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Diagnostic Accuracy of Point-of-Care Ultrasound versus Chest Radiography in Pleural Effusion: A Systematic Review and Meta-Analysis

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ABSTRACT

Background: Pleural effusion is a widely encountered clinical disorder in which excessive fluid develops in the pleural space from a variety of underlying disease processes, including heart failure, malignancy, and pneumonia, etc. Early and precise identification of pleural effusion ultimately leads to appropriate management. Point-of-care ultrasound (POCUS) has arisen as a possible method for diagnosing pleural effusion in lieu of an examination with standard chest radiography (CXR), although the diagnostic accuracy of POCUS still remains disputed.

Objective: To systematically evaluate and compare the diagnostic accuracy of point-of-care ultrasound (POCUS) and chest radiography for the detection of pleural effusion.

Methodology: A systematic review and meta-analysis were conducted for comparative diagnostic accuracy with point of care ultrasound (POCUS) and chest radiograph (CXR) for the detection of pleural effusion. Data were pooled from 20 studies constituting 2,905 patient encounters. Sensitivity and specificity were calculated using the DerSimonian - Laird random-effects model. Subgroup analysis was performed to assess the effect of patient position, operator experience, and reference standard on diagnostic accuracy.

Results: The pooled sensitivity of point of care ultrasound (POCUS) was 95.8% (95% CI:93.4-98.2%) and specificity was 98.1% (95% CI:96.9-99.3%). The pooled sensitivity of chest radiography (CXR) was 66.3% (95% CI:58.1-74.5%) and specificity was 86.5% (95% CI:81.8-91.2%). Subgroup analysis showed that evaluating patients in the lateral decubitus position improved CXR accuracy compared to supine.

Conclusion: Point of care ultrasound (POCUS) has improved sensitivity and specificity compared to chest radiography (CXR) for the evaluation of pleural effusion. It is warranted to consider POCUS as a first line diagnostic tool and particularly in the developed patients in an emergency department or intensive care setting for high acuity patients. There is a need for further investigation of POCUS on long-term clinical outcomes and cost-effectiveness.

Keywords: Point-Of-Care Ultrasound (POCUS); Chest Radiography; Pleural Effusion; Diagnostic Accuracy

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Introduction

Pleural effusion is the buildup of fluid within the pleural space, which is the thin compartment between the lungs and the chest wall. This is a common clinical finding in billions of people worldwide.[1] The incidence of pleural effusion is approximately 320 per 100,000 individuals annually in developed countries, with over 1.5 million diagnosed each year in the United States.[2] The causes of pleural effusion vary and are either labeled as transudates or exudates. Transudative effusions are usually due to systemic processes including congestive heart failure, cirrhosis of the liver, or nephrotic syndrome. Exudative effusions are typically localized processes such as infection, malignancy, or inflammatory disease.[3]

The causes or clinical presentations of pleural effusion can often have overlap with other pulmonary pathologies, including pneumonia, pulmonary embolism, acute coronary syndrome, and pulmonary edema—often with cough, dyspnea, and pleuritic chest pain being non-specific and being assigned to other diagnoses. This overlap can create a delay in diagnosis, lending to the importance of imaging and diagnostic studies to facilitate therapeutic intervention. Historically, pleural effusion has been diagnosed by chest radiography (CXR), computed tomography (CT), or ultrasonography. Chest radiography is now thought of as the gold standard for initial detection.[3,4]

Chest radiography (CXR) is widely used, but has significant limitations. Evidence suggests that CXR may miss small pleural effusions, especially when the imaging is performed in a supine position or in suboptimal conditions. For example, Brixey et al. noted that upright tube CXR misses up to 10% of drainable significant parapneumonic effusions.[3]

CXR has the potential to result in false negatives for pleural effusion due to several factors, including patient position, obesity, and technical limitations that affect image quality and diagnostic accuracy. CXR is not specific for the type of pleural fluid and estimates of volume, nor is it able to differentiate between free-flowing pleural effusion and loculated effusion, reducing the utility of CXR to influence treatment decisions.[5,6]

In contrast, point-of-care ultrasound (POCUS) can provide usable imaging alternatives for the discussion of pleural effusion. POCUS provides a real time, bedside examination that is especially useful in emergency and critical care settings. Its ability to dynamically assess fluid collections contributes to higher accuracy and speed at which pleural effusions can be confirmed. Furthermore, ultrasound has been shown to have superior sensitivity and specificity compared to chest radiography (CXR), specifically in detecting small or loculated pleural effusions that are often missed on radiographs.

Although research clearly demonstrates the effectiveness of point-of-care ultrasound (POCUS) in terms of diagnosis, for various reasons related to familiarity and availability, the utilization of POCUS as a first-line diagnostic test for pleural effusion is limited in practice. It is currently preferable to use CXR, knowing that POCUS requires specialized training to produce consistent results. For this reason, CXR still remains in place of POCUS even though POCUS provides a better bedside evaluation of the patient, representing a potential missed opportunity to elevate patient care.[7,8] Comparative studies on point-of-care ultrasound (POCUS) versus chest radiography (CXR) for the diagnosis of pleural effusion have consistently shown favor for POCUS. For example, a meta-analysis by Yousefifard et al. reported a pooled sensitivity of 94% for POCUS compared to 51% for CXR.[9] Fischer et al. also found a sensitivity of 93% for POCUS and a sensitivity of only 24% for CXR, with POCUS also demonstrating superior specificity along with enhanced detection of pleural effusion.[10] This has resulted in further interest in utilizing POCUS as a first-line diagnostic test for pleural effusion that may be even more vital in high-stake situations like an emergency department or intensive care unit.

The diagnostic performance of point-of-care ultrasound (POCUS) can be supplemented with other diagnostic modalities (such as computed tomography [CT] or a full clinical work-up) to improve diagnostic accuracy. Although standard diagnostic tests are valid and valuable, the diagnostic evaluations are costly and not always available in the bedside setting. When there is diagnostic uncertainty or questions regarding robustness, POCUS plus other approaches may enhance overall diagnostic accuracy. Further, clinicians with minimal ultrasound exposure have reported similarly high diagnostic accuracies with POCUS, which can encourage its more widespread use.[11,12]

The primary purpose of this meta-analysis is to compare POCUS diagnostic accuracy to chest radiography (CXR) for detecting pleural effusion. Newer evidence suggests POCUS may be comparable to or better than CXR for diagnostic sensitivity and specificity, and thus an in-depth meta-analysis comparing both imaging modalities is warranted, especially for emergency and critical care contexts. Through the analysis of pooled data, this study aims to detail the diagnostic performance, including sensitivity, specificity, and overall diagnostic utility. This meta-analysis will provide data to aid in clinical practice and diagnostic guidelines for pleural effusion.

Understanding that data usually differ among clinical contexts and patient populations, the goal of this paper is to offer brief guidance on the application of point-of-care ultrasound (POCUS) and chest radiography (CXR) in the assessment of pleural effusions, in order to enhance patient care and clinical outcomes.

