Role of transthoracic ultrasound in evaluating patients with chronic obstructive pulmonary disease

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Background Conventional ultrasound with frequencies ranging from 2 to 10 MHz is increasingly used for the diagnosis of pulmonary diseases including pneumothorax, pleural effusion, alveolar–interstitial syndrome, and lung consolidation. Transthoracic ultrasound (TTUS) can be useful in evaluating diaphragmatic function, air trapping, and A lines for the assessment of patients with chronic obstructive pulmonary disease (COPD) and differentiation from other mimicking conditions.

Aim This study was carried out to assess the role of TTUS in evaluating patients with COPD.

Patients and methods This was a prospective study carried out on 60 male participants: 40 of them were COPD patients (cases) and 20 were healthy individuals (controls). All cases were examined by TTUS B-mode, low-frequency and high-frequency transducer to detect the regularity of the pleura lines and the prominence of A lines, and all of them were examined by M-mode to assess diaphragmatic excursion.

Results There was a statistically significant difference with regard to irregularity of pleura lines and prominence of A lines between COPD and control groups with a *P* value less than 0.001. Regarding diaphragmatic excursion, there was a statistically significant difference between the two groups ($P<0.001$). A cut-off value of 2.95 cm for diaphragmatic excursion was assigned with 83.7% sensitivity and 70.6% specificity to differentiate mild and moderate COPD from severe and very severe cases.

Conclusion TTUS is a helpful tool for evaluating COPD patients and for assessing disease severity.

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Keywords: chronic obstructive pulmonary disease, diaphragmatic excursion, transthoracic ultrasound

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Introduction

Chronic obstructive pulmonary disease (COPD) is a common, preventable, and treatable disease characterized by persistent airflow limitation that is usually progressive and associated with an enhanced chronic inflammatory response in the airways and the lungs to noxious particles or gases. Exacerbations and comorbidities contribute to the overall severity in individual patients [1].

Transthoracic ultrasound (TTUS) is quick to perform, portable, repeatable, nonionizing, and independent of specific acoustic windows, and therefore suitable for a meaningful evaluation in many different settings, both inpatient and outpatient, in both acute and chronic conditions [2].

Conventional ultrasound with frequencies ranging from 2 to 10 MHz is increasingly used for the diagnosis of pulmonary diseases including pneumothorax, pleural effusion, alveolar–interstitial syndrome, and lung consolidation. However, its application is restricted to superficial examination and to abnormally dense lungs [3].

Many studies have been carried out to evaluate chronic obstructive lung disease by ultrasonography through observation of diaphragmatic function, air trapping, and A lines for the assessment of patients with COPD and differentiation from other mimicking conditions [4].

Aim

This study was carried out to assess the role of TTUS in evaluating patients with COPD.

Patients and methods

This prospective study was conducted at the Chest Department of Kasr El-Aini Hospital, Cairo University, in the interval between February 2015 and March 2016. The study included 60 male participants: 40 of them were COPD patients who were diagnosed on the basis of postbronchodilator pulmonary function test together with 20 healthy individuals as controls. COPD patients included in the study were all diagnosed by clinical examination together with spirometry (Forced expiratory volume in the first second (FEV1)/Forced vital capacity

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(FVC)<70%). The controls had normal pulmonary function tests. Patients with clinical or radiographic evidence of other chest diseases apart from COPD were excluded from our study. On M-mode, the distances between the probe and the copula during full inspiration and resting expiration were measured, and the difference between the two distances was equal to the diaphragmatic excursion range (Fig. 1).

All patients were subjected to the following:

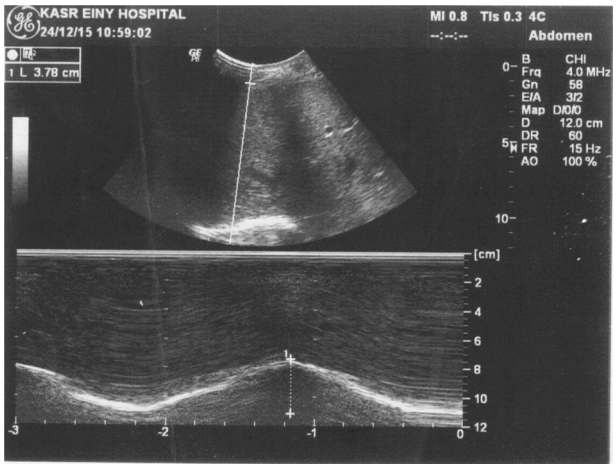
(1) Complete history assessment and clinical examination.
(2) Posteroanterior chest radiography.
(3) Spirometric assessment: COPD patients were classified according to postbronchodilator FEV1 into mild, moderate, severe, and very severe cases, indicating the degree of airflow limitation [5].
(4) Measurement of oxygen saturation through arterial blood sample.
(5) COPD assessment test: this is an eight-item, one-dimensional measure of health status in COPD patients [6].
(6) TTUS.

