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Comparing the Diagnostic Performance of Lung Ultrasonography and Chest Radiography for Detecting Pneumothorax in Patients with Trauma: A Meta-Analysis

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Keywords
Ultrasonography · Chest radiography · Pneumothorax · Patients with trauma · Meta-analysis

Abstract
Introduction: The objective of this study was to compare the diagnostic performance of ultrasonography (US) and chest radiography for detecting pneumothorax in patients with trauma using a meta-analytic approach. ***Methods:*** PubMed, Embase, and the Cochrane Library were systematically searched to identify eligible studies until March 2023. The diagnostic performance of US and chest radiography was assessed using sensitivity, specificity, positive likelihood ratio (PLR), negative likelihood ratio (NLR), diagnostic score, diagnostic odds ratio (DOR), and area under the receiver operating characteristic curve (AUC). ***Results:*** Overall, 21 studies involving 4,087 patients with trauma were included. The overall sensitivity, specificity, PLR, NLR, diagnostic score, DOR, and AUC of US for detecting pneumothorax were 0.83, 0.99, 73.72, 0.17, 6.06, 427.80, and 0.99, respectively. The corresponding values of chest radiography for detecting pneumothorax were 0.37, 1.00, 175.59, 0.63, 5.63, 279.97, and 0.86. US was associated with a higher sensitivity (ratio: 2.24; 95% confidence interval [CI]: 1.70–2.95; $p < 0.001$) or AUC (ratio: 1.15; 95% CI: 1.11–1.19; $p < 0.001$) and lower NLR (ratio: 0.27; 95% CI: 0.17–0.43; $p < 0.001$) compared with chest radiography. ***Conclusion:*** Lung US was associated with better diagnostic performance than chest radiography for detecting pneumothorax in patients with trauma.

Introduction

Pneumothorax, characterized by the accumulation of air within the pleural cavity, represents a serious medical emergency that can severely compromise respiratory function [1, 2]. Pneumothorax is a common condition, with a primary spontaneous incidence of 7.4/100,000 per year in males and 1.2/100,000 per year in females. The incidence of secondary spontaneous pneumothorax is 6.3/100,000 per year in males and 2.0/100,000 per year in females [3]. Traumatic pneumothorax can occur as a result of penetrating injuries (such as stabs or gunshot wounds) or blunt chest trauma [4]. Regardless of the cause, timely and accurate detection followed by immediate treatment is crucial in preventing catastrophic outcomes [5].

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Traditionally, chest radiography is performed on patients with chest trauma to look for pneumothorax. However, due to overlapping spinal structures and other injuries, the characteristic features of pneumothorax may not always be clearly discernible on chest radiography taken in the supine position [6, 7]. Although appropriate screening for pneumothorax via chest radiography is a crucial treatment intervention, the signs of pneumothorax on chest radiography are subtle, resulting in missed diagnoses in up to 20% of cases [8]. The reasons for these missed diagnoses may include low interobserver consistency in the interpretation of chest radiography findings and a clinical chest radiography workload that far exceeds the number of radiologists available [9, 10].

Currently, lung ultrasonography (US) is considered effective in detecting pneumothorax in clinical practice, especially in emergency and bedside examinations, US can quickly and noninvasively provide diagnostic information. Moreover, US exams do not involve ionizing radiation, making them safer for patients, particularly those who require frequent monitoring or specific groups such as pregnant women and children [11]. The characteristic ultrasound features of pneumothorax include the absence of lung sliding, absence of B lines, and presence of lung points, which can help diagnose pneumothorax more accurately [11]. However, whether the diagnostic performance of US is superior to that of chest radiography for detecting pneumothorax remains controversial. Thus, this systematic review and meta-analysis aimed to compare the diagnostic performance of US and chest radiography for detecting pneumothorax in patients with trauma.

Methods

Data Sources, Search Strategy, and Selection Criteria

This systematic review and meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Statement issued in 2009 [12]. Studies investigating the diagnostic performance of US and chest radiography for detecting pneumothorax were included, and the publication language was restricted to English. PubMed, Embase, and the Cochrane Library were systematically searched to identify potential eligible studies from their inception until March 2023. The following search terms were used: ("ultrasound" or "sonography" or "ultrasonography" or "radiography" or "chest film" or "chest radiograph") and ("pneumothorax" or "aerothorax") and ("sensitivity" and "specificity"). The reference lists of relevant studies and reviews were manually reviewed to identify further eligible studies.

Two reviewers independently performed the literature search and study selection, and conflicts between reviewers were resolved via mutual discussion until a consensus was reached. Studies were included if they met the following criteria: (1) patients: trauma patients at risk of pneumothorax in the emergency department setting; (2) diagnostic tool: US and chest radiography; (3) outcomes: true- and false-positive data and true- and false-negative data; and (4) study design: not restricted.

Data Collection and Quality Assessment

Two reviewers independently extracted the following information: first author's surname, publication year, region, sample size, mean age, male proportion, operator, sampling, disease status, diagnostic tool, true- and false-positive data, and true- and false-negative data. Then, these two reviewers assessed the quality of the included studies using the 14-item QUADAS-2 tool based on patient selection, index tests, reference standards, and flow and timing. Each item was divided into low, high, and unclear risks [13]. Any disagreement between the reviewers was resolved by another reviewer by referring to the original article.

Statistical Analysis

The sensitivity, specificity, positive likelihood ratio (PLR), negative likelihood ratio (NLR), diagnostic score, diagnostic odds ratio (DOR), and area under the receiver operating characteristic curve (AUC) were calculated based on true- and false-positive data and true- and false-negative data. Furthermore, the bivariate generalized linear mixed model and random-effects model were used in pooled analyses [14, 15]. I^2 and Q statistics were used to assess the heterogeneity across included studies, and significant heterogeneity was defined as an I^2 value of ≥50.0% or p value of <0.10 [16, 17]. Subsequently, the ratio of diagnostic parameters for detecting pneumothorax using US and chest radiography was calculated using the random-effects model [14, 15, 18]. Subgroup analyses were performed for sensitivity, specificity, PLR, NLR, DOR, and AUC based on region (Eastern and Western countries), operator (physician, radiologist, and surgeon), and sampling (consecutive and nonconsecutive sampling). Publication bias was assessed using funnel plots and Deeks' asymmetry tests [19]. The p value for pooled conclusions was two-sided, and the inspection level was set at 0.05. All analyses were performed using STATA version 14.0 (StataCorp, TX, USA).

