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Investigating the correlation between Pleural Effusion Volume and Diaphragmatic Function using Ultrasound Imaging

Aziz Ur Rehman [1], Shehla Aman [2]✉, Mehrin Farooq [3], Faiza Shafqat [4], Syed Khurram Shehzad Kazmi [3], Sobia Humerah [5]

[1]Department of Radiology, Rawal Medical and Dental College, Islamabad - Pakistan [2]Department of Anatomy, Gomal Medical College, Dera Ismail Khan – Pakistan [3]Department of General Medicine, Lahore Medical and Dental College/Ghurki Trust Teaching Hospital, Lahore – Pakistan [4]Department of Anatomy, CMH Lahore Medical College and Institute of Dentistry Lahore - Pakistan [5]Department of Physiology, Al Nafees Medical College and Hospital, Isra University, Islamabad - Pakistan

Corresponding Author:
Shehla Aman
Department of Anatomy, Gomal Medical College, Dera Ismail Khan – Pakistan
Email: shehlakhan7272@gmail.com

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ABSTRACT

Background: The diaphragm is the necessary respiratory muscle and its abnormal function may be caused by pleural effusion. Thoracic ultrasound is an accurate and simple method to investigate the relationship between diaphragmatic functions and pleural effusion.

Objective: To determine the relationship between diaphragm functions and pleural effusion using ultrasound.

Methodology: This study was a prospective case-control study conducted at the Department of Medicine, Lahore Medical and Dental College, Lahore, from January 2021 to December 2021. A total of 100 study cases were included in this study. For study purposes, these patients were divided into 2 groups, case (GI) and control (GII). Both groups comprise 50 study cases. The GI group comprised 50 patients with pleural effusion, whereas the GII group comprised 50 patients without pleural effusion. In both groups, diaphragmatic functions were also assessed through ultrasound.

Results: Significant changes in diaphragm function, such as end-inspiratory thickness, fractional diaphragm thickening, and a shift in the amount of pleural effusion during deep breathing and quiet breathing, were observed during gastrointestinal thoracic ultrasound. When ultrasounds from GI and GII groups were assessed, significant changes were observed in end-inspiratory thickness, end-expiratory thickness, fractional diaphragm thickening, excursion during quiet breathing, and excursion during deep breathing. The amount of pleural fluid is directly related to these changes.

Conclusion: Thoracic ultrasonography has shown that various amounts of pleural effusion have a negative impact on diaphragmatic functioning.

Keywords: Pleural Effusion; Thoracic Ultrasound; Diaphragmatic Functions

Introduction

Pleural effusion, the accumulation of excess fluid in the pleural cavity, presents a significant clinical challenge, often complicating the course of various pulmonary, cardiac, and systemic diseases. The impact of pleural effusion on respiratory mechanics, particularly diaphragmatic function, is a crucial area of investigation. The diaphragm, as the primary muscle of respiration, plays a vital role in maintaining effective ventilation. Its function can be compromised by the presence of pleural effusion, potentially leading to respiratory distress and compromised oxygenation.[1] Patients with hydro-pleural effusion may experience abnormal diaphragm motion and movement during breathing because the diaphragm is an important part of the respiratory system. Because pleural effusion affects the respiratory system, people with pleural effusion may experience changes in the shape and movement of the diaphragm during breathing.[2]

Ultrasound imaging has emerged as a valuable non-invasive tool for assessing both pleural effusion volume and diaphragmatic function. Compared to other imaging modalities, such as chest X-ray or computed tomography (CT), ultrasound offers real-time visualization, portability, and the absence of ionizing radiation. This makes it particularly suitable for repeated evaluations and bedside assessments. Ultrasound can accurately quantify pleural effusion volume and evaluate diaphragmatic movement and thickening, providing comprehensive insights into the functional status of the diaphragm.[3]

When inspiration occurs during ultrasound imaging, the diaphragm on the affected side may appear flat or, in the case of pleural effusion, inverted. This is because fluid collected in the pleural space blocks the lower part of the diaphragm, reducing its ability to expand chest volume and draw air into the lungs. In patients with a large or rapidly expanding pleural effusion, changes in diaphragm quality and mobility can have a significant impact on lung function, leading to lung failure, shortness of breath, and poor breathing. Characteristics of diaphragm movement, such as movement during breathing or changes in diaphragm thickness, can be evaluated using ultrasound.[4,5]

