Study of diaphragmatic mobility by chest ultrasound and echocardiographic changes in chronic obstructive pulmonary disease patients on different modes of mechanical ventilation

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Objective This study aimed to assess diaphragmatic mobility by chest ultrasonography and echocardiographic changes in mechanically ventilated chronic obstructive pulmonary disease patients on different modes of mechanical ventilation.

Patients and methods The present study was carried out on 50 mechanically ventilated chronic obstructive pulmonary disease patients. Chest ultrasonography for the assessment of diaphragmatic mobility in addition to echocardiography was performed on different modes of mechanical ventilation in the same session at any time since mechanical ventilation.

Results There was a highly statistically significant relation between diaphragmatic excursion and different modes of mechanical ventilation, where excursion increased significantly, with its peak at pressure-support ventilation (PSV). In terms of diaphragmatic thickness, the thickness of diaphragm decreased significantly at PSV. No significant correlation was detected between echocardiography in Ejection fraction, right ventricular systolic pressure, tricuspid annular plane systolic excursion, and different modes of mechanical ventilation.

Conclusion The best diaphragmatic mobility was on PSV, which improved lung volumes and ventilation, and may accelerate the weaning process. In addition, we concluded that the echocardiographic finding was not affected by different modes of mechanical ventilation.

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Keywords: chronic obstructive pulmonary disease, diaphragmatic excursion; dynamic hyperinflation, positive end-expiratory pressure, tricuspid annular plane systolic excursion

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Introduction

Airway obstruction, pulmonary hyperinflation, and air trapping, as pathological mechanisms of chronic obstructive pulmonary disease (COPD), might be involved in the process of impairment of diaphragmatic dysfunction [1]. Diaphragm dysfunction is one of the leading causes of prolonged mechanical ventilation and weaning failure [2]. Diaphragmatic assessment by chest ultrasound has gained popularity recently in the ICU [3]. Echocardiography is being used routinely in ICUs. It enables direct observation of all cardiac structures [4]. Diaphragmatic displacement measured by ultrasound is one of the most sensitive, specific, and accurate parameters for the assessment of COPD patients for weaning from mechanical ventilation [5].

Aim of the study

This study aimed to assess diaphragmatic mobility by chest ultrasonography and echocardiographic changes in mechanically ventilated COPD patients on different modes of ventilation.

Patients and methods

The present study was carried out on 50 mechanically ventilated COPD patients at Ain Shams University hospitals and Abbassia chest hospital respiratory ICU during the period between August 2016 and Jun 2018. Approved from ethical committee.

Inclusion criteria

All patients who fulfilled the diagnosis criteria of COPD and mechanically ventilated, 40 years of age or older, hemodynamically stable, and fully conscious were included.

Exclusion criteria

Intubation because of surgical or medical problems other than COPD, presence of ascites, colonic distension, lung collapse, fibrosis or pleural effusion, mass, or any mechanical factor in the chest or abdomen interfering with diaphragmatic mobility, patients with diaphragmatic paralysis or diaphragmatic hernia, patients with chest deformities that can affect diaphragmatic mobility such as kyphoscoliosis, patients with primary cardiac diseases (myocardial infarction, cardiomyopathy, pericardial effusion, etc.), unstable hemodynamics, and comatosed not oriented patients, and any patient with known neuromuscular disorder were excluded.

All the patients were subjected to an assessment of full history and a general, local examination, ECG, chest radiography anteroposterior view, routine laboratory investigations such as complete blood count, hepatorenal profile, electrolytes, and assessment of diaphragmatic mobility using baseline chest ultrasound and transthoracic echocardiography at different modes of mechanical ventilation in the same session at any time since mechanical ventilation using a Mindray M7 ultrasound device from Guangzhou Medsinglong Medical Equipment Co., China, Mainland Siemens SONOLINE G60 S system (Diasonic Electro Medical Birati, Kolkata, West Bengal).

Diaphragmatic excursion

Examination of the right diaphragmatic cupola was performed and the B mode was set as the default mode on the device screen. The right side was preferred because of the better sonographic view provided by the liver [6]. Examination was performed using a 3.5°C (bandwidth 2–5 MHz) convex phased array probe (a low-frequency probe with greater depth and enabling assessment of excursion) of ultrasound placed at the anterior axillary line, right subcostal, after the application of ultrasound gel, and was directed medially, cephalic, and dorsally using the liver as an acoustic window for a better view of the diaphragm. Then, a switch was made to the M-mode to observe diaphragmatic movement during inspiration and expiration during quiet breathing, and then the freeze button was pressed on ultrasound device. The difference between the diaphragmatic position during inspiration and expiration was determined and recorded as diaphragmatic excursion (DE).

