Assessment of diaphragmatic mobility by chest ultrasound in patients with chronic obstructive pulmonary disease on different modes of mechanical ventilation

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Background Chronic obstructive pulmonary disease (COPD) is a disease characterized by airway obstruction and air trapping that is not fully reversible. The diaphragm is the principal respiratory muscle, and its dysfunction can prolong the duration of mechanical ventilation. Ultrasonography is a fast, easy, and accurate method of bedside evaluation for diaphragmatic function. In the ICU population, it can quantify normal and abnormal movements in a variety of clinical conditions.

Patients and methods A prospective observational study was carried on 32 patients with COPD admitted to the respiratory ICU. Diaphragmatic excursion had been assessed by chest ultrasonography in every mode of mechanical ventilation and was correlated with weaning off mechanical ventilation and other physiological parameters.

Results Of 32 patients with COPD included in the study, 24 patients were successfully weaned versus eight patients failed to be weaned off mechanical ventilation. Diaphragmatic excursions in every mode of mechanical ventilation (noninvasive, volume control, bilevel positive airway pressure, and pressure support) were higher in weaned patients with best cutoff values of 1.4, 1.3, 1.5, and 1.6 cm, respectively. Moreover, the diaphragmatic excursions were directly correlated with tidal volumes and inversely correlated with days of mechanical ventilation and rapid shallow breathing index.

Conclusion Diaphragmatic displacement assessed by ultrasound is a good predictor for weaning off mechanical ventilation in patients with COPD, as it is sensitive, specific, and accurate. Diaphragmatic excursions are directly related to tidal volumes and inversely related with rapid shallow breathing index and days of mechanical ventilation.
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Introduction

Chronic obstructive pulmonary disease (COPD) is mainly defined as a disease characterized by airway obstruction and air trapping that is not fully reversible. As diaphragm is the principal generator of tidal volume (TV), studies dealing with inspiratory muscle weakness in patients with COPD focus mostly on diaphragm [1].

Diaphragmatic ultrasonography can provide valuable information in the evaluation of patients during partial ventilatory support. Simultaneous recordings of diaphragmatic ultrasonography and airway pressures waveforms can allow visualization of whether each patient's inspiratory effort triggers the ventilator appropriately. Therefore, real-time hemi-diaphragmatic ultrasonography could be used in the evaluation of patient–ventilator interactions in clinical practice, to detect cases of patient–ventilator asynchrony. In these cases, diaphragmatic ultrasonography could even allow a proper adjustment of the ventilator settings to optimize synchronization of the patient's inspiratory effort with the assisted mechanical breath. Mechanical ventilation in controlled mode and possibly with high levels of partial ventilatory assist can also result in ventilator-induced diaphragmatic dysfunction [2].

The aim of the work was to study the role of diaphragmatic excursion measured by chest ultrasound in each mode of mechanical ventilation in patients with COPD as an independent parameter for successful weaning and its relation to other weaning parameters.

Patients and methods

The study was conducted on 32 patients with COPD (predominantly chronic bronchitis phenotype) who were admitted at Respiratory ICU of Ain Shams University Hospitals from October 2016 till October 2018. The study included patients with COPD who were mechanically ventilated and put on different modes of mechanical ventilation, including noninvasive (NIV), volume control (VC), bilevel positive airway pressure (BIPAP), and pressure support (PS). Institutional ethics committee approval was obtained, and verbal consents from the patients' relatives were taken rather than written consents, as it is a simple, NIV, and useful parameter for the patients.

Chest ultrasound was done to assess diaphragmatic mobility with each mode of mechanical ventilation and correlation between diaphragmatic excursion and successful weaning (defined as extubation and the absence of ventilator support 48 h following the extubation) versus weaning failure (defined as failed spontaneous breathing trial or reintubation following successful extubation within 48 h) and with other physiological parameter such as TV and rapid shallow breathing index (RSBI) during pressure support ventilation (PSV) [RSBI is defined as the ratio of respiratory frequency to TV (f/VT)] and days of mechanical ventilation.

All patients were subjected to full medical history taking, clinical examination, chest radiography, and frequent chest ultrasounds throughout the period of mechanical ventilation till weaning to assess the diaphragmatic function.

Exclusion criteria

(1) Uncontrolled comorbid disease affecting the weaning of the patients.
(2) Intubated patients owing to surgical or other medical problem other than COPD.
(3) Presence of ascites or colonic distension.
(4) Presence of lung collapse or fibrosis or pleural effusion.
(5) Presence of any mass or mechanical factor in chest or abdomen interfering with the diaphragmatic mobility.
(6) Age less than18 years.
(7) Prior pleurodesis.

