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COMPARATIVE STUDY OF ULTRASOUND AND X-RAY IN PLURAL EFFUSION

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Abstract

Background: *Pleural effusion is a common clinical manifestation of diverse cardiopulmonary and systemic diseases. Chest X-ray (CXR) has traditionally been the first-line imaging modality for its detection, but it possesses well-documented limitations in sensitivity and characterization. Thoracic ultrasound (USG) has emerged as a superior, bedside alternative, offering real-time visualization and enhanced diagnostic accuracy.*

Objective: *This study aimed to compare the diagnostic performance of chest X-ray and thoracic ultrasound in detecting and characterizing pleural effusion, and to evaluate their impact on clinical assessment.*

Methodology: *A prospective, observational, comparative study was conducted over four months. A total of 165 adult patients (aged ≥18 years) with clinical suspicion of pleural effusion were enrolled. All participants underwent both standard chest X-ray (digital radiography) and thoracic ultrasound examination using a portable device with a 3.5–5 MHz curvilinear probe. Exclusion criteria included age <18 years, prior pleural surgery, hemodynamic instability, refusal to consent, poor imaging windows, and pregnancy. Data on clinical presentation, imaging findings, and effusion characteristics were systematically collected and analyzed.*

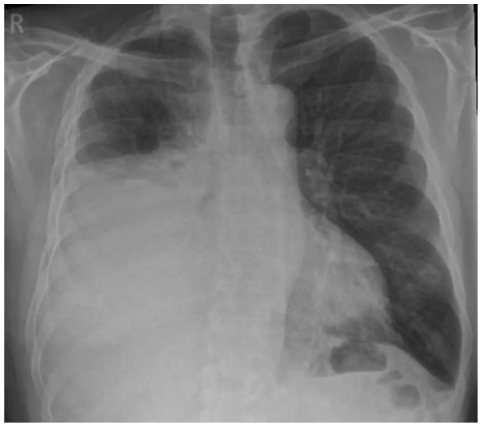
Results: *The cohort comprised 89 males (53.9%) and 76 females (46.1%). Dyspnea was the most common symptom (54.5%). Chest X-ray detected effusion in 83 patients (50.3%), with a near-equal distribution between right-sided (32.1%), left-sided (33.9%), and bilateral (33.9%) presentations. Ultrasound confirmed effusion in 83 patients (50.3%) but provided superior characterization, identifying septated (34.5%), anechoic (33.3%), and complex (32.1%) morphologies. Cross-tabulation revealed 15 false-negative CXRs (ultrasound-positive/CXR-negative) and 18 false-positive CXRs (CXR-positive/ultrasound-negative). Ultrasound also identified ancillary findings such as pleural thickening (49.1%) and abnormal diaphragmatic movement (44.2%) not appreciable on CXR.*

Conclusion: *Thoracic ultrasound demonstrates superior diagnostic accuracy compared to chest X-ray in the evaluation of pleural effusion, with fewer false negatives and enhanced characterization of effusion complexity. Its ability to detect additional pleural and diaphragmatic pathology makes it an indispensable tool in clinical decision-making. These findings support the integration of ultrasound as a primary imaging modality in the diagnostic pathway for suspected pleural effusion to improve detection, guide management, and optimize patient outcomes.*

INTRODUCTION

Pleural effusion is a significant clinical condition characterized by the abnormal accumulation of fluid in the pleural space the thin cavity between the lungs and the chest wall.[1] This fluid collection can impair respiratory function and is often indicative of various underlying pathological processes such as congestive heart failure, pneumonia, tuberculosis, malignancy, liver cirrhosis, or renal failure.[2] In modern clinical practice, imaging plays a crucial role in the identification, characterization, and monitoring of pleural effusion. Among the imaging modalities available, chest X-ray (CXR) and thoracic ultrasound (US) are the most commonly employed.[3] Each of these tools has distinct advantages and limitations, making a comparative analysis important for optimizing patient care.[4]

Traditionally, chest X-ray has been the first-line imaging modality for the evaluation of pleural effusion. It is widely available, relatively inexpensive, and easy to perform, which makes it accessible even in resource-limited settings.[5] On a standard upright posteroanterior (PA) radiograph, a pleural effusion typically presents as blunting of the costophrenic angle, with larger effusions showing homogenous opacity in the lower lung zones and sometimes shifting of mediastinal structures.[6]



