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Ultrasound Assessment of Diaphragmatic Excursion in Patients with Chronic Obstructive Pulmonary Disease as a Predictor for Disease Severity

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ABSTRACT
Background: Out of all the primary causes of death and morbidity globally, chronic obstructive pulmonary disease (COPD) ranks third. Possible causes of dyspnea and exercise intolerance in COPD patients include disruptions in the load-capacity ratio of the respiratory muscles.
Objective: This study aimed to use ultra-sonographic (U/S) techniques to assess diaphragmatic excursion at tidal and maximal lung volumes in patients with different degrees of COPD severity and its relation to the severity of the disease.
Patients and methods: A Case-control study was carried out on 80 subjects, 60 individuals undergoing follow-up treatment at The Outpatient Clinic of The Chest Department at Kafr El- Sheikh University Hospitals for clinically stable COPD, and twenty healthy individuals serving as a control group. The patients in this COPD group were identified and categorized into three equal (20 patient each) groups based on GOLD 2023 criteria (groups A, B & E COPD).
Results: There was a decrease in diaphragmatic excursion in COPD patients compared to increasing severity.
Conclusions: Ultrasound is a noninvasive, simple, bedside valuable diagnostic tool for the severity examination of COPD patients.
Keywords: Ultrasound, Diaphragmatic excursion, Chronic obstructive pulmonary disease.

INTRODUCTION
Chronic obstructive pulmonary disease (COPD) patients usually have imbalanced respiratory muscles regarding their load/capacity ratio [(1)]. Hypercapnic respiratory failure due to muscle weakness leading to increased risk of mortality in COPD patients [(2)].

Chronic flow limitation and air entrapment put strain on respiratory muscles, which in turn changes the structure and function of the diaphragm muscle and reduces its tension-generating capacity [(3)]. Respiratory muscle activity can be compromised in COPD patients for a variety of reasons, including protease activation, oxidative stress, starvation, advanced age, and systemic variables associated with medical conditions. Contrarily, alterations in the shape of the chest wall are the most studied factors that contribute to respiratory muscle dysfunction [(4)]. The diaphragm's impairment is a critical factor that is linked to dynamic lung hyperinflation in COPD patients that are experiencing an exacerbation [(5)].

The inspiratory muscles are subjected to a mechanical strain as a consequence of the increased resistive and elastic loading that are associated with increased airway resistance and decreased dynamic pulmonary compliance. Air entrapment causes thoracic hyperinflation, which decreases the efficacy of the contraction during lower rib cage expansion, by changing the orientation of diaphragm muscle fibers in a zone of apposition (ZOA). Remodeling causes muscles to enlarge, which in turn reduces diaphragmatic excursion [(6)]. So, understanding the physiological principle of respiratory muscle performance is essential for managing COPD patient's condition [(7)].

Several recent studies reported the benefit of diaphragmatic ultrasonography for COPD patients. US is commonly used and has little radiation risk [(8)]. Ultrasonography was employed in a recent study to assess the diaphragmatic excursion in patients with COPD and to identify its potential for predicting the severity of the condition.

PATIENTS AND METHODS
A Case-control study that was carried out on 80 subjects, 60 individuals undergoing follow-up treatment at The Outpatient Clinic of Chest Department at Kafr El Sheikh University Hospitals for clinically stable COPD, and twenty healthy individuals serving as a control group. The patients in this COPD group were identified and categorized into three groups based on GOLD 2023 criteria in addition to a control group of 20 healthy subjects:

- Group A COPD): twenty cases.
- Group B COPD): twenty cases.
- Group E COPD): twenty cases.
- Control group: twenty healthy subjects

Inclusion criteria: According to GOLD 2023, confirmed cases of stable COPD on a scale from mild to severe, using the following [(9)]: Comprehensive history-taking, chest examinations (general and local) and the GOLD guidelines for 2023, which require that spirometry be employed to confirm the presence of COPD in patients if the ratio of post-bronchodilator forced expiratory volume

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1 (FEV1) to forced vital capacity (FVC) is less than 0.70 [9].