COPD patients were further divided according to Global Initiative for Chronic Obstructive Lung Disease (GOLD) classification for combined COPD assessment into low-risk patients (classes A and B) and high-risk patients (classes C and D) [7].

Transthoracic ultrasound technique

All cases were examined by B-mode, low-frequency and high-frequency transducer to detect the regularity of the pleura lines and the prominence of the A lines, and all of them were examined by M-mode to assess the diaphragmatic excursion.

Figure 1



Transthoracic ultrasound image showing assessment of diaphragmatic mobility.

B-mode, or brightness modulation, is the display of two-dimensional maps of B-mode data, and it is the most common form of ultrasound imaging. It is based on brightness with the absence of vertical spikes. Therefore, as the brightness depends upon the amplitude or intensity of the echocardiograph using the B-mode, we were able to detect pleura lines, whether they were regular or not, and check the prominence of A lines.

On the other hand, M-mode, or motion mode, is the display of a one-dimensional image that is used for analyzing moving body parts [8]. This can be accomplished by recording the amplitude and rate of motion in real time by repeatedly measuring the distance of the object from the single transducer at a given moment. The single sound beam is transmitted and the reflected echoes are displayed as dots of varying intensities, thus creating lines across the screen. Therefore, B-mode can measure diaphragmatic thickness, but M-mode measures the movement of the diaphragm.

Patients were allowed to rest in the supine position on a firm surface, exposing the chest and abdomen. A curvilinear transducer was placed on the right subcostal angle to determine diaphragmatic excursion, which ranged between deep inspiration up to the level of Total lung capacity (TLC) and resting expiration to the level of Functional residual capacity (FRC). Patients were scanned intercostally in the anterior axillary line with the ultrasound transducer (curvilinear array transducer 3.5 MHz) angled cranially, so as to have the diaphragm cranially as close as possible at 90° to the probe. The liver was used as a window. The M-mode line of sight was angled to obtain the maximum diaphragmatic excursion. M-mode was performed in conjugation with conventional B-mode ultrasound. Normal inspiratory diaphragmatic movement is caudal, with the corresponding M mode trace being upwards as the diaphragm moves toward the probe, the expiratory trace is downwards as the diaphragm moves away from the probe [9]. On M-mode, the distances between the probe and the copula during full inspiration and resting expiration were measured, and the difference between the two distances was equal to the diaphragmatic excursion range.

Statistical analyses

Data were coded and entered using the statistical package for the social science (SPSS, version 23; SPSS Inc., Chicago, Illinois, USA). Data were summarized using mean, SD, median, minimum, and maximum for quantitative data and using frequency (count) and relative frequency (%) for

categorical data. Comparisons between quantitative variables were carried out using the nonparametric Kruskal–Wallis and Mann–Whitney tests. For comparing categorical data, χ^2-test was performed. Exact test was used when the expected frequency was less than 5. Correlations between quantitative variables were obtained using the Spearman correlation coefficient [10]. *P* values of less than 0.05 were considered as statistically significant.

Results

This study was conducted at the Chest Department of Kasr El-Aini Hospital, Cairo University, during the interval between February 2015 and March 2016, in which 60 men were included. Participants were divided into two groups: the first group included 40 patients who were diagnosed as COPD patients using postbronchodilator spirometry, and the second group included 20 normal individuals.

All the COPD patients and control individuals were males, with age ranging between 42 and 75 years for COPD patients with a mean of 56.68±8.17 years. Patients in the control group had an age range between 41 and 71 years with a mean of 54.3±4.79 years. No statistically significant difference was detected with regard to mean age between the two groups (P=0.27).

There was a statistically significant difference between COPD patients and normal individuals with regard to oxygen saturation with a mean of 93.05±3.80 for COPD patients and a mean of 97.60±1.43 for normal individuals.

