidence

Returning to our clinical scenario in which we questioned the evidence behind the utility of US for the detection of pneumothorax in our trauma patient, we conclude after our review of the literature that US is a more sensitive test than supine AP chest radiography for the detection of pneumothorax during the initial assessment of blunt trauma victims. Our analysis of the four trials showed a higher sensitivity of bedside US performed by EPs for the detection of pneumothorax.

Several high-quality studies were excluded because the ultrasonographers were radiologists, intensivists, or surgeons. The diagnostic performance of US for the

Table 2
Characteristics of Four Included Trials

Study	Population	Test Interpretation	Reference Standard
Blaivas et al., 2005[10]	Inclusion: blunt trauma patients receiving a FAST exam, CXR, and chest or abdominal (including lung windows) CT Exclusion: subjects in whom the US could not be completed for any reason *n* = 176 Age: >17 yr Sex: 57% male	Timing: secondary survey Operator: EPs Interpreter: EPs Assessor (of radiographs): radiologists Positive test: absence of lung sliding	Helical CT, rush of air during tube thoracostomy (unstable patients)
Soldati et al., 2006[11]	Inclusion: blunt chest trauma patients Exclusion: 1) need for immediate operative intervention, 2) chest wall injuries precluding US evaluation, 3) inability to obtain informed consent *n* = 186 Age: mean = 52 yr Sex: 63% male	Timing: initial assessment Operator: EPs Interpreter: EPs Assessor (of radiographs): radiologists Positive test: absence of lung sliding and absence of comet tail artifact	Helical CT
Zhang et al., 2006[9]	Inclusion: blunt multitrauma patients Exclusion: subjects with subcutaneous emphysema and/or cardiac arrest *n* = 135 Age: mean = 45 yr Sex: 84% male	Timing: initial assessment Operator: EPs Interpreter: EPs Assessor (of radiographs): radiologists Positive test: absence of lung sliding and absence of comet tail artifacts	Helical CT, bubbling in chest drain after tube thoracostomy (unstable patients)
Soldati et al., 2008[12]	Inclusion: blunt chest or multitrauma patients Exclusion: 1) inability to obtain consent, 2) subcutaneous emphysema, 3) need for immediate decompression, 4) need for mechanical ventilation, 5) chest wall injuries that precluded US evaluation, 6) hemodynamic instability *n* = 109 Age: mean = 41 yr Sex: 67% male	Timing: initial assessment Operator: EPs Interpreter: EPs Assessor (of radiographs): radiologist Positive test: absence of lung sliding and absence of comet tail artifacts	Helical CT

CT = computed tomography of the chest; CXR = supine anteroposterior chest radiography; FAST = focused assessment with sonography in trauma; US = ultrasound.

Table 3
Diagnostic Performance of Transthoracic US for Detection of Pneumothorax

Study	Prevalence, % (95% CI)	Sensitivity, % (95% CI)	Specificity, % (95% CI)	LR(+) (95% CI)	LR(−) (95% CI)
Blaivas et al., 2005[10]	30.1 (23.6–37.6)	98.1 (88.6–99.9)	99.2 (94.9–100)	120.7 (17.1–850.2)	0.02 (0–0.13)
Soldati et al., 2006[11]	30.1 (23.7–37.3)	98.2 (89.2–99.9)	100 (96.4–100)	Infinity	0.02 (0–0.12)
Zhang et al., 2006[9]	21.5 (15.1–29.5)	86.2 (67.4–95.5)	97.2 (91.3–99.3)	30.5 (9.9–93.8)	0.14 (0.06–0.35)
Soldati et al., 2008[12]	11.5 (7.7–16.6)	92 (72.5–98.6)	99.5 (96.7–100.0)	177.6 (25.1–1258.4)	0.08 (0.02–0.3)

LR(+) = likelihood ratio of a positive test; LR(−) = likelihood ratio of a negative test; US = ultrasound.

detection of pneumothorax, whether iatrogenic or traumatic, was similar to those found in the four trials we reviewed. Future studies should focus on elaborating the minimal training requirements necessary for the performance of thoracic sonography for the detection of pneumothorax, as the studies reviewed have considerable heterogeneity in terms of operator training and experience.

As the included studies used a limited number of operators, some with extensive US experience, it is unclear whether these results apply to other populations of EPs. To the best of our knowledge, no study to date has determined the minimum number of examinations necessary to achieve competence in this application; however, recent American College of Emergency Physicians guidelines[22] suggest that physician-sonologists should perform a minimum of 25 to 50 examinations to achieve competency.