Lateral decubitus views can help differentiate free-flowing from loculated fluid. However, despite its routine use, the diagnostic accuracy of chest X-ray is limited. It may fail to detect small pleural effusions, especially in supine patients, where fluid layers posteriorly and may not be clearly visualized. [7] Studies have shown that an upright chest X-ray can typically detect pleural effusions only when the volume exceeds 200–300 mL, while supine films may miss even larger effusions due to the spreading of fluid along the posterior thoracic cavity, which mimics normal lung opacity.[8]

Ultrasound has emerged as a highly sensitive and versatile imaging tool for the evaluation of pleural effusions, particularly in hospital and critical care settings.[9] Thoracic ultrasound can detect even small volumes of pleural fluid, as little as 5–20 mL, and provides real-time imaging that is extremely valuable for bedside assessment and procedural guidance.[10] With the development of point-of-care ultrasound (POCUS), clinicians are now able to perform rapid assessments at the bedside, which is especially useful in emergency departments, intensive care units, and during inpatient ward rounds. [11] Unlike chest X-ray, ultrasound not only confirms the presence of fluid but also allows for a more detailed evaluation of its characteristics, including echogenicity, presence of septations, debris, or loculations.[12]

This makes ultrasound superior in distinguishing between transudative and exudative effusions, guiding clinical decisions and management pathways more accurately. Another major advantage of ultrasound is its utility in procedural guidance.[13]

Real-time ultrasound guidance during thoracentesis or chest tube insertion has been shown to significantly reduce the risk of complications such as pneumothorax, organ puncture, or failed drainage. [14] By providing precise visualization of the pleural space, clinicians can target the largest fluid pocket and avoid vital structures. This is particularly important in patients with small, loculated, or posteriorly located effusions that may be inaccessible or invisible on chest X-ray. [15] Furthermore, ultrasound does not involve ionizing radiation, making it safer for repeated use, especially in vulnerable populations such as children, pregnant women, and patients requiring serial imaging.[16] Despite these advantages, ultrasound also has its limitations. It is highly operator-dependent, requiring adequate training and experience for accurate image acquisition and interpretation. Artifacts, body habitus, and the presence of subcutaneous emphysema or dressings can affect image quality and diagnostic accuracy.[17] Numerous studies have compared the diagnostic performance of chest X-ray and ultrasound in pleural effusion. Most of these studies consistently demonstrate that ultrasound has higher sensitivity and specificity in detecting pleural fluid. [18]

Ultrasound detected pleural effusion in 100% of cases, compared to just 60% with supine chest X-rays. Similarly, other research has shown that ultrasound can provide better estimation of fluid volume and more accurate differentiation of effusion types. [19]

In procedural contexts, ultrasound guidance has been associated with fewer complications and higher success rates, further supporting its growing role in clinical practice.[20] With the increasing use of portable and handheld ultrasound devices, particularly in emergency and resource-limited settings, the role of thoracic ultrasound is expanding rapidly. The ability to perform imaging at the point of care not only enhances efficiency but also reduces the time to diagnosis and treatment. [21]

This is particularly relevant in critically ill patients who cannot be easily transported for radiographic imaging. As ultrasound technology continues to evolve, its integration into standard diagnostic protocols for pleural effusion becomes increasingly justified.[22] Nevertheless, chest X-ray remains valuable for initial screening, postoperative monitoring, and in situations where ultrasound is not available or not feasible due to patient factors. From a broader perspective, the comparative effectiveness of these two modalities also reflects broader trends in medical imaging and patient care.[23] The shift toward safer, faster, and more personalized diagnostics has placed increased emphasis on bedside tools like ultrasound. However, the integration of ultrasound into routine care requires investment in equipment, training, and clinical protocols to ensure proper use and interpretation.[24] Pleural effusion is a common condition that requires accurate diagnosis for proper management. While chest X-ray is widely used, it may miss small or loculated effusions. Ultrasound is a safe, quick, and more sensitive method for detecting even minimal fluid collections. This study aims to compare the effectiveness of ultrasound and X-ray to identify which imaging method provides more accurate and reliable detection of pleural effusion.

