Role of ultrasound in assessment of diaphragmatic function in chronic obstructive pulmonary disease patients during weaning from mechanical ventilation

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Objectives The aim of the study was to investigate the role of ultrasound in the evaluation of movement of the diaphragm and its value in predicting successful extubation in mechanically ventilated chronic obstructive pulmonary disease (COPD) patients in relation to other weaning parameters.

Introduction Chest ultrasound is a beneficial tool for evaluation of the diaphragm during weaning from mechanical ventilation in COPD patients. Chest ultrasound offers some advantages over fluoroscopy, including the lack of ionizing radiation and the possibility of use at the bedside of the patient, as well as facilitating direct quantification of the movement of the diaphragm.

Patients and methods The present study was conducted on 50 patients in the respiratory ICU and the Chest Department of Ain Shams University Hospitals. Patients were divided into two groups: group A and group B. Group A consisted of 30 mechanically ventilated COPD patients admitted to the respiratory ICU and group B consisted of 20 COPD patients not mechanically ventilated during attendance at the Chest Department.

Results Diaphragmatic movement was assessed in the two groups. The mean value of diaphragmatic displacement was higher in group B. In group A this value was higher among those with successful weaning using a cutoff value of 1.1 cm with sensitivity of 86.4%, specificity of 87.5%, and accuracy of 89.5%. There was a significant correlation between diaphragmatic displacement and other weaning parameters, which was better in the group with successful weaning.

Conclusion Diaphragmatic displacement measured by ultrasound is one of the most sensitive, specific, and accurate parameters for weaning of COPD patients from mechanical ventilation, especially in relationship with other weaning parameters.
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Keywords: chronic obstructive pulmonary disease, diaphragm, mechanical ventilation, ultrasound, weaning

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Introduction

Chronic obstructive pulmonary disease (COPD), the fourth leading cause of death in the world, represents an important public health challenge that is both preventable and treatable [1].

Ultrasound receives increasing recognition as a fast, easy, and accurate method of noninvasively evaluating diaphragmatic function at the bedside. In the ICU population, it can quantify normal and abnormal movements in a variety of clinical conditions [2].

Extubation failure is one of the most frequently encountered events in the management of patients receiving mechanical ventilation: as many as 20% of such patients require reintubation within 72 h of extubation. A failed extubation attempt substantially prolongs the duration of mechanical ventilation and ICU stay, and results in increased risk for hospital mortality [3].

Various weaning parameters have been suggested to be useful, such as rapid shallow breathing index (RSBI), maximum inspiratory pressure (PI max), spontaneous tidal volume (VT), and transdiaphragmatic pressure. However, the prediction rate of these parameters may not be satisfactory [4].

Evaluating the strength of the respiratory muscles becomes important, as the imbalance between respiratory demand and supply will lead to weaning failure through the development of respiratory muscle fatigue [5].

The diaphragm is a fundamental respiratory muscle whose dysfunction may be very common in patients undergoing mechanical ventilation. Diaphragm dysfunction is associated with prolonged mechanical ventilation and weaning failure [6].

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The diagnostic tools traditionally used to study diaphragm dysfunction, such as fluoroscopy, phrenic nerve conduction study, and transdiaphragmatic pressure measurement, present some limitations and disadvantages, including the use of ionizing radiation, low availability, invasiveness, and the need for patient transportation and skilled or specifically trained operators. Recently, ultrasound has been used to evaluate diaphragmatic function. Advantages of ultrasound include safety, avoidance of radiation hazards, and availability at the bedside [7].

The objective of this work was to study the role of ultrasound in the evaluation of movement of the diaphragm and its value in predicting successful extubation in mechanically ventilated COPD patients in relation to other weaning parameters.

Patients and methods

The present study was a prospective observational study approved by the institutional ethics committee. The study was conducted on 50 patients in the respiratory ICU and Chest Department of Ain Shams University Hospitals from November 2012 to October 2014. Patients were divided into two groups: group A and group B. Group A consisted of 30 mechanically ventilated COPD patients admitted to the respiratory ICU and group B consisted of 20 COPD patients not mechanically ventilated during attendance at the Chest Department.