While not studied as a primary outcome, it appears that the size and location of pneumothoraces affects the diagnostic performance of thoracic US; small,[9,11] apical,[10] and medial[12] pneumothoraces are poorly detected

Table 4
Diagnostic Performance of Supine AP Chest Radiography for Detection of Pneumothorax

Study	Prevalence, % (95% CI)	Sensitivity, % (95% CI)	Specificity, % (95% CI)	LR(+) (95% CI)	LR(−) (95% CI)
Blaivas et al., 2005[10]	30.1 (23.6–37.6)	75.5 (61.4–85.8)	100 (96.2–100)	Infinity	0.25 (0.15–0.39)
Soldati et al., 2006[11]	30.1 (23.7–37.3)	53.6 (39.9–66.8)	100 (96.4–100)	Infinity	0.46 (0.35–0.62)
Zhang et al., 2006[9]	21.5 (15.1–29.5)	27.6 (13.4–47.5)	100 (95.6–100)	Infinity	0.72 (0.58–0.91)
Soldati et al., 2008[12]	11.5 (7.7–16.6)	52 (31.8–71.7)	100 (97.6–100)	Infinity	0.48 (0.32–0.72)

AP = anteroposterior; LR(+) = likelihood ratio of a positive test; LR(−) = likelihood ratio of a negative test.

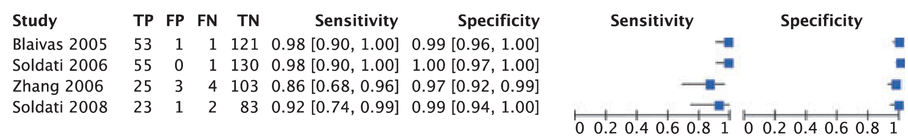

Figure 2. Forest plot illustrating the diagnostic performance of US in the included trials. FN = false negative; FP = false positive; TN = true negative; TP = true positive; US = ultrasound.

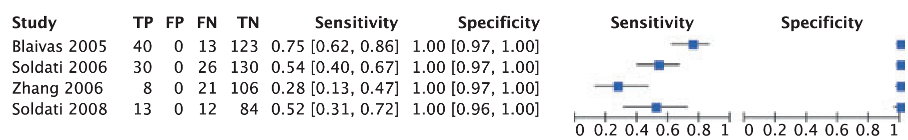

Figure 3. Forest plot illustrating the diagnostic performance of supine AP chest radiography in the included trials. AP = anteroposterior; FN = false negative; FP = false positive; TN = true negative; TP = true positive; US = ultrasound.

using thoracic US. CT detects pneumothoraces missed by ultrasonography and supine AP chest radiography, but necessitates transfer from the clinical care area and additional ionizing radiation. CT may be clinically indicated in specific patients, but these studies did not aim to identify which patients require CT.

Management of radiooccult posttraumatic pneumothorax remains controversial. While some studies suggest that patients may be observed without tube thoracostomy even while receiving positive-pressure ventilation,[5,23] other studies describe expansion of occult pneumothoraces and progression to tension physiology when conservatively managed in patients receiving positive pressure ventilation.[24] At this point, there is insufficient evidence to suggest that radiooccult pneumothoraces are of no clinical significance.

LIMITATIONS

Our review did not include a review of scientific abstracts from emergency medicine and trauma conferences. We did not directly contact study authors or other experts in an attempt to identify additional nonpublished studies that met our inclusion criteria.

Our systematic review was limited to a single outcome variable: the detection of pneumothorax in adult blunt trauma patients. We did not study the effect on patient care that early detection of radiooccult pneumothorax might provide. We did not study the diagnostic performance of US for the detection of iatrogenic pneumothorax, spontaneous pneumothorax, or pneumothorax resulting from penetrating trauma or the ability of EPs to detect other significant chest injuries (rib fractures, hemothorax, pulmonary contusions, great vessel injuries) using bedside US. As such we cannot recommend that US supplant supine AP chest radiography in the evaluation of patients suffering blunt thoracic trauma.

There are several features shared by the studies included in this review that limit their overall quality: convenience sampling, lack of interobserver agreement assessment, nonrandomized design, and exclusion of patients in whom US examinations could not be completed. Given these limitations, there is insufficient data to suggest that bedside US examinations should replace the supine AP chest radiograph or CT in the initial management of a victim of blunt trauma. None of the studies evaluated the sensitivity or specificity of serial US examinations for the detection of pneumothorax, and this may represent an area for future investigation.

CONCLUSIONS

Our evidence-based medicine review demonstrates superior sensitivity and similar specificity of EP-performed bedside ultrasound, compared to supine anteroposterior chest radiography, for the identification of pneumothorax in adults suffering blunt trauma. Future studies need to better define the effect on patient care that early identification of pneumothorax may provide and describe the minimal necessary training to accurately perform these examinations.