Ethics Statement

This study is a meta-analysis, which does not involve any examination of patients. Thus, ethics approval and informed consent are not applicable.

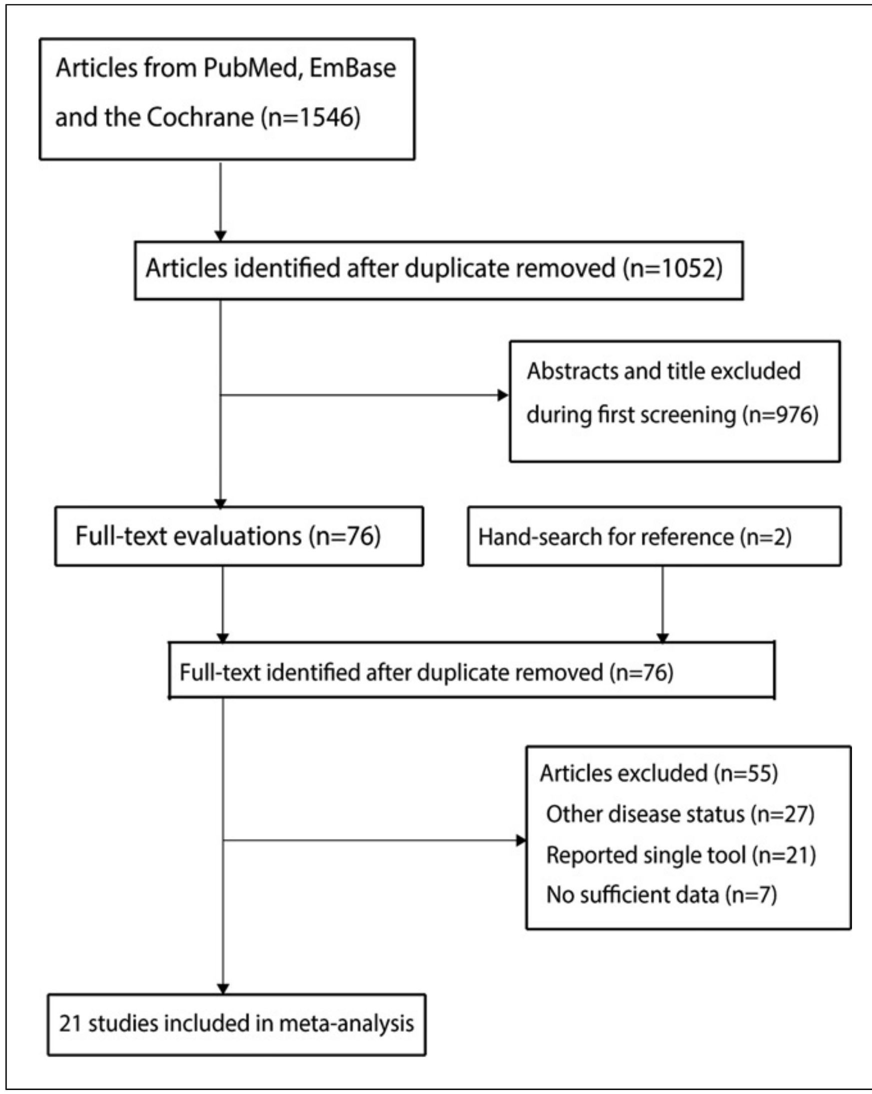

Fig. 1. Flow diagram of the literature search and study selection process.

Results

Literature Search

In total, 1,546 articles were identified from the initial electronic search, and 1,052 studies were retained after the removal of duplicate articles. In addition, 976 studies were removed owing to irrelevant titles and abstracts, and the remaining 76 studies were retrieved for full-text evaluations. After detailed evaluations, 55 studies were removed because of the following reasons: other disease status ($n = 27$), use of single diagnostic tool ($n = 21$), and insufficient data ($n = 7$). Reviewing the reference lists of relevant articles did not yield any new eligible study that met the inclusion criteria. Finally, the remaining 21 studies were included in the final meta-analysis (Fig. 1) [20–40].

Study Characteristics

The characteristics of the included studies and involved patients are summarized in Table 1. From the 21 included studies, 4,087 patients with trauma were identified, and the sample size ranged from 27 to 756. Overall, 11 studies were performed in western countries, and the remaining 10 were conducted in eastern countries. Pneumothorax was diagnosed by radiologists in 7 studies, emergency physicians in 12 studies, and surgeons in the remaining 2 studies. In total, 9 studies used consecutive sampling, whereas the remaining 12 used nonconsecutive sampling. The methodological quality of the identified studies is presented in Table 2, and the overall quality was determined as moderate-to-high.

Table 1. Baseline characteristics of included studies and involved patients

Study	Region	Sample size	Age, years	Male, %	Operator	Sampling	Disease status	Diagnostic tool	TP	FP	FN	TN
Rowan et al. [20] (2002)	Canada	27	42.0	92.6	Radiologist	NC	Trauma	US Chest radiography	11 4	1 0	0 7	15 16
Kirkpatrick et al. [21] (2004)	Canada and USA	225	37.0	74.0	Surgeon	NC	Trauma	US Chest radiography	33 12	3 1	23 44	205 207
Blaivas et al. [22] (2005)	USA	176	>17.0	57.0	Emergency physician	NC	Trauma	US Chest radiography	52 40	1 0	1 13	122 123
Soldati et al. [23] (2006)	Italy	186	52.4	62.9	Emergency physician	C	Trauma	US Chest radiography	55 30	0 0	1 26	130 130
Zhang et al. [24] (2006)	China	135	45.0	84.4	Emergency physician	NC	Trauma	US Chest radiography	25 8	3 0	4 21	103 106
Soldati et al. [25] (2008)	Italy	109	41.4	62.9	Emergency physician	C	Trauma	US Chest radiography	23 13	1 0	2 12	83 84
Brook et al. [26] (2009)	Israel	169	31.0	85.0	Radiologist	C	Trauma	US Chest radiography	20 7	1 0	23 36	125 126
Nandipati et al. [27] (2011)	USA	204	43.0	74.5	Emergency physician	C	Trauma	US Chest radiography	20 15	1 1	1 4	182 182
Nagarsheth and Kurek [28] (2011)	USA	125	44.5	66.4	Surgeon	NC	Trauma	US Chest radiography	18 7	0 0	4 15	57 57
Hyacinthe et al. [29] (2012)	France	119	39.0	82.0	Emergency physician	NC	Trauma	US Chest radiography	28 10	3 0	25 43	63 66
Donmez et al. [30] (2012)	Turkey	68	>18.0	NA	Radiologist	NC	Trauma	US Chest radiography	32 24	3 5	3 11	98 96
Abbasi et al. [31] (2013)	Iran	146	37.0	87.6	Emergency physician	NC	Trauma	US Chest radiography	32 18	0 0	5 19	109 109
Ku et al. [32] (2013)	USA	549	38.0	75.0	Emergency physician	C	Trauma	US Chest radiography	27 19	3 0	20 28	499 502
Ojaghi Haghighi et al. [33] (2014)	Iran	150	NA	82.7	Emergency physician	NC	Trauma	US Chest radiography	50 18	0 2	2 34	98 96
Abdulrahman et al. [34] (2015)	Qatar	305	34.0	98.0	Radiologist	C	Trauma	US Chest radiography	32 8	10 6	43 67	525 529
Ziapour and Haji [35] (2015)	Iran	84	NA	NA	Radiologist	NC	Trauma	US Chest radiography	14 4	5 1	4 7	61 48