A medical procedure called thoracentesis or thoracentesis is used to remove air or fluid from the pleural space for diagnostic or treatment procedures. Inserting a hollow needle or cannula into the chest, usually under local anesthesia, requires extra care. Ultrasound can be used to guide thoracentesis and to measure and characterize pleural effusion. This can help determine if therapeutic or diagnostic drainage is required.[6]

Previous studies have highlighted the detrimental effects of pleural effusion on diaphragmatic function, including reduced excursion and muscle thinning. However, the relationship between the volume of pleural effusion and the extent of diaphragmatic dysfunction remains inadequately explored. Understanding this correlation is essential for optimizing therapeutic strategies, such as thoracentesis, and for predicting patient outcomes.

This study aims to investigate the correlation between pleural effusion volume and diaphragmatic function using ultrasound imaging. By systematically analyzing ultrasound measurements of pleural effusion volume and diaphragmatic parameters, we seek to elucidate the extent to which pleural effusion impacts diaphragmatic mechanics. The findings of this study could inform clinical practice, guiding interventions to alleviate respiratory compromise in patients with pleural effusion and potentially improving their quality of life and prognosis.

Objective

To determines the relationship between the functions of diaphragm and pleural effusion using ultrasound.

Methodology

This study was a prospective case-control study conducted at the Department of Medicine, Lahore Medical and Dental College, Lahore from January 2021 to December 2021. A total of 100 study cases were included in this study. For study purposes, these patients were divided into 2 groups, case (GI) and control groups (GII). Both groups comprise 50 study cases. The GI group comprised 50 patients with pleural effusion, whereas the GII group comprised 50 patients without pleural effusion. In both groups, diaphragmatic functions were assessed through ultrasound.

The examination began with the patient lying flat on their back, without a cushion, to obtain supine measurements (in millimeters). Using a transducer perpendicular to the chest wall, the chest was scanned through the intercostal spaces. Patients were instructed to hold their breath at maximum inspiration while the measurements were taken. The largest distance between the parietal and visceral pleura was recorded. It was crucial to avoid angling or tilting the probe to prevent overestimating the effusion and to ensure the scan was aligned with the transverse plane.

Every measurement was performed three times, and statistical analysis was performed on the average outcome.

The effusion volume estimations were calculated using the following equation:

$EV = 20 \times X$

Where, "EV" is the estimated effusion volume (ml) and "X" is the greatest distance (mm) between the visceral and parietal pleura in the supine position.[6]

Diaphragmatic sonography was performed using a phased array probe with a frequency range of 3.5–5 MHz. The probe was positioned either at the right or left costal margin, directly below the mid-clavicular line, or the right

Table 1. Statistical comparison of demographic data of GI and GII

Studied variables	GI cases (N=50)	GII control (N=50)	Test of significance	P value
Mean Age (years) ± SD	48.90 ± 11.44	47.70 ± 11.45	t=0.590	0.521
Range	27–59	31–67		
Sex				
Male Female	30 (60%) 20 (40%)	27 (54%) 23 (46%)	χ^2=0.112	0.812

or left anterior axillary line. It was oriented medially, cephalad, and dorsally to ensure the ultrasound beam passed perpendicularly through to the posterior third of the corresponding hemi-diaphragm.

Initially, the two-dimensional mode was used to identify the optimal course of action and select the exploration line. Subsequently, the M-mode was utilized to visualize the anatomical structures along the selected line. The liver served as the right acoustic window and the spleen as the left acoustic window when the probe was advanced along the long axis of the intercostal gaps.

Diaphragmatic mobility, referring to the diaphragm moving towards the probe, and cranial diaphragmatic movement, indicating the diaphragm moving away from the probe, were assessed. The diaphragmatic excursion, measured in centimeters, was determined at the end of both inspiration and expiration using the M-mode. Additionally, diaphragmatic thickness was measured at the zone of opposition, where the diaphragm attaches to the rib cage.

