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Chest Sonography in the Diagnostic Stratification of Pleural Effusion

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ABSTRACT

Background: Pleural effusion is a common clinical finding in respiratory and systemic disorders. Differentiating between transudative and exudative effusions is critical for determining etiology and management. Conventional biochemical methods based on Light's criteria require invasive sampling, whereas Thoracic Ultrasonography (TUS) offers a safe, bedside, radiation-free alternative capable of characterizing pleural fluid by internal echo patterns and dynamic signs.

Objectives: To evaluate the diagnostic accuracy of TUS in distinguishing exudative from transudative pleural effusions, using biochemical Light's criteria as the reference standard.

Methods: This prospective study included 216 patients with radiologically confirmed pleural effusion attending the Department of Respiratory Medicine, Ashwini Hospital, Cuttack (May 2023-October 2024). Each underwent standardized thoracic ultrasound examination followed by diagnostic thoracentesis. Sonographic parameters-echogenicity, complexity, septations, and dynamic signs ("jellyfish," "plankton," "hematocrit")-were compared with biochemical classification.

Results: Of 216 patients (mean age 54.7 ± 13.7 years; 61.1 % male), 193 (89.4 %) effusions were exudative and 23 (10.6 %) transudative by Light's criteria. Ultrasound classified 176 (81.5 %) as exudates and 40 (18.5 %) as transudates, yielding sensitivity 91.2 %, specificity 100 %, PPV 100 %, and NPV 57.5 %. Anechoic, non-septate patterns with "jellyfish" sign correlated with transudates, whereas complex, septate, "plankton," and "hematocrit" signs indicated exudates ($p < 0.05$).

Conclusion: TUS demonstrates excellent diagnostic accuracy for differentiating pleural effusions and can serve as a first-line, non-invasive diagnostic tool, particularly valuable in critical-care and resource-limited settings.

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Introduction

Pleural effusion, the abnormal accumulation of fluid in the pleural cavity, is a frequent clinical presentation in both pulmonary and systemic disorders. It may arise from a wide spectrum of causes including heart failure, pneumonia, tuberculosis, malignancy, hepatic or renal disease, and connective tissue disorders. The initial step in managing such cases is to determine whether the effusion is **Transudative or Exudative**, since the distinction guides further diagnostic testing and specific therapy [1-10].

Traditionally, differentiation is achieved through **Diagnostic Thoracentesis** and **Biochemical Evaluation** of pleural fluid based on **Light's Criteria**, which use ratios of pleural to serum protein and lactate dehydrogenase (LDH) [4]. Although reliable, this approach is invasive, time-consuming, and occasionally contraindicated, particularly in critically ill patients or those with small or loculated collections [11,12].

In recent years, **Thoracic Ultrasonography (TUS)** has become a widely accepted bedside imaging tool for pleural evaluation [13]. It is portable, radiation-free, and capable of detecting even small volumes of fluid [5,6,14]. Moreover, it provides additional information regarding the **Nature and Internal Characteristics** of effusions-such as echogenicity, presence of septations, and dynamic movement of the lung within the fluid cavity. Distinct sonographic appearances have been correlated with fluid composition: the "**Jellyfish Sign**" of freely floating lung tissue within clear fluid typically represents transudates, while "**Plankton**" and "**Hematocrit**" signs reflect particulate or hemorrhagic exudates [15,16].

Studies from Europe and Asia have demonstrated that TUS can achieve sensitivity and specificity exceeding 90% for differentiating exudative and transudative effusions. Despite these reports, data from Indian tertiary centers remain limited. Furthermore, ultrasonography is now an essential component of **Point-of-Care Ultrasound (POCUS)** in respiratory and critical-care medicine, underscoring the need to validate its diagnostic accuracy in local clinical practice [17,18].

Objectives of the Study

- To assess the diagnostic accuracy of thoracic ultrasonography in differentiating exudative and transudative pleural effusions.
- To identify characteristic sonographic patterns associated with each type of effusion.
- To compare the ultrasonographic findings with biochemical Light's criteria as the gold standard.

This study therefore seeks to establish the reliability of TUS as a non-invasive diagnostic tool that can complement or, in selected cases, replace routine biochemical analysis in the initial evaluation of pleural effusion.