Diaphragmatic thickness

An M12L linear array probe (bandwidth: 5–13 MHz) was placed at the anterior axillary line of the site of examination by probe of ultrasound put at intercostal space number 7 and intercostal space number 8, yielding an image showing the liver and the lung and a zone of apposition between them using the B mode. Both the pleural lining and the peritoneal lining appeared clearly as two approximately parallel echogenic lines. The space between them resembles diaphragmatic thickness.

Transthoracic echocardiography

A subcostal four-chamber view was preferred as all the patients were emphysematous. Examinations were performed using the available Doppler echocardiogram and a transducer array of 4-2 MHz.

Left ventricular systolic function

Ejection fraction was assessed by M-mode, 2-D techniques in the left parasternal short-axis and long-axis views. Computer software on the echo machine was used to provide a quantitative assessment of left ventricular function. Ejection fraction is normally greater than or equal to 55% and it is mild abnormal when it is from 45 to 54%, moderate (30–44%), severe (<30%) [7].

Right ventricular size

This was assessed by measurement of the right internal mid cavity dimension. It was measured in the apical four-view. The right internal mid cavity dimension is normally less than 34 mm [8].

Tricuspid annular plane systolic excursion

Tricuspid annular plane systolic excursion (TAPSE) was assessed by placing the M-mode cursor on the lateral tricuspid annulus. The maximum plane systolic excursion of the lateral annulus was calculated. TAPSE is normally greater than 1.6 cm [8].

Assessment of the severity of tricusped regurge (TR) was performed by:

Color flow Doppler:

(1) Color flow imaging was performed by visualization of retrograde systolic flow from the right ventricle to the right atrium.
(2) Rapid estimation of TR severity was performed as the larger the jet, the more significant the TR.
(3) TR severity was classified according to the Relative TR Jet Area (Jet Area over Right atrium RA):
    (a) Mild TR: jet area (JA)/RA area <20%.
    (b) Moderate TR: JA/RA area 20–40%.
    (c) Severe TR: JA/RA area >40% [9].

Continuous wave Doppler

Continuous wave Doppler examination was performed in views where parallel alignment with the regurgitant jet was possible and was color Doppler-guided. Qualitative estimation of TR severity was performed on the basis of the shape and density of the signal. The denser the envelope compared with the forward flow, the more severe the TR.

Right ventricular systolic pressure

(1) Right ventricular systolic pressure (RVSP) was estimated on the basis of the modified Bernoulli equation and was considered to be equal to the sPAP.

(2) RVSP=transtricuspid pressure gradient+right atrial pressure.
(3) Transtricuspid gradient is $4v^2$ (v=peak velocity of tricuspid regurgitation, m/s).
(4) Right atrial pressure was estimated from the end-expiratory diameter of the inferior vena cava. A mild increase in RVSP ranges from 35 to 49 mmHg, moderate RVSP ranges from 50 to 60 mmHg, and severe RVSP greater than 60 mmHg [10].

Statistical methodology

Data were collected, revised, coded, and entered into the statistical package for the social sciences (SPSS; SPSS Inc., Chicago, Illinois, USA) version 23. Quantitative data with a normal distribution were presented as means, SD, and ranges and compared between two groups using an independent *t*-test, whereas more than two groups were compared using the one-way analysis of variance test. Also, the qualitative data were presented as numbers and percentages and compared between groups using the χ^2-test. The confidence interval was set to 95% and the margin of error accepted was set to 5%. Therefore, the *P* value was considered significant at the level of less than 0.05 [11].

Results

The populations studied were men, ranging in age from 44 to 79 years, with a mean±SD age of 58.68±6.69 years; 64% were manual workers, and had a history of smoking and comorbidities (Table 1). There was a highly statistically significant relation between volume control (VC) and pressure control (PC) in DE, where excursion increased in PC; there was also a highly significant relation between them in diaphragmatic thickness, where the thickness increased in VC. There was a highly statistically significant relation between VC and synchronized intermittent mandatory ventilation (SIMV) in DE, where excursion increased in SIMV; there was also a highly significant relation between them in diaphragmatic thickness, where thickness increased in VC. There was a highly significant relation between VC and pressure-support ventilation (PSV) in DE, where excursion increased significantly in PSV; there was also a highly significant relation between them in diaphragmatic thickness, where the thickness increased in VC. There was a statistically significant relation between pressure control ventilation (PCV) and SIMV in DE, where excursion increased in PCV, but there was a nonsignificant relation between them in diaphragmatic thickness. There was a highly statistically significant relation between PCV and PSV in DE, where excursion increased significantly in PSV, but there was a nonsignificant relation between them in diaphragmatic thickness. There was a highly significant relation between SIMV and PSV in DE, where excursion increased in PSV, but there was a nonsignificant relation between them in diaphragmatic thickness (Table 2). No significant correlation was detected between echocardiography in ejection fraction, RVSP, TAPSE, and different modes of mechanical ventilation (Table 3).