Chest ultrasound examination methodology

Mindray M7 (Guangzhou Medsinglong Medical Equipment Co. Ltd, Guangdong, China) with double probe was used for examination of diaphragmatic excursions of patients with COPD during every mode of mechanical ventilation till weaning. Examination was done using a 3.5C (bandwidth 2–5 MHz) convex phased array probe (low-frequency probe with greater depth that allows to assess excursion).

Patients were examined in a supine position, and the transducer was put on anterior subcostal abdominal wall at the midclavicular line operating a transverse scanning with cranial direction to display the best imaging of the hemi-diaphragmatic dome in B-mode imaging. A fixed point was taken in the outer surface (point A), and the distance from it to the diaphragm (point B) was measured during inspiration and expiration while the transducer was in the same place. The diaphragmatic displacement was calculated by extracting the distance between both. This was repeated three to five times, and then, the mean value was calculated. The right hemi-diaphragmatic excursion measurement was preferred as it is easier and clearer than the left side.

M-mode was also used to confirm the diaphragmatic excursion by applying it during inspiration and expiration and then measuring the distance between the dome and bottom of the diaphragmatic line in freeze mode. M-mode was more accurate and easier for interpretation and less time consuming than B-mode.

Statistical analysis

The collected data were revised, coded, tabulated, and introduced to a PC using statistical package for social science (SPSS 17) Statistical Package for Social Science (IBM SPSS) version 20.0. (SPSS Inc., Chicago, Illinois, USA). Data were presented, and suitable analysis was done according to the type of data obtained for each parameter.

(1) Description of quantitative variables as mean, SD, and range.
(2) Description of qualitative variables as number and percentage.
(3) Unpaired t test was used to compare quantitative variables, in parametric data (SD<50% mean).
(4) Receiver operator characteristic (ROC) curve was used to find out the best cutoff value and the validity of certain variable.
(5) Sensitivity=(true positive)/(true positive+false negative)=ability of the test to detect positive cases.
(6) Specificity=(true negative)/(true negative+false positive)=ability of the test to exclude negative cases.
(7) Positive predictive value=(true positive)/(true positive+false positive)=% of true positive cases to all positive cases.
(8) Negative predictive value=(true negative)/(true negative+false negative)=% of the true negative to all negative cases.

(9) *P* value more than 0.05 is insignificant, *P* value less than 0.05 is significant, and *P* value less than 0.01 is highly significant [3].

Results

A total of 32 male patients with COPD were enrolled in our study, with mean age of 58.84 years, ranging from 48 to 69 years. All patients underwent invasive mechanical ventilation on VC, BIPAP, and PS modes; 24 (75%) patients were successfully weaned versus eight (25%) patients failed to be weaned from mechanical ventilation. Only nine among the 32 patients were put on NIV mode before invasive mechanical ventilation; three patients failed to be weaned versus six patients were successfully weaned at the terminal outcome. The duration of mechanical ventilation ranged from 3 to 15 days, with a mean of 6.94 days, including duration of mechanical ventilation in patients failed to be weaned till failure of weaning or death. Mean RSBI was 86.97, mean TV was 410.97 ml, and their mean diaphragmatic excursions on NIV, VC, BIPAP, and PS were 1.88, 1.55, 1.99, and 1.96 cm, respectively (Table 1).

There was a highly significant correlation between successful weaning and diaphragmatic excursions in every mode of mechanical ventilation, including NIV, VC, BIPAP, and PS and TVs and highly significant inverse correlation with RSBI and days of mechanical ventilation (Tables 2 and 3). The patients with failed weaning were mechanically ventilated from 4 to 15 days, with a mean±SD of 10.38±3.50 in comparison with 3–9 days with a mean±SD of 5.79±1.93 in successfully weaned patients (Tables 2 and 4), and by using a cutoff value of less than or equal to 8 days, the sensitivity and specificity of weaning were 91.67 and 75%, respectively (Table 5).

Using RSBI as an indicator for successful weaning, results revealed an inverse correlation between RSBI and successful weaning, ranging from 98 to 144 breath/m/l and a mean±SD of 124.13±15.56 breath/m/l in patients failed to be weaned in comparison with range of 50–106 breath/m/l and a mean±SD of 74.58±14.60 breath/m/l in successfully weaned patients (Table 3). By using a cutoff point 97 breath/m/l, the sensitivity and specificity for successful weaning was 95.83 and 87.5%, respectively (Table 5).