Materials and Methods

Study Design and Setting

This was a **Prospective Observational Study** conducted in the **Department of Respiratory Medicine, Ashwini Hospital, Cuttack, Odisha, India**, from **May 2023** to **October 2024**. The study protocol was reviewed and approved by the institutional ethics committee. Written informed consent was obtained from all participants prior to enrolment.

Study Population

All adult patients with clinically or radiologically diagnosed pleural effusion were evaluated.

Inclusion Criteria

- Age ≥ 18 years.
- Presence of pleural effusion confirmed by chest X-ray or preliminary ultrasound.
- Willingness to participate and provide informed consent.

Exclusion Criteria

- Hemodynamic instability precluding safe examination or thoracentesis.
- Known diagnosis of pleural disease before enrolment.
- Patients unwilling to participate.

Sample Size Determination

Using Buderer's formula (1996), with expected sensitivity 91 %, specificity 92 %, disease prevalence 17 %, and precision of 10 %, the minimum required sample size was calculated as **186** [19]. To compensate for attrition, **216 patients** were finally enrolled.

Clinical Evaluation

Each patient underwent detailed clinical assessment including history, physical examination, and routine investigations. Symptoms such as **Dyspnea, Cough, Chest Pain, and Fever** were recorded. The severity of dyspnea was graded using the **Modified Medical Research Council (MMRC)** scale.

Table 1: MMRC Grading of Breathlessness

Grade	Description
0	Breathless only with strenuous exercise
1	Breathless when hurrying or walking up a slight hill
2	Walks slower than people of same age or stops after normal pace
3	Stops after 100 yards or a few minutes on level ground
4	Too breathless to leave the house or during dressing

Thoracic Ultrasonography

Thoracic ultrasonography was performed for all patients using a **Philips Clear Vue 350** system equipped with a **3.5 MHz curvilinear probe**. The patient was positioned sitting or semi-recumbent depending on comfort and condition. Scanning was performed along posterior axillary and intercostal lines, examining both hemi thoraces.

The Following Features Were Evaluated and Documented

- **Echogenicity:** Anechoic or Echoic Pattern.
- **Complexity:** Homogeneous, Non-Septate, or Septate.
- **Dynamic signs:** Presence of "Jellyfish," "Plankton," or "Hematocrit" signs.
- **Associated findings:** Pleural Thickening, Lung Collapse, or Loculations.