Table 1 Smoking history and co-morbidity among the studied group

	N=50 [*n* (%)]
Number of packs per day	
1 pack	24 (48.0)
2 packs	26 (52.0)
Duration (years)	
Mean±SD	30.26±7.94
Range	20–50
Smoking index	
Mean±SD	43.04±15.37
Range	20–80
Co-morbidity	
HTN	11 (22.0)
DM	4 (8.0)
HTN and DM	13 (26.0)
ISHD	4 (8.0)
Others (renal, liver)	15 (30.0)
NO	3 (6.0)
Range	1–6

DM, diabetes mellitus; HTN, hypertension; ISHD, ischemic heart disease.

Discussion

Management of dynamic hyperinflation at bedside is very difficult in COPD patients because the disease may not have a reversible component [12]. In patients on controlled MV, there is severe diaphragmatic dysfunction and atrophy, and, for this reason, attempts should be made for the patient to early initiate with spontaneous breathings, adjusting the work of breathing [13]. When weaning is difficult or there is refractory hypoxemia that cannot be explained by lung disease alone, echocardiography can yield cardiac morphological and functional analyses that may influence weaning [14]. The present study was carried out on fifty mechanically ventilated COPD patients by assessment of DE and thickness using chest ultrasound at different modes of mechanical ventilation (VC, PC, SIMV, and PS) and assessment of end diastolic volume, ejection fraction, and right-sided systolic pressure using transthoracic echocardiography at different modes of mechanical

Table 2 Relation between diaphragmatic mobility and diaphragmatic thickness with different modes of mechanical ventilation

	VC-assisted mode (*n*=50)	PC-assisted mode (BIPAP) (*n*=50)	SIMV mode (*n*=50)	Pressure-support mode (*n*=50)	Test value	*P* value	Significance
DE (cm)							
Mean±SD	2.17±0.33	2.53±0.41	2.38±0.31	2.97±0.25	52.517••	0.000	HS
Range	1.5–2.8	1.9–3.1	1.9–3	2.4–3.9			
DTF %							
Mean±SD	27.64±5.62	24.20±5.13	22.92±4.37	22.92±4.37	10.348••	0.000	HS
Range	15–35	10–29	12–28	12–28			
Post-hoc analysis using the LSD test							
Variables	VC vs. PC	VC vs. SIMV	VC vs. PS	PC vs. SIMV	PC vs. PS	SIMV vs. PS	
DE (cm)	0.000	0.002	0.000	0.024	0.000	0.000	
DTF %	0.001	0.000	0.000	0.193	0.193	1.000	

DE, diaphragmatic excursion; DTF, diaphragmatic thickness fraction; PC, pressure control; PS, pressure support; SIMV, synchronized intermittent mandatory ventilation; VC, volume control. $P>0.05$, nonsignificant. $P<0.05$, significant. $P<0.01$, highly significant. ••One-way analysis of variance test.

Table 3 Relation between echocardiography and different modes of mechanical ventilation

	VC-assisted mode (*n*=50)	PC-assisted mode (BIPAP) (*n*=50)	SIMV mode (*n*=50)	Pressure-support mode (*n*=50)	Test value	*P* value	Significance
EF %							
Mean±SD	59.34±6.99	58.98±5.74	59.72±6.01	59.22±6.94	0.115••	0.951	NS
Range	48–74	50–72	49–73	49–74			
LVDs (mm)							
Mean±SD	35.63±6.79	35.47±7.18	35.63±6.79	35.63±6.79	0.007••	0.999	NS
Range	22–46.5	15–46.5	22–46.5	22–46.5			
LVDd (mm)							
Mean±SD	55.25±6.72	55.25±6.72	55.25±6.72	55.25±6.72	0.000••	1.000	NS
Range	37.5–67.4	37.5–67.4	37.5–67.4	37.5–67.4			
TR [*n* (%)]							
No TR	2 (4.0)	2 (4.0)	2 (4.0)	2 (4.0)	0.000*	1.000	NS
Minimal	10 (20.0)	10 (20.0)	10 (20.0)	10 (20.0)			
Mild	11 (22.0)	11 (22.0)	11 (22.0)	11 (22.0)			
Moderate	16 (32.0)	16 (32.0)	16 (32.0)	16 (32.0)			
Severe	11 (22.0%)	11 (22.0)	11 (22.0)	11 (22.0)			
RVSP (mmHg)							
Mean±SD	34.98±10.55	36.84±10.03	35.72±10.03	35.04±10.32	0.357••	0.784	NS
Range	16–65	20–65	19–65	20–64			
TAPSE (cm)							
Mean±SD	2.54±0.39	2.62±0.36	2.53±0.38	2.51±0.35	0.959••	0.413	NS
Range	1.8–3.8	1.8–3.8	1.8–3.8	1.8–3.78			