Intubated patients receiving mechanical ventilation in the RICU were evaluated for their eligibility to enter this study. Only patients who were prepared for extubation after spontaneous breathing trials were evaluated. The decision for extubation was made by the attending physicians according to the clinical condition, weaning parameters, and results of the spontaneous breathing trials of the patients. The attending physicians were blinded to the results of ultrasound measurements. Failure of weaning was considered if the patient was reventilated again within 48 h.

Spontaneous breathing trial tolerance

(1) No symptoms of distress, such as chest pain, shortness of breath, agitation, anxiety, or diaphoresis.
(2) No signs of distress, such as respiratory rate greater than 35 for more than 5 min, SpO_2 less than 90% for 30 s, heart rate greater than 140 beats/min, or change of plus or minus 20% ($\Delta \pm 20\%$) of baseline for greater than 5 min, and systolic blood pressure greater than 180 or less than 90 for more than 5 min.

All groups were subjected to the following:

(1) Full medical history taking.
(2) Clinical examination.
(3) Chest radiography.
(4) Spirometry for group B only.
(5) Chest ultrasound to assess diaphragmatic function (diaphragmatic displacement) during the period of weaning in group A and during attendance at the Chest Department for group B.
(6) Measurement of minute ventilation, respiratory rate, VT, RSBI [respiratory rate divided by VT (*f*/VT)], and PI max in group A during the period of weaning.

Exclusion criteria

(1) Unstable hemodynamics, disturbed conscious level.
(2) Uncontrolled comorbid disease affecting weaning.
(3) Intubation due to surgical or other medical problem other than COPD.
(4) 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.

Chest ultrasound examination methodology

(1) Mindray DP 1100 ultrasound machine with double probe was used for examination of the patients during the spontaneous breathing trial.
(2) Examination was carried out using a 3.5C (bandwidth 2–5 MHz) convex phased array probe (low-frequency probe with greater depth and allowing assessment of excursion).
(3) Patient position: The patient was in the supine position and the transducer was on the anterior subcostal abdominal wall at the midclavicular line operating a transverse scanning with cranial direction to display the best imaging of the hemidiaphragmatic dome in B-mode imaging.
(4) A fixed point was taken on the outer surface (point A) and the distance from this point to the diaphragm (point B) was measured during inspiration and expiration (Fig. 1). The diaphragmatic displacement was calculated by extracting the distance between both. This was done three to five times and the mean value was calculated.

Statistical methodology

The collected data were revised, coded, tabulated, and introduced into a PC using the Statistical Package for Social Science (SPSS 17).

Description of quantitative variables as mean, SD, and range.

Description of qualitative variables as number and percentage.

The χ^2-test was used to compare qualitative variables between groups.

The unpaired *t*-test was used to compare quantitative variables in parametric data (SD<50% mean).

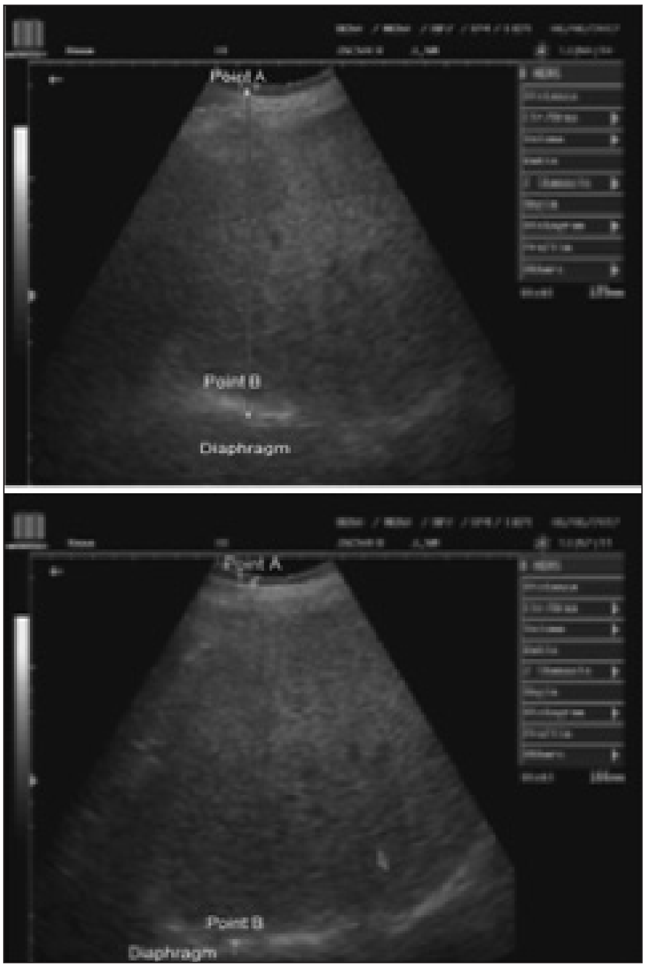
The receiver operator characteristic curve was used to find out the best cutoff value and the validity of certain variables.