Table 1 (continued)

Study	Region	Sample size	Age, years	Male, %	Operator	Sampling	Disease status	Diagnostic tool	TP	FP	FN	TN
Kaya et al. [36] (2015)	Turkey	212	45.8	67.9	Emergency physician	C	Trauma	US Chest radiography	22 8	1 0	3 15	186 187
Vafaei et al. [37] (2016)	Iran	152	31.4	77.6	Radiologist	C	Trauma	US Chest radiography	46 37	2 7	9 18	95 90
Subramaniam and Chakaravarthy [38] (2017)	India	140	NA	88.6	Radiologist	NC	Trauma	US Chest radiography	42 10	0 0	16 48	82 82
Zieleskiewicz et al. [39] (2018)	France	756	37.0	82.0	Emergency physician	C	Trauma	US Chest radiography	137 73	13 0	61 125	1,284 1,290
Attia et al. [40] (2023)	Egypt	50	37.7	82.0	Emergency physician	NC	Trauma	US Chest radiography	14 3	1 2	6 17	29 28

C, consecutive sampling; FN, false negative; FP, false positive; NA, not available; NC, nonconsecutive sampling; TN, true negative; TP, true positive.

Sensitivity and Specificity

The sensitivity and specificity of US for detecting pneumothorax were 0.83 (95% confidence interval [CI]: 0.74–0.89) and 0.99 (95% CI: 0.98–1.00), respectively. Significant heterogeneity was observed in the sensitivity (I^2 = 90.96%; $p < 0.01$) and specificity (I^2 = 82.09%; $p < 0.01$) of US across all included studies (Fig. 2a). Furthermore, the overall sensitivity and specificity of chest radiography for detecting pneumothorax were 0.37 (95% CI: 0.28–0.47) and 1.00 (95% CI: 0.99–1.00), respectively. Significant heterogeneity was observed in the sensitivity (I^2 = 87.13%; $p < 0.01$) and specificity (I^2 = 89.52%; $p < 0.01$) of chest radiography across the included studies (Fig. 2b). In addition, the sensitivity of US was significantly higher than that of chest radiography for detecting pneumothorax (ratio: 2.24; 95% CI: 1.70–2.95; $p < 0.001$), whereas the specificities of US and chest radiography for detecting pneumothorax showed no statistically significant difference (ratio: 0.99; 95% CI: 0.98–1.00; $p = 0.162$). Finally, US were associated with high sensitivity than chest radiography in all subgroups, whereas no significant difference in specificity was observed between US and chest radiography in the subgroup analysis (Table 3).

PLR and NLR

The pooled PLR and NLR of US for detecting pneumothorax were 73.72 (95% CI: 44.75–121.46) and 0.17 (95% CI: 0.11–0.27), respectively, and significant heterogeneity was observed in PLR (I^2 = 73.81%; $p < 0.01$) and NLR (I^2 = 93.38%; $p < 0.01$) of US across the included studies (Fig. 3a). Moreover, the PLR and NLR of chest radiography for detecting pneumothorax were 175.59 (95% CI: 38.77–795.28) and 0.63 (95% CI: 0.54–0.73), respectively, and significant heterogeneity was observed in the PLR (I^2 = 70.72%; $p < 0.01$) and NLR (I^2 = 89.67%; $p < 0.01$) of chest radiography across the included studies (Fig. 3b). In addition, no significant difference in PLR was noted between US and chest radiography (ratio: 0.42; 95% CI: 0.09–2.06; $p = 0.285$), whereas US was associated with lower NLR compared with chest radiography (ratio: 0.27; 95% CI: 0.17–0.43; $p < 0.001$). Finally, in the subgroup analysis, no significant difference in PLR was noted between US and chest radiography in all subgroups, whereas US was associated with lower NLR compared with chest radiography in all subgroups (Table 3).

Diagnostic Score and DOR

The overall diagnostic score and DOR of US for detecting pneumothorax were 6.06 (95% CI: 5.25–6.86) and 427.80 (95% CI: 191.13–957.54), respectively, and significant heterogeneity was observed in the diagnostic score (I^2 = 84.35%; $p < 0.01$) and DOR (I^2 = 100.00%; $p < 0.01$) of US (Fig. 4a). Furthermore, the diagnostic score and DOR of chest radiography for detecting pneumothorax were 5.63 (95% CI: 4.10–7.17) and 279.97 (95% CI: 60.18–1,302.39), respectively. Significant heterogeneity was observed in the diagnostic score