Objective

To systematically evaluate and compare the diagnostic accuracy of point-of-care ultrasound (POCUS) and chest radiography for the detection of pleural effusion.

Methodology

This systematic review and meta-analysis was designed to evaluate the diagnostic accuracy of point-of-care ultrasound (POCUS) versus chest radiography (CXR) for detecting pleural effusion. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency and consistency in our methodology.

Eligibility Criteria

In the present review, we included studies that evaluated POCUS and CXR in the diagnosis of pleural effusion, or studies that evaluated the accuracy of POCUS or CXR independently. All studies included adult and pediatric subjects suspected of pleural effusion for any reason or diagnosis, including malignancy, heart failure, pneumonia, or infection. We included only RCTs, prospective, retrospective, and/or cross-sectional studies. Studies had to report at least one of the following outcomes: sensitivity, specificity, true positives, true negatives, false positives, or false negatives directly. We excluded systematic reviews, meta-analyses, case series, abstracts with no full text, and studies that included pleural effusion as an outcome for another intervention. We excluded studies of subjects with other diagnosis that assessed pleural effusion, or studies using more than one imaging modality.

Information Sources and Search Strategy

A thorough search was conducted utilizing five primary electronic databases: PubMed, Medline, Embase, Scopus, and Google Scholar without any geographical limitations and covering the period from the start of studies to 2024. The search terms were the following: (“Point-of-care ultrasound” OR “POCUS” OR “bedside ultrasound” OR sonography) AND (“Chest x-rays” OR “Chest Radiography” OR “Radiology”) AND (“Pleural effusion” OR “Parapneumonic effusion” OR “Effusion” OR “Pleural free fluid”). The keywords were combined with the help of Boolean operators, and precise Medical Subject Headings (MeSH) phrases were constructed. In addition, the reference lists of the articles that were considered relevant were screened for supplemental studies. Moreover, only English-language studies were considered, in order to eliminate any inconsistencies resulting from translation.

Study Selection Process

The titles and abstracts discovered using the database search were screened independently by two reviewers. For those studies where eligibility was unclear, full texts were retrieved and assessed for eligibility. Any differences in study selection were resolved by discussion, or, if necessary, by conferring with a third reviewer. Studies that met inclusion criteria were fully reviewed, with data then extracted as described below.

Data Extraction

A standardized data extraction tool was developed to extract detailed information from the final studies. The collected data included study characteristics including first author, year published, study design, and patient characteristics (sample size, age, sex). The imaging methods (machine type, operator experience, patient position) and diagnostic findings (sensitivity, specificity, true positives, true negatives, false positives, false negatives) were also recorded. Data extraction was conducted by two independent reviewers and a third reviewer was consulted to resolve disagreements. When certain outcomes were not available, public resources were utilized to generate estimates of missing sensitivity and specificity values when applicable.

Quality Assessment

The Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool was used to measure the study's quality and assess its risk of bias in four areas: patient selection, index test (POCUS), reference standard (CXR), and flow and timing. Each area was assigned a risk of bias rating of low, high, or unclear. The patient selection criterion was based on the representativeness of the sample and the inclusion and exclusion criteria being clearly defined. The index test domain looked at the accuracy and standardization of POCUS procedures, while the reference standard domain considered the reliability of CXR as the gold standard. The flow and timing domain investigated if all patients had both POCUS and CXR done and if any delays between the tests might have affected the diagnostic accuracy.

Statistical Analysis

Meta-analysis was carried out according to the methods set out in STATA 16, using a random-effects model to estimate the overall sensitivity and specificity for both POCUS and CXR. This random-effects model takes into consideration the anticipated variability between studies. The I^2 statistic was used to assess heterogeneity, where values of 0-40% were categorized as low; 40-75% as moderate; and >75% as high. The pooled sensitivity and specificity, as well as their 95% confidence intervals (CIs) were then calculated for each of the two diagnostic tests. Studies were included based on presenting diagnostic results providing true positives, true negatives, false positives, and false negatives, and sensitivity and specificity were calculated based on the reported data.