The sensitivity and specificity of weaning parameters were calculated; *P*-values less than 0.05 were considered statistically significant.

Results

The present study was conducted on 50 patients: on 30 mechanically ventilated COPD patients admitted to the respiratory ICU and 20 COPD patients not mechanically ventilated during attendance at the Chest Department (Tables 1–9 and Fig. 2).

Fig. 1



Diaphragmatic movement during inspiration and expiration.

Discussion

COPD is a major cause of chronic morbidity and mortality throughout the world; many people suffer from this disease for years, and die prematurely from it or from its complications. Globally, the COPD burden is projected to increase in coming decades because of continued exposure to COPD risk factors and aging of the population [1].

COPD is one of the classical causes of the imbalance between the ventilatory demands and the

Table 1 Comparison between group A and group B in terms of age

Age (years)	Group A (*N* = 30)	Group B (*N* = 20)	*t*	*P*-value
Mean ± SD	59 ± 6	56.2 ± 7.1	1.3	0.18

Table 2 Comparison between successful and failed weaning groups as regards age

Age (years)	SW (*N* = 21)	FW (*N* = 9)	*t*	*P*-value
Mean ± SD	56.4 ± 7	59 ± 6.5	1.3	0.17

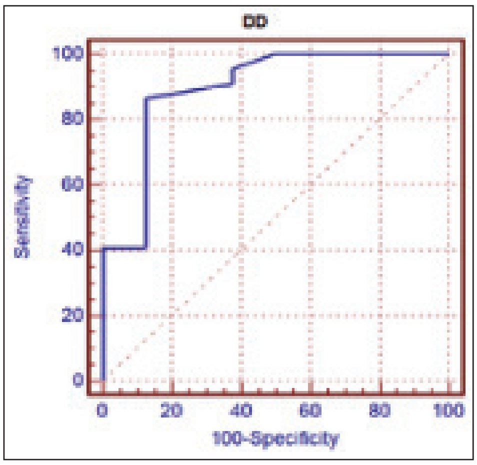
FW, failed weaning; SW, successful weaning.

Table 3 Comparison between successful and failed weaning groups as regards the number of comorbidities

No of comorbidities	Fate		
	SW [*N* (%)]	FW [*N* (%)]	Total [*N* (%)]
0	6 (27.3)	1 (12.5)	7 (23.33)
1	7 (31.8)	2 (25.00)	9 (30.00)
2	6 (27.3)	3 (37.5)	9 (30.00)
3	3 (13.6)	2 (25.00)	5 (16.66)
Total	22 (100.00)	8 (100.00)	30 (100.00)
χ^2-Test			
χ^2		29.3	
P-value		<0.001	

FW, failed weaning; SW, successful weaning.

Fig. 2



Sensitivity and specificity of diaphragmatic displacement (receiver operator characteristic curve).

cardioneurorespiratory capacity that eventually leads to muscle fatigue, hypercapnia, and finally weaning failure; this imbalance is in part related to respiratory muscle weakness, which is due to acidosis, hypercapnia, malnutrition, and steroid therapy (if present), and more importantly the mechanical disadvantage that is created by hyperinflation of the lungs, making the fibers of the inspiratory muscles act at unfavorable fiber length (shorter than the optimal length), thus decreasing the tension generated [5].

The diaphragm is the major respiratory muscle, contributing to 75% of resting lung ventilation, with an excursion of 1–2 cm. During forced breathing, its excursion reaches 7–11 cm, variable with individual characteristics and methods [8].

Ultrasonography has been shown to be a promising tool in the evaluation of diaphragm function and in predicting extubation failure through evaluation of diaphragmatic mobility [9].

In the present study, the mean age of the patients was 59 ± 6 in group A and 56.2 ± 7.1 in group B.

As regards group A, the number of patients with successful weaning was 22 out of 30 patients (73.3%), whereas the number of patients with failed weaning was eight out of 30 patients (26.7%).

