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Investigating the influence of Chronic Obstructive Pulmonary Disease severity on the thickness of the Diaphragm Muscle

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ABSTRACT

Background: Chronic Obstructive Pulmonary Disease (COPD) is a progressive lung disease that is defined by airflow limitation and diaphragm respiratory muscle dysfunction. Diaphragm thickness and contractility, which can be quantified by ultrasound, are extremely informative regarding respiratory muscle function.

Objective: To assess the effect of COPD severity on diaphragm muscle thickness and its correlation with clinical and functional parameters.

Methods: Cross-sectional observational study was performed on 240 COPD patients, as per the GOLD staging system divided into four groups (GOLD I–IV; n = 60 each). Thickness of the diaphragm at end-expiration (Texp) and end-inspiration (Tinsp), and thickening fraction of the diaphragm (TF%) were measured by B-mode ultrasonography. Pulmonary function tests (FEV_1, FVC, FEV_1/FVC), symptom scores (mMRC), and anthropometric measures (age, BMI, smoking history, COPD duration) were ascertained.

Results: Significant reduction in diaphragm thickness and TF% with increasing severity of COPD ($p < 0.001$ for all). Texp and Tinsp significantly reduced from GOLD I to GOLD IV (Texp: 2.6 ± 0.4 mm to 1.7 ± 0.2 mm; Tinsp: 4.3 ± 0.6 mm to 2.6 ± 0.3 mm). TF% also reduced significantly (65.4 ± 12.2% in GOLD I compared to 50.1 ± 8.4% in GOLD IV). High positive correlations were found between diaphragm parameters and FEV_1 (Texp: $r = 0.51$; Tinsp: $r = 0.56$; TF%: $r = 0.48$; all $p < 0.001$).

Conclusion: Diaphragm thickening and thickening fraction diminish substantially with severity of COPD. Both measurements strongly correlate with pulmonary function and are independently affected by FEV_1, BMI, disease duration, and age.

Keywords: COPD; Diaphragm Thickness; Ultrasound; FEV_1; GOLD stages

Introduction

Chronic Obstructive Pulmonary Disease (COPD) is a chronic and progressive illness that is mainly brought on by prolonged exposure to air pollutants, cigarette smoke, and occupational dangers. It is defined by a chronic restriction in airflow. It comprises the two main conditions of emphysema and chronic bronchitis, which both cause irreversible harm to the lungs' alveolar structures and airways. Thus, people with COPD experience breathing problems, persistent coughing, sputum production, and in extreme situations, respiratory failure.[1]

According to the World Health Organization (WHO), COPD is a major cause of death globally, accounting for about 3 million deaths per year. The illness has a major negative influence on a person's quality of life, resulting in reduced physical activity, more hospitalizations, and high medical expenses.[2] Based on spirometry measurements of lung function, the Global Initiative for Chronic Obstructive Lung Disease (GOLD) divides the severity of COPD into stages, from mild (GOLD 1) to very severe (GOLD 4). Although improving airflow and reducing symptoms have traditionally received a lot of attention in the management of COPD, the significance of respiratory muscle dysfunction in the course of the disease is becoming increasingly apparent. One of the main respiratory muscles, the diaphragm, is essential for regular breathing, and its dysfunction can greatly increase the morbidity linked to COPD.[3]

The diaphragm is a big, dome-shaped muscle that divides the abdominal and chest cavities. Its ability to contract and flatten during inhalation, which permits the lungs to expand and take in air, makes it crucial for ventilation. Its optimal operation is essential for efficient breathing and the lungs' exchange of carbon dioxide and oxygen. Because advanced COPD is frequently characterized by hyperinflation of the lungs, the diaphragm is frequently subjected to abnormal mechanical forces. The loss of elastic recoil and the breakdown of lung tissue lead to hyperinflation, which keeps the lungs partially inflated even when exhaling. The diaphragm experiences additional strain as a result, which alters its structure and function.[4]

As COPD worsens, the diaphragm may thin and flatten, which can significantly reduce its contractility and respiratory effectiveness. Thinning, or diaphragm atrophy, is a sign of muscle dysfunction and is linked to worse breathing, a decreased capacity for exercise, and a decreased quality of life. Although it is thought that the degree of diaphragm muscle thinning corresponds with the severity of COPD, it is still crucial to investigate the precise relationship between diaphragm thickness and COPD stage.[5]