To generate adequate images of diaphragmatic thickness using both M-mode and two-dimensional mode, a linear high-frequency probe (C10 MHz) was employed. Diaphragmatic thickness was measured during deep and quiet breathing. The M-mode facilitated the calculation of the thickening fraction, defined as the difference in thickness at end expiration and end inspiration. This thickening fraction was used to evaluate the diaphragm's efficacy as a pressure generator.

SPSS v20 was used for statistical analysis and a p-value less than 0.05 was taken as significant.

The study was approved by the medical ethics committee's institutional review board Lahore Medical and Dental College, Lahore.

Results

A total of 100 study cases were selected for study purposes. For study purposes, these cases were divided into two groups, GI (cases) and GII (control). Each group consists of 50 patients. The mean age of the GI cases was

Table 2. Correlations between age and ultrasonographic findings

Correlations		
Ultrasound Findings	Age	
	R	P-value
Quantity of pleural effusion (cm3)	0.251	0.199
Thickness of the diaphragm at end of expiration (mm)	–0.427	0.139
Thickness of the diaphragm at end of inspiration (mm)	–0.511	0.050*
Diaphragmatic thickening fraction	–0.345	0.159
Excursion of the diaphragm at quiet breathing (cm)	–0.201	0.389
Excursion at deep breathing (cm)	–0.523	0.030*

Table 3. Relations between gender and ultrasonographic findings in GI group cases

Ultrasonographic Findings	Gender			
	Male	Female	t test	
	Mean ± SD	Mean ± SD	t	P-value
Quantity of pleural effusion (cm3)	1610.167 ± 872.899	1678.000 ± 799.959	–0.312	0.809
Thickness of the diaphragm at end of expiration (mm)	1.401 ± 0.700	1.069 ± 0.620	1.002	0.290
Thickness of the diaphragm at end of inspiration (mm)	2.088± 1.323	1.489 ± 0.801	1.201	0.198
Diaphragmatic thickening fraction	35.678 ± 25.709	43.819 ± 20.965	–0.767	0.443
Excursion of the diaphragm at quiet breathing (cm)	1.765 ± 0.389	1.352 ± 0.430	1.349	0.324
Excursion at deep breathing (cm)	3.299 ± 1.598	3.145 ± 1.798	0.206	0.753

48.90 ± 11.44 (years ±SD), among which 60% of them were males and 40% were females. Moreover, it shows the number and percentage of males and females of both groups, with a statistically insignificant difference (P=0.812). The age range and mean ± SD for groups GI and GII were statistically insignificant (P=0.521) (Table 1).

A positive correlation was found between the quality of pleural effusion and age. A negative correlation was observed between the thickness of the diaphragm at both the end of expiration and inspiration and age. Age correlated significantly with the thickness of the diaphragm at the end of inspiration (P=0.050) and the excursion of the diaphragm during deep breathing (P= 0.030) (Table 2).

A positive correlation was found between the Thickness of the diaphragm at the end of expiration and inspiration, Excursion of the diaphragm at quiet breathing and deep breathing, and gender. A negative correlation was observed between the Quantity of pleural effusion and Diaphragmatic thickening fraction and gender. There was no significant correlation between the gender of the patients and any of the studied ultrasonographic findings (Table 3).

A positive correlation was found between the smoking status of study cases and the quantity of pleural effusion and Diaphragmatic thickening fraction. A negative correlation was observed between the Thickness of the diaphragm at the end of expiration and inspiration, the thickness of the diaphragm at the end of inspiration Quantity of pleural effusion, and Diaphragmatic thickening fraction with smoking. There was no significant correlation between smoking and any of the studied ultrasonographic findings (Table 4).

The quantity of pleural effusion is significantly correlated with excursion of the diaphragm at quiet breathing (P=0.003), and excursion at deep breathing (P=0.013). Other parameters such as the thickness of the diaphragm at the end of expiration (P=0.523) and inspiration (P=0.169) are not significantly correlated with the quantity of pleural effusion (Table 5).