There was also a statistically significant difference between FEV1% and FEV1 and between COPD and normal individuals, which ranged between 40.00 and 69.00%, with a mean of 58.95±8.16%, for FEV1% in COPD patients and ranged between 70.00 and 83.00%, with a mean of 76.55±3.38%, for FEV1% in normal individuals, respectively. Moreover, for FEV1 in COPD, it ranged between 79.00 and 22.00%, with a mean of 50.97±13.31, and for normal individuals it ranged between 60.00 and 75.00%, with a mean of 66.25±3.73%.

Our study included 40 patients in group 1 diagnosed as COPD cases – 23 patients were moderate COPD cases based on their FEV1 results, 15 patients were diagnosed as severe COPD cases, and only two patients were diagnosed as very severe COPD cases; no mild cases were included.

There was a statistically significant difference between COPD and control individuals (P<0.001), with 18 patients classified as GOLD A,12 patients as GOLD B, three patients as GOLD C, and seven patients as GOLD D.

There was a statistically significant difference between pleura lines in COPD and control groups with *P* value less than 0.001, as only four patients showed regular pleura lines, whereas the rest of them showed irregular pleura lines; in contrast, all controls showed regular pleura lines. In addition, there was a statistically significant difference between COPD and control groups considering A lines: 60% of COPD patients showed prominent A lines, whereas 40% showed nonprominent A lines, and all the healthy individuals showed nonprominent A lines (P<0.001).Considering diaphragmatic excursion, there was a statistically significant difference between the two groups (P<0.001), with a mean of 3.00±0.94 for COPD patients and a mean of 4.77±1.07 for controls.

There was a significant negative correlation between GOLD staging of COPD patients and diaphragmatic excursion (P=0.003), with a correlation coefficient of −0.451, which reveals that progression of GOLD staging of COPD patients is associated with more decline in diaphragmatic excursion value. No significant correlation was found between GOLD staging with A lines or pleura lines (P=0.857 and 0.642, respectively).

There was a significant negative correlation between oxygen saturation and GOLD staging of COPD (P=0.047), with a correlation coefficient of 0.316, but there was no significant correlation between oxygen saturation with pleura lines, A lines, and diaphragmatic excursion with *P* values of 0.113, 0.48, and 0.332, respectively, and thus no relationship between oxygen saturation and ultrasonographic findings in COPD.

There was a statistically significant positive correlation between FEV1 and diaphragmatic excursion with a *P* value of 0.016. There were no mild cases of COPD in our study, and thus we analyzed moderate cases with diaphragmatic excursion that ranged between 2.10 and 6.00 cm, with a mean of 3.35±0.88 cm, severe cases with diaphragmatic excursion that ranged between 2.50 and 3.80 cm, with a mean of 2.43±0.82 cm, and very severe cases with diaphragmatic excursion that ranged between 0.90 and 3.70 cm, with a mean of 2.3 ±0.92 cm. This correlation highlights the linear

relationship between FEV1 and diaphragmatic excursion.

Using the data collected in our study, we were able to deduce a cut-off value for diaphragmatic excursion, helping us classify patients with COPD into mild and moderate cases on the one hand or severe and very severe cases on the other hand using receiver operating characteristic curve analysis. A cut-off value of 2.95 was assumed with a *P* value less than 0.001 (95% confidence interval: lower bound=0.755 and upper bound=0.950), 83.7% sensitivity, and 70.6% specificity; patients with values above this cut-off point were considered as mild or moderate cases and below it were considered as severe or very severe cases.

Using receiver operating characteristic curve analysis, we were also able to obtain a cut-off value using diaphragmatic excursion to differentiate between low-risk patients and high-risk patients (according to GOLD classification), which was 2.95 with a *P* value 0.021 (95% confidence interval: lower bound=0.550 and upper bound=0.943), 80% sensitivity, and 63.3% specificity. Any value above this cut-off point classified the patient into a low-risk category and any value below it classified the patient into a high-risk category.

Discussion

COPD patients suffer from diaphragmatic dysfunction. There are different causes for this – a mechanical disadvantage due to over-inflation of the lungs is the oldest known reason for diaphragmatic dysfunction in COPD patients. Remodeling, oxidative stress, and a reduction in myosin filaments due to reduced protein production and increased apoptosis of muscle cells are more recently recognized reasons for diaphragmatic weakness [11]. It is clinically important to know the functional condition of this structure, which is the most important respiratory muscle [12].