A key clinical indicator of respiratory muscle strength and function is the measurement of diaphragm muscle thickness. Physicians can determine the diaphragm's thickness using ultrasound imaging and other non-invasive imaging methods, which gives them important information about the health of the muscle. Diaphragm thinning is thought to be an early indicator of respiratory muscle dysfunction and may predict worsening respiratory symptoms and a greater need for mechanical ventilation. A patient's capacity to carry out everyday tasks may be severely impacted by reduced diaphragm thickness in COPD patients, which is frequently linked to worsened dyspnea (breathlessness), increased fatigue, and decreased exercise capacity. Furthermore, in patients with COPD, muscle weakness may be a factor in hospitalization rates and mortality.[6] Therefore, for both prognosis and management, it is essential to figure out the connection between diaphragm muscle thickness and the severity of COPD. Health care providers may be better able to comprehend how COPD develops and how respiratory muscle dysfunction relates to the overall severity of the disease by looking at diaphragm thickness at various stages of the illness.

Objective

To find out how the severity of COPD as determined by the GOLD stages related to the thickness of the diaphragm muscle.

Methodology

A cross-sectional observational study was conducted between November 2022 and September 2023 at Fatima Medical University, Lahore. According to the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria, 240 patients with a diagnosis of COPD were enrolled from different hospitals of the province. Using GOLD stages I via IV, patients were categorized into four groups based on the severity of their COPD. Adults aged 40 years or older were required to meet the inclusion criteria and COPD was clinically diagnosed based on stable COPD with no exacerbations in the previous four weeks and post-bronchodilator FEV1/FVC < 0.70. Coexisting pulmonary conditions (such as asthma or interstitial lung disease) were a criterion for exclusion and diaphragmatic neuromuscular disorders and a history of abdominal or thoracic surgery. The severity of COPD was categorized using post-bronchodilator spirometry in accordance with the GOLD guidelines. FEV1 percentage predicted: Mild (≥80%) is GOLD I; moderate (50–79%) is GOLD II; severe (30–49%) is GOLD III; and very severe (<30%) is GOLD IV. In contrast, B-mode ultrasonography using a linear transducer operating between 7.5 and 10 MHz was used to measure the diaphragm's thickness. With the patient in the supine position during end-expiration (Texp) and end-inspiration (Tinsp), measurements were made at the zone where the diaphragm

Table 1. Baseline characteristics of the study population

Variable	Total (N = 240)	GOLD I (n = 60)	GOLD II (n = 60)	GOLD III (n = 60)	GOLD IV (n = 60)	p-value
Age (years)	65.3 ± 9.2	61.2 ± 7.4	63.8 ± 8.6	66.7 ± 8.7	69.5 ± 9.1	0.001
Male (%)	156 (65%)	36 (60%)	39 (65%)	42 (70%)	39 (65%)	0.73
BMI (kg/m^2)	23.7 ± 4.5	25.8 ± 4.1	24.3 ± 3.8	22.1 ± 4.2	21.5 ± 3.9	<0.001
Smoking history (%)	192 (80%)	42 (70%)	48 (80%)	51 (85%)	51 (85%)	0.04
Duration of COPD (yrs)	7.2 ± 4.8	3.5 ± 2.1	5.6 ± 3.2	8.5 ± 4.3	11.2 ± 5.1	<0.001

appoints to the rib cage (8th–10th intercostal space, mid-axillary line).Diaphragm thickness at end-inspiration (Tinsp), diaphragm thickness at end-expiration (Texp), and thickening fraction (TF) = (Tinsp - Texp) / Texp × 100 were all noted. Every measurement was made three times, and the analysis was based on the mean value. A qualified sonographer performed each measurement while blinded to blinded clinical data.

SPSS version 23 was used to analyze the data. The mean ± SD was used to represent continuous variables. Diaphragm thickness was compared across GOLD stages using ANOVA. The association between the diaphragm thickness/thickening fraction and the predicted FEV1 percentage was evaluated using Pearson correlation. Statistical significance was defined as a p-value < 0.05.