Regarding TV, there was a highly significant correlation between it and weaning success. It was higher in patients who were weaned successfully with a mean 461.25 ml and range from 313 to 600 ml versus a mean 260.13 and range from 127 to 370 in patients failed to be weaned (Table 3), and by using a cutoff value of 370 ml, the sensitivity and specificity were 87.5 and 75%, respectively (Table 5).

Table 1 Descriptive analysis for the studied parameters

	N=32
Sex [*n* (%)]	
Male	32 (100.0)
Age	
Mean±SD	58.84±5.38
Range	48–69
DE in NIV (only 9 patients)	
Mean±SD	1.88±0.65
Range	1–2.7
DE in VC	
Mean±SD	1.55±0.48
Range	0.9–2.6
DE in BIPAP	
Mean±SD	1.99±0.66
Range	1–3.2
DE in PS	
Mean±SD	1.96±0.60
Range	1–3.4
TV	
Mean±SD	410.97±112.57
Range	127–600
RSBI	
Mean±SD	86.97±26.23
Range	50–144
Fate [*n* (%)]	
Failure	8 (25.0)
Success	24 (75.0)
Days of MV	
Mean±SD	6.94±3.10
Range	3–15

BIPAP, bilevel positive airway pressure; DE, diaphragmatic excursion; MV, mechanical ventilation; NIV, noninvasive; PS, pressure support; RSBI, rapid shallow breathing index; TV, tidal volume; VC, volume control.

From the aforementioned data, follow-up of diaphragmatic excursions in different modes (NIV, VC, BIPAP, and PS) during mechanical ventilation till weaning revealed the following results:

(1) Only nine patients of the 32 patients were put on NIV mode, and by using a cutoff point of 1.4 cm, the sensitivity and specificity for successful weaning were 83.3 and 66.7%, respectively, with area under the curve (AUC) 0.667.
(2) In VC mode, using a cutoff point of 1.3 cm, the sensitivity and specificity for successful weaning were 79.17 and 75%, respectively, with AUC 0.776.
(3) In BIPAP mode, using a cutoff point 1.5 cm, the sensitivity and specificity for successful weaning were 91.67 and 87.5%, respectively, with AUC 0.995.
(4) In PS mode, using a cutoff point of 1.6 cm, the sensitivity and specificity for successful weaning

Table 2 Comparison between successful weaning and failed weaning regarding diaphragmatic excursions in each mode of mechanical ventilation (noninvasive, volume control, bilevel positive airway pressure, and pressure support)

	Failure	Success	Test value	*P* value	Significance
DE in NIV (9 patients)					
Mean±SD	1.10±0.10	2.27±0.36	5.401	0.001	HS
Range	1–1.2 (3 patients)	1.8–2.7 (6 patients)			
	Failure (*N*=8)	Success (*N*=24)			
DE in VC					
Mean±SD	1.05±0.19	1.72±0.43	–4.248	0.000	HS
Range	0.9–1.3	1–2.6			
DE in BIPAP					
Mean±SD	1.26±0.17	2.23±0.58	–4.583	0.000	HS
Range	1–1.5	1.5–3.2			
DE in PS					
Mean±SD	1.25±0.19	2.19±0.49	–5.283	0.000	HS
Range	1–1.6	1.2–3.4			

Only nine from 32 patients underwent NIV, of which three patients failed to be weaned versus nine patients were successfully weaned. BIPAP, bilevel positive airway pressure; DE, diaphragmatic excursion; HS, highly significant; NIV, noninvasive; PS, pressure support; VC, volume control.

Table 3 Comparison between success and failure of weaning regarding tidal volume, rapid shallow breathing index, and days of mechanical ventilation

	Failure (*N*=8)	Success (*N*=24)	Test value	*P* value	Significance
TV					
Mean±SD	260.13±74.88	461.25±69.42	–6.965	0.000	HS
Range	127–370	313–600			
RSBI					
Mean±SD	124.13±15.56	74.58±14.60	8.181	0.000	HS
Range	98–144	50–106			
Days of MV					
Mean±SD	10.38±3.50	5.79±1.93	4.691	0.000	HS
Range	4–15	3–9			

HS, highly significant; MV, mechanical ventilation; RSBI, rapid shallow breathing index; TV, tidal volume.

were 95.83 and 87.5%, respectively, with AUC 0.943.

(5) The best correlation between diaphragmatic excursions and successful weaning using AUC were during BIPAP mode followed by PS mode, then VC mode, and finally during NIV mode (Table 4).

