RESEARCH PAPER

Correlation Of Pleural Fluid Volume With Improvement In Pulmonary Function And Diaphragmatic Excursion Following Therapeutic Pleurocentesis

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ABSTRACT

Background: Breathlessness and functional limitation in patients with pleural effusion arise predominantly from mechanical compression of the lung parenchyma and impaired diaphragmatic kinematics. While therapeutic pleurocentesis provides immediate symptom relief, the precise dose-response relationship between the volume of fluid removed and the quantitative magnitude of physiological recovery remains inadequately characterized in clinical practice.

Methods: This prospective observational study was conducted at a tertiary care teaching hospital over twelve months. A total of 85 adult patients presenting with symptomatic pleural effusion who underwent ultrasound-guided therapeutic pleurocentesis were included. Pre- and post-procedural assessments incorporated spirometry (FVC) and M-mode ultrasonography to quantify diaphragmatic excursion. The cohort was stratified into three categories based on the volume of pleural fluid drained: <500 ml, 500-1000 ml, and >1000 ml.

Results: The study population demonstrated a high prevalence of comorbidities, with diabetes mellitus being the most frequent (37.6%). Following drainage, significant improvements in mMRC dyspnea grades and oxygen saturation (SpO_2 increasing from 94.0% to 98.3%) were noted. A clear, positive linear correlation was identified between the drained volume and functional gains. Drainage of <500 ml yielded a mean FVC increase of 0.3 L and an excursion increase of 0.6 cm. Drainage of 500-1000 ml resulted in an FVC increase of 0.55 L and an excursion increase of 1.0 cm. The most profound improvements occurred in patients with >1000 ml drained, demonstrating a 0.9 L increase in FVC and a 1.5 cm improvement in diaphragmatic excursion.

Conclusion: There is a direct, volume-dependent relationship between pleural fluid drainage and the restoration of respiratory mechanics. Larger volumes of fluid impose greater mechanical restrictions, and their removal corresponds to significantly higher, proportional gains in lung volumes and diaphragmatic mobility.

Keywords: Diaphragmatic Excursion, Dyspnea, Lung Volumes, Pleural Fluid Volume, Respiratory Mechanics, Thoracentesis

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Introduction

Pleural effusion is a ubiquitous respiratory pathology that precipitates substantial morbidity through breathlessness, thoracic discomfort, and a marked reduction in exercise tolerance. [1] Historically, the clinical evaluation of pleural effusion heavily prioritized the biochemical and cytological analysis of the fluid to determine etiology. [2] However, recent physiological analyses have shifted the paradigm, demonstrating that the primary driver of symptomatic distress—specifically dyspnea—is the mechanical distortion of the respiratory system. [3,4]

The accumulation of fluid within the pleural space effectively acts as a space-occupying lesion. It increases intrapleural hydrostatic pressure, which directly compresses the adjacent lung tissue and severely diminishes alveolar ventilation. [5] More critically, the weight and volume of the fluid displace the diaphragm inferiorly. [6] The diaphragm, which is the principal muscle of inspiration, loses its optimal dome-shaped curvature, becomes flattened, and suffers a profound mechanical disadvantage that compromises its contractile efficiency and downward excursion. [7]

Therapeutic pleurocentesis rapidly alleviates these symptoms by decompressing the hemithorax. [8] Nevertheless, the existing literature—particularly from South Asian cohorts—lacks robust, quantitative data correlating the exact volume of fluid drained with the corresponding degree of functional recovery. [9] Clinicians frequently rely on subjective symptom relief rather than objective physiological parameters to gauge procedural success. [10]

Understanding the precise dose-response relationship between pleural fluid volume and mechanical recovery is crucial. It aids in predicting which patients will benefit most significantly from drainage and helps establish physiological thresholds for intervention. This study specifically addresses this gap by utilizing integrated spirometric and ultrasonographic assessments to quantify the relationship between drained fluid volume, lung expansion, and diaphragmatic excursion.

Aim To assess the relationship between the volume of pleural fluid drained and the subsequent improvement in pulmonary function and diaphragmatic excursion in symptomatic patients.

Objectives To assess the clinical improvement post-pleurocentesis utilizing objective oxygen saturation (SpO_2) and subjective mMRC dyspnea grading.

To quantify the changes in diaphragmatic movement patterns utilizing M-mode ultrasonography.

To determine the dose-response correlation between discrete categories of drained pleural fluid volume (<500 ml, 500-1000 ml, >1000 ml) and the magnitude of functional respiratory recovery (FVC and Excursion).

Methodology

Study design, setting, and duration:

This was a prospective, hospital-based observational study undertaken in the Department of Respiratory Medicine at a tertiary care centre over a 12-month period.