Many studies have been performed using M-mode ultrasound to assess diaphragmatic kinetics by many techniques in both diseased and healthy individuals. B-mode ultrasound has also been used in many studies to evaluate diaphragmatic thickness and excursion [13].

This study was conducted at the Chest Department of Kasr Al-Aini Hospital, Cairo University, in which 60 male patients were included. They were divided into two groups: the first group included 40 COPD patients, and the second group included 20 normal individuals. COPD patients had a mean age of 56.68 ±8.17 years, whereas healthy individuals had a mean age of 54.3±4.79 years (Table 1). The mean oxygen saturation in the COPD group was 93.05±3.80 compared with a mean oxygen saturation of 97.60 ±1.43 in the control group.

Spirometric measurements in our study included FEV1, FEV1%, FVC, and Maximum expiratory flow (MEF) 25–75. There was a statistically significant difference in all spirometric values between the COPD group and the control group (Table 1).

COPD patients in our study were classified as follows: 23 patients with moderate COPD, 15 patients with severe COPD, and two patients with very severe COPD. No cases of mild COPD were included (Table 2).

Our COPD patients were further classified according to GOLD classification for combined COPD assessment into low-risk patients (classes A and B) and high-risk patients (classes C and D) (Table 3).

Table 1 Demographic data of the chronic obstructive pulmonary disease patients and control individuals

	Group										
	COPD					Control					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	P value
Age	56.68	8.17	58.50	42.00	75.00	54.30	4.79	55.50	41.00	71.00	0.27
Smoking index/year pack	46.80	31.04	42.50	0.00	120.00	13.55	11.99	10.00	0.00	35.00	<0.001
Oxygen saturation in room air (%)	93.05	3.80	93.00	85.00	99.00	97.60	1.43	97.50	95.00	100.00	<0.001
FEV1%	58.95	8.16	59.50	40.00	69.00	76.55	3.38	76.00	70.00	83.00	<0.001
FEV1	50.97	13.31	50.50	22.00	79.00	66.25	3.73	65.50	60.00	75.00	<0.001
FVC	68.48	15.31	69.50	27.00	100.00	75.40	4.72	74.50	70.00	85.00	0.035
MEF 25–75	31.25	14.99	30.50	11.00	62.00	66.45	3.25	66.50	59.00	73.00	<0.001

COPD, chronic obstructive pulmonary disease.

TTUS in our study aimed at detecting regularity of pleura lines, prominence of A lines, and measuring the diaphragmatic excursion (Table 4). There were 36 (90%) COPD patients with irregular pleura lines and four (10%) patients with regular pleura lines; in contrast, all the controls showed regular pleura lines. Sperandeo *et al*. [14] noticed irregular pleura lines by TTUS in patients with pulmonary fibrosis where nearly 100% of his patients showed that sign. In addition, Buda *et al*. [15] obtained similar results to that of Sperandeo *et al*.'s [14] study. Light *et al*. [16] mentioned the presence of irregular pleura lines by TTUS in COPD patients having lung bullae; however, Lichtenstein [17] in his lung ultrasound study of critically ill patients noticed regular pleural lines in COPD patients.

Table 2 Classification of chronic obstructive pulmonary disease patients according to severity using FEV1

Classifications	Count [*n* (%)]
Mild COPD	0 (0.0)
Moderate COPD	23 (57.5)
Severe COPD	15 (37.5)
Very severe COPD	2 (5.0)

COPD, chronic obstructive pulmonary disease.

Table 3 Classification of chronic obstructive pulmonary disease patients according to Global Initiative for Chronic Obstructive Lung Disease staging

	COPD [count (%)]	Control [count (%)]	*P* value
Gold staging			
A (low risk, low symptoms)	18 (45.0)	0 (0.0)	<0.001
B (low risk, high symptoms)	12 (30.0)	0 (0.0)	
C (high risk, low symptoms)	3 (7.5)	0 (0.0)	
D (high risk, high symptoms)	7 (17.5)	0 (0.0)	

COPD, chronic obstructive pulmonary disease; GOLD, Global Initiative for Chronic Obstructive Lung Disease.