In the present study, patients with multiple comorbid diseases were associated with a high rate of weaning failure.

Ongel *et al.* [10], who studied the effect of COPD comorbidities in the ICU outcome of COPD patients, reported that patients with multiple comorbidities, especially cardiac comorbidities, had a higher risk of mechanical ventilation and failure of weaning, with higher rates of mortality.

In the present study, the mean number of days of mechanical ventilation in the group of successfully weaned patients was 5.7 days, whereas the mean number of days of mechanical ventilation in the group with failed weaning was 11.4 days. This revealed that, the longer the duration of mechanical ventilation, the more difficult it is to wean the patients from mechanical ventilation, with a high incidence of weaning failure. This may be attributed to patient dependence on the ventilator, the respiratory muscles weakness that is associated with undernutrition in the ICU, and the use of systemic steroids in COPD patients.

In the present study, the mean value of PI max in the group with successful weaning was better (more negative) than the mean value in the group with failed weaning, revealing the ability of the respiratory muscles of the group with successful weaning to create more negative pressure than the group with failed weaning. However, PI max still needs a cooperative patient and maximal respiratory effort other than diaphragmatic displacement measured in quiet breathing [6].

Table 4 Comparison between groups with successful weaning and those with failed weaning as regards days of mechanical ventilation

Groups	Days of mechanical ventilation		*t*-Test	
	Range	Mean ± SD	*t*	*P*-value
Successful weaning	3–13	5.77 ± 2.79	3.78	0.001
Failed weaning	7–15	11.44 ± 3.186		

Table 5 Comparison between group A and group B regard diaphragmatic displacement

Groups	Diaphragmatic displacement (cm)		*t*-Test	
	Range	Mean ± SD	*t*	*P*-value
Group A	0.8–2	1.33 ± 0.32	−4.19	<0.001
Group B	1.17–2.1	1.67 ± 0.4		

Table 6 Comparison between groups with successful weaning and those with failed weaning as regards diaphragmatic displacement

Groups	Diaphragmatic displacement (cm)		*t*-Test	
	Range	Mean ± SD	*t*	*P*-value
Successful weaning	1.14–2	1.4 ± 0.26	3.6	<0.001
Failed weaning	0.8–1.34	1.05 ± 0.22		

Table 7 Validity of different parameters in prediction of weaning status

Variables	DD (cm)	RSBI (breaths/min/l)	VT (ml)	PI max (cmH_2O)	VE (l/min)	PaO_2/FiO_2
Best cutoff value	>1.1	<105	>300	<−20	9.8	283
Area under the curve	0.895	0.85	0.846	0.724	0.673	0.528
Sensitivity	86.4%	88.7%	85.6%	82.5%	54.5	77.3%
Specificity	87.5%	73.2%	75%	62.6%	87.5	50%
PPV	95%	78.5%	90.5%	86.3%	92.3	81%
NPV	70%	91.3%	66.7%	66.5%	41.2	44.4%
Accuracy	89.5%	85%	84.6%	72.4%	67.3	52.8%

DD, diaphragmatic displacement; NPV, negative predictive value; PI max, maximum inspiratory pressure; PPV, positive predictive value; RSBI, rapid shallow breathing index; VE, minute ventilation; VT, tidal volume.

Table 8 Relationship between diaphragmatic displacement and other parameters

Variables	Diaphragmatic displacement	
	r	*P*-value
Age	−0.667	<0.001
Days of mechanical ventilation	−0.566	0.001
Maximum inspiratory pressure	−0.664	<0.001
Rapid shallow breathing index	−0.675	0.000
Tidal volume	0.501	0.005
Minute ventilation	−0.249	0.185
PaO_2/FiO_2 ratio	0.502	0.005
Peak pressure	−0.297	0.111

Table 9 Comparison of the different parameters between groups with successful weaning and those with failed weaning

Variables	SW	FW
Diaphragmatic displacement (cm)	1.4 ± 0.26	1.05 ± 0.22
RSBI (breaths/min/l)	91 ± 10	123.6 ± 15
Tidal volume (ml)	448 ± 144	286.6 ± 47
Maximum inspiratory pressure (cmH_2O)	−33 ± 9.57	−21.6 ± 13
Minute ventilation (l/min)	9.155 ± 0.83	11.038 ± 0.686
PaO_2/FiO_2 ratio	313.7 ± 39	221 ± 21
Peak pressure (cmH_2O)	31 ± 8	38 ± 7

FW, failed weaning; RSBI, rapid shallow breathing index; SW, successful weaning.

