



Test Characteristics of Ultrasonography for the Detection of Pneumothorax

A Systematic Review and Meta-analysis

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Background: A pneumothorax is a potentially life-threatening condition. Although CT scan is the reference standard for diagnosis, chest radiographs are commonly used to rule out the diagnosis. We compared the test characteristics of ultrasonography and supine chest radiography in adult patients clinically suspected of having a pneumothorax, using CT scan or release of air on chest tube placement as reference standard.

Methods: We searched for English literature in MEDLINE and EMBASE and performed hand searches. Two independent investigators used standardized forms to review articles for inclusion, quality (QUADAS tool), and data extraction. We calculated κ agreement for study selection and evaluated clinical and quality homogeneity before meta-analysis.

Results: We reviewed 570 articles and selected 21 for full review (κ , 0.89); eight articles (total of 1,048 patients) met all inclusion criteria (κ , 0.81). All studies but one used the ultrasonographic signs of lung sliding and comet tail to rule out pneumothorax. Chest radiography data were available for 864 of 1,048 patients evaluated with ultrasonography. Ultrasonography was 90.9% sensitive (95% CI, 86.5-93.9) and 98.2% specific (95% CI, 97.0-99.0) for the detection of pneumothorax. Chest radiography was 50.2% sensitive (95% CI, 43.5-57.0) and 99.4% specific (95% CI, 98.3-99.8).

Conclusions: Performance of ultrasonography for the detection of pneumothorax is excellent and is superior to supine chest radiography. Considering the rapid access to bedside ultrasonography and the excellent performance of this simple test, this study supports the routine use of ultrasonography for the detection of pneumothorax. *CHEST 2012; 141(3):703-708*

Abbreviations: NPV = negative predictive value; PPV = positive predictive value

Pneumothoraces can occur spontaneously, as a result of trauma, or from iatrogenic causes such as central IV line insertion, thoracentesis, and lung biopsy. A recently published systematic review demonstrated

that thoracentesis resulted in a 6.0% rate of pneumothorax, 34.1% of which required a therapeutic chest tube insertion.¹ Pneumothoraces can quickly develop into medical emergencies and have significant morbidity and mortality.² In particular, missed pneumothoraces can expand in patients undergoing positive pressure ventilation or in those being transported by air at high altitude. The reference standard for the diagnosis of pneumothorax is CT scan. However, accessibility, cost, and radiation exposure often limit its use.

Chest radiographs are more commonly used to both make and rule out the diagnosis of pneumothorax in the setting of trauma or after invasive medical procedures. However, the reliability of chest radiographs is limited, particularly in the supine patient in whom up to 30% of pneumothoraces are missed.³⁻⁵ Ultrasonography has been described as being possibly

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more accurate than chest radiography.⁶ The first documented use of ultrasound to identify a pneumothorax was in 1986.⁷ Several ultrasound signs have been described to diagnose pneumothorax. Lung sliding sign⁸ refers to the appearance of the hyperechoic line that represents the interface of the visceral and parietal pleura, the pleural line. In normal subjects, a sliding motion can be appreciated at that interface as the visceral and parietal pleura rub during respiration. In pneumothorax, the presence of air in the pleural space prevents the visualization of the visceral pleura, leaving only the parietal pleura visible, with no sliding motion detected despite respiration. Another commonly used sign uses the comet-tail artifacts.⁹ These are reverberation artifacts that appear as a hyperechoic vertical ray that extends from the pleural line to the end of the screen. More information about the technique and images can be found in the review article by Volpicelli.¹⁰ As part of the extended Focused Assessment with Sonography in Trauma examination, ultrasonography is commonly used to diagnose hemothorax and pneumothorax in the setting of trauma.¹¹ To our knowledge, no meta-analysis has ever been published to determine the accuracy of ultrasonography for the diagnosis of pneumothorax. The aim of this systematic review and meta-analysis was to determine the test characteristics of ultrasound in adult patients clinically suspected of having a pneumothorax and to compare ultrasonography test characteristics to those of chest radiography, using CT scan or release of air on chest tube placement as reference standards.

MATERIALS AND METHODS

Study Design, Subjects, and Interventions

We systematically reviewed the literature for prospective studies in which chest ultrasonography was used for diagnosis in patients with clinically suspected pneumothorax of any cause. We included studies in which the reference standard used was either CT scan findings or release of air on chest tube insertion. We excluded studies on the pediatric population.

Outcome Measures and Search Strategy

Our main outcome measure was to determine the sensitivity, specificity, negative predictive value (NPV), and positive predictive value (PPV) of ultrasonography for the diagnosis of pneumothorax and to compare those findings to the performance of chest radiography. We searched MEDLINE and EMBASE through the OVID interface for English language literature with no restrictions for year or status of publication. Our search strategy included subject headings, truncated terms, and text words (e-Appendix 1). We also reviewed references of included articles and recent reviews and contacted a convenience sample of experts in the field to explore the possibility of missed studies.