A lines that are seen in normal lungs may be more prominent in COPD lungs [4]. This finding was observed in our study and it was detected in 24 COPD patients (60% of the total COPD patients), whereas 16 (40%) patients did not show this finding. A statistical significance ($P<0.001$) was noticed between COPD patients and controls where none of them showed this sign. Lichtenstein and Mezière [18] commented on the A lines in COPD patients where predominant A lines plus lung sliding indicated obstructive lung disease with 89% sensitivity and 97% specificity. In another study, Zhou *et al*. [19] investigated the diagnostic accuracy of bedside lung ultrasound examination in patients with COPD and cardiac pulmonary edema. The A lines or horizontal lines arising from the pleural line showed a sensitivity of 81.30% and a specificity of 87.70%, with a positive predictive value of 78.80% and a negative predictive value of 89.30% in the diagnosis of COPD. On the other hand, radiographic examination showed a sensitivity of 65.50%, a specificity of 86.00%, a positive predictive value of 72.40%, and a negative predictive value of 81.70% in the diagnosis of COPD [19].

Using M-mode in TTUS, we were able to measure diaphragmatic excursion during deep inspiration up to the level of TLC and resting expiration at the level of FRC; we only measured the excursion at the right hemidiaphragm as the left hemidiaphragm has a smaller window due to the spleen, and it was frequently obscured by the expanding lung.

Our results revealed mean diaphragmatic excursion of 3.00±0.94 cm in the first group, whereas in the control

Table 4 Ultrasound findings (pleura lines, A lines, and diaphragmatic excursion) in chronic obstructive pulmonary disease patients and controls

	Groups										
	COPD					Control					
	Mean	SD	Median	Minimum	Maximum	Mean	SD	Median	Minimum	Maximum	*P* value
Excursion (cm)	3.00	0.94	3.00	0.90	6.00	4.77	1.07	4.70	3.30	7.30	<0.001
	COPD [count (%)]			Control [count (%)]		*P* value					
Pleura lines											
Regular	4 (10.0)			20 (100.0)		<0.001					
Irregular	36 (90.0)			0 (0.0)							
A lines											
Prominent	24 (60)			0 (0)		<0.001					
Nonprominent	16 (40)			20 (100)							

COPD, chronic obstructive pulmonary disease.

group the mean value was 4.77±1.07 cm, with a high statistically significant difference between the two groups ($P<0.001$).

Examinations of the diaphragm can be performed during quiet breathing, voluntary sniffing, and deep breathing [20].

In accordance with our findings, Dos Santos Yamaguti *et al.* [21] conducted TTUS assessment in 54 COPD patients with pulmonary hyperinflation and 20 healthy individuals. Patients were tested for pulmonary function, maximal respiratory pressures, and diaphragm mobility using ultrasound to measure the craniocaudal displacement of the left branch of the portal vein. COPD patients had less diaphragmatic mobility (36.5±10.9 mm) than healthy individuals (46.3±9.5 mm) ($P=0.001$) [21].

Paulin *et al.* [22] used the B-mode in TTUS to examine diaphragmatic excursion (indirectly through craniocaudal displacement of the portal vein). COPD patients presented lower diaphragmatic mobility compared with controls (36.27±10.96 vs. 46.33±9.46 mm), which is comparable with our study but we used M-mode ultrasonography instead of B-mode [22].

Using M-mode TTUS, Aka Aktürk *et al.* [23] included 76 COPD patients and 30 controls to assess diaphragmatic motion during tidal breathing and deep breathing. They found that diaphragmatic motion during tidal breathing was 2.21±0.56 cm in the control group and it was 1.65±0.66 cm in COPD patients. The difference was statistically significant. During deep breathing, the mean diaphragmatic excursion was 6.23±0.74 cm in the control group and 4.64±1.34 cm in COPD patients, which was also statistically significant [$P<0.001$) [23].

In contrast to the above findings, Gorman *et al.* [24] used M-mode ultrasound to compare 10 patients with severe COPD with 10 healthy controls, measuring diaphragm length and ability to shorten in the setting of hyperinflation. Despite noting that patients with COPD have a shorter diaphragm length at functional residual capacity, patients with COPD could not be differentiated from healthy controls on the basis of diaphragm excursion during tidal breathing. These findings could mostly be attributed to the small sample size used in the study [24].

According to our results, a statistically significant negative correlation ($P=0.003$) was detected between GOLD staging of COPD patients and diaphragmatic excursion as assessed by TTUS, but there was no significant correlation between prominence of A lines or irregularity of pleura lines with GOLD staging (Table 5).