Exclusion criteria: People suffering from various chest conditions, people who have abnormalities of the chest wall or neuromuscular diseases, people whose health is compromised due to systemic diseases that impact muscle function, such as endocrine, neoplastic, or metabolic disorders; or who are taking prescription medications that cause myopathy like long-term corticosteroids, people whose intra-abdominal pressure is elevated for whatever reason, people who have recently had surgery on their chest or upper abdomen and individuals who declined to take part in the research.

- The severity of the COPD that was based on GOLD, 2023[9] report depends on: PFT measurement of spirometry parameters (FEV1, FEV1/FVC, FVC). When evaluating the seriousness of dyspnea, two standard instruments are employed: the COPD Assessment Test (CAT) and the Modified British Medical Research Council (mMRC) scale. Annually, the frequency of worsening symptoms and the aforementioned methods are integrated into a single COPD assessment known as the ABE classification tool.

Measurement of oxygen saturation using pulse oximetry. Laboratory workup: Assessment of liver and kidney functions, arterial blood gases (ABG), as well as complete blood picture (CBC). A chest X-ray with both an anterior and lateral view. Ultrasonography of the diaphragm: By Sonoscape E2 Pro Color Doppler Ultrasound Machine, Medical Corp, China, 2022 with (C 2-5 MHz) curved low-frequency probe for diaphragm.

Measured variables: We measured diaphragmatic excursion as follows: With the patient semi-seated, a low-frequency phased-array or curved-array ("abdominal") equipment measuring 2-5 MHz is placed in the midclavicular line, directly below the costal arch, during the subcostal approach excursion. An ultrasonic beam is angled perpendicular to the diaphragmatic dome and as far cranially as possible [6]. The liver and spleen were spanned by a luminous line that was identified as the diaphragm [8].

The spleen's inadequate acoustic aperture can make it challenging to acquire a distinct image of the left hemi diaphragm. As you breathe in, the diaphragm should move toward the tool. When measuring the excursion in M-mode, it is important to keep the M-line perpendicular to the motion direction. With a sweep speed of about 10 mm/s, you can get three respiratory cycles in one picture [9].

Ethics approval: It was approved by Kafr Elsheikh University Faculty of Medicine's Ethics Committee, commenced in April 2023, and concluded in December 2024. The ethics reference number is KFSIRB200-481. Informed signed consents were obtained from all patients. The study adhered to Helsinki' Declaration through its execution.

Statistical analysis

The social science program SPSS, specifically Statistical Computer Package version 11, was used to analyze the data. P-value, or probability value > 0.05 was considered non-significant. P-value ≤ 0.05 was considered significant. Furthermore, p-value < 0.001 was considered highly significant. The following tests were done: When comparing three or more sets of normally distributed data, one-way analysis of variance (One-way ANOVA) was used. A t-test for independent samples that compared two independently distributed groups of variables. The difference between qualitative variables was calculated using the Chi-square (χ^2) and Fisher exact tests. Receiver operating characteristic (ROC) analysis: Utilizing the ROC curve, which encompasses the ideal cutoff value, AUC, SE, and P-value test features were estimated. Calculations for accuracy, specificity, sensitivity, and negative predictive value (NPV) were also within the optimal range for assessing the test's efficacy.

RESULTS

Of the 60 patients with COPD who were enrolled in the study, 50 were males and 10 were females. The range of their ages was 49 to 76 years, with a mean of 59.86 ± 6.53 (Table 1).

Table (1): demographic data of the cases included in the study

Items		Cases (n= 60)
Age (years)	**Mean ± SD**	59.86 ± 6.53
	Median (min-max)	59 (49-76)
BMI (kg/m^2)	**Mean ± SD**	26.25 ± 3.39
	Median (min-max)	25.9 (20- 33)
Sex		
Males		**50 (90%)**
Females		**10 (10%)**

Data presents as mean ± SD, Median (min-max) or frequency (%), BMI (body mass index).

The observed groups' smoking indeices ranged from 17 to 120, with a mean of 60.65 ± 23.06. Of the patients, 56.25% were current smokers, 36.25% were ex-smokers, and 7.5% were non-smokers. Patients who were current smokers exhibited a higher level of D than those in other categories (37% and 33% respectively). Additionally, groups A and B had a higher proportion of ex-smokers (33% and 45% respectively), while group A had a higher proportion of non-smokers with COPD (Table 2).