Results

A total 240 patients were involved in our study which are classify based on the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria. Patients were classified into four groups according to COPD severity: GOLD stages I to IV in each group 60 patients were enrolled. The mean age increased progressively from GOLD I (61.2 ± 7.4 years) to GOLD IV (69.5 ± 9.1 years). Patients with more severe COPD tend to be older, which aligns with the natural progression of chronic lung diseases. The difference was statistically significant (p = 0.001), suggesting age may influence disease severity or reflect cumulative exposure to risk factors like smoking. The overall male percentage was 65%. There were no significant differences in sex distribution among GOLD groups (p = 0.73). Body Mass Index (BMI) showed a significant decline from GOLD I (25.8 ± 4.1 kg/m^2) to GOLD IV (21.5 ± 3.9 kg/m^2) (p < 0.001). Lower BMI in advanced COPD suggests the presence of systemic effects like muscle wasting, cachexia, or nutritional deficiency. This can negatively impact diaphragm function and respiratory muscle strength. Smoking prevalence increased with disease severity: 70% in GOLD I and 85% in GOLD III and IV (p = 0.04). The duration of diagnosed COPD increased with severity, from 3.5 ± 2.1 years (GOLD I) to 11.2 ± 5.1 years (GOLD IV) (p < 0.001). Longer duration of COPD is significantly associated with more severe stages (Table 1).

Forced Expiratory Volume in 1 Second (FEV_1 % predicted) declines significantly with increasing GOLD stage from 84.5% in GOLD I to 28.2% in GOLD IV. FEV_1 is the key spirometry measurement used in GOLD staging. This progressive reduction confirms the classification and illustrates the declining expiratory airflow due to

Table 2. Pulmonary Function parameters by GOLD stage

Parameter	GOLD I	GOLD II	GOLD III	GOLD IV	p-value
FEV1 (% predicted)	84.5 ± 4.3	65.1 ± 6.2	42.3 ± 5.1	28.2 ± 4.6	<0.001
FVC (% predicted)	90.2 ± 5.6	74.7 ± 6.9	58.4 ± 6.7	45.6 ± 6.3	<0.001
FEV1/FVC ratio (%)	69.1 ± 3.2	63.5 ± 4.1	58.2 ± 3.8	53.4 ± 4.0	<0.001
mMRC score	0.8 ± 0.6	1.6 ± 0.7	2.5 ± 0.9	3.2 ± 0.8	<0.001

Table 3. Diaphragm thickness measurements by COPD severity

Diaphragm Parameter	GOLD I	GOLD II	GOLD III	GOLD IV	p-value
Texp (mm)	2.6 ± 0.4	2.3 ± 0.3	2.0 ± 0.3	1.7 ± 0.2	<0.001
Tinsp (mm)	4.3 ± 0.6	3.7 ± 0.5	3.1 ± 0.4	2.6 ± 0.3	<0.001
Thickening Fraction (%)	65.4 ± 12.2	60.3 ± 10.6	54.0 ± 9.5	50.1 ± 8.4	<0.001

worsening airway obstruction. The statistically significant difference ($p < 0.001$) reflects reliable stage-based disease stratification.

Forced Vital Capacity (FVC % predicted) also progressively decreases across stages (90.2% in GOLD I to 45.6% in GOLD IV). The FVC decline indicates reduced lung capacity, which is likely due to air trapping, hyperinflation, and decreased elastic recoil seen in advanced COPD. It complements FEV_1 in evaluating overall ventilatory capacity.

FEV_1/FVC Ratio (%) falls from 69.1% in GOLD I to 53.4% in GOLD IV. The FEV_1/FVC ratio is a hallmark of obstructive lung disease. The lower the ratio, the more severe the obstruction. Although already reduced in GOLD I (<70%), its further decline in advanced stages confirms increasing severity of airflow limitation.

Dyspnea Scale Increases sharply with COPD severity from 0.8 in GOLD I to 3.2 in GOLD IV. The Modified Medical Research Council (mMRC) score reflects patient perceived breathlessness. The progressive increase demonstrates the growing impact of COPD on daily activity and quality of life, especially in GOLD III and IV. The significant p-value indicates this is a robust clinical marker associated with spirometric decline (Table 2).