Table 2. Methodological quality of included studies

Study	Risk of bias					Applicability concerns			
	patient selection	index test: US	index test: CXR	reference standard	flow and timing	patient selection	index test: US	index test: CXR	reference standard
Rowan et al. [20] (2002)	High	Low	Low	Unclear	Unclear	High	Low	Low	Low
Kirkpatrick et al. [21] (2004)	Unclear	Unclear	Unclear	Unclear	High	Low	Low	Low	Unclear
Blaivas et al. [22] (2005)	High	Low	Low	Low	Unclear	Low	Low	Low	Low
Soldati et al. [23] (2006)	High	Low	Unclear	Unclear	Unclear	Low	Low	Low	Low
Zhang et al. [24] (2006)	Unclear	Low	Unclear	Unclear	High	Low	Low	Low	Low
Soldati et al. [25] (2008)	High	Unclear	High	High	Low	High	Low	Low	Low
Brook et al. [26] (2009)	Low	Low	Unclear	Unclear	Unclear	Low	Low	Low	Low
Nandipati et al. [27] (2011)	Unclear	Low	Unclear	Unclear	Unclear	Low	Low	Low	Low
Nagarsheth and Kurek [28] (2011)	High	Low	Unclear	Unclear	High	Low	Low	Low	Low
Hyacinthe et al. [29] (2012)	Unclear	Low	Low	Low	Low	Unclear	Low	Low	Low
Donmez et al. [30] (2012)	Unclear	Low	Unclear	Unclear	High	Unclear	Low	Low	Low
Abbasi et al. [31] (2013)	High	Unclear	Unclear	Unclear	High	High	Low	Low	Low
Ku et al. [32] (2013)	Low	Low	Unclear	Unclear	Unclear	Low	Low	Low	Low
Ojaghi Haghighi et al. [33] (2014)	High	Low	Unclear	Unclear	Unclear	High	Low	Low	Low
Abdulrahman [34] (2015)	Low	Low	Unclear	Unclear	High	Low	Low	Low	Low
Ziapour and Haji [35] (2015)	High	Unclear	Unclear	Unclear	Unclear	Unclear	Low	Low	Low
Kaya et al. [36] (2015)	High	Unclear	Unclear	Unclear	Unclear	Low	Low	Low	Low
Vafaei et al. [37] (2016)	Low	High	Low	Low	Low	Low	Low	Low	Low
Subramaniam and Chakaravarthy [38] (2017)	Unclear	Low	Unclear	Unclear	Unclear	Unclear	Low	Low	Low
Zieleskiewicz et al. [39] (2018)	Low	Unclear	Unclear	Low	Unclear	Low	Low	Low	Low
Attia et al. [40] (2023)	High	Low	Unclear	Unclear	Unclear	High	Low	Low	Low

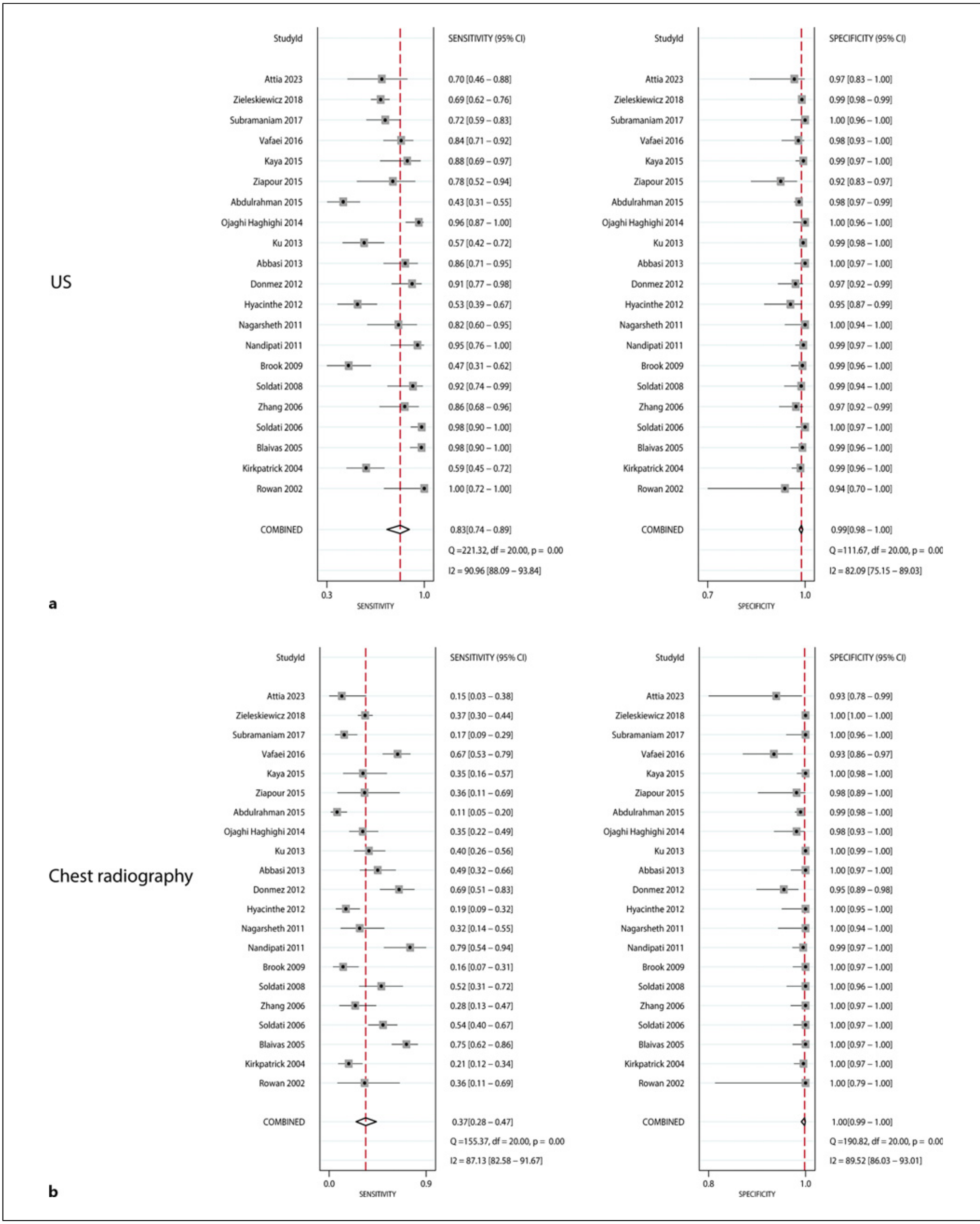

Fig. 2. Overall sensitivity and specificity of US (**a**) and chest radiography (**b**) for detecting pneumothorax.

