CHEST

Original Research

PULMONARY PROCEDURES

Diagnosis of Pneumothorax by Radiography and Ultrasonography

A Meta-analysis

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Objective: This study compares, by meta-analysis, the use of anterior-posterior chest radiography (CR) with transthoracic ultrasonography for the diagnosis of pneumothorax.

Methods: English-language articles on the performance of CR and ultrasonography in the diagnosis of a pneumothorax were selected. In eligible studies, data were recalculated, and the forest plots and summary receiver operating characteristic (sROC) curves were analyzed.

Results: Pooled sensitivity and specificity were 0.88 and 0.99, respectively, for ultrasonography, and 0.52 and 1.00, respectively, for CR. For ultrasonography performed by clinicians other than radiologists, pooled sensitivity and specificity were 0.89 and 0.99, respectively. The sROC areas under the curve were compared, and no significant differences between ultrasonography and CR were found. Meta-regression analysis implied that the operator is strongly associated with accuracy (relative diagnostic OR, 0.21; 95% CI, 0.05-0.96; P5 .0455).

Conclusions: The meta-analysis indicated that bedside ultrasonography performed by clinicians had higher sensitivity and similar specificity compared with CR in the diagnosis of pneumothorax, but the accuracy of ultrasonography in the diagnosis of pneumothorax depended on the skill of the operators.
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Abbreviations: AUC5 area under curve; CR5 chest radiography; DOR5 diagnostic OR; PNX5 pneumothorax; QUADAS5 the quality of diagnostic accuracy studies; sROC5 summary receiver operating characteristic

Pneumothorax (PNX) frequently occurs in the ED and ICU, especially in patients with trauma and those who are ventilated. Tension PNX is a very serious condition that can potentially lead to cardiac arrest and requires early diagnosis and urgent treatment. A small or medium PNX generally is not life-threatening, but delays in diagnosis and treatment may result in progression of respiratory and circulatory compromise in unstable patients. The diagnosis of PNX generally is confirmed by chest radiography (CR), but unreliable examination.[1-4] Kirkpatrick and colleagues[5] evaluated the use of anterior-posterior supine CR with CT scanning for the diagnosis of PNX. In their study of 225 trauma patients, the sensitivity of CR

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was only 20.9%. CT scanning is considered the gold standard for detection of PNX. Sometimes, however, CT scanning. The high doses of radiation in CT scanning also cannot be neglected.

Ultrasonography was first used in the diagnosis of PNX in humans in 1987.[6] In recent years, some characteristic signs have been identified for the diagnosis of PNX with ultrasonography, such as lung sliding,[7] comet tail artifacts,[8] the A line sign[8] and lung point.[9] Because lung ultrasonography can be performed easily and quickly at the bedside by intensivists, pneumologists, and emergency physicians, it can be used in the diagnosis of PNX in ventilated patients,[7,10] in trauma patients,[11-13] and after lung biopsy.[14,15] The accuracy of ultrasonography in the detection of PNX varies across studies and is associated with the operator's experience. In the study by Sartori et al,[16] the sensitivity and specificity were 100% for transthoracic ultrasonography to detect PNX in 285 patients after lung biopsy. However, in another study, the sensitivity of ultrasonography was 58.9% and specificity, 99.1%. Slater and colleagues[17] concluded that sometimes ultrasonography only could exclude but not confidently be used to diagnose PNX without the use of other imaging modalities.

Static and dynamic ultrasonography features of PNX have been identified in a number of studies, but the contemporary diagnostic performance of ultrasonography in the detection of PNX has not been well characterized. Should we use the thoracic sonographic examination in addition to the standard focused abdominal sonography for trauma examination in the ED, which is designated the extended focused abdominal sonography for trauma?[5] We undertook a meta-analysis of the published literature to compare the accuracy of ultrasonography and CR in the diagnosis of PNX.

Materials and Methods

Study Design and Data Sources

A literature review and meta-analysis were conducted. Original articles published in English up to the end of October 2010 were searched in Medline, EMBASE, and the Cochrane Library. We used combinations of the following key words to identify all original articles in which ultrasonography, CR, or both were used in diagnosing PNX: ("ultrasound" or "sonography" or "ultrasonography" or "radiography" or "chest film" or "chest radiograph") and ("pneumothorax" or "aerothorax" or "aeropleura") and ("sensitivity"

standard that included clinical presentation and documentation of the escape or aspiration of intrapleural air at the time of drainage); (3) reporting of results in sufficient detail to allow reconstruction of contingency tables of the raw data (ie, true-positive, true-negative, false-positive, and false-negative results); and (4) having diagnostic criteria for abnormal test results (eg, on ultrasonography, the disappearance of lung sliding; on CR, the appearance of air within the pleural space). Two of the authors (W. D. and Y. S.) independently reviewed the articles and ascertained the criteria for inclusion in the pooled data analysis, with disagreements resolved by discussion. Articles with the same authors were carefully investigated, and some were excluded to avoid duplicate data analysis.