Representative Figure Placeholders

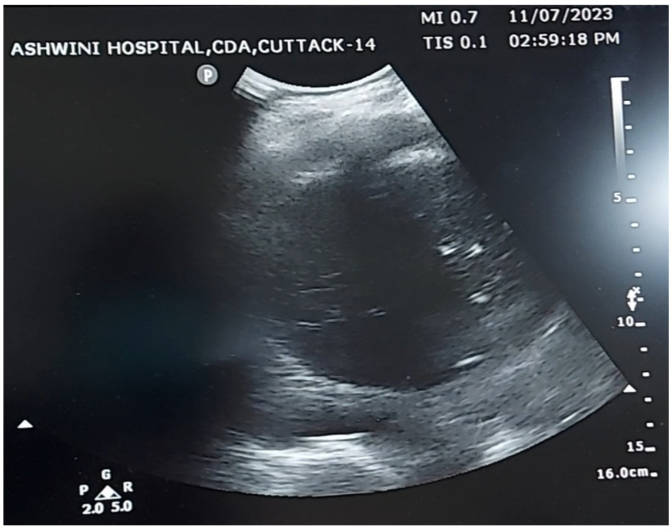

Figure 1: Echoic Ultrasonography Finding

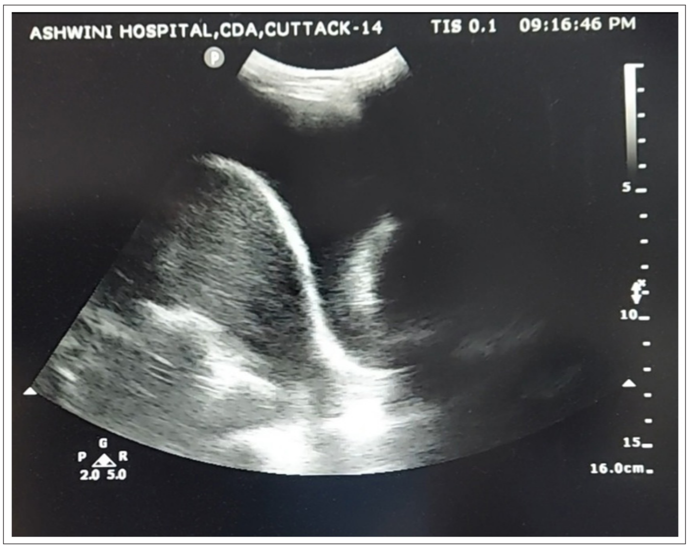

Figure 2: Anechoic Ultrasonography Finding

Figure 3: Complex Septate Pleural Fluid

Figure 4: Complex Non-Septate Pleural Fluid

Figure 5: "Jellyfish" Sign of Pleural Fluid

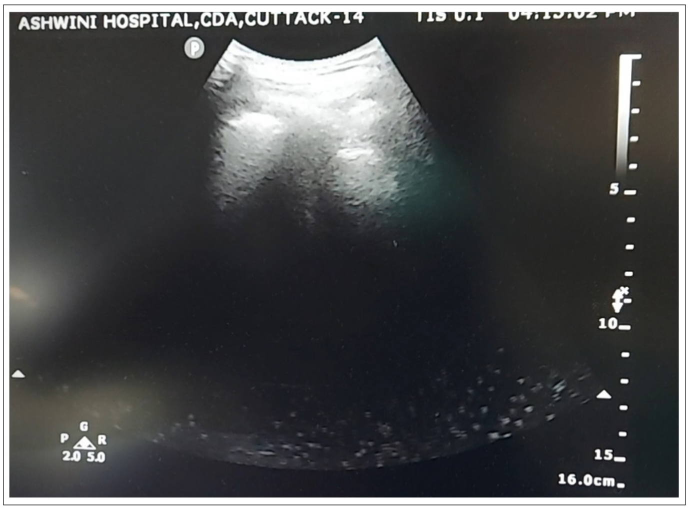

Figure 6: "Plankton" Sign of Pleural Fluid

Thoracentesis and Biochemical Analysis

Under sterile precautions and ultrasound guidance, **Diagnostic Thoracentesis** was performed to obtain pleural fluid. Samples were analyzed for:

- Total protein and serum protein
- Lactate dehydrogenase (LDH) and serum LDH
- Glucose
- Adenosine deaminase (ADA)
- Cytology and microbiological culture, when indicated

Effusions Were Classified Using Light's Criteria

An effusion was considered **Exudative** if **any** of the following criteria were met:

1. Pleural fluid protein / serum protein > 0.5
2. Pleural fluid LDH / serum LDH > 0.6
3. Pleural fluid LDH > ⅔ upper limit of normal serum LDH

Effusions not meeting these were considered **Transudative**.

Outcome Assessment

Clinical outcomes were recorded, including:

- Need for intercostal tube drainage
- Duration of hospital and ICU stay
- Procedure-related complications (pain, cough, trauma, pneumothorax)
- Final disposition (discharge, referral, death)

Statistical Analysis
Data were entered into **Microsoft Excel 2007** and analyzed using **SPSS v27.0** (IBM Corp., Armonk, NY). Continuous variables were expressed as mean ± SD, and categorical variables as frequencies and percentages.
Statistical tests used:

- **Chi-Square or Fisher's Exact Test:** categorical variables
- **Student's t-Test:** continuous variables
- **Sensitivity, Specificity, Positive Predictive Value (PPV), and Negative predictive value (NPV)** calculated using Light's criteria as reference standard.

A p-value < 0.05 was considered statistically significant.

Results
Baseline Demographics and Clinical Profile
A total of **216 Patients** with pleural effusion were included in the analysis. The **Mean Age** was **54.7 ± 13.7 years**, and **132 (61.1 %)** were male. Most patients (83.3 %) were above 40 years of age.

Dyspnea (100 %) was the most common symptom, followed by **Cough (70.4 %), Fever (63.4 %),** and **Chest Pain (37.0 %)**.

The majority of patients (40.2 %) had **MMRC grade ≥ 3** breathlessness.