Table 3. Subgroup analyses for diagnostic performance of US and chest radiography

Parameters	Factors	Subgroups	US	Chest radiography	US versus chest radiography
Sensitivity	Region	Eastern	0.81 (0.68–0.89)	0.33 (0.22–0.48)	2.45 (1.62–3.71)
		Western	0.74 (0.71–0.78)	0.40 (0.28–0.54)	1.85 (1.33–2.58)
	Operator	Physician	0.88 (0.77–0.94)	0.42 (0.31–0.54)	2.10 (1.56–2.81)
		Radiologist	0.77 (0.58–0.89)	0.32 (0.17–0.53)	2.41 (1.31–4.42)
		Surgeon	0.65 (0.54–0.76)	0.24 (0.15–0.35)	2.71 (1.72–4.28)
	Sampling	Consecutive	0.70 (0.66–0.74)	0.41 (0.27–0.57)	1.71 (1.17–2.49)
		Nonconsecutive	0.84 (0.74–0.91)	0.35 (0.24–0.47)	2.40 (1.69–3.41)
Specificity	Region	Eastern	0.99 (0.97–0.99)	0.99 (0.97–1.00)	1.00 (0.98–1.01)
		Western	0.99 (0.99–0.99)	1.00 (0.99–1.00)	0.99 (0.99–1.00)
	Operator	Physician	0.99 (0.99–1.00)	1.00 (0.99–1.00)	1.00 (0.99–1.00)
		Radiologist	0.97 (0.96–0.98)	0.98 (0.96–0.99)	0.99 (0.97–1.01)
		Surgeon	1.00 (0.94–1.00)	1.00 (0.98–1.00)	1.00 (0.97–1.03)
	Sampling	Consecutive	0.99 (0.99–0.99)	1.00 (0.98–1.00)	0.99 (0.98–1.00)
		Nonconsecutive	0.98 (0.97–0.99)	0.99 (0.98–1.00)	0.99 (0.98–1.00)
PLR	Region	Eastern	61.25 (27.69–135.47)	34.98 (12.40–98.68)	1.75 (0.47–6.46)
		Western	49.60 (27.76–88.64)	555.73 (41.57–7,429.92)	0.09 (0.01–1.27)
	Operator	Physician	118.00 (63.31–219.92)	825.75 (38.10–17,895.20)	0.14 (0.01–3.30)
		Radiologist	29.50 (18.62–46.74)	16.78 (9.68–29.09)	1.76 (0.86–3.60)
		Surgeon	46.09 (16.01–132.73)	42.16 (8.16–217.73)	1.09 (0.16–7.71)
	Sampling	Consecutive	62.15 (36.09–107.04)	586.62 (27.50–12,512.66)	0.11 (0.00–2.37)
		Nonconsecutive	53.95 (25.33–114.93)	61.19 (14.98–250.00)	0.88 (0.48–4.36)
NLR	Region	Eastern	0.20 (0.11–0.34)	0.67 (0.55–0.82)	0.30 (0.16–0.54)
		Western	0.23 (0.15–0.35)	0.60 (0.48–0.75)	0.38 (0.24–0.62)
	Operator	Physician	0.13 (0.06–0.25)	0.58 (0.48–0.71)	0.22 (0.11–0.47)
		Radiologist	0.24 (0.12–0.47)	0.69 (0.53–0.90)	0.35 (0.17–0.72)
		Surgeon	0.32 (0.15–0.66)	0.77 (0.68–0.87)	0.42 (0.20–0.88)
	Sampling	Consecutive	0.24 (0.15–0.39)	0.59 (0.45–0.77)	0.41 (0.24–0.70)
		Nonconsecutive	0.16 (0.09–0.28)	0.66 (0.55–0.79)	0.24 (0.13–0.44)
DOR	Region	Eastern	312.14 (105.73–921.51)	52.10 (18.23–148.84)	5.99 (1.33–27.07)
		Western	298.52 (117.21–760.27)	930.88 (63.76–13,591.28)	0.32 (0.02–5.49)
	Operator	Physician	939.72 (311.26–2,837.08)	1,424.77 (62.25–32,607.96)	0.66 (0.02–18.24)
		Radiologist	124.51 (56.49–274.47)	24.25 (13.10–44.90)	5.13 (1.89–13.99)
		Surgeon	124.58 (39.12–396.74)	56.18 (10.41–303.23)	2.22 (0.29–17.15)
	Sampling	Consecutive	323.37 (122.23–855.51)	995.85 (45.82–21,644.62)	0.32 (0.01–8.20)
		Nonconsecutive	340.39 (113.02–1,025.21)	93.11 (21.70–399.47)	3.66 (0.59–22.71)
AUC	Region	Eastern	0.99 (0.97–0.99)	0.90 (0.87–0.93)	1.10 (1.06–1.14)
		Western	1.00 (0.99–1.00)	0.91 (0.88–0.93)	1.09 (1.06–1.13)
	Operator	Physician	1.00 (0.98–1.00)	0.86 (0.82–0.88)	1.16 (1.12–1.20)
		Radiologist	0.98 (0.96–0.99)	0.93 (0.91–0.95)	1.05 (1.03–1.08)
		Surgeon	–	–	–
	Sampling	Consecutive	1.00 (1.00–1.00)	0.88 (0.85–0.90)	1.13 (1.10–1.17)
		Nonconsecutive	0.99 (0.97–0.99)	0.89 (0.86–0.92)	1.11 (1.07–1.15)

(I^2 = 71.03%; $p < 0.01$) and DOR (I^2 = 100.00%; $p < 0.01$) of chest radiography (Fig. 4b). In addition, no significant differences were noted in the diagnostic score (ratio: 1.08; 95% CI: 0.79–1.47; p = 0.641) and DOR (ratio: 1.53; 95% CI: 0.27–8.67; p = 0.632) of US and chest radiography. Finally, the results of subgroup analyses revealed that US was associated with a higher DOR than chest radiography when the studies were pooled based on eastern countries (region) and radiologists (operator) (Table 3).

AUC

The AUC of US and chest radiography for detecting pneumothorax were 0.99 (95% CI: 0.98–1.00) and 0.86 (95% CI: 0.83–0.89), respectively (Fig. 5). The AUC of US was significantly higher than that of chest radiography (ratio: 1.15; 95% CI: 1.11–1.19; $p < 0.001$). Results of subgroup analyses revealed that compared with chest radiography, US was associated with higher AUCs in all subgroups (Table 3).