Study population:

The cohort included adult patients who presented with symptomatic pleural effusion and were clinically indicated for therapeutic pleurocentesis.

Inclusion criteria:

Patients were enrolled if they were >18 years old, had clinically symptomatic pleural effusion, were hemodynamically stable enough to undergo spirometry, and provided informed consent.

Exclusion criteria:

Individuals were excluded if they possessed a previously confirmed malignant pleural effusion, a history of thoracic surgery, loculated effusions unsafe for standard drainage, or severe underlying obstructive airway disease.

Sampling technique and Sample size:

Participants were recruited via consecutive sampling. The sample size of 85 was calculated utilizing the standard epidemiological formula

$$n = \frac{Z^2pq}{d^2}$$

Also, based on a prevalence of 28% from the Pleural Effusion and Symptom Evaluation (PLEASE) study [11], a 95% confidence interval, an allowable error of 10%, and a 10% non-response rate.

Procedure:

At enrollment, a comprehensive clinical evaluation was conducted, and dyspnea severity was documented using the Modified Medical Research Council (mMRC) scale. Baseline oxygen saturation (SpO2) and vital signs were recorded. Lung volumes (FVC) were measured via spirometry. Diaphragmatic excursion and morphological movement patterns were assessed utilizing M-mode ultrasonography (subcostal approach, deep inspiration).

Therapeutic pleurocentesis was executed under ultrasound guidance using a safe-triangle approach. The exact volume of pleural fluid drained was carefully measured and recorded in millilitres. Within 24 hours following the intervention, follow-up assessments—including repeat spirometry, ultrasonography, SpO2 monitoring, and mMRC grading—were systematically recorded.

Outcomes measured:

The primary outcome of interest was the correlation between the volume of fluid removed (categorized into <500 ml, 500-1000 ml, and >1000 ml) and the absolute improvement in FVC and diaphragmatic excursion.

Statistical analysis:

Data processing was performed using SPSS version 26.0. Categorical variables (e.g., dyspnea grades, movement categories) were analysed as frequencies and percentages. The relationship between volume categories and continuous functional variables was evaluated using correlation analysis and Paired t-test. Significance was designated at a p-value <0.05.

Ethical consideration:

The study protocol was approved by the Institutional Ethics Committee of Chettinad Hospital and Research Institute. All procedures adhered strictly to ethical guidelines regarding patient consent and data privacy.

Results

The final analysis included 85 patients.

Table 1: Socio-demographic Profile and Comorbidity Distribution of Participants (N=85)

Age-wise distribution		
Mean age ± SD (years)		35.7 ± 9.2
Sex distribution		
Sex	**Frequency (n)**	**Percentage (%)**
Males	60	70.6%
Females	25	29.4%
Total	85	100.0%
Comorbidity distribution		

Comorbidities	Frequency (n)	Percentage (%)
Diabetes mellitus (DM)	32	37.6%
Hypertension (HTN)	24	28.2%
Both DM & HTN	9	10.6%
Coronary Artery Disease	2	2.4%
None	18	21.2%
Total	85	100.0%

Table 1 outlines the distribution of socio-demographic profile and comorbidities of the study population. The predominant age group comprised young-to-middle-aged males. A significant proportion of the patients presented with metabolic or cardiovascular comorbidities, with 37.6% having Diabetes Mellitus and 28.2% having isolated Hypertension, which may influence underlying baseline pulmonary mechanics and fluid dynamics.

Table 2: Clinical Improvement Post-Pleurocentesis (SpO2 and mMRC) (N=85)

Parameter	Pre-procedure (Mean)	Post-procedure (Mean)	p-value
SpO_2 (%) (Mean + SD)	94.01 ± 3.4	98.3 ± 2.1	**<0.001***
mMRC Dyspnea Grade 3 & 4 (n, %)	45 (53.0%)	9 (10.6%)	-
mMRC Dyspnea Grade 0 & 1 (n, %)	12 (14.1%)	56 (65.9%)	-

Paired t-test done
*p-value < 0.05 – Statistically significant

Table 2 demonstrates profound clinical relief post-drainage. Mean oxygen saturation significantly increased from 94.01% to near-normal levels of 98.3%. Subjectively, prior to the procedure, 53% of patients suffered from severe dyspnea (mMRC Grades 3 and 4). Post-procedure, this proportion plummeted to 10.6%, with the vast majority (65.9%) shifting to minimal or no dyspnea (Grades 0 and 1).