Table (2): Classification of COPD according to severity of obstruction

	Control group [N=20]	Group A [N= 20]	Group B [N=20]	Group E [N=20]	P-Value
Age (years)	46.60 ± 12.35	56.15 ± 6.31	62.95±8.30	59.60±5.09	F=13.553 P<0.001*
BMI (Kg/m²)	25.50±2.99	26.69±1.96	25.27±2.63	25.97±4.01	F=1.108 P=0.358
Smoking index	NON	40 (17-90)	66 (26-90)	77.5 (34-120)	F=55.023 P<0.001*
Current smoker	NON	7 (15%)	6 (13%)	15 (33%)	χ^2=95.749 P<0.001*
Ex-smoker		10 (34%)	13 (45%)	5 (17%)	
Non-smoker	20 (100%)	3 (50%)	1 (17%)	0 (0%)	

Data presents as mean ± SD or frequency (%), BMI (body mass index), * highly significant p-value < 0.001

The reduction in FEV1 was more pronounced in groups B and E COPD patients than in other subgroups. Furthermore, the mMRC scale grading increased in tandem with the severity of COPD, as evidenced by group E mMRC (grade 2 represented 15% of the cases, grade 3 represented 60%, and grade 4 represented 25% with 5 cases). The severity classification of COPD was consistent with the fact that groups B and E had significantly higher CAT scores than the average (Table 3).

Table (3): Classification of COPD according to the severity of obstruction as regards FEV1, exacerbation per year, mMRC, and CAT

	Group A [N= 20]	Group B [N=20]	Group E [N=20]	p-value
FEV1 (L)	2.45± 0.12	1.67± 0.44	1.22± 0.22	F=93.044 P<0.001*
No. exacerbations	5 (25%)	4 (20%)	0 (0%)	FET=5.308 P=0.045*
1 time	15 (75%)	16 (80%)	0 (0%)	FET=23.624 P<0.001*
2 times	0 (0%)	0 (0%)	11 (55%)	FET=16.227 P<0.001*
3 times	0 (0%)	0 (0%)	7 (35%)	FET=6.132 P= 0.029*
4 times	0 (0%)	0 (0%)	2 (10%)	FET=0.648 P= 0.754
Grade 1	20 (100%)	0 (0%)	0 (0%)	FET=46.384 P<0.001*
Grade 2	0 (0%)	16 (80%)	3 (15%)	FET=27.347 P<0.001*
Grade 3	0 (0%)	4 (20%)	12 (60%)	FET=21.573 P<0.001*
Grade 4	0 (0%)	0 (0%)	5 (25%)	FET=5.648 P= 0.041*
CAT	7.95 ± 1.05	21.60 ± 4.60	28.35± 3.72	F=221.808 P<0.001*

Data presents as frequency (%), FEV1 (forced expiratory volume), mMRC (modified medical research council), CAT (COPD Assessment Test) * highly significant p-value < 0.001.

There was a notable disparity in tidal excursion and max excursion between the control group and the COPD group (60 patients), with a p-value of less than 0.001 (Table 4).

Table (4): Comparison between studied groups as regards the diaphragmatic excursion

	COPD group [N= 60]	Control group [N=20]	P-VALUE
Tidal excursion(cm)	2.53±0.48	3.56 ±0.18	T=9.307 P< 0.001*
Max excursion(cm)	5.15± 0.68	6.56 ±0.31	T=9.030 P< 0.001*

Data presents as mean ± SD,* Highly significant p-value < 0.001.

Statistically significant differences in diaphragmatic (tidal, max) excursion (cm) were observed within the various COPD subgroups and between the COPD subgroups and control group in this study, as determined by ultra-sonographic assessments (p<0.001). With a considerably greater reduction in the same parameter in groups B and E (P<0.001) (Table 5).