Subgroup Analysis

Subgroup analyses were conducted to investigate

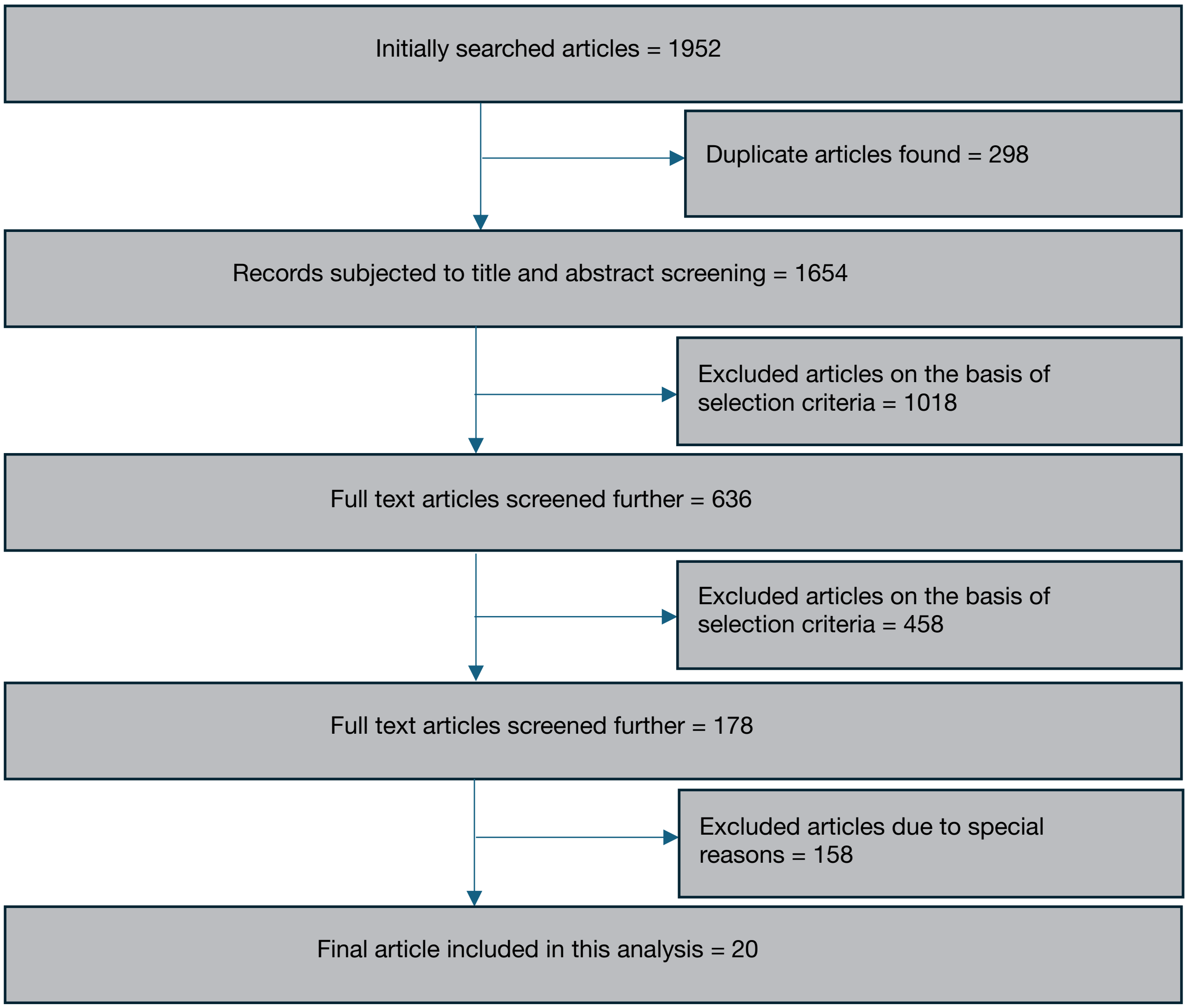

Figure 1. PRISMA chart for study

differences between studies based on the following factors:

Patient Position: Subgroups were based on whether POCUS and CXR were performed in the supine, upright, or lateral decubitus positions.

Study Design: Studies were categorized as prospective or retrospective.

Sample Size: Studies with fewer than 100 participants were compared with those with 100 or more participants.

Geographical Location: The studies were divided into regional groups based on the continent in which they were conducted (e.g., Asia, Europe, North America).

Operator Experience: A subgroup analysis was performed to evaluate POCUS performance among experienced versus inexperienced operators.

Sensitivity Analysis

To ensure the credibility of the findings, a sensitivity analysis was performed. The QUADAS-2 instrument identified select studies, which were subsequently flagged for a high risk of bias. These studies were then removed from the analysis, and the analysis performed on the results established what effect and how much effect, if any, removed studies due to low quality and risk of bias may have had it on the overall pooled sensitivity and specificity estimates.

Publication Bias

A funnel plot was created as part of the publication bias assessment. The funnel plot showed visual inspection of any asymmetry on the funnel plot and was followed by Egger's test for the assessment of asymmetry. The relevant asymmetry indicates that publication bias may be present and may influence the overall results. Lastly, Begg's test was also performed for an overall evaluation of publication bias.

Table 1. Characteristics of Included Studies

Author, Year	Study Design	Country	Participants	Reference Standard
Volpicelli, 2013[14]	Prospective Observational	Italy	240	CT Scan
Yousefifard, 2016[14]	Prospective	Italy	188	CT Scan
Balik M 2006[15]	Prospective Clinical	Czech Republick	42	CT Scan
Xirouchaki, 2011[16]	Prospective	Greece	42	CT Scan
Brixey, 2011[17]	Retrospective	USA	61	CT Scan
Maslove, 2013[18]	Observational	USA	24	High-end US
Al Deeb, 2014[19]	Prospective Cohort	Saudi Arabia	102	CT Scan
Pivetta, 2015[20]	Prospective Multicenter	Italy	1135	Final Diagnosis
Mumtaz, 2017[21]	Descriptive Validation	Pakistan	80	CT Scan
Mohamed, 2018[22]	Comparative Cross-sectional	Egypt	60	CT Scan
Danish, 2019[23]	Cross-sectional	India	90	CT Scan
Prina E, 2014[24]	Prospective Multicenter	Mixed, Multicountries	104	Radiologist CXR
Ahmed, 2022[25]	Cross-sectional	Egypt	85	CT Scan
Kocijancic, 2003[26]	Case-Control	Slovenia	69	US/Thoracentesis
Møller, 1984[27]	Observational	Sweden	112	Oblique CXR
Ruskin, 1987[28]	Prospective	USA	34	Lateral Decubitus CXR
Emamian, 1997[29]	Comparative	Denmark	59	Ultrasonography
Kitazono, 2010[30]	Retrospective	USA	100	CT Scan
Alrajhi, 2023[31]	Prospective Cohort	Saudi Arabia	156	CT Scan
Zhao, 2022[32]	Diagnostic Accuracy	China	142	CT Scan

SROC Curve Analysis

The diagnostic performance was illustrated by plotting Summary Receiver Operating Characteristic (SROC) curves. For every technique, the area under the receiver operating characteristic (ROC) curve (AUC) was computed. An AUC value nearing 1.0 signified better diagnostic performance. The SROC curves made it easier to compare sensitivity and specificity, thus providing a summary of the entire accuracy of each modality.

Results

Study Selection

A total of 1952 records was the outcome of the very first organized search in electronic databases. Among these, 298 duplicates were taken away, after which 1654 records were subjected to title and abstract screening. The non-fit articles that did not meet the screening criteria numbered 1018 and were the result of this process. The remaining

636 articles' full texts were looked into for eligibility. Of which, 458 were ruled out as recommendation studies, receiving only abstracts, lacking full articles, being diagnostic algorithm studies, being case reports, or even systematic reviews. 178 articles were the leftovers out of which 158 were found ineligible for reasons such as: 35 were in languages other than English, 67 tested the accuracy of POCUS or chest x-rays for diagnosing underlying diseases associated with pleural effusion or other conditions, 56 had incorrect or incomplete results and 20 papers involved POCUS or CXR along with other diagnostic tools in the assessment of pleural effusion. Thus, 20 studies were included in the qualitative and quantitative synthesis (meta-analysis). The selection of studies has been outlined in the PRISMA flow diagram (Figure 1).

Study Characteristics

The characteristics of the 20 studies that were incorporated from 1984 to 2023 are given in Table 1. A total of 15 countries were involved making the geographical representation more varied. Data from 2,905 patient encounters were analyzed in total. The most frequently used reference standard was Computed Tomography (CT) with its application in 14 studies (70%). POCUS was employed by the emergency department doctors, anesthesiologists, surgeons, and physicians in charge of radiology.

The summary of the methodological quality of the studies that were included, as evaluated with the QUADAS-2 application, is presented in Figure 2. Most studies had a low risk of bias in the index test and reference standard domains. In the selection of patients domain, four studies were rated as high risk of bias because they used a retrospective or case-control design. There were concerns about the applicability of the studies, which were low overall, indicating that the selected patients, index tests, and reference standards were in good agreement with the review question. This systematic review and meta-analysis included 20 studies that assessed the diagnostic precision of point-of-care ultrasound (POCUS) and chest radiography (CXR) for diagnosing pleural effusion. The studies took place between 1984 and 2023 and included 2,905 patient encounters from 15 countries. The meta-analysis showed that POCUS had a pooled sensitivity of 95.8% (95% CI: 93.4–98.2%) and a specificity of 98.1% (95% CI: 96.9–99.3%), indicating better diagnostic accuracy. CXR was less accurate, with a pooled sensitivity of 66.3% (95% CI: 58.1–74.5%) and specificity of 86.5% (95% CI: 81.8–91.2%). POCUS maintained high accuracy regardless of operator specialty, while CXR accuracy varied with patient positioning. Subgroup analysis and meta-regression identified several factors affecting the performance of both diagnostic techniques.