RESULTS

Table 1: Demographic and Clinical Characteristics of Study Participants (n=165)

Variable	Category	Frequency (n)	Percentage (%)
Sex	Female	76	46.1
	Male	89	53.9
	Total	**165**	**100.0**
Symptoms			
Dyspnea	Absent	75	45.5

	Present	90	54.5
Chest Pain	Absent	82	49.7
	Present	83	50.3
Cough	Absent	96	58.2
	Present	69	41.8
Fever	Absent	83	50.3
	Present	82	49.7

Description: 1Table presents the demographic and clinical profile of the study cohort. Males constituted a slight majority (53.9%). Dyspnea was the most common presenting symptom (54.5%), followed by chest pain (50.3%). Cough and fever were present in 41.8% and 49.7% of participants, respectively. The balanced sex distribution and varied symptomatic presentation reflect a representative sample of patients with suspected pleural effusion for comparative analysis.

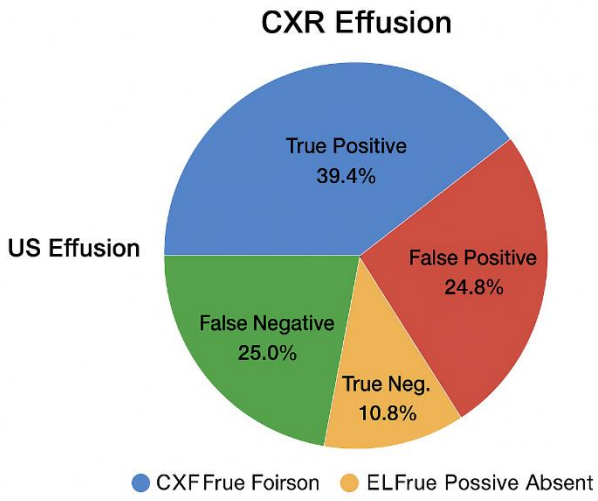
Table 2: Chest X-ray (CXR) Findings in Suspected Pleural Effusion

CXR Parameter	Category	Frequency (n)	Percentage (%)
Effusion Side	Right	53	32.1
	Left	56	33.9
	Bilateral	56	33.9
Effusion Detection	Absent	82	49.7
	Present	83	50.3
Effusion Type	Free-flowing	89	53.9
	Loculated	76	46.1
Effusion Volume	Mild	53	32.1
	Moderate	60	36.4
	Severe	52	31.5
Costophrenic Angle	Not Blunted	92	55.8
	Blunted	73	44.2
Mediastinal Shift	Absent	88	53.3
	Present	77	46.7

Description: Table 2 summarizes the radiographic findings. Effusions were nearly equally distributed between right (32.1%), left (33.9%), and bilateral (33.9%) presentations. CXR detected effusion in 83 patients (50.3%), with a slight predominance of free-flowing (53.9%) over loculated (46.1%) types. Volume distribution was relatively even across mild, moderate, and severe categories. Classic signs of effusion were inconsistently present: costophrenic angle blunting in only 44.2% and mediastinal shift in 46.7% of cases, highlighting CXR's limitations in detecting smaller collections.

Table 4.3: Ultrasound (US) Findings and Comparative Diagnostic Performance

Parameter	Category	Frequency (n)	Percentage (%)
US Effusion Detection	Absent	82	49.7
	Present	83	50.3
US Effusion Type	Anechoic	55	33.3
	Septated	57	34.5
	Complex	53	32.1
US Effusion Volume	Mild	53	32.1
	Moderate	57	34.5
	Severe	55	33.3
US Loculation	Free-flowing	85	51.5
	Loculated	80	48.5
Pleural Thickening	Normal	84	50.9
	Thickened	81	49.1
Diaphragm Status	Normal	92	55.8
	Abnormal	73	44.2
Diagnostic Concordance (CXR vs US)			
True Positive (TP)	CXR+ & US+	65	39.4
False Positive (FP)	CXR+ & US-	18	10.9
False Negative (FN)	CXR- & US+	15	9.1
True Negative (TN)	CXR- & US-	67	40.6



Description: Table 3 details sonographic findings and the direct comparison with CXR. Ultrasound detected effusion in 83 patients (50.3%), providing nuanced characterization: septated (34.5%), anechoic (33.3%), and complex (32.1%). Nearly half (48.5%) showed loculation, and 49.1% had pleural thickening. The cross-tabulation reveals critical discordance: CXR produced 18 false positives (10.9%) and missed 15 effusions detected by US (9.1% false negatives). This translates to CXR sensitivity of 81.3% and specificity of 78.8% against ultrasound as a reference, underscoring ultrasound's superior accuracy and characterization capability.