Quality of Study Reports

The quality of diagnostic accuracy studies (QUADAS) tool[18] (e-Table 1) was applied in our analysis to assess the quality of the studies included. The 14-item QUADAS tool assesses study design-related issues and the validity of the study results. Each item may be scored "yes" if reported, "no" if not reported, or "unclear" if no adequate information is available in the article to make an accurate judgment. We considered the quality items 1 (about the spectrum of patients), 4 (about the time period between reference standard and index test), 12 (whether the same clinical data were available when test results were interpreted as would be available when the test is used in practice), and 13 (whether uninterpretable/intermediate test results were reported) not relevant for our analysis; thus, only the remaining 10 items were applied.

Data Extraction

In many of the studies included, hemithorax was used as the study unit for interpretation of the results instead of patient number. Because the diagnosis of PNX in one lateral hemithorax has no relationship with the other side, and usually both hemithoraces must be examined to exclude PNX in one patient, we reconstructed some results as the number of hemithoraces. If there was no specific description, we recalculated one patient as two hemithoraces. For those postbiopsy, one biopsy specimen in one patient was counted as one hemithorax.

Data Analysis

We analyzed the forest plots and summary receiver operating characteristic (sROC) curves with freeware Meta-DiSc, version 1.4 software (http://www.hrc.es/investigacion/metadisc_en.htm; Ramon y Cajal Hospital; Madrid, Spain). The Spearman correlation coefficient between the logit of sensitivity and the logit of 1-specificity was calculated to test the threshold/cutoff effect. Meta-DiSc allows users to test for heterogeneity (other than threshold effect) among various studies by statistical tests, including x^2 and Cochran Q. A low P value suggests the presence of heterogeneity beyond what would be expected by chance alone. In addition to these heterogeneity statistics, Meta-DiSc computes the inconsistency index (I^2), which has been proposed as a measure to quantify the amount of heterogeneity.

Table 1—Characteristics of Eligible Studies

							Us				CR			
	Design	Modality[a]	Patient Type	No.[a]	Us Operator	Diagn Crit[b]	TP	FP	FN	TN	TP	FP	FN	TN
	NR	Us, CR	Critically ill	148[c]	NR	1[d]	41 (100)	6	0	101 (94.4)	40 (93)	0	3	41 (100)
s	Retrospect	CR	Trauma	1,684[c]							107 (65.6)	0	56	1,521 (100)
	Prospect	Us	Critically ill	184	NR	2[d,e,f]	41 (100)	5	0	138 (96.5)				
om	Prospect	CR	Postbiopsy	41							6 (46.2)	0	7	28 (100)
	Prospect	Us, CR	Critically ill	299	Intensivist	3[d,e,f]	66 (100)	11	0	222 (95.3)	60 (85.7)	0	10	58 (100)
s	Prospect	CR	Trauma	1,076[c]							13 (52)	0	12	1,051 (100)
	Prospect	Us, CR	Trauma	54[c]	Radiologist	2[f]	11 (100)	1	0	42 (97.7)	4 (36.4)	0	7	43 (100)
	NR	Us, CR	Trauma	266	Trauma surgeon	2[f]	21 (48.8)	3	22	220 (98.7)	9 (20.9)	1	34	222 (99.6)
s	Prospect	Us, CR	Trauma	352[c]	Emergency physician	1[d]	52 (98.1)	1	1	298 (99.7)	40 (75.5)	0	13	299 (100)
	Prospect	Us, CR	Postbiopsy	53	Pneumologist	3[d,e,f]	4 (100)	0	0	49 (100)	3 (75)	0	1	49 (100)
	NR	Us, CR	Postbiopsy	97	Radiologist	NR	28[g] (80)	3.75[g]	7[g]	58.25[g] (94)	16.5[g] (47.1)	3.75[g]	18.5[g]	58.25[g] (94)
	Retrospect	CR	Trauma	676[c]							46 (44.7)	0	57	573 (100)
	NR	Us, CR	Postbiopsy	184	NR	3[f]	44 (95.7)	0	2	138 (100)	19 (41.3)	0	27	138 (100)
	Prospect	Us, CR	Trauma	270[c]	Emergency physician	3[f]	28 (87.5)	3	4	235 (98.7)	8[h] (27.6)	0[h]	21[h]	106[h] (100)
	Prospect	Us, CR	Trauma	372[c]	Emergency physician	3[f]	55 (98.2)	0	1	316 (100)	30 (53.6)	0	26	316 (100)
	Prospect	Us, CR	Postbiopsy	285	NR	3[f]	8 (100)	0	0	277 (100)	7 (87.5)	0	1	277 (100)
	Prospect	Us, CR	Trauma	218	Emergency physician	3	23 (92)	1	2	192 (99.5)	13 (52)	0	12	193 (100)
s	Prospect	CR	Trauma	810[c]							26 (24.3)	0	81	703 (100)
	Prospect	Us, CR	Trauma	338	Radiologist	2[f]	20 (46.5)	3	23	292 (99)	7 (16.3)	0	36	295 (100)
	Prospect	Us, CR	Postdrainage	162	Intensivist	3	33 (100)	1	0	128 (99.2)	20 (60.6)	0	13	129 (100)