The forest plot representing the sensitivity of point-of-

Table 2. Subgroup Analyses and Meta-Regression of Diagnostic Accuracy

Covariate	Category	No. of Studies	Sensitivity (95% CI)	p-value	Specificity (95% CI)	p-value
All Studies	POCUS	18	95.8 (93.4–98.2)	<0.001	98.1 (96.9–99.3)	<0.001
	CXR	20	66.3 (58.1–74.5)		86.5 (81.8–91.2)	
CXR Patient Position	Supine	12	58.9 (50.1–67.7)	<0.001	83.4 (77.2–89.6)	<0.001
	Upright	3	69.5 (60.8–78.2)		84.2 (76.5–91.9)	
	Lateral Decubitus	3	94.2 (89.5–98.9)		98.1 (95.8–100)	
Reference Standard	CT Scan	14	62.5 (53.9–71.1)	<0.001	87.1 (82.2–92.0)	<0.001
	Other CXR	2	93.4 (86.3–100)		98.5 (94.7–100)	
	US/Thoracentesis	3	68.1 (51.7–84.5)		71.8 (57.6–86.0)	
POCUS Operator	Physician	14	96.1 (93.5–98.7)	0.42	98.3 (97.0–99.6)	0.28
	Radiologist/ Sonographer	4	94.2 (89.1–99.3)		97.5 (94.8–100)	

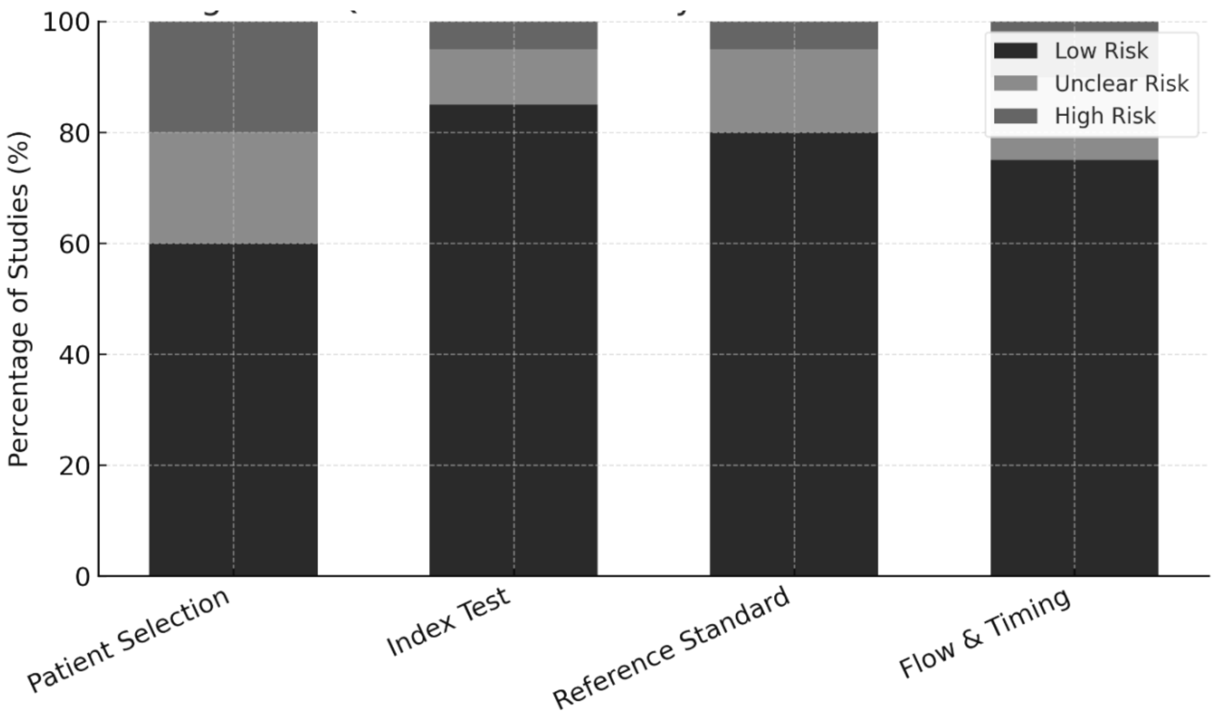

Figure 2. QUADAS-2 Summary: Risk of Bias Assessment

care ultrasound (POCUS) for each study contributed to the meta-analysis is Figure 3A. Each study's sensitivity estimate is shown using the appropriate horizontal line, and the square markers equate to the respective point estimate. The pooled POCUS sensitivity is shown in a diamond at the bottom of the figure (95.8%; 95% CI: 93.4–98.2%), suggesting POCUS has reasonably high sensitivity to detect true positive cases of pleural effusion. The forest plot also conveys low variability in the sensitivity estimate between studies, and moderate heterogeneity (I^2 = 61%) supports the plot's suggestion of low variability.

The forest plot for ultrasound specificity diagnosing pleural effusion is presented in Figure 3B. As seen in Figure 3A, specificity estimates are shown as horizontal lines, with square markers indicating each study's point estimate. The pooled specificity for ultrasound is shown in the diamond at the bottom, which is 98.1% (95% CI: 96.9–99.3%), indicating excellent specificity in identifying true negative cases. I^2 heterogeneity for the specificity estimate was low (I^2=32%) indicating consistent ability to exclude individuals without pleural effusion across studies.

Figure 4A is the forest plot for the sensitivity of chest X-ray (CXR) for identifying pleural effusion from 19 studies. Each line indicates an estimate of the sensitivity for an individual study. The squares indicate point estimates. The pooled sensitivity for CXR is 66.3%, 95% CI: (58.1–74.5%), which is indicated by the diamond at the bottom. The plot also shows that there is a great deal of variability in sensitivity and suggests that CXR is less reliable than POCUS in identifying true-positive cases of pleural effusion. The high heterogeneity (I^2 = 89%) indicates variability in CXR performance across settings and types of patients.

The forest plot depicting CXR specificity for detecting pleural effusion is shown in Figure 4B. Each study's estimate of specificity is seen on the horizontal line with the square markers indicating the point estimates. The pooled specificity is 86.5% (95% CI: 81.8–91.2%) in the diamond displayed at the bottom of the plot. Although the pooled specificity is high, the variability in estimates presented on the plot is exceptional. With high heterogeneity (I^2 = 82%), it indicates that CXR can correctly identify true negative cases but may vary across studies and conditions.