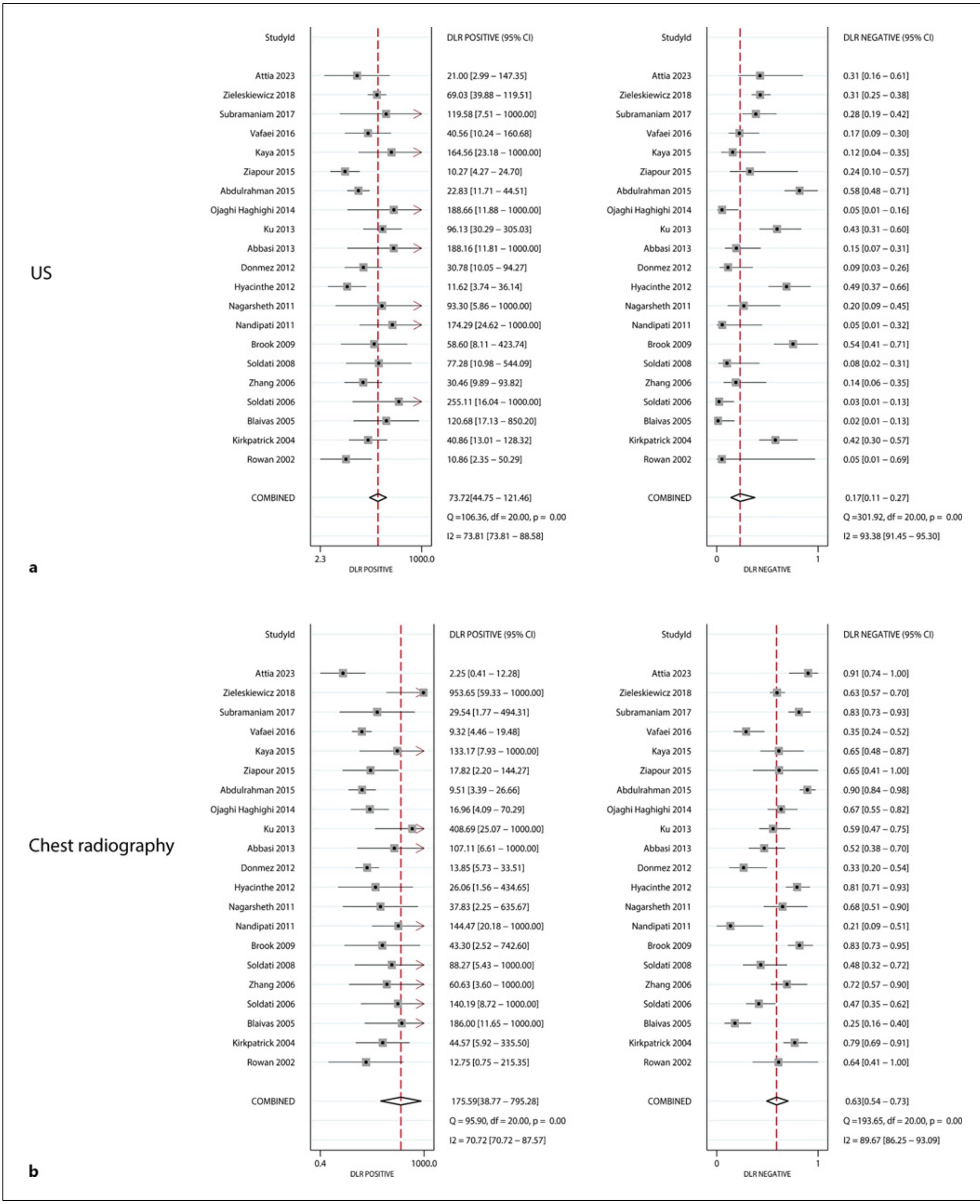

Fig. 3. Overall PLR and NLR of US (**a**) and chest radiography (**b**) for detecting pneumothorax.

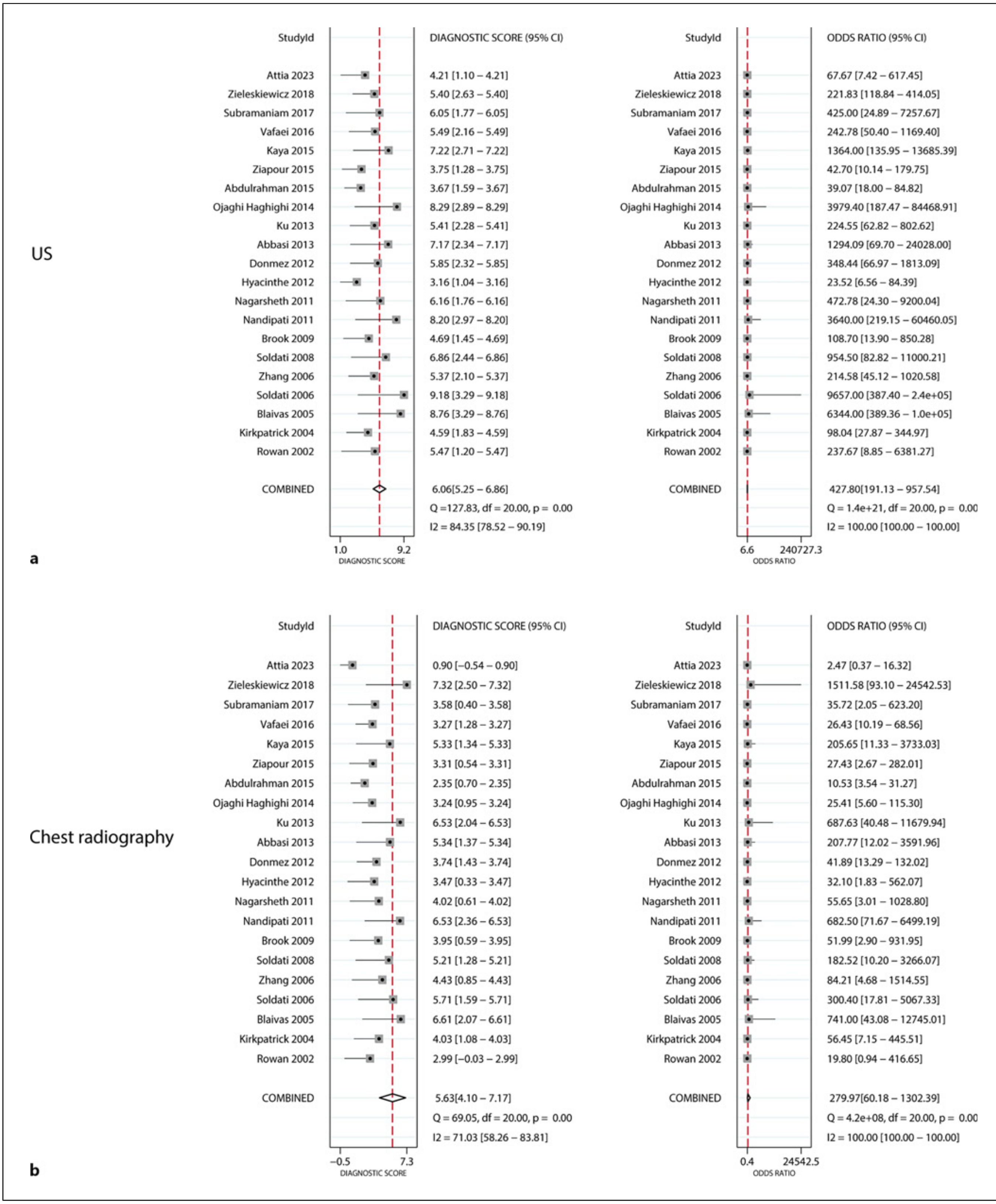

Fig. 4. Overall diagnostic score and DOR of US (**a**) and chest radiography (**b**) for detecting pneumothorax.