Table 3: Ultrasonographic Diaphragm Movement Grading (N=85)

Movement Grading	Pre-procedure (n, %)	Post-procedure (n, %)
Markedly reduced	56 (65.9%)	0 (0.0%)
Reduced / Mild Residual	29 (34.1%)	13 (15.3%)
Normal / Adequate	0 (0.0%)	72 (84.7%)
Total	85	100.0%

Table 3 illustrates the morphological recovery of the diaphragm. At baseline, 100% of the cohort exhibited pathological diaphragm kinematics, with 65.9% displaying markedly reduced movement. Following fluid evacuation, 84.7% of patients completely normalized their diaphragmatic motion patterns.

Table 4: Relationship Between Volume Drained and Functional Improvement (N=85)

Volume Drained Category	No. of Patients (n, %)	Mean FVC Improvement (L)	Mean Excursion Improvement (cm)
< 500 ml	20 (23.5%)	0.30	0.6
500 – 1000 ml	38 (44.7%)	0.55	1.0
> 1000 ml	27 (31.8%)	0.90	1.5

Table 4 represents the relationship between volume drained and functional improvement of the study participants. This table highlights the central finding of this study: a distinct dose-response relationship. As the volume of drained fluid increased, the magnitude of physiological recovery scaled proportionately. Patients who had more than 1000 ml removed experienced a massive 1.5 cm mean gain in diaphragmatic excursion and a 0.90 L expansion in vital capacity.

Discussion

This study elegantly demonstrates that the respiratory impairment caused by pleural effusion is fundamentally a biomechanical issue, intricately tied to the absolute volume of fluid occupying the thoracic cavity. By stratifying functional outcomes against the precise volume of fluid drained, we have established a clear, linear dose-response relationship that bridges clinical observation with objective physiological measurement.

The baseline data reveal a cohort severely burdened by respiratory restriction. Prior to intervention, 100% of the participants exhibited abnormal diaphragmatic movement, and over half suffered from severe, life-limiting dyspnea (mMRC Grades 3 and 4). The presence of massive fluid collections forces the diaphragm into a flattened configuration, increasing its radius of curvature. [12,13] According to Laplace's law, this flattened state vastly increases the muscular tension required to generate the negative intrathoracic pressure necessary for normal inspiration, thereby skyrocketing the work of breathing. [14,15]

The evacuation of this fluid yields immediate, quantifiable relief. [16] The most striking data from this study (Table 4) shows that the physiological benefit of pleurocentesis is not uniform; it is highly dependent on the initial mechanical load. In the low-volume group (<500 ml), a modest excursion gain of 0.6 cm and an FVC gain of 0.3 L were observed. However, in patients burdened with massive effusions (>1000 ml), the removal of that fluid resulted in dramatic mechanical decompression: FVC surged by nearly a full litre (0.9 L), and diaphragmatic excursion improved by 1.5 cm.

These findings provide vital empirical support to the concepts proposed by Aguilera et al., who utilized ultrasonography to show that diaphragmatic excursion is inversely proportional to effusion size. [17] Our data provides the crucial interventional counterpart to that concept: as you remove larger volumes, the recovery trajectory is steepest. Furthermore, these results align with imaging studies by Skaarup et al. and Fitzgerald et al., which emphasized that significant fluid volumes (>500 mL) represent major space-occupying lesions within the rigid confines of the thorax. [18,19] Removing this volume directly restores the optimal geometric advantage of the diaphragm, allowing it to contract forcefully and efficiently. [19]

This dose-response dynamic underscores a critical clinical mandate: while early, low-volume drainage may yield modest benefits, therapeutic pleurocentesis in the setting of moderate-to-large effusions is not merely a palliative maneuver; it is a profound physiological reset that rapidly restores vital capacity and normalizes respiratory muscle mechanics. [20]

Limitations

The study's primary limitation is the absence of concurrent pleural manometry. Without directly measuring intrapleural pressure changes during drainage, the intricate relationship between fluid volume removal, pressure gradients, and the phenomena of trapped lung or non-expanding lung could not be fully delineated. Additionally, patient positioning and specific BMI indices, which can subtly alter diaphragmatic kinematics, were not formally modelled as covariates in the volume analysis.

Conclusion

There is a definitive, volume-dependent dose-response relationship between pleural fluid drainage and the recovery of pulmonary mechanics. The magnitude of improvement in Forced Vital Capacity and diaphragmatic excursion scales proportionately with the volume of fluid removed.

This data robustly confirms that large effusions impose severe mechanical restrictions, and extensive, timely fluid removal is critical for maximizing physiological decompression and symptomatic relief. Routine integration of bedside ultrasound to estimate fluid volume and track diaphragmatic recovery should become a standard of care in managing pleural disease.

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