(6) The study also showed that diaphragmatic excursion in the different modes (VC >1.3 cm, BIPAP >1.5 cm, and PS >1.6 cm), TV more than 370 ml, RSBI less than or equal to 97 breaths/min/l, and days of mechanical ventilation less than or equal to 8 days were found to be independent predictors for successful weaning among the studied cases, with *P* values of 0.011, 0.001, 0.001, 0.003, 0.001, and 0.001, respectively, but no statistically significant association was found between diaphragmatic excursion in NIV mode and successful weaning of the studied cases, with *P* value of 0.161, mostly owing to the small number of patients who underwent NIV mechanical ventilation. The high gap in 95% confidence interval for odds ratio in logistic regression analysis for predictors of successful weaning may be owing to the small number of patients with wide variability in patients parameters with high SD around the mean (Table 6).

Discussion

COPD is a major cause of chronic morbidity and mortality throughout the world. Many people have 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 [4].

Ultrasound which is widely available inside the ICU provides direct, bedside, and rapid visualization and assessment of the diaphragmatic mobility and diaphragmatic function, as diaphragm is the main respiratory muscle and can be used as an indicator for weaning outcome [5].

The decision on the initiation of weaning process depends on multiple indices and parameters, mainly the arterial blood gases and the respiratory mechanics, with all parameters reflecting the diaphragmatic function in an indirect manner [5]. The weaning process of ICU patients is a complex process, with an estimated 20% failure rate [6].

This prospective study was carried out on 32 patients with COPD who underwent mechanical ventilation and were put on different modes (VC, BIPAP, and PS); among them, only nine patients passed on NIV mechanical ventilation. Patients were followed up by chest ultrasound measuring diaphragmatic excursion in each mode, and the results were correlated with other parameters before weaning such as TV, RSBI, and duration of mechanical ventilation.

Table 4 Receiver operating characteristic for diaphragmatic excursions in each mode of mechanical ventilation as predictors of successful weaning

Parameters	AUC	Cut of point	Sensitivity	Specificity	PPV	NPV
DE in NIV (9 patients)	0.667	>1.4	83.3	66.7	83.3	83.3
DE in VC	0.776	>1.3	79.17	75.0	90.5	54.5
DE in BIPAP	0.995	>1.5	91.67	87.5	95.7	77.8
DE in PS	0.943	>1.6	95.83	87.5	95.8	87.5

AUC, area under the curve; BIPAP, bilevel positive airway pressure; DE, diaphragmatic excursion; NIV, noninvasive; NPV, negative predictive value; PPV, positive predictive value; PS, pressure support; VC, volume control.

Table 5 Receiver operating characteristic for tidal volume, rapid shallow breathing index, and days of mechanical ventilation as predictors of successful weaning

Parameters	AUC	Cut of point	Sensitivity	Specificity	PPV	NPV
TV	0.875	>370	87.50	75.0	91.3	66.7
RSBI	0.872	≤97	95.83	87.5	95.8	87.5
Days of MV	0.878	≤8	91.67	75.00	91.7	75.0

AUC, area under the curve; MV, mechanical ventilation; NPV, negative predictive value; PPV, positive predictive value; RSBI, rapid shallow breathing index; TV, tidal volume.

From this work, there was a direct correlation between diaphragmatic excursions and TV and inverse correlation with RSBI and days of mechanical ventilation. These results matched with Kim *et al.* [7] who stated that regarding the relationship between the whole criteria of weaning (TV/ml/kg, RR/min, mechanical ventilation/l/min, and RSBI) and the diaphragmatic excursion (DE)/cm before and after weaning, there was a significant positive correlation, and a significant statistical difference appeared between TV/ml/kg, minute volume, and DE/cm, meaning that the more the diaphragmatic excursion, to the more the lung expansion, leading to more TV, and minute volume, with an inverse correlation with RSBI.

In this study, results revealed an inverse correlation between outcome and duration of mechanical ventilation. These results corresponded with the study by Saeed *et al.* [8], which was conducted on 30 patients with COPD. They found that the mean number of days of mechanical ventilation in successfully weaned patients was 5.7 days, whereas the mean number of days of mechanical ventilation in failed weaning was 11.4 days. This revealed that, the longer the duration of mechanical ventilation, the more difficult it was to wean the patients from mechanical ventilation, with a high incidence of weaning failure. This might be attributed to patient dependence on the ventilator, the respiratory muscles' weakness associated with undernutrition in the ICU, and the use of systemic steroids in patients with COPD.