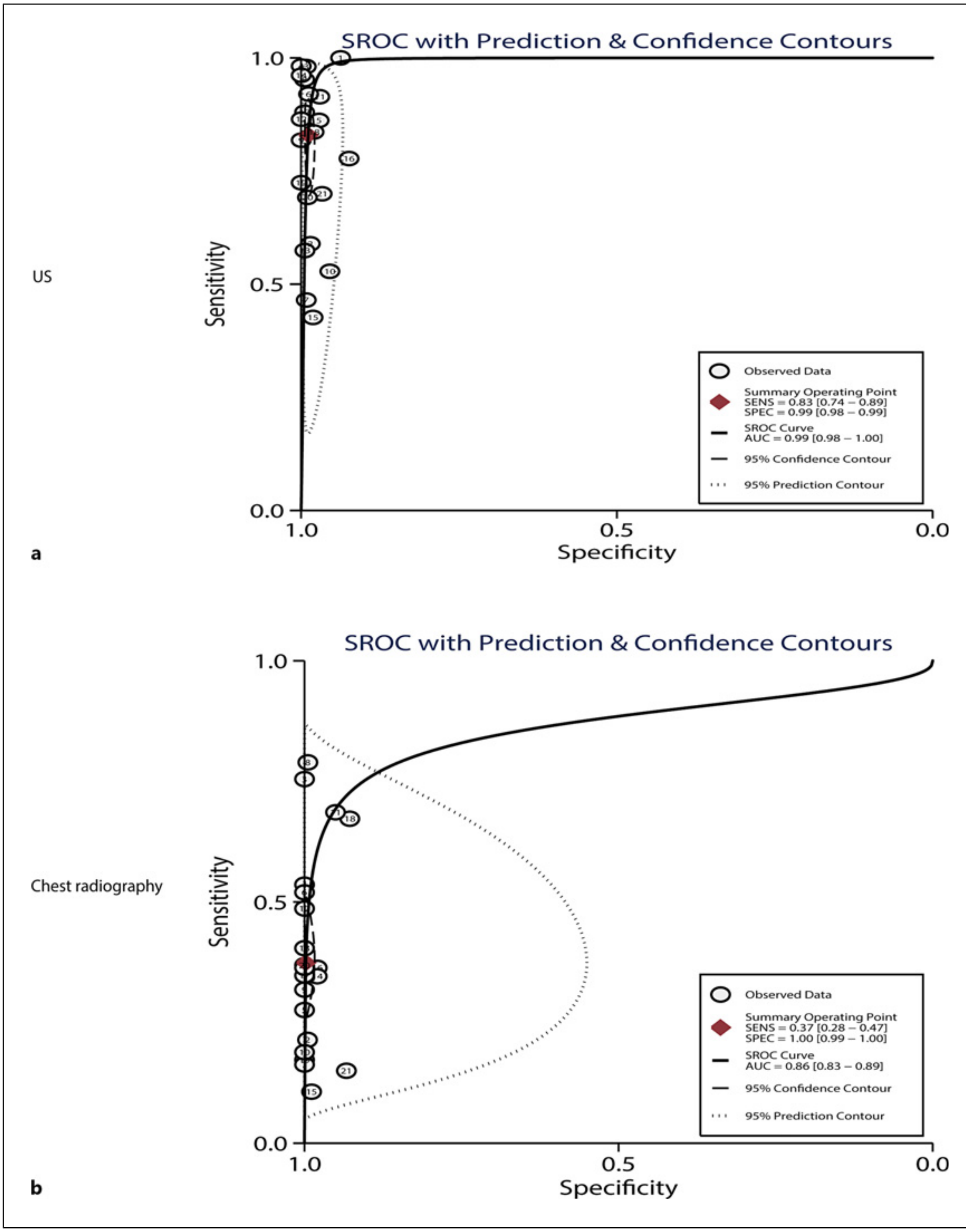

Fig. 5. Overall AUC of US (**a**) and chest radiography (**b**) for detecting pneumothorax.

Publication Bias

Reviewing the funnel plot could not rule out potential publication bias (Fig. 6). Deeks' asymmetry tests indicated no significant publication bias for the diagnostic performance of US ($p = 0.47$), whereas potential significant publication bias was noted for the diagnostic performance of chest radiography ($p = 0.01$).