Table (5): Comparison between COPD subgroups and control regarding diaphragmatic excursion

	Control group [N=20]	Group A [N= 20]	Group B [N=20]	Group E [N=20]	P-VALUE
Tidal excursion(cm)	3.56±0.18	2.91±0.30	2.22±0.39	2.15±0.27	F=68.552 P<0.001* P^1<0.001* P^2<0.001* P^3<0.001*
Max excursion(cm)	6.56±0.31	5.91±0.16	4.80±0.60	4.53±0.45	F=84.483 P<0.001* P^1<0.001* P^2<0.001* P^3<0.001*

Data presents as mean ± SD. P= Represents differences within the COPD subgroups, P^1= Represents differences between the control group and Group A, P^2= Represents differences between the control group and Group B, P^3= Represents differences between the control group and Group E, * Highly significant p-value < 0.001.

The cutoff points for tidal excursion were 3.35 cm with a sensitivity of 96% and specificity of 80%, and the cutoff point for maximum excursion was 6.5 cm with a sensitivity of 97% and specificity of 90%, according to a statistical comparison of different ultrasonographic parameters that were used to differentiate between control and all COPD patients (Table 6 & Figure 1).

Table (6): Statistical comparison between different ultra-sonographic parameters for all COPD patients

	Tidal Excursion(cm)	Max Excursion (cm)
AUC	0.976	0.995
Cut off point	3.350	6.150
Sensitivity	96.3%	97.5%
Specificity	80.0%	90.0%
PPV	95.1%	97.5%
NPV	84.2%	90.0%
P value	< 0.001*	< 0.001*

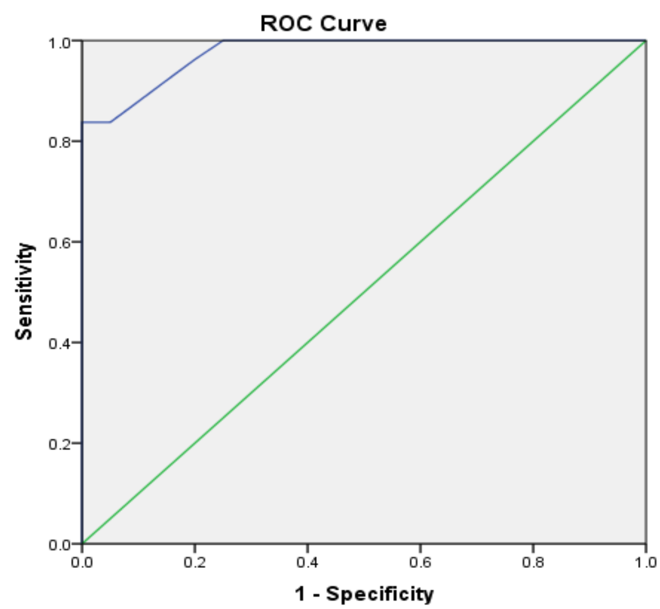

Figure (1): Roc curve of tidal excursion for all COPD patients.

Data presents as numbers, **PPV:** positive predictive value, **NPV:** negative predicted value.

Also, as shown in table (7), when comparing group A with the control group, tidal and maximal diaphragmatic excursion were significantly different. On the other hand, the diaphragmatic thickness fraction did not differ significantly (P = 0.839). For both groups, the sensitivity was 70% and the specificity 40% (Figure 2).

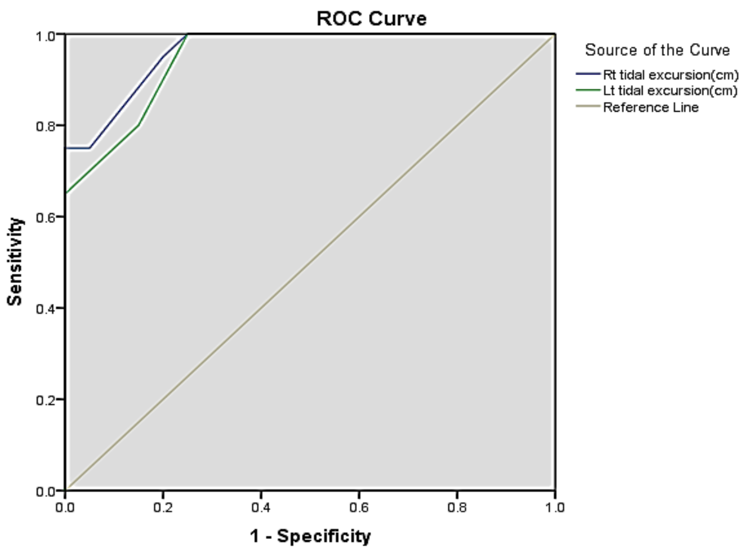

Figure (2): Prediction of the ability of diaphragm tidal excursion to differentiate between control & group A.