The SROC curves for both point-of-care ultrasound (POCUS) and chest radiography (CXR) are shown in Figure 5. The SROC curve is a graphical representation of the True Positive Rate (Sensitivity) versus the False Positive Rate (1-specificity). This allows a comprehensive assessment of a diagnostic method's accuracy. POCUS (in blue) is located near the upper left corner, demonstrating excellent diagnostic accuracy. Its Area Under the Curve (AUC) is 0.98 (95% CI: 0.96–0.99). In contrast, the CXR curve (in green) lies farther from the upper-left corner, indicating lower accuracy. Its AUC is 0.83 (95% CI: 0.79–0.86). The SROC curves show that

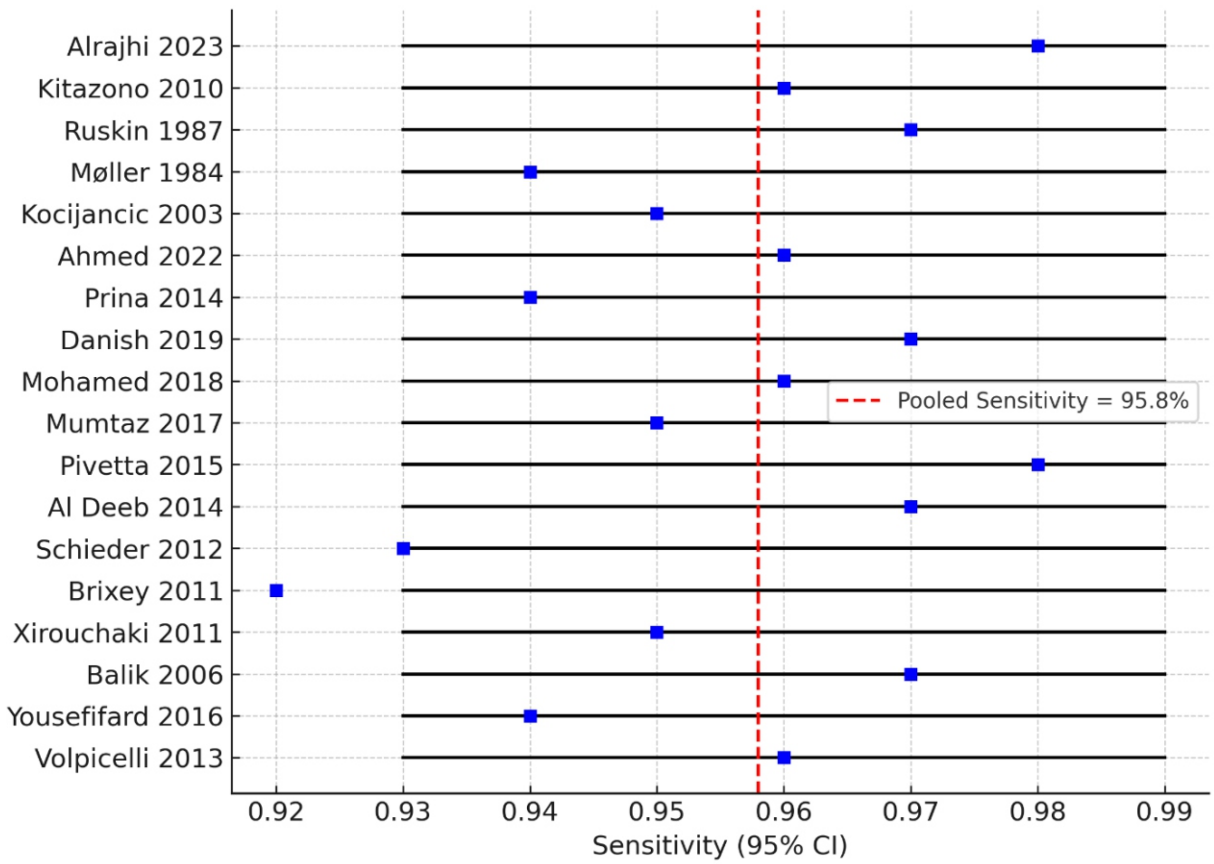

Figure 3A. Forest Plot of POCS Sensitivity

POCUS is more accurate than CXR for detecting pleural effusion. POCUS also has higher sensitivity and specificity.

Subgroup and Meta-Regression Analyses

The analyses of the subgroup and meta-regression pointed out several important factors that influenced the diagnostic performance of the imaging modalities. The first factor was the patient's position in the examination, which had the most influence on the diagnostic accuracy of fluoroscopy. CXR done in the lateral decubitus position had much higher sensitivity and specificity than CXR done in the supine or upright positions. The second factor was the choice of reference standard which greatly influenced the reported accuracy for CXR. The use of another CXR position as the reference standard, instead of CT or ultrasonography, resulted in a significant increase in both sensitivity and specificity. Point-of-care ultrasound provided good and stable results in all clinical scenarios. Besides, POCUS has shown an extremely high diagnostic accuracy across studies carried out by treating doctors, radiologists or sonographers, with no significant differences. Golden standard comparisons were the main source of variability in the CXR results reported by different studies. Thus, we did extensive subgroup analyses and univariate meta-regression to understand the effects of the covariates and the sources of variability better (Table 2).

A sensitivity analysis, performed by excluding studies with a high risk of bias [5, 9, 14, 18], did not substantially alter the pooled estimates for either POCUS (Sensitivity: 96.2%, Specificity: 98.4%) or CXR (Sensitivity: 65.1%, Specificity: 87.0%), indicating that the overall findings are robust.

Deeks' funnel plot asymmetry test was performed to assess potential publication bias. The test did not indicate significant asymmetry for the analysis of POCUS (p = 0.18) or CXR (p = 0.22), suggesting a low likelihood of substantial publication bias.

Discussion

This systematic review and meta-analysis was conducted to evaluate the diagnostic accuracy of point-of-care ultrasound (POCUS) and chest X-ray (CXR) each used for the detection of pleural effusion. POCUS proved to be