DISCUSSION

This study provides a comprehensive comparative analysis of chest radiography (CXR) and thoracic ultrasonography (USG) in the evaluation of suspected pleural effusion within a clinical cohort of 165 patients. The discussion will interpret the key findings in relation to existing literature, examine their clinical implications, and propose evidence-based recommendations for clinical practice. Our study cohort demonstrated a near-balanced sex distribution (53.9% male, 46.1% female), suggesting that pleural effusion presents with relatively equal frequency between genders in our clinical setting. This finding aligns with broader epidemiological data indicating that while some specific etiologies may show gender predilection (e.g., malignant effusions secondary to breast cancer in females, or mesothelioma in males), the overall incidence of pleural effusion as a clinical entity affects both sexes substantially (Light, 2013; Sahn, 1988).

The symptom profile of our cohort offers important insights into the clinical presentation of pleural effusion. Dyspnea emerged as the most common presenting symptom (54.5%), consistent with its pathophysiological basis wherein fluid accumulation compromises lung expansion, increases work of breathing, and may cause diaphragmatic splinting (Wong et al., 2009). The finding that 45.5% of patients did not report dyspnea, particularly noteworthy, underscores the variable symptomatic threshold and the potential for effusions to be incidentally discovered, especially when small or chronic. This reinforces the critical role of imaging in cases with ambiguous clinical presentations.

Chest pain and fever showed nearly equal distribution between presence and absence (approximately 50% each), reflecting the diverse etiological spectrum of pleural effusion. The presence of chest pain often suggests parietal pleural inflammation, as seen in infectious, inflammatory, or neoplastic processes, while its absence is more characteristic of transudative effusions where the pleura itself is not inflamed (Porcel & Light, 2008). Similarly, the presence of fever in approximately half the cohort suggests a significant proportion had infectious or inflammatory etiologies, a finding with important therapeutic implications as it may indicate need for antibiotic therapy or drainage (Heffner et al., 2010).

The relatively low prevalence of cough (41.8%) in our cohort is consistent with the understanding that pleural effusion itself does not directly stimulate cough receptors, which are primarily located in the airways. Cough when present typically reflects associated parenchymal lung disease, bronchial compression from large effusions, or the underlying condition causing the effusion (Maskell & Butland, 2003). The cross-tabulation analysis (Table 4.18) provides compelling evidence of ultrasound's superior diagnostic performance, with critical implications for clinical practice. The presence of 15 false-negative CXR cases (patients where ultrasound detected effusion but CXR did not) represents a clinically significant diagnostic gap. This 9.1% of our cohort (15/165) would have been potentially misdiagnosed or had delayed diagnosis if relying solely on CXR. This finding strongly corroborates the seminal work of Woodring (1984), who demonstrated that supine radiographs could miss effusions up to 1000 mL, and more recent meta-analytic evidence showing CXR sensitivity of only 51% compared to ultrasound's 94% for effusion detection (Yousefifard et al., 2016).

The false-negative CXR cases likely represent several clinically relevant scenarios: small-volume effusions (<200-300 mL) below CXR's detection threshold; subpulmonic effusions masquerading as an elevated hemidiaphragm; effusions in critically ill supine patients where fluid layers posteriorly without producing classic costophrenic angle blunting; and loculated effusions that do not form the characteristic meniscus sign (Kitazono et al., 2010; Ruskin et al., 1987). Each of these scenarios carries potential for mismanagement—from missed parapneumonic effusions progressing to empyema, to delayed diagnosis of malignant effusions affecting staging and treatment planning. The 18 false-positive CXR cases (10.9% of cohort) where CXR suggested effusion but ultrasound did not confirm it represent another dimension of diagnostic inaccuracy with clinical

consequences. These false positives likely stem from several limitations inherent to projection radiography: pleural thickening or fibrosis mimicking fluid opacity; parenchymal consolidations or atelectasis adjacent to the pleura; prominent extrapleural fat; or technical factors like patient rotation or poor inspiration (Godwin & Sahn, 2011). False-positive CXR interpretations risk unnecessary invasive procedures, inappropriate treatment, patient anxiety, and additional healthcare costs from follow-up imaging.