Table 2: Baseline Demographic and Clinical Characteristics (N = 216)

Parameter	Frequency (%)
Age > 40 years	180 (83.3)
Male sex	132 (61.1)
Cough	152 (70.4)
Fever	137 (63.4)
Chest pain	80 (37.0)
MMRC grade ≥ 3	87 (40.2)
Hypertension	66 (30.6)
Diabetes mellitus	53 (24.5)
COPD/asthma	33 (15.3)

Ultrasonographic Characteristics
Among all effusions, **Echoic Effusions** predominated **(85.6 %)** compared with **Anechoic (14.4 %)**.
Complex Homogeneous effusions were most common (74.5 %), while **Non-Septate** and **Septate** patterns were seen in 24.5 % and 15.3 %, respectively.

Dynamic Sonographic Patterns Observed Were

- "Plankton" Sign: 137 patients (63.4 %)
- "Jellyfish" Sign: 76 patients (35.2 %)
- "Hematocrit" Sign: 48 patients (22.2 %)

These features showed strong correlation with the biochemical nature of effusion (p < 0.05).

Table 3: Distribution of Ultrasonographic Features

Feature	Frequency (%)	Common in
Anechoic	31 (14.4)	Transudate
Echoic	185 (85.6)	Exudate
Complex homogeneous	161 (74.5)	Exudate
Complex non-septate	53 (24.5)	Exudate
"Jellyfish" sign	76 (35.2)	Transudate
"Plankton" sign	137 (63.4)	Exudate
"Hematocrit" sign	48 (22.2)	Exudate

Biochemical and Sonographic Correlation
Using **Light's Criteria, 193 (89.4 %)** effusions were **Exudative**, and **23 (10.6 %)** were **Transudative**.

Thoracic ultrasonography identified **176 (81.5 %)** as **Exudative** and **40 (18.5 %)** as **Transudative**.

Table 4: Correlation Between Ultrasound and Biochemical Classification

	Biochemical Transudate	Biochemical Exudate	Total
USG Transudate	23	17	40
USG Exudate	0	176	176
Total	23	193	216

Diagnostic Accuracy of Ultrasonography

Table 5: Diagnostic Performance of Ultrasonography

Parameter	Value (%)
Sensitivity	91.19
Specificity	100
Positive Predictive Value	100
Negative Predictive Value	57.5

Ultrasonography demonstrated **Excellent Diagnostic Accuracy**, with **Sensitivity 91.19 %, Specificity 100 %**, and **Overall Accuracy 92.6 %**.

All effusions identified as exudates on ultrasound were confirmed biochemically, while minor discrepancies occurred in borderline transudates misclassified as exudates.

Procedural Safety and Clinical Outcomes
Thoracentesis performed under ultrasound guidance was safe in all patients.
Minor complications included **Local Pain (25.9 %), Cough (4.2 %),** and **Minor Trauma (7.9 %)**.
Pneumothorax Occurred in 3.2 % of cases, none requiring surgical intervention.
Mean Hospital stay: 5.3 ± 1.9 days
Mean ICU stay (when required): 3.6 ± 1.7 days

Outcome: 84.7 % discharged after recovery, 8.3 % referred for advanced care, 7.0 % mortality (primarily due to underlying disease).

Discussion
This prospective study of 216 patients evaluated the role of Thoracic Ultrasonography (TUS) in differentiating transudative and exudative pleural effusions, using Light's criteria as the reference standard [8]. The findings demonstrate that ultrasonography is a Highly Accurate, Safe, and Readily Available Diagnostic Tool, with sensitivity 91.19 %, specificity 100 %, and positive predictive value 100 % for exudative effusions.

Comparison with Existing Literature
The results of this study are consistent with previous international

and Indian research.

- **Kocijancic and Vidmar (2015)** reported sensitivity 90.6 % and specificity 97.3 % for chest ultrasound in distinguishing effusion types.
- **Prabhu et al. (2017)** observed sensitivity 93 % and specificity 95 % based on internal echogenicity and presence of septations.
- **Qureshi et al. (2019)** and **Kashyap et al. (2020)** found diagnostic accuracies above 90 %, closely matching the current data.

These findings reaffirm that **Sonographic Features of Pleural Fluid Closely Mirror Biochemical Characteristics**, thereby allowing early differentiation without invasive sampling in many cases.

Interpretation of Sonographic Patterns

Ultrasound provides valuable insights into pleural fluid composition through analysis of internal echoes and dynamic signs.