resenting the sensitivity (TP) and the specificity (TN). CR5 chest radiography; Diagn Crit5 diagnostic criteria; FN5 false negative; FP5 false positive; NR5 not reported; spect5 retrospective study; TN5 true negative; TP5 true positive; Us5 ultrasonography.

data that fulfilled the inclusion criteria were analyzed.

ax by ultrasonography contains the absence of lung sliding sign, absence of comet tail sign, and the presence of lung point. 15 the absence of lung sliding sign; 25 the nd comet tail sign; 35 the absence of both lung sliding sign and comet tail sign and the seek of lung point.

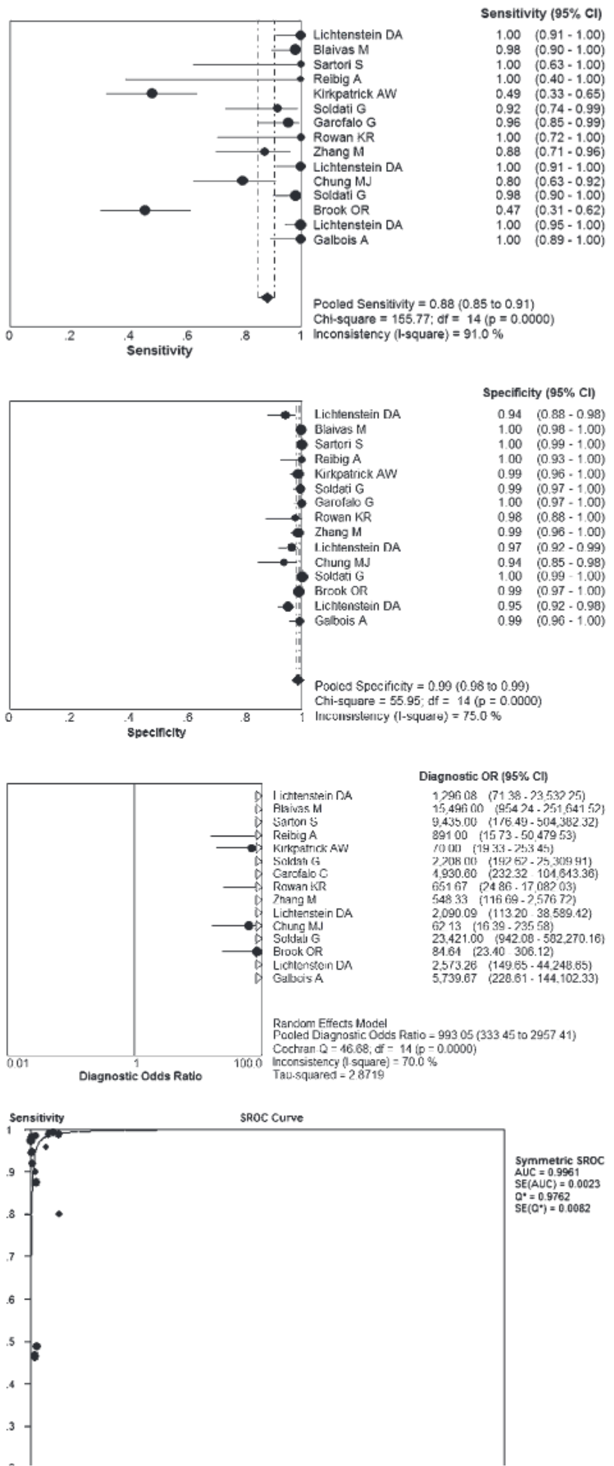
s: diagnosing pneumothorax by the absence of lung sliding sign.