A sensitivity of 95% and specificity of 95% were observed in group B for tidal and maximal diaphragmatic excursion, with a P value of < 0.001* (Table 7 & figure 3).

Table (7): Diaphragmatic excursion Roc curve for all COPD patients

Group	Tidal Excursion	Max Excursion
Group A **Cut off point.** **Sensitivity** **Specificity**	 3.05 75% 100%	 6.05 85% 100%
Group B **Cut off point.** **Sensitivity** **Specificity**	 3.00 95% 100%	 5.95 100% 100%
Group E **Cut off point.** **Sensitivity** **Specificity**	a 3 100% 100%	 5.07 100% 100%

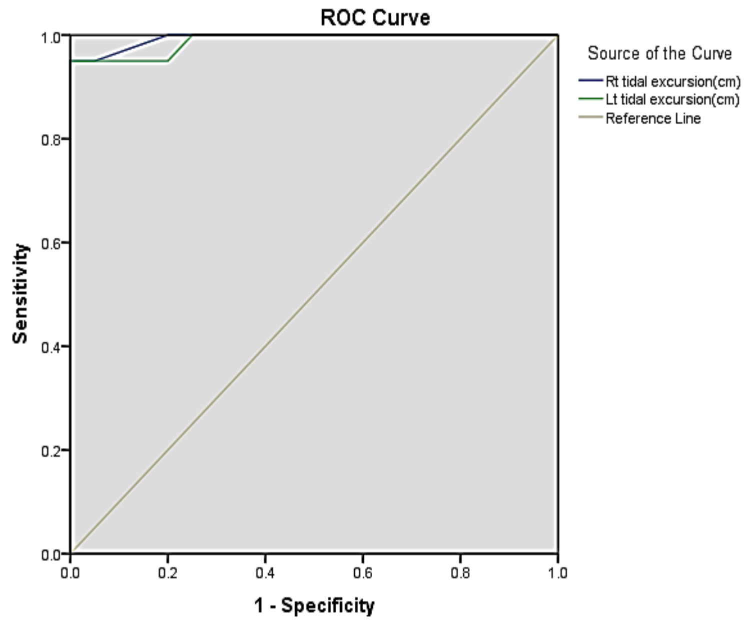

Figure (3): Prediction of the ability of diaphragm tidal excursion to differentiate between control & group B.

In conclusion, group E exhibited statistically significant differences in tidal and maximal diaphragmatic excursion (P value < 0.001) with a specificity of 100% and a selectivity of 100% (Table 7 & figure 4).

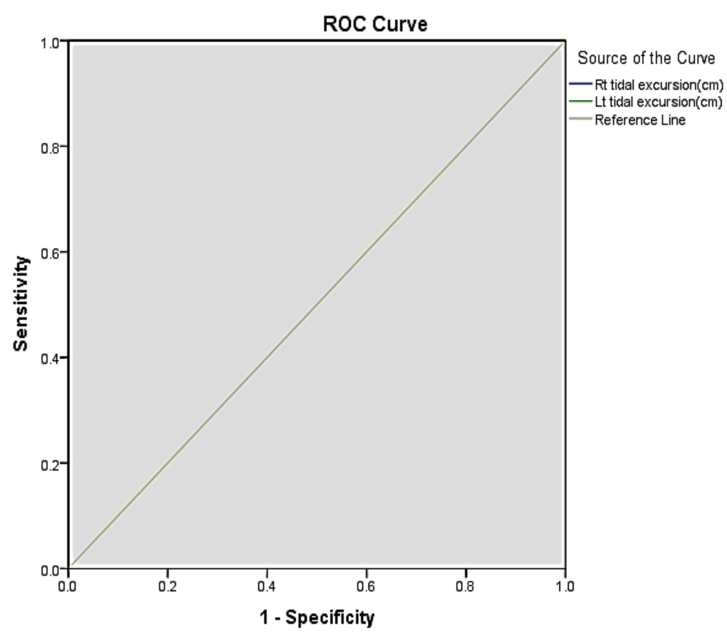

Figure (4): Prediction of the ability of diaphragm tidal excursion to differentiate between control and group E.