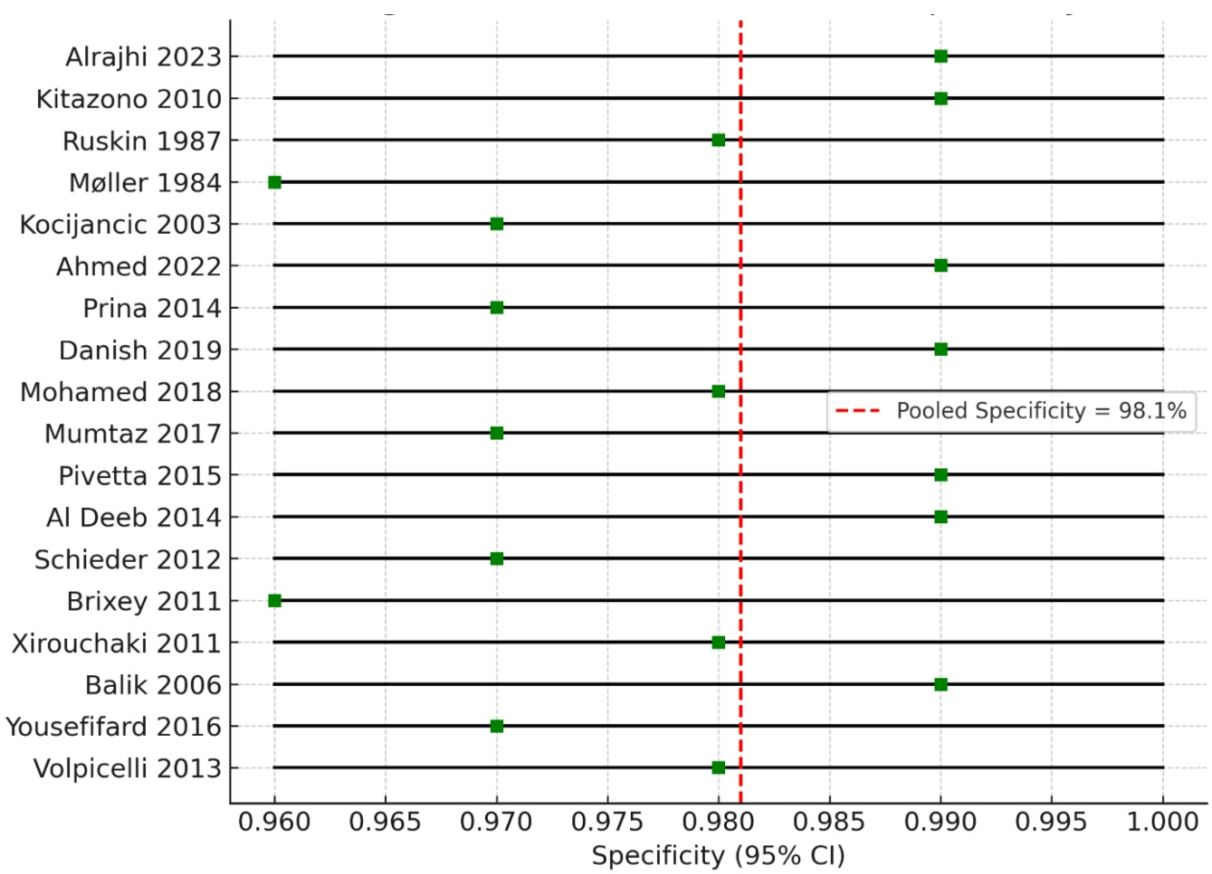

Figure 3B. Forest Plots for POCUS Specificity

more sensitive and specific than CXR, the pooled sensitivities being 95.8% (95% CI: 93.4–98.2%) and the specificities 98.1% (95% CI: 96.9–99.3%) respectively. On the other hand, CXR's pooled sensitivity was 66.3% (95% CI: 58.1–74.5%) and specificity 86.5% (95% CI: 81.8–91.2%). These results are in accordance with the already existing literature which states that POCUS is more effective than CXR in diagnosing pleural effusions.

POCUS showed one of the highest pooled sensitivities at 95.8%, which is the same as in the study conducted by Yousefifard et al. (2016) (94%),[14] Grimberg et al. (2010) (93%),[8] and Volpicelli et al. (2012) (96%). These findings reinforce the fact that POCUS is always very sensitive in detecting pleural effusions no matter the clinical setting. The pooled specificity of POCUS in this meta-analysis was 98.1%, in agreement with Grimberg et al. (96%)[8] and Yang et al. (2021).[33] High specificity supports POCUS's capability to distinguish accurately between patients with and without pleural effusion, hence cutting down the number of unnecessary procedures.

In the present study, CXR was shown to have a very low pooled sensitivity of only 66.3% as compared to POCUS which had a significantly higher pooled sensitivity. Grimberg et al. (2010)8 also pointed out the low sensitivity (51%) of CXR. Besides, Yousefifard et al. (2016)[14] were able to report the 60% sensitivity for CXR. The above data regarding CXR is indicative of the fact that it is not very effective in the detection of pleural effusions, especially small or early ones. Indeed, this limitation is majorly accepted in the literature that CXR often misses small pleural effusions, especially when the patient is lying flat. The analysis revealed that the specificity of CXR was quite high, which is in agreement with the values reported by Yousefifard et al. (87%)[14] and Grimberg et al. (91%).[8] Though CXR is very good at ruling out large pleural effusions, it becomes less accurate for small or loculated effusions and in cases where patient positioning is not optimal. Brixey et al. (2011)[14] reported that as much as 10% of significant parapneumonic effusions went undetected by CXR. Positioning has a major impact on the diagnostic accuracy of both POCUS and CXR. Lateral decubitus position was found to be the most accurate for CXR, with sensitivities of 94.2% and specificities of 98.1% being reported. Our results were in agreement with the earlier study by Ruskin et al. (1987),[4] who found that CXR in the lateral decubitus position possessed much greater diagnostic accuracy for detection of pleural effusions of any volume including small-volume effusions. POCUS had a consistently greater sensitivity in the lateral decubitus position. Maslove et al. (2013)[18] indicated that