s: diagnosing pneumothorax by the absence of comet tail sign.

diagnosing pneumothorax by the absence of both lung sliding sign and comet tail sign.

e four observers' numbers.

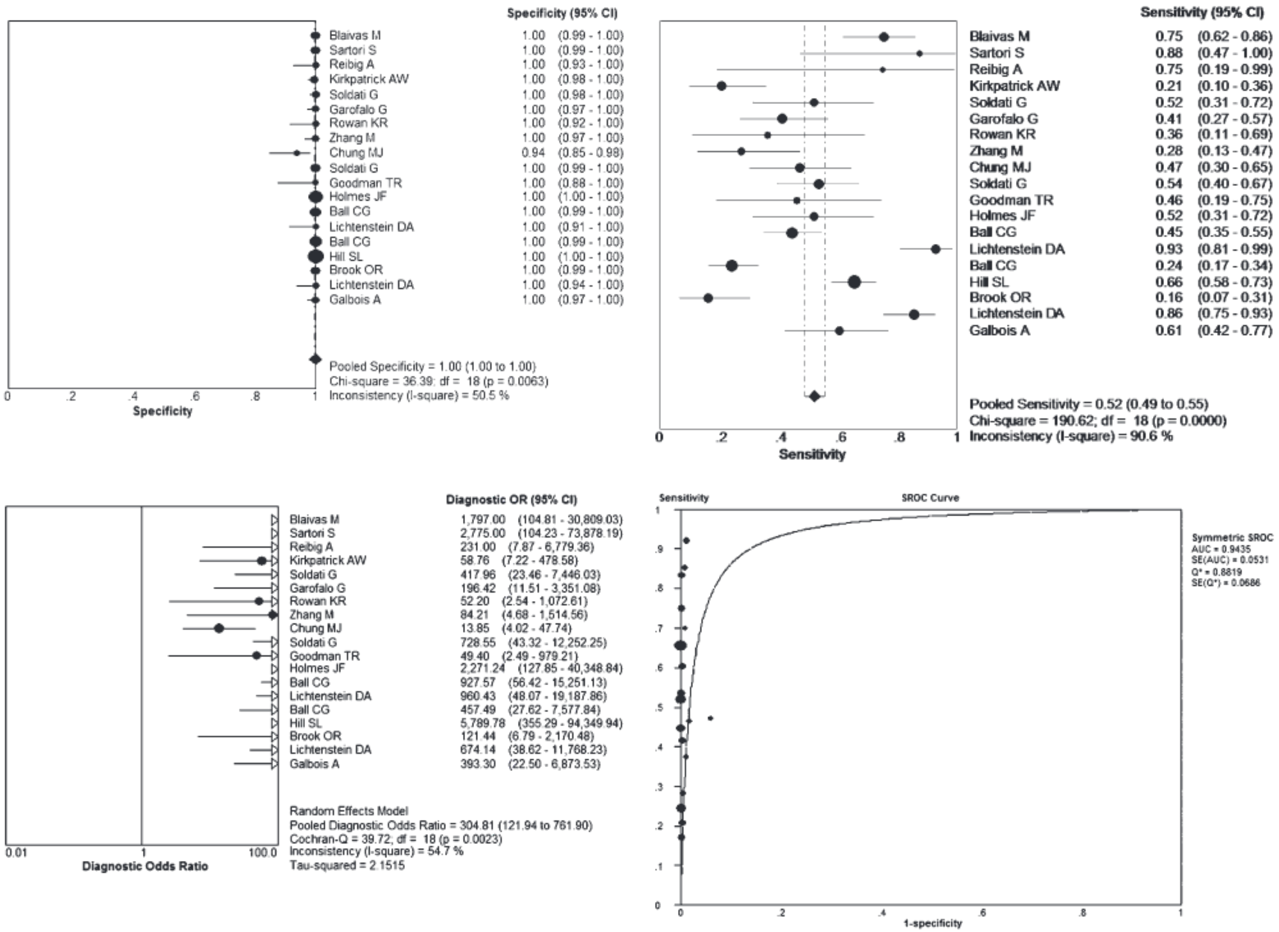
he results to recalculate the data per patient as opposed to per hemithorax; thus, original data of the article were used.