Oancea *et al.* [25] proved the same correlation between GOLD staging and diaphragmatic dysfunction. He included 38 COPD patients, classified according to GOLD classification into B, C, and D, and 17 healthy controls. He noticed a significant decrease in diaphragmatic muscle thickness compared with healthy participants (7.81 mm control group vs. 7.35 mm COPD A, 6.21 mm COPD C, and 3.37 mm COPD D; $P=0.0314$). Our study also discussed this relationship but by measuring diaphragmatic excursion and not thickness and comparing it with the different COPD classes [25].

Table 5 Correlation between Global Initiative for Chronic Obstructive Lung Disease staging and pleura lines, A lines, and diaphragmatic excursion

	GOLD staging				
Excursion (cm)					
Correlation coefficient	–0.451				
P value	0.003				
N	40				
	GOLD staging [count (%)]				
	A (low risk, low symptoms)	B (low risk, high symptoms)	C (high risk, low symptoms)	D (high risk, high symptoms)	*P* value
Pleura lines					
Regular	1 (5.6)	2 (16.7)	0 (0.0)	1 (14.3)	0.642
Irregular	17 (94.4)	10 (83.3)	3 (100.0)	6 (85.7)	
A lines					
Prominent	6 (33)	8 (66)	3 (100)	7 (100)	0.857
Nonprominent	12 (67)	4 (34)	0 (0)	0 (0)	

GOLD, Global Initiative for Chronic Obstructive Lung Disease.

Table 6 Correlation between oxygen saturation and diaphragmatic excursion, Global Initiative for Chronic Obstructive Lung Disease staging, pleura lines, and A lines

	Oxygen saturation on room air (%)					
GOLD staging						
Correlation coefficient	–0.316					
P value	0.047					
N	40					
Excursion (cm)						
Correlation coefficient	0.160					
P value	0.323					
N	40					
	Oxygen saturation on room air (%)					
	Mean	SD	Median	Minimum	Maximum	*P* value
Pleura lines						
Regular	90.25	2.87	89.50	88.00	94.00	0.113
Irregular	93.36	3.79	93.50	85.00	99.00	
A lines						
Prominent	89.5	3.5	92.00	85.00	94.00	0.48
Nonprominent	94.50	4.5	95.00	90.00	99.00	

Oxygen saturation was estimated in both the studied groups; however, this parameter showed no statistical significance with any of our ultrasound findings including pleura line regularity, A lines, and diaphragmatic excursion (Table 6).

Scheibe *et al.* [26] also correlated oxygen saturation with diaphragmatic mobility and found a weak correlation between both parameters (r=0.13). Another study by Kang *et al.* [27] did not find a significant correlation between partial pressure of arterial oxygen and diaphragmatic mobility (r=0.028, P=0.873).

A statistically significant positive correlation was observed in our study between FEV1 and diaphragmatic excursion (P=0.016) (Table 7).

Dos Santos Yamaguti *et al.* [21] concluded that diaphragmatic mobility using B-mode ultrasound correlated moderately with airway obstruction (r=0.55, P<0.001). Patients in the moderate and severe obstruction subgroups had less diaphragmatic mobility (34.7±8.0 and 30.7±7.5 mm, respectively) compared with those in the mild obstruction subgroup (44.2±12.3 mm) (P<0.001) [21].

Kang *et al.* [27] assessed the mobility of the right hemidiaphragm by ultrasound measurement of the craniocaudal displacement of the left branch of the portal vein in B-mode. The mean value for diaphragmatic mobility was 19.8±7.5 mm. Diaphragmatic mobility correlated with FEV1 (r=0.415, P=0.011) [27].

Although we used M-mode for the assessment of diaphragmatic excursion, our results were, nevertheless, similar to the above two studies, which proved the presence of a strong correlation between FEV1 value and diaphragmatic mobility.

Scheibe *et al.* [26] used two methods to assess diaphragmatic excursion, which were the lung silhouette method and the anterior method. It was concluded that in the COPD GOLD II patient group the median distance of the upward and downward movement of the right hemidiaphragm measured with the lung silhouette method was 43 mm and that measured with the anterior method was 46 mm. In the COPD GOLD III patient group, the, respective, results were 30 and 37 mm, in the GOLD IV patient group 25 and 31 mm, and in the control group 65 and 68 mm, which were strongly correlated [26].