Diaphragm Thickness at End-Expiration

(T_{exp}): Gradual reduction across severity stages: GOLD I: 2.6 mm, GOLD IV: 1.7 mm. The thickness of the diaphragm at rest (expiration) significantly decreases as COPD becomes more severe. This thinning is indicative of muscle atrophy or disuse associated with chronic hyperinflation and reduced respiratory effort in advanced stages.

Diaphragm Thickness at End-Inspiration

(T_{insp}): Consistent decline with increasing GOLD stage: GOLD I: 4.3 mm, GOLD IV: 2.6 mm. This reflects the contractile capacity of the diaphragm. The reduction in T_{insp} suggests weakened inspiratory strength, potentially due to mechanical disadvantage caused by lung hyperinflation and chronic muscle fatigue.

Thickening Fraction (TF%),

(TF = [(T_{insp} – T_{exp}) / T_{exp}] × 100): GOLD I: 65.4% and GOLD IV: 50.1%. Thickening Fraction is a key indicator of diaphragmatic function and contractility. A significant decrease across COPD stages suggests impaired diaphragm mechanics. Even though the diaphragm may thin, the reduction in thickening is more clinically relevant, indicating functional degradation rather than just anatomical change (Table 3).

Table 4 presents the correlation between diaphragm measurements (via ultrasonography) and pulmonary function, specifically FEV_1 (% predicted) the key spirometry indicator of COPD severity.

Thickness at End-Expiration

(T_{exp}), Correlation (r = 0.51): This indicates a moderate positive correlation between T_{exp} and FEV_1. As FEV_1 increases (i.e., better lung function), T_{exp} also tends to be thicker. This suggests that diaphragm thinning at rest is associated with worsening airflow limitation.

Table 4. Correlation Between Diaphragm Parameters and FEV1 (% Predicted)

Parameter	Pearson Correlation (r)	p-value
Texp	0.51	<0.001
Tinsp	0.56	<0.001
Thickening Fraction (%)	0.48	<0.001

Thickness at End-Inspiration

(T_{insp}), Correlation (r = 0.56): The strongest correlation observed in this table, suggesting a moderate to strong positive relationship between inspiratory diaphragm thickness and FEV_1. Better lung function is significantly associated with greater diaphragm thickening during inspiration. This implies that patients with higher inspiratory effort and less hyperinflation maintain better diaphragm contractility and structure.

Thickening Fraction (%),

Correlation (r = 0.48): A moderate positive correlation, indicating that as FEV_1 improves, the diaphragm's thickening capacity during inspiration also improves. A reduced thickening fraction reflects weakened diaphragm function, which correlates with reduced airflow (FEV_1). This is functionally significant, as TF is a direct indicator of diaphragmatic contractile efficiency.
This regression model identifies independent predictors of diaphragm thickening fraction (TF%), a key functional marker of diaphragm performance during breathing. The coefficient reflects the strength and direction of association between each variable and TF%, adjusted for the other variables in the model.

FEV_1 (% predicted),

$\beta = 0.38$, $p < 0.001$: A strong and statistically significant positive predictor. For every 1% increase in FEV_1, the diaphragm thickening fraction increases by 0.38%.

Body Mass Index (BMI),

$\beta = 0.21$, $p = 0.003$: BMI is also a significant positive predictor. Higher BMI is associated with higher diaphragm thickening fraction. Low BMI in COPD often reflects muscle wasting or cachexia. This finding suggests that nutritional status and muscle mass preservation are important for maintaining diaphragmatic function.

Duration of COPD (years),

$\beta = -0.19$, $p = 0.001$: A longer disease duration is significantly associated with a lower thickening fraction. This reflects progressive diaphragm fatigue or deconditioning over time, supporting the need for early intervention and possibly pulmonary rehabilitation to preserve respiratory muscle strength.

Age (years),

$\beta = -0.11$, $p = 0.04$: Increasing age is a weaker, but still statistically significant, negative predictor of diaphragm function. Age-related muscle decline (sarcopenia) may affect diaphragm contractility, independent of COPD severity (Table 5).