2, 3, 8, and 9. The sample of 17 studies (85%) achieved verification using the standard of diagnosis (item 5). QUADAS item 6 (patients received the same reference standard regardless of the index test result) was reported in 75% of the studies. Item 7 (the reference standard was independent of the index test) was achieved in 95% of the studies. Thirteen studies (65%) reported on blinding in the results of the reference test (item 10), whereas six (30%) reported on blinding in the index test results (item 11). Of the nine studies withdrawn from the study, all had an explanation (item 14).

The pooled sensitivity, specificity, diagnostic OR (DOR), and curves for detection of PNX with ultrasonography and CR are shown in Figures 1 and 2, respectively. Pooled sensitivity and specificity were 0.88 (0.85-0.91) and 0.99 (0.98-0.99), respectively, for ultrasonography and 0.52 (0.49-0.55) and 1.00 (1.00-1.00), respectively, for CR. Pooled DOR was 993.05 (333.45-2,957.41), and sROC area under the curve (AUC) was 0.9961 (SE, 0.0023) for ultrasonography. For CR, the DOR was 304.81 (121.94-761.90), and sROC AUC, 0.9435 (SE, 0.0531).

The Spearman correlation coefficient between the log of sensitivity and log of 1-specificity was 0.136 (P5 .629) for ultrasonography and 0.069 (P5 .778) for CR. The significant x^2 P values, shown in the forest plots for each test, implied that there were causes of variations other than a cutoff effect. Possible sources of heterogeneity across the studies were explored using meta-regression analysis with the following covariates as predictor variables: study design (prospective vs retrospective), type of patient (eg, critically ill, trauma), blinded test or not, ultrasonography diagnostic criteria, and operator. Results suggest that the operator is strongly associated with accuracy (relative DOR, 0.21; 95% CI, 0.05-0.96; P5 .0455) (Table 2). Subgroup analyses based on the ultrasonography operator (clinicians other than radiologists) were performed. In the x^2 test, pooled sensitivity was 79.93 (P5 .0000), and pooled specificity was 26.71 (P5 .0004). The Cochran Q was 25.02 (P5 .0008) for DOR, which implied that heterogeneity resulted from factors other than the way a study was designed. We considered that the differences between the operators (their skill, experience, knowledge of chest



Figur e 2. Forest sensitivity, specificity, diagnostic OR, and the sROC of chest radiography. See Figure 1 legend for explanation of the statistics and expansion of abbreviations.

We compared the two sROC curves by the Z statistic as follows:

$$Z = \frac{\left|Q_1^* - Q_2^*\right|}{\sqrt{SE(Q_1^*)^2 + SE(Q_2^*)^2}} \qquad \text{(Equation 1)}$$

where Z was 1.36 (P .05), which means that there was no significant difference between the two diagnostic methods for detection of PNX.

The accuracy of ultrasonography performed by clinicians other than radiologists in detecting PNX was analyzed. The pooled results are shown in e-Figure 1

The pooled results are shown in e-Figure 2. Only two articles contained extractable data based on the ultrasonography diagnostic criterion of the presence of lung point, which was not enough for a meta-analysis. Compared with one another and with the sROC of CR, all the sROC curves showed no significant difference according to the Z statistic.

Discussion

The results of the present study demonstrat superior sensitivity and similar specificity in the use of ultrasonography compared with CR for the diagnosis