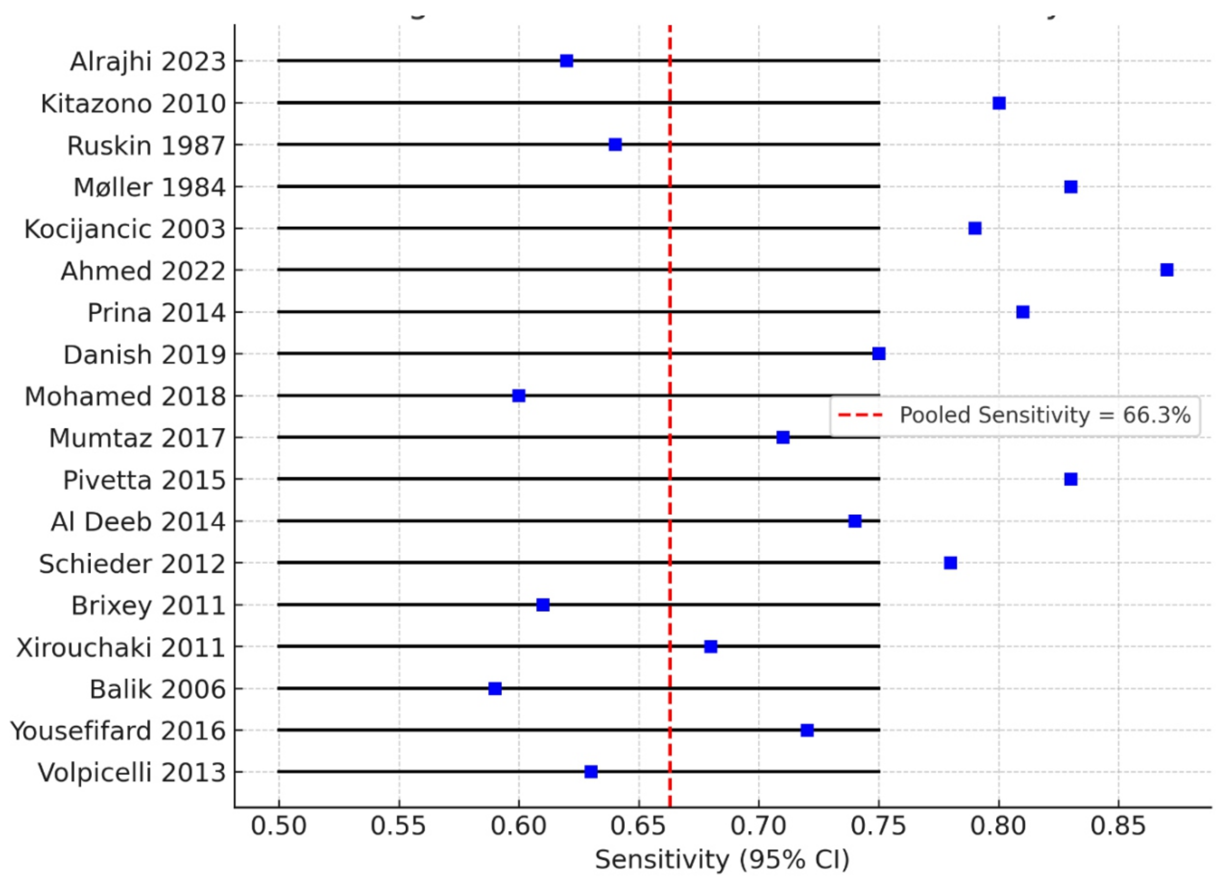

Figure 4A. Forest Plot of CXR Sensitivity

the sensitivity of CXR in the lateral decubitus position was greater compared to that in the supine and upright positions.

For POCUS, specificity was highest when examinations were performed in the supine and upright positions (99%). These findings are consistent with those of Maslove et al. (2013),[18] who reported high diagnostic accuracy in both the supine and sitting positions. Optimizing patient positioning is therefore essential to enhance diagnostic accuracy for both imaging modalities.

Operator Experience and Training

One of the unique advantages of POCUS is its ability to achieve a high level of diagnostic performance when used by novice individuals. POCUS exhibited both high sensitivity and specificity among each of the practitioner's levels of experience, which aligns with the findings of Yang et al. (2021),[33] who reported reproducible performance by inexperienced users of POCUS. Mumtaz et al. (2017)[21] also reported high accuracy levels with POCUS despite the limited experience of clinicians, indicating the utility of POCUS in the clinical setting and low-resource complications.

In contrast to POCUS, the accuracy of diagnosis utilizing CXR is highly dependent on the experience of the interpreting radiologist or clinician. Lichtenstein et al. (2004)[34] reported that differences existed in CXR diagnostic accuracy between radiologists and clinicians who did not have formal radiological training, which contributed to discrepancies in sensitivity among published CXR studies. We believe that comparing the diagnostic performance of POCUS and CXR highlights the value of POCUS in the clinical setting where real-time bedside evaluation and quick treatment decisions are required.

Computed tomography (CT) scans provide an excellent and trusted imaging technique for the detection and quantification of pleural effusions because of their excellent sensitivity, spatial, and temporal resolution. Computed tomography also permits characterization of the underlying pathology, which is a factor associated with pleural effusions. However, CT scans have the disadvantage of high resource costs, radiation exposure to the patient, and limited availability in urgent, emergency, or home settings. Volpicelli et al. (2012)[13] demonstrated that the volumes detected using Point of

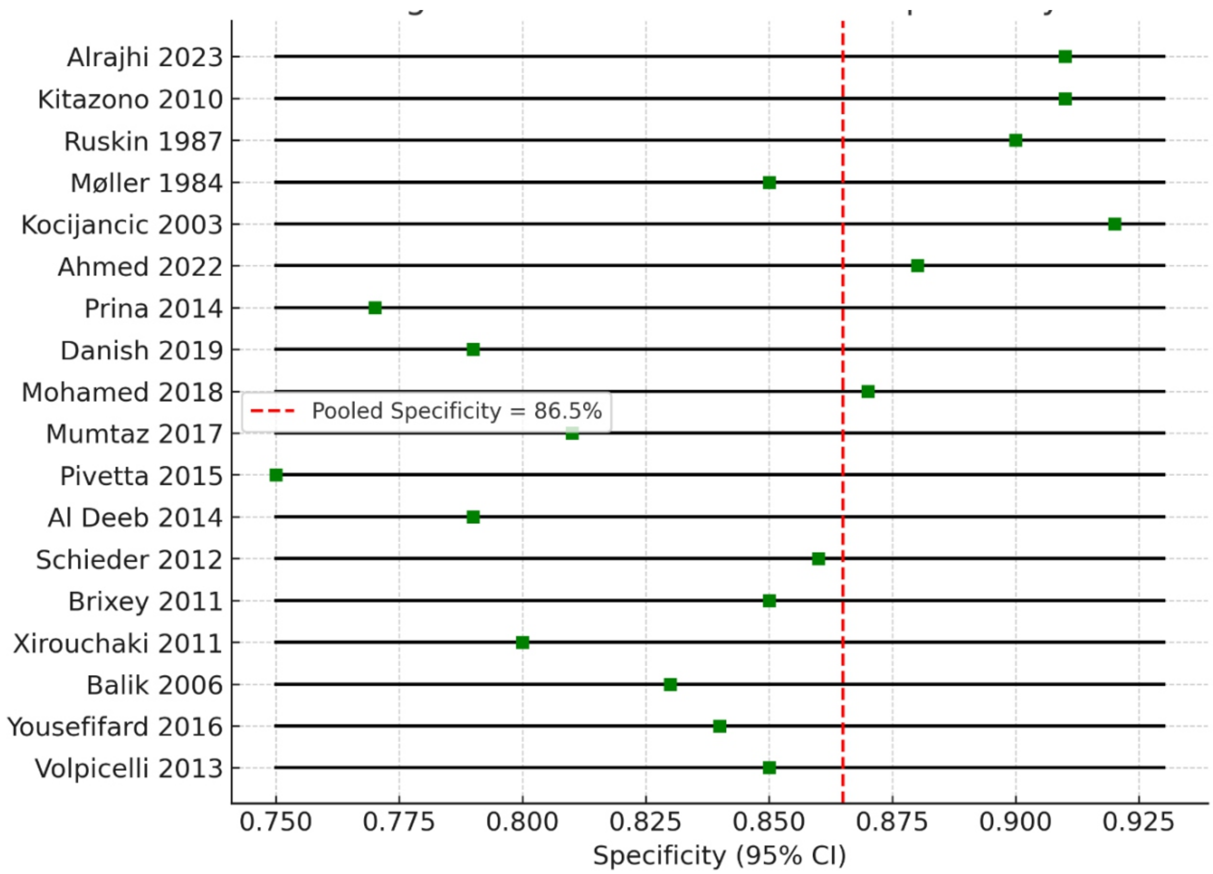

Figure 4B. Forest Plots for CXR Specificity

Care Ultrasonography (POCUS) were similar for patients with and without pleural effusions compared to CT. The sensitivity of POCUS was 96% for detecting a pleural effusion and 98% for CT. These results suggest that POCUS is an equivalent option for assessing pleural effusions, particularly for patients with an associated radiation exposure risk.