Positive significant association was found between the thickness at the end of inspiration (P<0.001), thickness at the end of expiration (P<0.001), diaphragmatic thickening fraction (P<0.001), excursion at quiet breathing (P <0.030), and excursion at deep breathing (P<0.001) and the ultrasound findings of GI and GII. These findings indicate decreased diaphragmatic functions in GI (Table 6).

Discussion

This study aimed to find the relationship between pleural effusion volume and diaphragmatic function using ultrasound imaging. The findings indicate a significant

Table 4. Correlation between smoking and ultrasonographic findings in GI

Ultrasonographic Findings	Smoking		t test	
	No	Yes		
	Mean ± SD	Mean ± SD	t	P value
Quantity of pleural effusion (cm3)	1595 ± 935.324	1489.000 ± 538.876	0.259	0.745
Thickness of the diaphragm at end of expiration (mm)	1.230 ± 0.599	1.521 ± 0.645	-1.006	0.279
Thickness of the diaphragm at end of inspiration (mm)	1.698 ± 1.357	2.223 ± 0.899	-0.409	0.701
Diaphragmatic thickening fraction	44.213 ± 26.934	34.956 ± 15.901	0.539	0.602
Excursion of the diaphragm at quiet breathing (cm)	1.556 ± 0.397	1.658 ± 0.402	-0.341	0.807
Excursion at deep breathing (cm)	3.114 ± 1.302	3.609 ± 2.211	-0.398	0.590

correlation between pleural effusion and various aspects of diaphragmatic function, emphasizing the clinical importance of monitoring diaphragmatic performance in patients with pleural effusion. Thickness and excursion of diaphragmatic ultrasonography indicate pleural effusion's impact on diaphragmatic functioning.

In the present study, a total of 100 study cases were selected for study purposes. For study purposes, these cases were divided into two groups, GI (cases) and GII (control). Each group consists of 50 patients. The mean age of the GI cases was 48.90 ± 11.44 (years ±SD), among which 60% of them were males and 40% were females. In GII, the mean age was 47.70± 11.45 with 54% being male. Moreover, it shows the number and percentage of males and females of both groups, with a statistically insignificant difference (P=0.812). The age range and mean ± SD for groups GI and GII were statistically insignificant (P=0.521). These findings suggest that the two groups are comparable in terms of both age and gender distribution. The statistically insignificant P-values indicate that neither age nor gender should bias the outcomes of the study. This comparability strengthens the internal validity of the study, allowing us to attribute any observed differences in outcomes more confidently to the interventions or conditions being studied, rather than demographic differences.

For study purposes, different ultrasonographic findings compared with the age of the study group and results showed that a positive correlation (R, 0.251; p-value, 0.199) was found between the quality of pleural effusion and age, whereas a negative correlation (R, -0.427; p-value, 0.199) was observed between the thickness of the diaphragm at both the end of expiration and inspiration ®, -0.511; p-value, 0.050) and age. Similarly, a negative correlation was found between diaphragmatic thickening fraction (R, -0.345; p-value, 0.159) with age. A negative correlation was also found between excursion of the diaphragm at quiet breathing (R, -0201; 0.389) and excursion at deep breathing (R, -0.523; p-value, 0.030) with age. A significant positive association (p-value, 0.050) was found between the thickness of the diaphragm at the end of inspiration (p-value, 0.030) and the age of study cases. This suggests that older patients may experience more pronounced diaphragmatic dysfunction in the presence of pleural effusion. Numerous studies have demonstrated the relationship between age and diaphragmatic functions, and one recent medical term (presbypnea) describes this relationship as respiratory sarcopenia. This term refers to sarcopenia throughout the body with decreasing respiratory muscle mass, which lowers respiratory functions and reduces respiratory muscle ability.[7-9]

Gender also significantly influences the functioning of various organs in the body. In the present study, a positive correlation was found between the thickness of the diaphragm at the end of expiration and inspiration, Excursion of the diaphragm at quiet breathing and deep breathing, and gender. A negative correlation was observed between the Quantity of pleural effusion and Diaphragmatic thickening fraction and gender. There was