Table 2—Metaregression Analysis for Possible Sources of Heterogeneity

Variance	Coeff Standard	Error	P Value	RDOR	95% CI
Inverse variance weights 1					
Cte	7.670	2.4070	.0129	…	…
S	0.322	0.2557	.2439	…	…
Design	1.091	1.0113	.3122	2.98	0.29-30.66
Patient	2 1.036	0.9913	.3265	0.35	0.04-3.49
Blind	1.332	1.6944	.4546	3.79	0.08-188.46
Diagnostic					
Criteria	0.168	0.7500	.8281	1.18	0.21-6.67
Operator	2 1.568	0.7330	.0648	0.21	0.04-1.13
Inverse variance weights 2					
Cte	8.070	1.3366	.0002	…	…
S	0.351	0.2276	.1578	…	…
Design	1.239	0.8480	.1779	3.45	0.51-23.52
Patient	2 1.190	0.8327	.1867	0.30	0.05-2.00
Blind	1.429	1.5401	.3777	4.17	0.13-136.03
Operator	2 1.613	0.6446	.0337	0.20	0.05-0.86
Inverse variance weights 3					
Cte	8.712	1.1164	.0000	…	…
S	0.253	0.1950	.2228	…	…
Design	1.549	0.7692	.0718	4.71	0.85-26.11
Patient	2 0.724	0.6473	.2895	0.48	0.11-2.05
Operator	2 1.836	0.5884	.0109	0.16	0.04-0.59
Inverse variance weights 4					
Cte	7.933	0.9033	.0000	…	…
S	0.182	0.2023	.3865	…	…
Design	1.286	0.8015	.1368	3.62	0.62-21.12
Operator	2 1.662	0.6079	.0194	0.19	0.05-0.72
Inverse variance weights 5					
Cte	8.705	0.8616	.0000	…	…
S	0.187	0.2310	.4330	…	…
Operator	2 1.550	0.6948	.0455	0.21	0.05-0.96
Inverse variance weights 6					
Cte	6.837	1.0165	.0000	…	…
S	0.295	0.2559	.2710	…	…
Design	0.874	1.0900	.4385	2.40	0.22-25.75

The RDOR (obtained by exponentiating the model coefficients) compared the DOR of studies of a given test that lacked a particular methodologic feature with those without the corresponding shortcomings in design. Coeff5 coefficient; Cte5 constant term in the equation; FPR5 false-positive rate; RDOR5 relative diagnostic OR; S5 indicator of threshold (logit TPR1 logit FPR); TPR5 true-positive rate.

compared with CR and CT scanning.[13] The research of Sistrom and colleagues[15] showed that ultrasonography was not useful in estimating the volume of a PNX, but studies by Garofalo et al,[25] Soldati et al,[12] and ourselves[13] found the opposite. Although there was no statistical significance, from our experience, we recommend that only if there is an absence of both the lung sliding sign and the comet tail sign can a diagnosis of PNX be made. The only part of

be made. The lung point is a specific sign that allows PNX to be confirmed and the PNX volume to be determined,[30] but it is rarely found. The use of additional ultrasonography signs, such as the seashore sign and power sliding, could improve the accuracy of the ultrasonography-based diagnosis of PNX, but there were not enough data for us to analyze these separately.

Despite its simplicity, security, and portability, the accuracy of ultrasonography depended on the skill of the operator, and the diagnostic accuracy might be lower if ultrasonography was performed by an inexperienced clinician.

The present analysis has some limitations. We did not identify unpublished studies, and no attempt was made to include articles in other languages. From a traditional viewpoint, because air stops the progression of the ultrasound beam, it might seem difficult to detect PNX with ultrasonography. Studies that concluded poor accuracy of ultrasonography or good accuracy of CR in the diagnosis of PNX might not have been published.

From the meta-analysis, the role of bedside ultrasonography in detecting PNX is very promising. It would appear to be an attractive alternative to bedside CR, especially in the emergency department, ICU, and other clinical situations where radiography is not available, such as in medical air transport and remote medical facilities. It has the potential to play a major role in the diagnosis of acute respiratory failure, effectively acting as a visual stethoscope.[32]

Conclusions

Clinician-performed ultrasonography is a reliable tool in the diagnosis of PNX. It has the advantage of portability, simplicity, rapidity, and higher sensitivity and similar specificity compared with CR. Ultrasonography provides a useful adjunct for clinicians in treating patients with multiple trauma or who are ventilated, but the accuracy of ultrasonography in the diagnosis of PNX depends on the skill of the operators.

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Author contributions: Dr Ding had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Dr Ding: contributed to the study design; data collection, analysis, and interpretation; preparation of the manuscript; and review and approval of the final manuscript.
Dr Shen: contributed to the data collection, analysis, and interpretation; preparation of the manuscript; and review and approval of the final manuscript.
Dr Yang: contributed to the preparation of the manuscript and review and approval of the final manuscript.
Dr He: contributed to the preparation of the manuscript and review and approval of the final manuscript.
Additional information: The e-Figures and e-Tables can be found in the Online Supplement at http://chestjournal.chestpubs.org/content/140/4/859/suppl/DC1.

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