Discussion

The diaphragm is the major respiratory muscle, with a key role in ventilatory mechanics. Progressive airflow limitation and hyperinflation of COPD place structural and functional burdens on the diaphragm that eventually affect its capacity to produce adequate inspiratory force.[5] The objective of this study was to investigate the correlation between the severity of COPD and muscle thickness and function of the diaphragm, as measured using ultrasonography, in 240 patients assigned to the GOLD stages (I–IV). The average age of the study population was 65.3 ± 9.2 years, with the progressive rise in age throughout GOLD stages from 61.2 years in GOLD I to 69.5 years in GOLD IV ($p = 0.001$). This is consistent with the natural course of COPD, which is a chronic progressive disease with increasing severity over time. Similar age trends have been reported in previous study Ottenheijm et al., 2005[7] reported increasing age in more severe COPD categories, suggesting age as a contributing factor to both lung and muscle degeneration. Males comprised 65% of the total population, with no statistically significant difference across GOLD stages ($p = 0.73$). This male predominance is consistent with historical smoking patterns and COPD prevalence data in many developing and developed countries. For example, in one study by Seymour et al. (2010)[8], about 60–70% of the COPD population was male. Gender disparities are diminishing across the world because of shifting cigarette-smoking habits among women. BMI markedly reduced with worsening COPD from 25.8 ± 4.1 in GOLD I to 21.5 ± 3.9 in GOLD IV ($p < 0.001$). This mirrors the nutritional catabolism and loss of muscle mass typically seen in severe COPD. In line with Schols et al. (2000)[9], who proved that low BMI in COPD is linked to increased mortality and lower diaphragm strength. High proportion (80%) of the entire cohort was a smoker, with rising prevalence in GOLD III and IV (85%) versus GOLD I (70%) ($p = 0.04$). This trend is consistent with the long-standing position of smoking as the major risk factor for the development and progression of COPD.
Reports such as GOLD Reports[10] and Laniado-Laborín (2009)[11] highlight that heavier and longer duration of smoking is linked to more severe COPD and greater lung tissue damage. The disease duration of COPD lengthened considerably between stages from 3.5 ± 2.1 years in GOLD I to 11.2 ± 5.1 years in GOLD IV ($p < 0.001$). More extensive disease duration is closely related to increased structural damage to the lungs and respiratory muscles, such as the diaphragm. This supports the fact that COPD is a progressive disease with a cumulative effect on the respiratory system. This observation is consistent with

Laghi and Tobin (2003)[12], who emphasized that long-standing COPD causes diaphragm fiber-type shift, oxidative stress, and ultimately functional impairment. Pulmonary function testing underlies classification and evaluation of COPD severity.

Results of the present showed a definitive and sequential worsening of pulmonary function parameters, as would be expected in the natural course of COPD. A marked drop in FEV_1 values between GOLD stages from 84.5% in GOLD I to 28.2% in GOLD IV ($p < 0.001$). This is the foundation of the GOLD staging system, where the severity of COPD is defined directly by post-bronchodilator FEV_1 percentage. These criteria are consistent with the GOLD 2023 recommendations,[13] which grade: GOLD I: $FEV_1 \geq 80\%$, GOLD II: $50\% \leq FEV_1 < 80\%$, GOLD III: $30\% \leq FEV_1 < 50\%$ and GOLD IV: $FEV_1 < 30\%$. Research like Celli et al. (2015)[14] and Agustí et al. (2012)[15] establishes that FEV_1 decline has good correlation with worsening symptoms, exercise intolerance, and prognosis in patients with COPD. Forced Vital Capacity (FVC) also fell substantially from 90.2% in GOLD I to 45.6% in GOLD IV ($p < 0.001$). Although FVC is not the central parameter for grading COPD, its progressive diminution indicates restrictive elements in advanced illness with hyperinflation and muscle weakness.

Research conducted by O'Donnell et al. (2007)[16] and Aliverti et al. (2008)[17] has indicated that with advancing COPD, dynamic hyperinflation and air trapping decrease effective lung volume and are responsible for a decrease in FVC, especially in GOLD III–IV. FEV_1/FVC ratio decreased gradually and significantly from 69.1% in GOLD I to 53.4% in GOLD IV ($p < 0.001$). This ratio is the first diagnostic criterion for airflow obstruction in COPD, and levels <70% indicate sustained obstruction.