- **Transudates** are typically **Anechoic** and **Non-Septate**, appearing uniformly black on ultrasound due to low protein and cellular content. The "**Jellyfish Sign**", representing floating lung within clear fluid, was observed in 35.2 % of cases and strongly correlated with transudates secondary to congestive heart failure or cirrhosis.
- **Exudates**, in contrast, display **Internal Echoes, Septations, or Fibrin Strands**. The "**Plankton Sign**" (floating particulate matter) and "**Hematocrit Sign**" (layered fluid levels in hemorrhagic effusions) were significantly associated with exudates, as seen in 63.4 % and 22.2 % of patients respectively.
- This correlation reflects the increased cellularity, fibrin, and debris in exudative fluid due to infection, malignancy, or inflammation.

Clinical Implications

Thoracic ultrasonography offers several important clinical advantages:

1. **Non-Invasive and Bedside Accessibility:** Ideal for critically ill patients where thoracentesis is risky.
2. **Real-Time Imaging:** Allows visualization of diaphragm, pleural space, and underlying lung simultaneously.
3. **Procedural Guidance:** Reduces complications during fluid aspiration or chest tube insertion.
4. **Monitoring Tool:** Enables repeated evaluation of effusion dynamics and treatment response.

In the current study, ultrasound-guided thoracentesis had **No Major Complications**, with pneumothorax incidence of **3.2 %**, substantially lower than historical rates for blind aspiration (10–15 %) [20,21].

Moreover, by reliably identifying the likely nature of pleural fluid, ultrasound supports **Early, Targeted Management**-such as initiating diuretics for transudates or antibiotics and drainage for exudates-while awaiting biochemical confirmation [23-30].

Correlation Between Sonographic and Biochemical Findings

In this cohort, 17 Effusions (7.9 %) were discordant-classified as transudative by ultrasound but exudative biochemically. This discrepancy can be attributed to:

1. **Low-Grade Exudates** with minimal internal echoes.
2. **Operator Settings** (gain, depth, and frequency) masking subtle complexity.
3. **Borderline Biochemical Values** close to Light's criteria cutoffs.

Importantly, **No False-Positive Exudates** were noted, affirming the **Specificity of Ultrasound for Exudative Pathology**. Thus, a positive ultrasound diagnosis of exudate is highly reliable.

Integration into Clinical Practice

Ultrasound should be integrated as a **Routine First-Line Investigation** for pleural effusion evaluation in all respiratory and critical care settings.

Its **Real-Time, Radiation-Free** capability enhances both diagnostic efficiency and patient safety.

Adoption of ultrasound-based protocols also aligns with current **British Thoracic Society (BTS) Guidelines (2023)**, which advocate mandatory ultrasound guidance for pleural procedures [31-35].

Training in point-of-care thoracic ultrasound (POCUS) should therefore form an essential component of respiratory medicine residency programs.

Study Limitations

Despite its strengths, a few limitations are acknowledged:

- **Single-Center Study:** Findings may not represent all demographic or equipment variations.
- **Operator Dependence:** Accuracy may vary with training; however, all scans were performed by an experienced pulmonologist in this study.
- **Etiologic Classification not Included:** The study focused on fluid type (exudate vs transudate) rather than cause (e.g., TB, malignancy).
- **Lack of Interobserver Validation:** Future multicentric studies should assess reproducibility and intraobserver variability.

Conclusion

Thoracic ultrasonography is an effective, non-invasive, and highly accurate diagnostic tool for evaluating pleural effusions.

In this prospective study of 216 patients, TUS demonstrated **91.19 % Sensitivity** and **100 % Specificity** in differentiating exudative from transudative effusions compared with biochemical Light's criteria [36-40].

Characteristic sonographic findings such as **Complex Echogenicity, Internal Septations, "Plankton," and "Hematocrit" Signs** were strongly associated with exudates, while **anechoic, Non-Septate Fluid with "Jellyfish" Sign** was typical of transudates.

These easily recognizable patterns allow clinicians to infer the probable nature of pleural fluid at the bedside—often before invasive sampling.

Incorporating TUS as a **Routine Component of Pleural Evaluation** enhances diagnostic efficiency, minimizes complications, and supports timely clinical decision-making.

Given its accessibility and safety, thoracic ultrasound should be recommended as the **First-Line Diagnostic Modality** for pleural effusion evaluation, particularly in resource-limited or critical-care settings [41-50].

Future multicentric studies incorporating **Advanced Ultrasound Techniques**-such as color Doppler, contrast-enhanced ultrasound, and elastography-may further improve diagnostic precision and allow etiologic differentiation [51-65].

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