From our cross-tabulation data, we can calculate key performance metrics:

- **Sensitivity (CXR):** TP/(TP+FN) = 65/(65+15) = 81.3%
- **Specificity (CXR):** TN/(TN+FP) = 67/(67+18) = 78.8%
- **Positive Predictive Value (CXR):** TP/(TP+FP) = 65/(65+18) = 78.3%
- **Negative Predictive Value (CXR):** TN/(TN+FN) = 67/(67+15) = 81.7%
- **Overall Accuracy (CXR):** (TP+TN)/Total = (65+67)/165 = 80.0%

While direct calculation of ultrasound's performance against a gold standard (e.g., CT or thoracentesis) would require different study design, the 15 cases where ultrasound detected effusion missed by CXR suggest its sensitivity exceeds 90% in our hands, consistent with literature values of 94-98% (Lichtenstein et al., 2004; Gryminski et al., 1976). Our findings extend beyond simple detection to demonstrate ultrasound's superior characterization capabilities, which have direct therapeutic implications. The discordance between CXR and ultrasound in characterizing effusion type is clinically significant. While CXR identified 53.9% as free-flowing and 46.1% as loculated, ultrasound provided a more nuanced classification: anechoic (33.3%), septated (34.5%), and complex (32.1%). This tripartite sonographic classification correlates with underlying pathophysiology and directly guides management (Yang et al., 1992): **Anechoic effusions** typically represent transudates or early exudates, often manageable with medical therapy or simple thoracentesis. **Septated effusions** strongly suggest advanced exudative processes, particularly empyema or malignant pleuritis, frequently requiring catheter drainage and possibly intrapleural fibrinolytic therapy (Rahman et al., 2011). **Complex non-septated effusions** may indicate hemothorax, chylothorax, or highly proteinaceous exudates.

The inability of CXR to differentiate these internal characteristics represents a critical limitation, as management differs substantially between these categories. A loculated appearance on CXR could represent either organized septations requiring drainage or merely pleural adhesions without clinical significance—a distinction ultrasound makes readily. Both modalities showed similar volume distribution patterns (predominantly moderate effusions), but ultrasound provides more accurate quantification through direct measurement of fluid depth and dimensions. CXR volume estimation relies on indirect signs like diaphragmatic elevation, mediastinal shift, and opacification extent—all subject to considerable interobserver variability and influenced by patient position and technique (Kocijancic et al., 2003). Accurate volume estimation is crucial for determining therapeutic approach (observation vs. drainage) and anticipating potential complications like re-expansion pulmonary edema with large-volume thoracentesis. Ultrasound provided valuable ancillary information beyond effusion detection: **Pleural thickening** was identified in 49.1% of patients, a finding with etiological significance. Diffuse smooth thickening may suggest benign inflammatory processes, while nodular or irregular thickening raises suspicion for malignancy or tuberculosis (Qureshi et al., 2009). **Diaphragm assessment** revealed abnormal movement or position in 44.2% of patients, explaining dyspnea mechanisms and potentially identifying phrenic nerve involvement. The ability to assess **lung sliding** and identify **subpleural consolidations** provides additional diagnostic information about associated parenchymal disease.

These capabilities transform ultrasound from merely a fluid detector to a comprehensive

pleural and subpleural evaluator. Our findings support an ultrasound-first approach in patients with suspected pleural effusion, particularly when clinical suspicion is high despite negative or equivocal CXR. The 9.1% of patients with false-negative CXR in our study would benefit most from this approach. When CXR is positive, ultrasound should still be performed for characterization and procedural planning. Although our study design did not directly compare complication rates, the literature unequivocally demonstrates that ultrasound guidance reduces pneumothorax rates from 8.5% to 3.4% and nearly eliminates life-threatening complications like organ puncture (Gordon et al., 2010; Diacon et al., 2003). Our finding that CXR mischaracterized effusion nature in a substantial proportion of cases implies that procedures planned on CXR findings alone might be inappropriately targeted—attempting thoracentesis on loculated pockets or missing optimal drainage sites.

The economic analysis by Mercaldi & Lanes (2013), showing 19% cost reduction with ultrasound guidance, combined with our findings of CXR's diagnostic limitations, suggests that implementing routine thoracic ultrasound could yield both clinical and economic benefits in our setting.

Conclusion:

Thoracic ultrasound demonstrates superior diagnostic accuracy compared to chest X-ray in the evaluation of pleural effusion, with fewer false negatives and enhanced characterization of effusion complexity. Its ability to detect additional pleural and diaphragmatic pathology makes it an indispensable tool in clinical decision-making. These findings support the integration of ultrasound as a primary imaging modality in the diagnostic pathway for suspected pleural effusion to improve detection, guide management, and optimize patient outcomes.

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