References

1. Rowan KR, Kirkpatrick AW, Liu D, Forkheim KE, Mayo JR, Nicolaou S. Traumatic pneumothorax detection with thoracic US: correlation with chest radiography and CT- initial experience. Radiology. 2002; 225:210–4.
2. Neff MA, Monk JS, Peters K, Nikjilesh A. Detection of occult pneumothoraces on abdominal computed tomographic scans in trauma patients. J Trauma. 2000; 49:281–5.
3. Tocino IM, Miller MH, Frederick PR, Bahr AL, Thomas F. CT detection of occult pneumothoraces in head trauma. Am J Roentgenol. 1984; 143:987–90.
4. Rhea JT, Novelline RA, Lawrason J, Sacknoff R, Oser A. The frequency and significance of thoracic injuries detected on abdominal CT scans of multiple trauma patients. J Trauma. 1989; 29:502–5.
5. Barrios C, Tran T, Malinoski D, et al. Successful management of occult pneumothorax without tube thoracostomy despite positive pressure ventilation. Am Surg. 2008; 74:958–61.
6. Rantanen NW. Diseases of the Thorax. Vet Clin N Am. 1986; 2:49–66.
7. Wernecke K, Galanski M, Peters PE, Hansen J. Pneumothorax: evaluation by ultrasound- preliminary results. J Thorac Imag. 1987; 2:76–8.
8. Lichtenstein D, Meziere G, Biderman P, Gepner A. The ''Lung Point'': an ultrasound sign specific to pneumothorax. Int Care Med. 2000; 26:1434–40.
9. Zhang M, Liu Z, Yang J, et al. Rapid Detection of Pneumothorax by Ultrasound in Patients with Multiple Trauma. Crit Care. 2006; 10:844–9.
10. Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. Acad Emerg Med. 2005; 12:844–9.
11. Soldati G, Testa A, Pignataro G, et al. The ultrasonographic deep sulcus sign in traumatic pneumothorax. Ultrasound Med Biol. 2006; 32:1157–63.
12. Soldati G, Testa A, Sher S, et al. Occult Traumatic Pneumothorax: Diagnostic Accuracy of Lung Ultrasonography in the Emergency Department. Chest. 2008; 133:204–11.
13. Jaffer U, McAuley D. Transthoracic ultrasonography to diagnose pneumothorax in trauma. Emerg Med J. 2005; 22:504–5.
14. Carley S. Is ultrasound or chest X-ray best for the diagnosis of pneumothorax in the emergency department? Emerg Med J. 2009; 26:434–5.
15. Chan SSW. Emergency bedside ultrasound to detect pneumothorax. Acad Emerg Med. 2003; 10:91–4.
16. Lichtenstein DA, Meziere G, Lascois N, et al. Ultrasound diagnosis of occult pneumothorax. Crit Care Med. 2005; 33:1231–8.
17. Kirkpatrick AW, Sirois M, Laupland KB. Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the extended focused assessment with sonography for trauma (EFAST). J Trauma. 2004; 57:288–95.
18. Whiting P, Rutjes AW, Reitsma JB, Bossuyt PM, Kleijnen J. The development of QUADAS: a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. BMC Med Res Methodol. 2003; 3:25.
19. Whiting PF, Weswood ME, Rutjes AW, Reitsma JB, Bossuyt PN, Kleijnen J. Evaluation of QUADAS, a tool for the quality assessment of diagnostic accuracy studies. BMC Med Res Methodol. 2006; 6:9.
20. Whiting P, Harbord R, Kleijnen J. No role for quality scores in systematic reviews of diagnostic accuracy studies. BMC Med Res Methodol. 2005; 5:19.
21. Bossuyt PM, Reitsma JB, Bruns DE, et al. The STARD statement for reporting studies of diagnostic accuracy: explanation and elaboration. Ann Int Med. 2003; 138:W1–W12.
22. American College of Emergency Physicians. Policy Statement. Emergency ultrasound guidelines. Ann Emerg Med. 2009; 53:550–70.
23. Wilson H, Ellsmere J, Talon J. Occult pneumothorax in the blunt trauma patient: tube thoracostomy or observation? Injury. 2009; 40:928–31.
24. Enderson BL, Abdalla R, Frame SB. Tube thoracostomy for occult pneumothorax: a prospective randomized study of its use. J Trauma. 1993; 35:726–30.

Supporting Information

The following supporting information is available in the online version of this paper:

Video Clip S1. Sliding of the lung at the pleural line.

Video Clip S2. Alveolar–interstitial edema.

Video Clip S3. Movement of the lung at the border of the pneumothorax.

The video clips are in QuickTime.

Appendix S1. Detailed search strategy.

The document is in Microsoft Word.

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