These observations are in line with worldwide COPD epidemiological statistics. For instance, the BOLD (Burden of Obstructive Lung Disease)[18] Study showed average FEV_1/FVC ratios in patients with COPD as 50–65%, declining with increasing severity. This gradual decline represents enhanced airway resistance, loss of elastic recoil, and expiratory flow limitation with advanced disease. The mMRC score, which measures the subjective experience of dyspnea, rose substantially from 0.8 in GOLD I to 3.2 in GOLD IV ($p < 0.001$). This trend indicates increased symptom burden in more advanced COPD. In the ECLIPSE study (Vestbo et al., 2008)[19], there was a similar relationship between GOLD stage and symptom burden, with increasing mMRC scores for GOLD III and IV patients. In addition, dyspnea measures such as mMRC and CAT are highlighted in newer GOLD revisions to improve the measurement of patient-outcomes greater than spirometry.

The three main parameters utilized here thickness at end-expiration (Texp), thickness at end-inspiration (Tinsp), and the thickening fraction (TF%) all represent structural and functional diaphragmatic changes. In End-Expiratory Diaphragm Thickness (Texp), GOLD I: 2.6 ± 0.4 mm, GOLD IV: 1.7 ± 0.2 mm with $p < 0.001$. There was a considerable decrease in Texp from GOLD I to GOLD IV, showing progressive atrophy of the diaphragm with worsening COPD. In a study by Corbellini et al. (2018)[20], mean values of Texp in normal controls were ~2.6 mm, whereas in patients with severe COPD, they were less than 2.0 mm, as in the current findings. Baria et al. (2014)[21] also showed that patients with severe COPD had thinner diaphragms during rest due to muscle disuse, systemic inflammation, and nutritional depletion. End-Inspiratory Diaphragm Thickness (Tinsp), GOLD I: 4.3 ± 0.6 mm, GOLD IV: 2.6 ± 0.3 mm with $p < 0.001$. Inspiratory thickness also significantly decreased with increasing disease. Tinsp measures contractile capacity of the diaphragm on inspiration, and decreased values in GOLD IV indicate impaired recruitment and decreased muscle force. In research by Smargiassi et al. (2014)[22], Tinsp values progressively diminished from mild to severe COPD and correlated highly with inspiratory muscle strength. Research utilizing MRI and sonography Han MK et al., 2011[23] demonstrate comparable decreases in Tinsp with compromised lung compliance and chronic hyperinflation. Diaphragm Thickening Fraction (TF%), GOLD I: 65.4 ± 12.2%, GOLD IV: 50.1 ± 8.4% with $p < 0.001$. The thickening fraction reflects the functional capability of the diaphragm to contract upon inspiration, calculated as: $TF\ (\%) = [(Tinsp - Texp) / Texp] \times 100$. The TF% decreased significantly through stages, reflecting impaired diaphragm function with advancing COPD. Decreased thickening fractions have been linked to decreased inspiratory effort, mechanical disadvantage secondary to hyperinflation, and muscle fatigue. Boon et al. (2016)[24] identified that TF% < 20% predicted diaphragm dysfunction in ICU patients, while even more elevated thresholds (~40–60%) can be indicative of compromised function in COPD. Grosu et al. (2012)[25] demonstrated decreased TF% in ventilator-dependent COPD patients, which was associated with poor weaning outcomes and decreased maximal inspiratory pressures.

Table 4 illustrates Pearson correlation coefficients for statistically significant positive correlations between diaphragm parameters Texp, Tinsp, and Thickening Fraction (TF%) and FEV_1 (% predicted) in patients with different severities of COPD. Texp and FEV_1: $r = 0.51$, $p < 0.001$, the moderate positive correlation between end-expiratory diaphragm thickness (Texp) and FEV_1 suggests that lower values of FEV_1 are linked to thinner diaphragm at rest. This mirrors diaphragm muscle atrophy at more advanced levels of COPD. Corbellini et al. (2018)[20] identified the same relationship ($r \approx 0.48$) between Texp and FEV_1 in stable patients with COPD, associating diaphragm thinning with decreased pulmonary capacity. Baria et al. (2014)[21] reported decreased Texp in GOLD III–IV patients and stressed the correlation between diminished muscle thickness and poor ventilatory

performance. Tinsp and FEV_1: r = 0.56, p < 0.001, Inspiratory diaphragm thickness (Tinsp) correlated best with FEV_1 of the three parameters. This is reasonable because Tinsp indicates diaphragm contraction and inspiratory effort, both of which are directly affected by pulmonary mechanics and muscle reserve.