Baria *et al.* [28], on the other hand, studied diaphragmatic thickness rather than mobility using B-mode ultrasound in 50 patients with COPD and 150 healthy individuals. Measurements were taken at maximum inspiration and maximum expiration on both hemidiaphragms. They concluded that there was no significant difference in diaphragmatic thickness between COPD and healthy groups. These results denied the effect of FEV1 deterioration on diaphragmatic thickness.

The collected data in our study helped us in calculating a cut-off value using diaphragmatic excursion to classify COPD patients. Diaphragmatic excursion

Table 7 Correlation between FEV1 classification of chronic obstructive pulmonary disease and diaphragmatic excursion

	Excursion (cm)					
	Mean	SD	Median	Minimum	Maximum	*P* value
Classification						
Mild COPD	0	0	0	0	0	0.016
Moderate COPD	3.35	0.88	3.30	2.10	6.00	
Severe COPD	2.43	0.82	2.50	2.50	3.80	
Very severe COPD	2.3	0.92	2.3	0.90	3.70	

COPD, chronic obstructive pulmonary disease.

Table 8 Predictive value of diaphragmatic excursion for chronic obstructive pulmonary disease severity assessment

Area under curve	P value	95% confidence interval		Cut-off value	Sensitivity (%)	Specificity (%)
		Lower bound	Upper bound			
0.852	<0.001	0.755	0.950	2.95	83.7	70.6

Table 9 Predictive value of diaphragmatic excursion for Global Initiative for Chronic Obstructive Lung Disease classification into high-risk and low-risk patients

Area under curve	P value	95% confidence interval		Cut-off value	Sensitivity (%)	Specificity (%)
		Lower bound	Upper bound			
0.747	0.021	0.550	0.943	2.95	80	63.3

with a cut-off value of 2.95 cm was set to distinguish mild and moderate COPD from severe and very severe patients using M-mode TTUS with 83.7% sensitivity and 70.6% specificity (Table 8).

The same idea was used to set another cut-off value to differentiate low-risk COPD (GOLD stages A and B) patients from high-risk COPD (GOLD stages C and D) patients, with a diaphragmatic excursion of 2.95 cm with 80% sensitivity and 63.3% specificity (Table 9).

Excursion is the movement of the thoracic diaphragm during breathing. Normal diaphragmatic excursion should be 3–5 cm, but can be increased in well-conditioned persons to 7–8 cm. The normal range of motion from the resting expiratory position to full inspiration in adults has been reported to be in the range of 1.9 to as much as 9 cm, with higher values reported in deep breathing or sniffing [29]. Diaphragmatic weakness is indicated by less-than-normal amplitude of excursion on deep breathing with or without paradoxical motion on sniffing [30].

Sarwal *et al.* [31] evaluated many methods to evaluate the diaphragm, diaphragmatic excursion, thickness, side-to-side variation, and diaphragmatic velocity. In their study, they put used cut-off values to detect several parameters. A diaphragm thickness of less than 0.2 cm, measured at the end of expiration, was proposed as the cut-off value to define diaphragmatic atrophy [31].

Paulin *et al.* [22] used B-mode ultrasound to examine diaphragm excursion (indirectly through craniocaudal displacement of the portal vein) and they used a cut-off value of 34 mm; those with less motion covered less distance and had worse subjective dyspnea.

Kim *et al.* [32] observed a normal excursion of the male left diaphragm of 1.8 cm during quiet breathing and 7.5 cm during deep breathing. Normal diaphragmatic excursion was slightly less in women and greater on the right side compared with the left. In our study, a drawback is that we did not include female patients, as all studies showed increase in diaphragmatic excursion in males more than in females, and thus our finding are applicable only for assessing male COPD patients.

Numis *et al.* [33] searched for a cut-off point using diaphragmatic excursion to detect failure of noninvasive ventilation (NIV) in COPD patients. Diaphragmatic movements were assessed by ultrasonography before starting ventilation, at 6 and 24 h, and at weaning from NIV.

A high sensitivity rate (100%) was achieved with a specificity rate of 86.7% and a cut-off value of 3.165 cm for a decision of weaning from NIV.

We conclude that TTUS is a helpful tool for the evaluation of COPD patients and for the assessment

of disease severity. According to our results, a cut-off value of 2.95 cm for diaphragmatic excursion was assigned with 83.7% sensitivity and 70.6% specificity to differentiate mild and moderate COPD from severe and very severe cases.

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Conflicts of interest
There are no conflicts of interest.

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