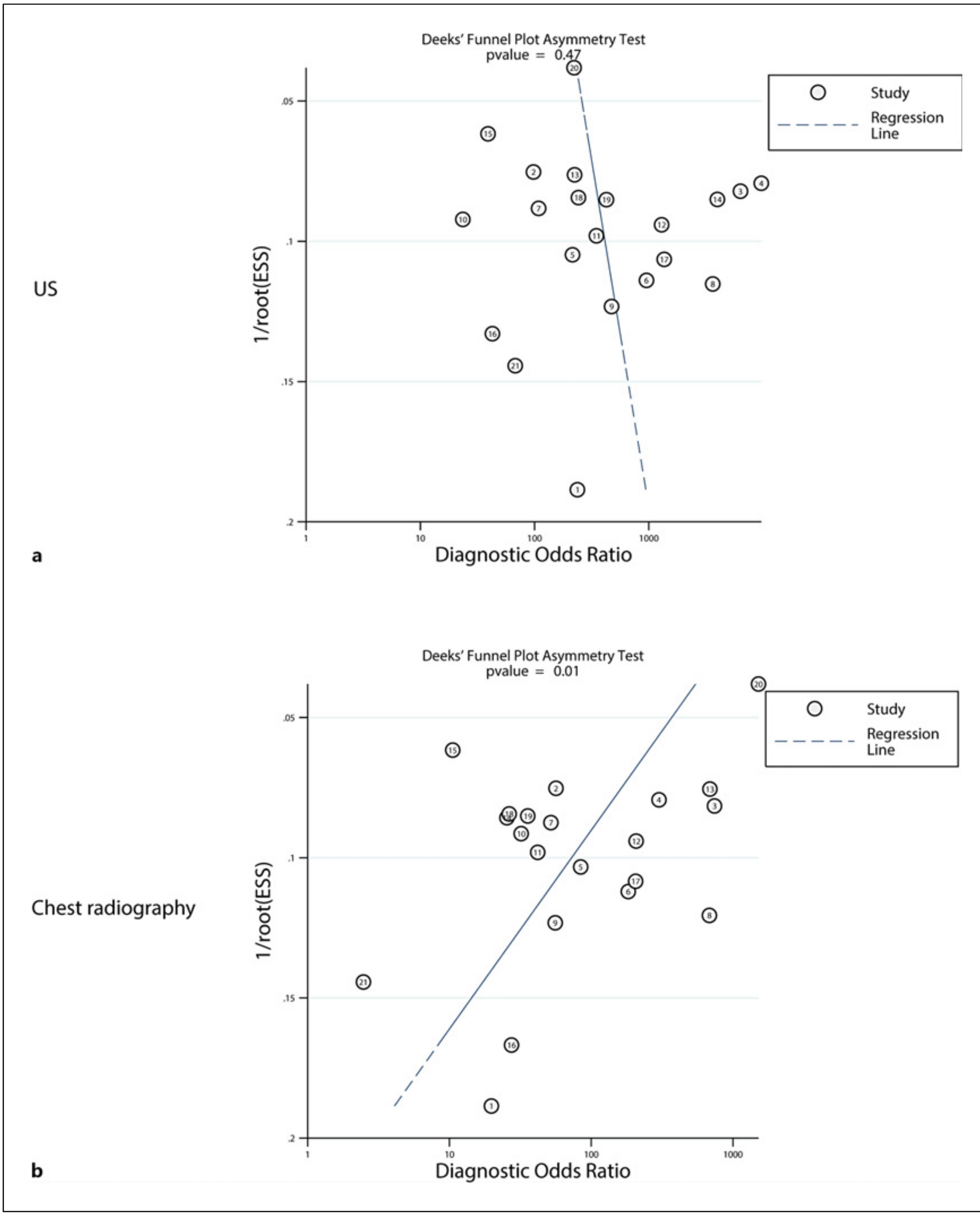

Fig. 6. Funnel plots based on Deeks' asymmetry tests of US (**a**) and chest radiography (**b**) for detecting pneumothorax.

Discussion

This study compared the diagnostic performance of US and chest radiography for detecting pneumothorax. The overall methodological quality of the included studies was moderate-to-high, and computed tomography was considered the gold standard for the diagnosis of pneumothorax [20–40]. In total, 4,087 patients with trauma were identified from 21 studies, and the characteristics of the patients varied across the studies. This study revealed that

US was associated with a higher sensitivity and AUC for detecting pneumothorax compared with chest radiography. Moreover, the NLR of US was lower than that of chest radiography. However, the specificity, PLR, diagnostic score, and DOR of US and chest radiography for detecting pneumothorax showed no statistically significant difference.

Several systematic reviews and meta-analyses have previously addressed the diagnostic performance of US and chest radiography for detecting pneumothorax [41–43]. Alrajab et al. [41] conducted a meta-analysis involving 13 articles and reported that US was more accurate than chest radiography for detecting pneumothorax; however, this study analyzed patients in trauma and nontrauma settings. A Cochrane review included nine studies and reported that the diagnostic performance of US by frontline nonradiologist physicians was better than via supine chest radiography for detecting pneumothorax in patients with trauma admitted to the emergency department [42]. Ron et al. [43] analyzed 17 studies and revealed that US showed improved sensitivity for detecting pneumothorax compared with chest radiography. However, several limitations of these previous meta-analyses must be addressed: (1) the disease states varied across the studies, including both trauma and nontrauma settings, and (2) all included studies did not provide direct comparison results for the diagnostic performance of US and chest radiography for detecting pneumothorax.

The current study revealed that the diagnostic performance of US was better than that of chest radiography for detecting pneumothorax in patients with trauma, revealing higher sensitivity, higher AUC, and lower NLR of the former method. The diagnostic value of US and chest radiography for detecting pneumothorax varied across the included studies, which could be explained by operator expertise and physicians employed at different academic institutions [44]. Moreover, pneumothorax could be misdiagnosed via chest radiography, especially in patients with severe injuries and those who could not be placed in an erect position.

Subgroup analyses revealed that the sensitivity and AUC of US were higher than those of chest radiography, whereas the NLR of US was lower than that of chest radiography for detecting pneumothorax in all subgroups. Moreover, US had a higher DOR than chest radiography when studies were pooled according to location (eastern countries) and operator (radiologists). These results may be due to the following reasons: (1) significant variability in diagnostic performance across the included studies in specific subgroups could affect the 95% CI of the pooled-effect estimates; (2) the number of studies in different subgroups varied, and the robustness of the pooled conclusions may be affected; (3) operator expertise and disease status varied across countries; and (4) the accuracy of US and chest radiography was higher when assessed by radiologists.

This study has several limitations. First, it included both prospective and retrospective studies, and the results may have been affected by selection and confounding biases. Second, the disease status was different across the included studies, which could affect the diagnostic performance of US and chest radiography. Third, substantial heterogeneity was noted across the included studies, which was not fully explained via subgroup analyses. Fourth, the analysis was based on published articles and previously pooled data, leading to restricted detailed analyses and inevitable publication bias.

In conclusion, this study revealed that the diagnostic performance of US is relatively better than that of chest radiography for detecting pneumothorax in patients with trauma, with a higher sensitivity, AUC, and lower NLR. Moreover, the DOR of US and chest radiography for detecting pneumothorax could be affected by the region and operator, and the detection rate is highly dependent on the technical expertise of the operator. Therefore, after appropriate operator training, US may be recommended for diagnosing pneumothorax in patients with trauma in clinical practice.

Statement of Ethics

An ethics statement is not applicable because this study is based exclusively on published literature.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

B.S. contributed to study design. L.T. contributed to data collection and statistical analysis. C.Z. and L.G. contributed to drafting of the manuscript and reviewing and editing of the manuscript. All authors have read and approved the final manuscript.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

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