Selection and Abstraction Process

We imported the references into a bibliographic database using RefWorks (www.refworks.com). Two investigators indepen-

dently examined the titles and abstracts of the search strategy results and selected studies that potentially met the inclusion criteria. Studies were also selected if a decision was not easy to make based on the title and abstract. All studies selected by either reviewer were included in the first selection. Full-text copies were obtained for those papers. Both reviewers independently assessed all articles using a standardized tool to determine final eligibility for inclusion. Reviewers then met to resolve eligibility disagreements. Using a standardized data collection tool, both reviewers extracted data from studies that made the final inclusion and met to resolve discrepancies. κ Values were calculated for both selection steps. Our data collection tool included >30 items relating to each study's methodology and results. We contacted authors of studies if clarifications were required. We used the QUADAS tool to evaluate quality homogeneity of studies before meta-analyses.¹²

Data Analyses

We calculated sensitivity and specificity with 95% CIs in addition to reporting positive and negative predictive values. We intended to meta-analyze studies only if clinical and quality homogeneity were present. We calculated weighted mean differences for sensitivity and specificity between the ability of ultrasonography and chest radiography to detect pneumothoraces using a commercially available statistical package (Review Manager, version 4.2). We used a fixed effect model when statistical homogeneity was present and a random effect model when it was not.

RESULTS

Characteristics of Selected Studies

We completed our initial search strategy in December 2009 and identified 570 potential articles. We did not identify any unpublished studies; our electronic search strategy identified all potential studies. We repeated our electronic search on November 30, 2010 and did not identify any additional published studies since our initial query. Based on manuscript titles and abstracts, we excluded 549 papers (κ , 0.89). After reviewing the full text of 21 studies that were potentially eligible for inclusion, we found eight that met all the inclusion criteria and were considered eligible for meta-analysis (κ , 0.81).^{10,13-19} Characteristics of the included and excluded articles are presented in Figure 1.

The QUADAS quality assessment showed that all included articles were of good to average quality. Ultrasonographers were blinded to the reference standard results in all eight included studies. A total of 1,048 patients were examined. One study did not report chest radiograph data.¹² Therefore, chest radiograph data were available for 864 of the 1,048 patients. Pneumothorax was traumatic in six of eight studies (767 of 1,048 patients)^{10,13,15-18} and iatrogenic in two of eight studies (281 of 1,048 patients).^{12,14} Table 1 summarizes the methodology used in the included studies.

Chest radiographs were performed in the semi-erect position in 34 patients in one study¹⁴ and in the

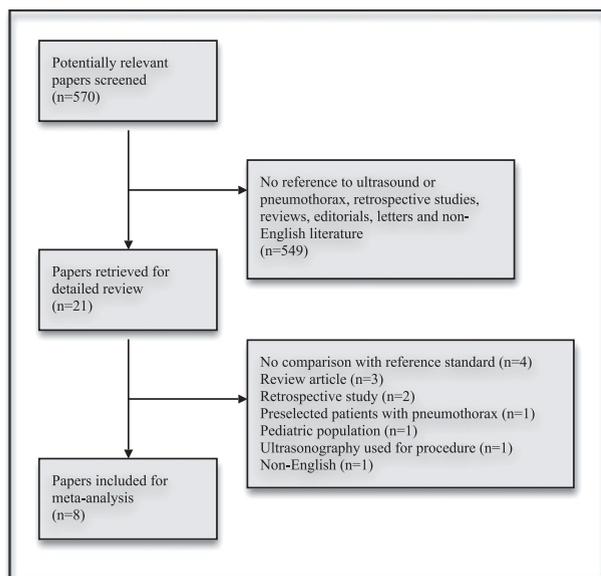


FIGURE 1. Characteristics of included and excluded articles.

supine position in all remaining included patients. None of the patients included had an erect chest radiograph. Two studies reported the numbers of hemithoraces scanned as opposed to patients.^{10,17} To avoid overrepresenting those studies in our weighted meta-analyses, we halved the number of patients in both studies, averaging the numbers of positive and negative test results to better reflect the findings as they pertain to the individual patient. With the exception of one study,¹³ all studies used the absence of lung sliding and comet-tail signs for the detection of pneumothorax.