In contrast, Mabrouk *et al.* [11], who evaluated some predictors for successful weaning from mechanical ventilation using different weaning modes, found no significant difference between the two groups as regards PI max, which may be because mechanically ventilated patients with nonrespiratory causes were included in his study; moreover, the weaning methods from mechanical ventilation were different in each group and the number of the patients was different.

In the present study, the mean value of the RSBI (the ratio of respiratory frequency to VT) was lower (91 breaths/min/ml) in patients with successful weaning than in patients with failed weaning (123.6 breaths/min/ml), as the patients with failed weaning had rapid respiratory rate and low VT. Similar data had been reported by Nemer *et al* [12] and Alvisi *et al* [13].

Fadaii *et al.* [14], who assessed the RSBI as a predictor of weaning in the respiratory care unit, reported that RSBI less than 105 breaths/min/ml was a helpful index for weaning, but the application of RSBI alone could be misleading; general status of the patient, concomitant diseases, and duration of ICU stay should all be taken into account for successful weaning.

In the present study, the mean value of VT in the group with successful weaning was higher (448 ml) than the mean value in the group with failed weaning (286.8 ml). This was in agreement with the results of Alvisi *et al.* [15].

This result did not match the study carried out by Nava *et al.* [16], who assessed the prediction of successful weaning in COPD patients. This may be explained by the long period of mechanical ventilation (more than 21 days), which may lead to dependence on mechanical ventilation and to muscle weakness.

As regards the PaO_2/FiO_2 ratio (the reference for the evaluation of oxygenation in patients with acute lung injury and acute respiratory distress syndrome), the mean value in the group with successful weaning was higher (313.7) than the mean value in the group with failed weaning (221).

The study carried out by Nemer and Barbas [16], who evaluated predictive parameters for weaning from mechanical ventilation, reported that the PaO_2/FiO_2 ratio was not highly accurate for weaning from mechanical ventilation, that the PaO_2/FiO_2 ratio cutoff values that predict successful weaning from mechanical ventilation vary greatly and the PO_2/FiO_2 ratio should remain as a reference for the evaluation of patients with acute respiratory distress syndrome and acute lung injury, and that it is not always an appropriate predictive parameter for weaning from mechanical ventilation.

In the present study, as regards the diaphragmatic displacement, the mean value in group B (nonmechanically ventilated COPD patients) was 1.6 cm, which is higher than the mean value in group A (mechanically ventilated COPD patients), which was 1.3 cm. This reveals the muscle dysfunction occurring in mechanically ventilated patients.

As regards group A, the mean value of diaphragmatic displacement in the group with successful weaning was 1.4 cm, which was higher than the mean value in the group with failed weaning, which was 1.05 cm, with sensitivity 86.8%, specificity 87.5%, and accuracy of 89% using cutoff value 1.1 cm. Similar data had been reported by Makhlouf *et al.* [17], El Hoffy and Khamis [18], and Jiang *et al.* [9].

There is a significant direct relationship between diaphragmatic displacement measured by ultrasound, VT, and PaO_2/FiO_2 ratio, and significant inverse relationship with age, days of mechanical ventilation, RSBI, and PI max.

In the present study, parameters of weaning including VT, PI max, RSBI, and diaphragmatic displacement were significantly better in the group with successful weaning than in the group with failed weaning.

Gerscovich *et al.* [19] reported that ultrasound in the evaluation of motion of the diaphragm is an accurate technique that has had no technical failures and is relatively easy to master. The modality is portable, which is very important for many seriously ill patients receiving mechanical ventilation, and uses no ionizing radiation. It should be the modality of choice in the examination of motion of the diaphragm.

Conclusion

Diaphragmatic displacement measured by ultrasound is one of the most sensitive, specific, and accurate parameters for weaning of COPD patients from mechanical ventilation, especially in relationship with the other weaning parameters such as VT, RSBI, and PI max; further, age, comorbid diseases, and days of mechanical ventilation should be kept in consideration during weaning from mechanical ventilation.

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Conflicts of interest

There are no conflicts of interest.

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