In research by Smargiassi et al. (2014)[22], Tinsp was significantly correlated with lung function (r = 0.55) and inspiratory pressures (PImax), further supporting the position of Tinsp as a dynamic indicator of respiratory muscle function. Grosu et al. (2012)[25] and Boon et al. (2016)[24] observed that Tinsp is decreased in both COPD patients and ICU patients with ventilatory dependence, frequently following concomitantly with FEV_1 reduction and requirement for assistance. Thickening Fraction and FEV_1: r = 0.48, p < 0.001, the thickening fraction (TF%), a measure of diaphragmatic contractility function, was also significantly moderately correlated with FEV_1. This result reinforces the notion that impaired lung function is associated with decreased diaphragm muscle strength and efficiency. Vivier et al. (2012)[26] described TF% less than 30–40% as being commonly predictive of diaphragm dysfunction and linked to decreased FEV_1 and poorer clinical outcomes. Among a population of COPD patients, Han MK et al. (2011)[23] illustrated parallel associations, indicating that diaphragm TF% may be used as a non-invasive marker of functional reserve and disease severity. Multivariate linear regression analysis in Table 5 reveals FEV_1 (% predicted), BMI, COPD duration, and age as independent predictors of diaphragm thickening fraction (TF%) in COPD patients. Each variable's β coefficient and confidence interval indicate the strength and direction of association with contractility of the diaphragm, adjusting for potential confounders.

FEV_1 (% Predicted): β = 0.38, p < 0.001. FEV_1's strongest positive relationship was with TF%, i.e., good pulmonary function is independently related to increased thickening of the diaphragm during inspiration. Grosu et al. (2012)[25] found that reduced FEV_1 is a strong predictor of diaphragm dysfunction on ultrasound. Corbellini et al. (2018)[20] and Smargiassi et al. (2014)[22] reported similarly strong FEV_1-TF% correlations, indicating that diminished airflow limitation is related to diminished diaphragm contraction capacity. BMI: β = 0.21, p = 0.003. Body mass index was a positive, significant predictor of TF%, indicating that improved nutritional status is supportive of diaphragm muscle bulk and function. Malnutrition and wasting of the muscles are common in COPD, especially in stages GOLD III–IV. Increased BMI can indicate sustained muscle mass and enhanced systemic metabolic support that has a positive effect on diaphragm contractility. Baria et al. (2014)[21] also reported that underweight patients with COPD had significantly thinner diaphragms and reduced TF%, validating the link between BMI and respiratory muscle function. Duration of COPD: β = -0.19, p = 0.001. More recent duration of COPD was independently related to reduced TF%, indicating worsening diaphragm over time.

Chronic respiratory illness places persistent mechanical stress and inflammatory load on the diaphragm. These over time cause fatigue, fibrosis, and type-shifting of the fibers, eventually compromising contractility. Vivier et al. (2012)[26] reported that increasing disease duration was associated with decreased diaphragm excursion and thickness on ultrasound. Likewise, Han MK et al. (2011)[23] recognized structural diaphragm remodeling with long-term COPD, especially when preceded by repeated exacerbations and corticosteroid treatment. Age: β = -0.11, p = 0.04. Greater age was an important but weak adverse predictor of TF%, illustrating the effect of aging on skeletal muscle function, including the diaphragm. Aging causes sarcopenia, decreased motor unit firing, and mitochondrial failure in skeletal muscle.

Conclusion

This study demonstrates a significant decline in diaphragm thickness and thickening fraction (TF%) with increasing severity of COPD, highlighting the progressive impairment of diaphragmatic function. Both inspiratory and expiratory diaphragm thicknesses, along with TF%, showed strong positive correlations with FEV_1, underscoring their potential role as non-invasive markers of disease severity. Furthermore, these diaphragm parameters were independently influenced by key clinical variables, including FEV_1, BMI, disease duration, and age. These findings suggest that sonographic assessment of the diaphragm can serve as a valuable adjunct to pulmonary function tests in evaluating and monitoring COPD progression.

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