Main Outcome Results

Overall, ultrasonography was 90.9% sensitive (95% CI, 86.5-93.9) and 98.2% specific (95% CI, 97.0-99.0), with a PPV of 94.4% and an NPV of 97.0%. In comparison, chest radiography had a sensitivity of 50.2% (95% CI, 43.5-57.0), a specificity of 99.4% (95% CI, 98.3-99.8), a PPV of 96.5%, and an NPV of 85.6% (Fig 2, Table 2). Release of air on chest

tube placement was used as the reference standard in 14 cases only, of which 10 had evidence of pneumothorax on both ultrasonography and chest radiograph. The remaining four cases had positive chest ultrasonography with no data available on the performance of chest radiography.

Secondary Outcome Results

Among 766 trauma patients, ultrasonography was 90.2% sensitive (95% CI, 84.7-93.9) and 98.8% specific (95% CI, 97.4-99.5), with 95.9% PPV and 97.0% NPV. In patients with iatrogenic pneumothorax (N = 281), ultrasonography was 92.6% sensitive (95% CI, 83.5-96.8) and 96.6% specific (95% CI, 92.8-98.5), with 91.1% PPV and 97.2% NPV. The time required to perform the examination was not uniformly reported, but ranged from < 2 min to 7 min.

DISCUSSION

In this systematic review and meta-analysis, we found that the performance of ultrasonography for the detection of pneumothorax is excellent. Ultrasonography is more sensitive than chest radiography for the detection of pneumothorax by a clinically and statistically significant margin. The performance of ultrasonography was consistent when pneumothoraces were caused by trauma or invasive procedures.

Although still performing better than chest radiography, ultrasonography sensitivity was low in one of the included studies,¹⁰ which was not in keeping with the other studies. The authors of that study chose to examine the pleural line in a transverse plane with no ribs in view. The lack of reference anatomic landmarks during the examination might explain the higher number of inaccurate tests. Chest radiography data were not available for analysis in one study.¹² The authors, however, reported a sensitivity of 42%.

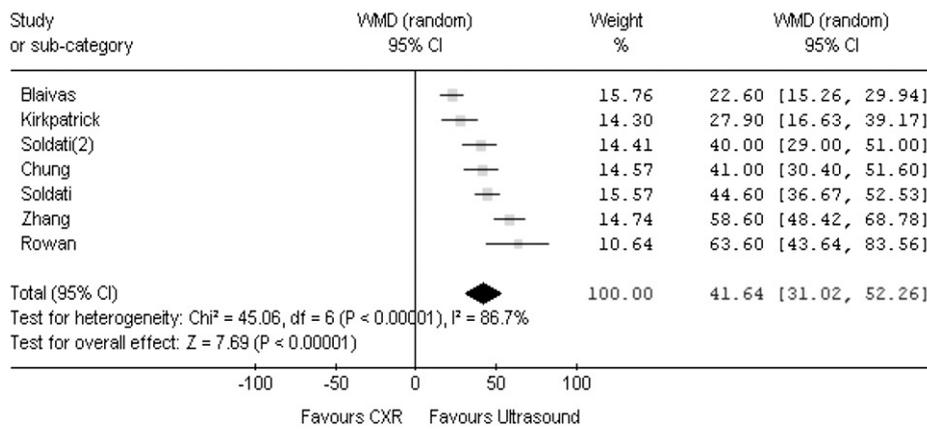
Although use of ultrasonography is common for trauma patients as part of the eFAST examination, its use for spontaneous or iatrogenic pneumothoraces is not as widely adopted. Chest radiography remains

Table 1—Summary of Methodology Used in the Included Studies

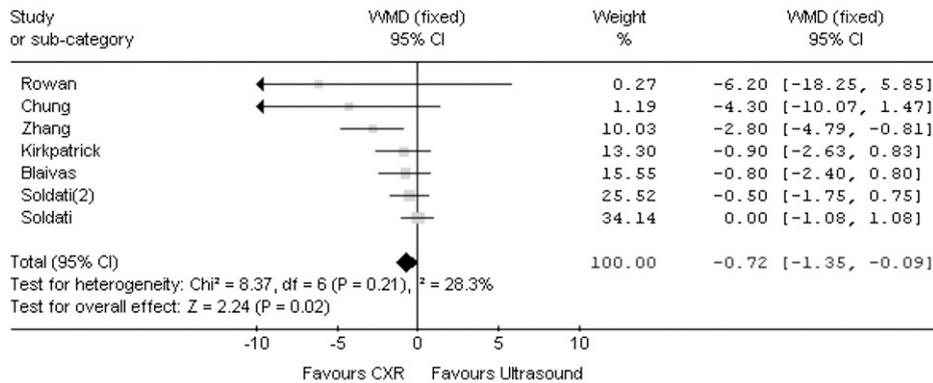
Study	Operator	Setting	Probe	Signs Used	No.
Blaivas et al ¹⁴	EP	Trauma	Microconvex	LS, PS	176
Chung et al ¹⁵	Radiologist	Iatrogenic	Linear	LS, CmT	97
Garofalo et al ¹³	Unknown	Iatrogenic	Curved	LS, CmT	184
Kirkpatrick et al ¹¹	Surgeon	Trauma	Linear	LS, CmT, PS	133
Rowan et al ¹⁶	Radiologist	Trauma	Linear	LS, CmT	27
Soldati et al ¹⁷	EP	Trauma	Curved	LS, CmT	186
Soldati et al ¹⁸	EP	Trauma	Curved	LS, CmT, M	109
Zhang et al ¹⁹	EP	Trauma	Curved + linear	LS, CmT	135

CmT = comet tail; EP = emergency physician; LS = lung sliding; M = M-mode; PS = power slide.