Different studies also suggested the same findings. Cardenas et al demonstrated that diaphra-gmatic mobility and thickness are influenced by sex, with females having lower mobility and thickness than males due to a 9% longer diaphragm in comparison.[9] Another study suggested that women are characterized by smaller lung volumes, maximum expiratory flow, diffusion surface, and airway diameters than men.[10]

In the present study, we observed a positive correlation between smoking status and the thickness of pleural effusion (t = 0.259; p = 0.745) as well as the diaphragmatic thickening fraction (t = 0.539; p = 0.602). However, the high p-values indicate that these relationships are not statistically significant. This suggests that while there may be a trend toward increased pleural effusion thickness and diaphragmatic thickening in smokers, the evidence is not robust enough to draw definitive conclusions. Conversely, negative correlations were observed between smoking status and the thickness of the diaphragm at the end of expiration (t = -1.006; p = 0.279) and inspiration (t = -0.409; p = 0.701), as well as the excursion of the diaphragm during quiet breathing (t = -0.341; p = 0.807) and deep breathing (t = -0.398; p = 0.590). These findings suggest a potential decrease in diaphragmatic thickness and excursion in smokers, yet the lack of statistical significance implies that these results should be interpreted with caution. Different factors may be responsible for this negative association, like, variations in the duration and intensity of smoking among the study participants could have contributed to the heterogeneity in the results. Additionally, the multi-factorial nature of pleural effusion and diaphragmatic changes, which can be influenced by a variety of factors such as underlying lung diseases, cardiovascular conditions, and overall health status, might have confounded the observed associations. Despite the lack of significant findings in this study, existing literature suggests that smoking can have detrimental effects on the respiratory system. Smokers have been found to exhibit higher levels of vasculariza-tion, oxidative stress, inflammation, and remodeling of the diaphragm muscle compared to nonsmokers. These physiological changes could potentially contribute to the observed trends in our study, even though the statistical evidence was not conclusive.[11,12]

The present study also suggested that positive significant association was found between the thickness at the end of inspiration (t = -11.023; P<0.001), thickness at the end of expiration (t = -5.329; P<0.001), diaphrag-matic thickening fraction (P<0.001), excursion at quiet breathing (P <0.030), and excursion at deep breathing (P<0.001) and the ultrasound findings of GI and GII. These findings indicate decreased diaphra-gmatic functions in GI. According to Umbrello et al.,[5] diaphrag-matic functions are improved when pleural effusion is removed. Hemi-diaphragm functions decline on the side of pleural effusion, whereas thoracocentesis restores functions, as demonstrated by Skaarup et al.[13]

Ultimately, the data presented above demonstrate the significance of ultrasonography in determining the correlation between diaphragmatic functions and the amount of pleural effusion.

The significant correlation between pleural effusion volume and diaphragmatic excursion during both quiet and deep breathing underscores the need for thorough respiratory assessments in patients with pleural effu-sion. These findings suggest that thoracic ultrasound should be routinely used to monitor diaphragmatic function in these patients. Early detection of diaphra-gmatic dysfunction could prompt timely interventions, such as therapeutic thoracentesis, to alleviate respira-tory compromise and improve patient outcomes.

While this study provides valuable insights, it has limitations that should be acknowledged. The sample size was relatively small, and the study was conducted at a single center, which may limit the generalizability of the findings. Future studies with larger, multi-center cohorts are necessary to validate these results and provide a more comprehensive understanding of the relationship between pleural effusion and diaphrag-matic function.

Conclusion

This study highlights the significant impact of pleural effusion on diaphragmatic function, as evidenced by ultrasound imaging. The findings underscore the importance of using thoracic ultrasound to assess diaphragmatic mechanics in patients with pleural effusion. By improving our understanding of this relationship, clinicians can better manage respiratory complications in these patients, ultimately enhancing their quality of life and prognosis.

Further research is warranted to explore the mechani-sms underlying the observed diaphragmatic dysfunc-tion in pleural effusion and to evaluate the long-term outcomes of patients undergoing therapeutic interven-tions based on ultrasonographic findings. Additionally, studies examining the role of different pleural effusion etiologies on diaphragmatic function could provide more tailored clinical approaches to managing this condition.

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