DISCUSSION

Ultrasound is a new tool for evaluating the efficiency of the respiratory muscles. Ultrasound imaging of the diaphragm is the first step in better detecting diaphragmatic dysfunction and creating a supportive and protective plan for its treatment [10]. Even a normal diaphragm might show signs of weakness, paralysis, impaired mobility, or loss of function. The diaphragm function excursion and thickness can be monitored using a variety of ultrasound methods, however one method does not preclude the other [11].

Portable ultrasound machines, which are safe, comparatively inexpensive, and available at bedside have become an indispensable instrument for evaluating the severity of COPD in chest outpatient clinics [12].

After comparing all subjects in the control group with those in the COPD group, researchers discovered a statistically significant difference in tidal excursion and peak excursion (P value < 0.005). The COPD group consisted of 60 patients, while the control group had 20. This is in agreement with **Scheibe *et al.*** [13] who reported that ultrasonographic technologies could potentially help evaluate diaphragmatic dysfunction in COPD patients. Similarly, **Paulin *et al.*** **[14]** discovered that diaphragmatic mobility was lower in the COPD group compared to the control group. When patients' diaphragmatic mobility was inadequate, their clinical condition deteriorated due to their increased dyspnea and shortened 6-minute walk distances. In contrast, **Baria *et al.*** [15] administered ultrasonographic diaphragmatic function tests to 150 healthy controls and 50 COPD patients. The control group and the COPD patients did not differ significantly with respect to diaphragmatic thickness and excursion. There was no analysis of diaphragmatic thickness in relation to clinical variables in this study.

There was a notable disparity in diaphragmatic tidal excursion (cm) and max excursion (cm) across all COPD subgroups and the control group, according to the study (p<0.001). The reason groups B and E exhibited more symptoms are explained by a notable decrease in the same parameter in those groups (P<0.001). This result agrees with **Paulin *et al.*** **[16]** who looked at COPD patients and discovered that diaphragmatic mobility was inversely related to dyspnea. This suggests that diaphragmatic shifts reduce respiratory capacity and heighten dyspnea by making ventilation more difficult.

In addition, **Abbas *et al.*** **[17]** using ultrasonography revealed a marked decrease in diaphragmatic excursion in comparison with healthy individuals. On the other hand, these results were against those of **Cohn *et al.*** **[18]** who claimed that diaphragmatic excursion was only related to body mass index (BMI) and failed to find any correlation between the two. Moreover, **Jain *et al.*** **[19]** reported that COPD patients exhibited more diaphragmatic movement compared to those in other studies.

It was determined that all COPD patients and the control group could be distinguished statistically using a battery of ultra-sonographic parameters. The sensitivity and specificity for differentiating between the COPD and control groups in relation to tidal excursion were 96% and 80% respectively and the maximum cutoff was 3.35 cm. The excursion was 6.5 cm and the sensitivity and specificity were 97% and 90%, respectively.

In group A, the cutoff points for tidal and maximum excursion were 3.0 and 6.05 respectively, with a sensitivity of 80% and specificity of 100% in this study. In group B, the cutoff points were 3.0 and 6.0 with a sensitivity of 100% and specificity of 100%. In-group E excursion, the cutoff points for tidal and max excursion were 3.35 and 7.5 respectively (with sensitivity and specificity both set at 100%).

Sarwal *et al.* [20] determined the diaphragm's excursion, girth, side-to-side fluctuation, and velocity where multiple approaches were used. As it pertains to this study, diaphragmatic atrophy was characterized as a diaphragm thickness below 0.2 cm at the conclusion of expiration.

CONCLUSION

To assess patients in outpatient clinics, TUS is a simple, noninvasive, and readily available diagnostic tool that can be done at the bedside. Diaphragmatic dysfunction and its relationship to severity in chronic obstructive pulmonary disease (COPD) patients could be found more accurately using this method. In order to get a better picture of the diaphragm in COPD patients, it is better to measure the fraction of diaphragmatic thickness rather than just diaphragmatic thickness, which are needed for measurement of diaphragmatic excursion and an evaluation of diaphragmatic function.

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