EF, ejection fraction; LVDd, left ventricular diameter in diastole; LVDs, left ventricular diameter in systole; RVSP, right ventricular systolic pressure; TAPSE, tricuspid annular plane systolic excursion; TR, tricuspid regurge. $P>0.05$, nonsignificant. $P<0.05$, significant. $P<0.01$, highly significant. *χ^2-test. ••One-way analysis of variance test.

ventilation (VC, PC, SIMV, and PS). Examinations were performed by the same operator using the same devices of ultrasonography. The majority of patients in this study were men, which may be related to smoking habits. This was in agreement with (GOLD 2015), as in their study, there was a predominance of male COPD patients, and with ElWahsh *et al.* [15] and also with Helala *et al.* [16], who found that the majority of COPD patients (97.4%) were men. This study showed that the patients' age ranged from 44 to 79 years, with a mean age of 58.68±6.69 years. A similar study was carried out by El-Shabrawy *et al.* [17]; the mean age of COPD patients in their study was 56.97 ±5.22 years. There was a statistically significant change in diaphragmatic thickness fraction, where the thickness of the diaphragm decreased significantly at PSV. This was in agreement with Umbrello *et al.* [18], who found that there was a highly statistically significant change in diaphragmatic thickness fraction, where the thickness of the diaphragm decreased with increasing ventilator support. This was also in agreement with the study of Emmanuel *et al.* [19], which assessed twelve patients during spontaneous breathing; it was found that there was a highly statistically significant change in the diaphragmatic thickness fraction, where the thickness fraction of the diaphragm decreased with increasing ventilator support. In contrast, Shereen and Ali [20] found that in terms of ultrasound diaphragmatic parameters, the diaphragmatic thickness fraction was significantly higher at pressure support of mechanical ventilation and this difference may be because of the difference in the number of days of mechanical ventilation, the age of the patients, and the degree to which the airways were affected in terms of spirometric findings. This study showed a significant change in DE and different modes of mechanical ventilation, where excursion increased significantly, with its peak at PSV. This was in agreement with Shereen and Ali [20], who found that in terms of ultrasound diaphragmatic parameters, DE was significantly higher at pressure support of mechanical ventilation. Our results may explain the results of Esteban *et al*. [21], who found that spontaneous breathing led to quicker extubation than intermittent mandatory ventilation and PSV. This also was in agreement with the MacIntyre [22] study, which found that PSV improves patient comfort, reduces the patient's ventilatory work, and provides a more balanced pressure. Also, Hurst *et al*. [23] found that PSV improves lung volumes and ventilation, and may expedite the weaning process. Brochard *et al*. [24] found that patients on pressure support had an optimal level of pressure identified as the lowest level maintaining diaphragmatic activity without fatigue. This was in contrast to Umbrello *et al*. [18], who found that there was no statistically significant change in DE with increasing ventilator support; this difference may have arisen because patients with airflow obstruction were excluded and patients admitted to the ICU after major elective surgery were included in their study. This study showed that there was an insignificant correlation between echocardiography in ejection fraction, RVSP, TAPSE, and different modes of mechanical ventilation.This was in agreement with Luciele *et al*. [25] and Alexandre *et al*. [26], who found that no echocardiographic differences were observed between PSV and T-tube. Our results are in contrast to those of Caille *et al*. [27], who found that a spontaneous breathing trial induced changes in central hemodynamics and enables identification of patients at high risk of cardiac-related weaning failure when documenting a depressed left ventricular ejection fraction. Also, this was in contrast to Cabello *et al*. [28], who found that PSV markedly modified the breathing pattern, inspiratory muscle effort, and cardiovascular response compared with the T-piece; this difference may have emerged because a Swan–Ganz catheter was used in the cabello study on different levels of pressure support.

Conclusion

The best diaphragmatic mobility was found on PSV, where improved lung volumes and ventilation were observed, and may have also led to expediting of the weaning process. In addition, we concluded that the echocardiographic finding was not affected by different modes of mechanical ventilation.

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Conflicts of interest

There are no conflicts of interest.

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