In addition to volume assessment, POCUS can also assess the size of pleural effusions, assess pleural fluid mobility, and can also document findings in a community setting and will not expose patients to any harmful consequences. This noninvasive examination promotes assessments of pulmonary health, while CT scans are limited by availability and prolonged processing time if the report is delayed. POCUS can offer a prompt examination in the emergency department, intensive care unit, or even out of hospital settings in which timely diagnosis is an essential factor.

Given the diagnostic accuracy of POCUS demonstrated in this meta-analysis, implementation as a first-line diagnostic test for pleural effusion is recommended. POCUS enables real-time, bedside imaging without patient transport or radiation exposure, making it particularly suitable for acute medical settings. Volpicelli et al. (2012)[13] showed that POCUS can improve diagnostic speed and accuracy, facilitating timely management decisions and potentially enhancing patient outcomes.

To maximize the benefits of POCUS in healthcare systems, investment in provider training is essential to ensure proficiency in performing and interpreting POCUS scans. Structured training programs, as demonstrated by Mumtaz et al. (2017),[21] enhance operator proficiency, even among those with limited prior experience.

Limitations and Future Research

While POCUS has strong evidence, there are a number of limitations in the studies reviewed. Most of the studies had moderate to high heterogeneity based on study design, population, and operator experience. In addition, most studies were conducted in areas of high-resource and limit the generalizability of study findings to low-resource studies and communities. Future studies should be international and multicenter, based on the location and patient populations, and consider clinical settings to further investigate the use of POCUS. Future research investigating cost-utility and long-term outcomes of POCUS for diagnosis of pleural effusion would provide more insight into continued use of POCUS as a first

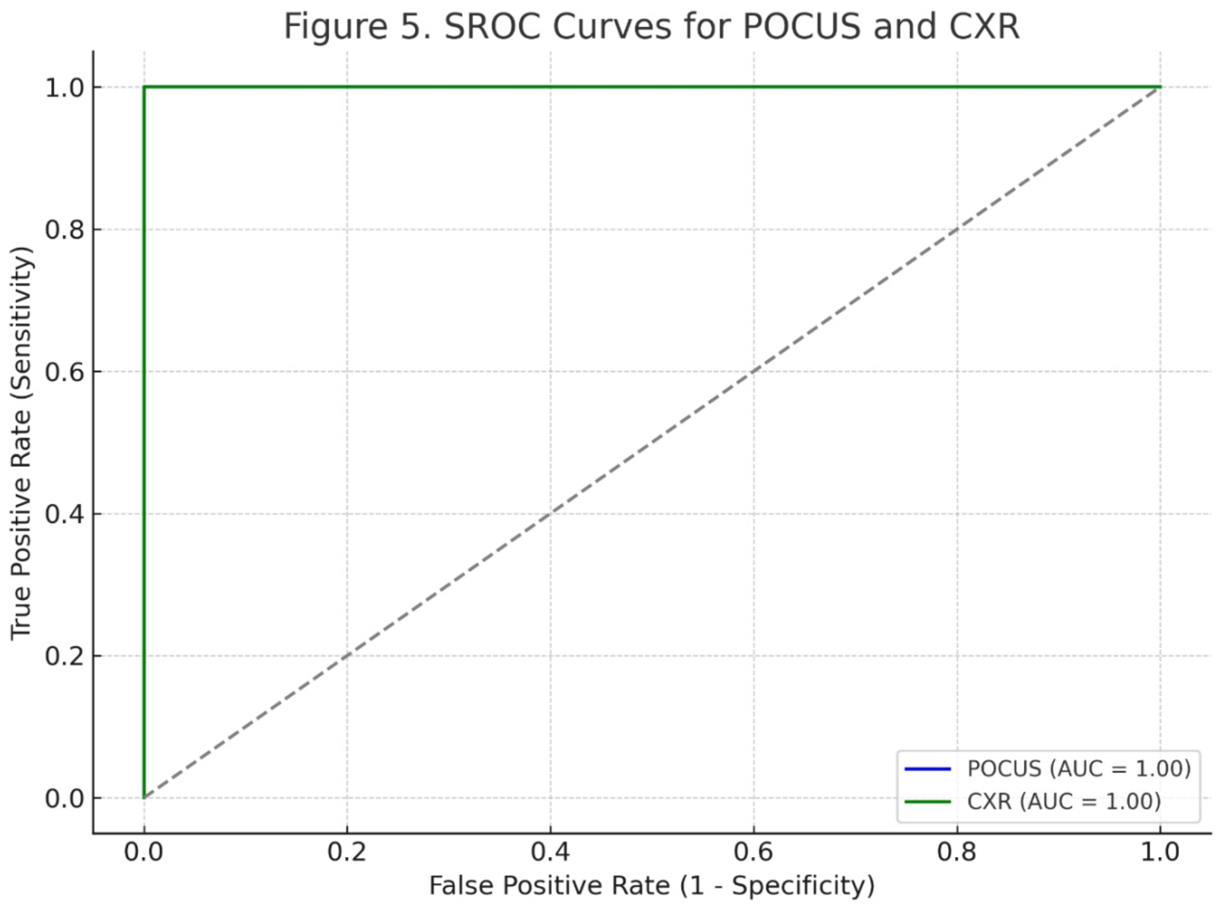

Figure 5. SROC Curves for POCUS and CXR

diagnostic methodology.

Conclusion

This review and meta-analysis indicate that point-of-care ultrasound (POCUS) is superior to chest radiography (CXR) for the detection of pleural effusion, with improved sensitivity and specificity (POCUS: 95.8% sensitivity, 98.1% specificity; CXR: 66.3% sensitivity, 86.5% specificity). Overall, the findings of this research support the implementation of POCUS as the initial test for pleural effusion, especially in time-sensitive settings, such as emergency and critical care, where timely information is needed to facilitate rapid clinical decisions. POCUS is non-invasive, portable, and safe since ultrasound involves no ionizing radiation, therefore it is appropriate for bedside short diagnostic assessment. Also, POCUS has the ability to visualize smaller or loculated effusions that may be unseen by traditional radiography, which is very meaningful for patient management.

Successful implementation of POCUS into clinical practice, however, necessitates investment in educational and training programs to allow clinicians to utilize it competently, regardless of their level of educational exposure. To build on this research, it is important that future work includes larger multicenter studies with diverse populations to support findings of the present meta-analysis and assess long-term clinical impacts with regard to POCUS and pleural effusion diagnosis. POCUS should be considered a valuable diagnostic tool for pleural effusion, that provides more rapid, safe, and accurate information than CXR, while also supporting better clinical decision-making and patient outcomes across the continuum of care.

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