A Sensitivity



B Specificity



WMD = weighted mean difference; CI = confidence interval

FIGURE 2. A, Forest plot presents the WMD in sensitivity comparing ultrasonography to CXR. B, Forest plot presents the WMD in specificity comparing ultrasonography to CXR. Results to the right of the midline favor ultrasonography, results to the left favor chest CXR. CXR = chest radiography; df = degrees of freedom.

the first choice in these situations, and CT scans are occasionally performed when the quality of chest radiograph is inadequate. In addition to the excellent performance of ultrasonography, this test is simple to perform, rapid, and accessible, and is safe, with no radiation exposure.

Strengths

To our knowledge, this is the first meta-analysis of studies examining the test characteristics of ultrasonography for the detection of pneumothorax. We believe our search strategy was wide enough to capture all relevant studies. The use of a standardized study selection and data collection tools to be used by two independent reviewers helped both in reducing potential bias and increasing interreviewer agreement.

Limitations

This study assesses the performance of ultrasound performed by trained individuals. The nature of training requirements was not investigated. The

performance of individual signs of pneumothorax on ultrasonography was not assessed, as the data available were not sufficient. Some of the authors allowed the investigators to use M-mode or power Doppler as adjuncts but did not report how often they were used. The Seashore sign on M-mode⁶ and the power slide sign²⁰ are different graphical displays of the same phenomenon, which is lung sliding. It is unlikely that the use of these adjuncts will change the test characteristics significantly. The techniques used to perform the ultrasound examination also varied between studies. Although the exact technique used to perform the ultrasound examination is not reported with enough detail in some studies, most agree on requiring the examination of more than one intercostal space in both the midclavicular line and laterally and inferiorly at the anterior or midaxillary lines. Another potential limitation relates to halving the number of hemithoraces scanned in two of the included studies.^{10,17} In these two studies, two readings (one for each hemithorax) were counted for each patient compared with one reading counted per patient

Table 2—Summary of Sensitivity and Specificity for Included Studies

Study	No.	Ultrasonography		Chest Radiography	
		Sensitivity, %	Specificity, %	Sensitivity, %	Specificity, %
Blaivas et al ¹⁴	176	98.1	99.2	75.5	100.0
Chung et al ¹⁵	97	88.2	89.3	47.1	94.0
Garofalo et al ¹³	184	95.7	100
Kirkpatrick et al ¹¹	133	48.8	98.7	20.9	99.6
Rowan et al ¹⁶	27	100	93.8	36.4	100.0
Soldati et al ¹⁷	186	98.2	100	53.6	100.0
Soldati et al ¹⁸	109	92.0	99.5	52.0	100.0
Zhang et al ¹⁹	135	86.2	97.2	27.6	100.0

in all other studies. We have attempted to contact the authors for data clarification. One author replied but did not have access to the data set, and the other did not respond. This has a potential for skewing the results, especially if a large number of patients had only one hemithorax scanned or if a large number had bilateral pneumothoraces. Neither is the case in these studies. The effect on the final result, if there was one, is likely negligible. Finally, most of the patients analyzed had a supine chest radiograph. This is the standard practice for most trauma patients. However, most patients with a nontraumatic pneumothorax undergo erect chest radiographs. Studies comparing the performance of erect and supine chest radiographs in detecting pneumothorax are lacking. Because none of the patients in this meta-analysis had an erect chest radiograph, it is not possible to conclude that our findings can be generalized to that population.

CONCLUSIONS

This study demonstrates that chest ultrasonography can help recognize pneumothoraces with a sensitivity significantly superior and a specificity clinically similar to that of supine chest radiography. Our findings support the adoption of chest ultrasonography for routine use in patients with clinically suspected pneumothoraces.

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Dr Woo: contributed to performing the abstraction, paper selection, data extraction, and editing the manuscript.

Dr Vaillancourt: contributed to writing and performing the search strategy, structuring the methods and performing the statistical analysis, and editing the manuscript.

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Additional information: The e-Appendix can be found in the Online Supplement at <http://chestjournal.chestpubs.org/content/141/3/703/suppl/DC1>.

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