Using RSBI as an indicator for successful weaning, results revealed an inverse correlation between RSBI and successful weaning. These findings coincided with those of the study by Saeed *et al.* [8] which was

Table 6 Logistic regression analysis for predictors of successful weaning

Parameters	*B*	SE	Wald	*P* value	Odds ratio	95% CI for OR	
						Lower	Upper
DE in NIV >1.4 (9 patients)	2.303	1.643	1.964	0.161	10	0.399	250.419
DE in VC >1.3	2.434	0.959	6.442	0.011	11.4	1.741	74.651
DE in BIPAP >1.5	4.344	1.299	11.176	0.001	77	6.032	98.879
DE in PS >1.6	5.081	1.479	11.81	0.001	61	8.876	92.349
TV >370	3.045	1.024	8.848	0.003	21	2.825	56.118
RSBI ≤97	5.081	1.479	11.81	0.001	16	8.876	29.349
Days of MV ≤8	3.497	1.101	10.086	0.001	33	3.814	28.533

BIPAP, bilevel positive airway pressure; DE, diaphragmatic excursion; MV, mechanical ventilation; NIV, noninvasive; PS, pressure support; RSBI, rapid shallow breathing index; TV, tidal volume; VC, volume control. *P* value more than 0.05 is insignificant; *P* value less than 0.05 is significant; *P* value less than 0.01 is highly significant. The table represents every parameter as independent factor as a predictor of successful weaning.

conducted up 30 patients with COPD for prediction of weaning using diaphragmatic excursion and other physiological parameters of weaning. They found that average RSBI was 91 between patients with successful weaning and 123.6 between patients with failed weaning. Moreover, the study by Osman and Hashim [5], which was conducted on 68 patients admitted to different ICU units at Ain Shams University Hospitals revealed that the RSBI ranged between 50 and 97 breath/min/l in patients who underwent successful weaning, with 71.6 average value of breath/min/l, whereas it ranged between 105 and 125 breath/min/l, with average value of 113.9 breath/min/l in failed patients.

A prospective study was carried out by Shaalan *et al.* [9] on 30 patients, where 21 (70%) patients had succeeded extubation and nine (30%) patients failed. By applying a cutoff level 1 cm of diaphragmatic excursion determined in their study, the sensitivity and specificity of mean liver and spleen displacement were 95.2 and 88.9%, respectively.

Our results regarding DE as a predictor of weaning was similar to Saeed *et al.* [8] who reported in their study on 30 patients with COPD that 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 of 86.8%, specificity of 87.5%, and accuracy of 89% using cutoff value of 1.1 cm.

Our study was in agreement with the study by Liu *et al.* [10] in which among 98 patients enrolled in that study, 74 were successfully weaned and 24 failed. There were significant differences between the two groups (success group and failure group) in left diaphragmatic excursion (1.12±0.97 vs. 0.69±1.00 cm, $P<0.001$), right diaphragmatic excursion (1.87±0.75 vs. 1.17±0.76 cm, $P<0.001$), and mean value of left and right diaphragmatic excursion (1.57±0.52 vs. 0.83±0.53 cm, $P<0.001$). The ventilation time [2.00 (2.00–4.00) vs. 4.00 (2.00–5.00) days] was also statistically significant in successfully weaned patients and patients with failed weaning, respectively (all $P<0.05$). The cutoff value of diaphragmatic excursion for predicting successful extubation was determined to be 1.14 cm by ROC curve analysis. The sensitivity of diaphragmatic excursion to predict successful weaning was 89.2% and the specificity was 75.0%, with the AUC (ROC) of 0.849. The study conclusion was that as an early predictor of diaphragmatic dysfunction, diaphragmatic excursion is probably superior to the traditional parameters in predicting weaning from ventilator in ICU patients [10].

Moreover, in the study of Nassar *et al.* [11], which was conducted in the Critical Care Department of Cairo University Hospital between March 2014 and March 2015, the ROC curves showed a cutoff value using DE as a weaning parameter (14 mm) for right hemi-diaphragm with an AUC of 0.8. These results were matched with our results regarding cutoff values of DE in each mode of mechanical ventilation and its relation to patients outcomes (14, 13, 15, and 16 mm in NIV, VC, BIPAP, and PS modes, respectively). The study recommended that diaphragmatic excursion may serve as a valuable tool for predicting weaning outcome as traditional volumetric respiratory indices.Regarding best mode in patients with COPD with higher DE, our results were matched with the study of Saeed *et al.* [12] which was carried out on 50 mechanically ventilated patients with COPD. Chest ultrasonography for the assessment of diaphragmatic mobility in addition to echocardiography was performed on different modes of mechanical ventilation. They found that the best diaphragmatic mobility was on PSV, which improved lung volumes and ventilation, and may accelerate the weaning process.

Finally, Gerscovich *et al.* [13] 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.

Limitation of the study

The small number of patients who underwent NIV mechanical ventilation was a limitation.

Conclusion

The primary outcome from this study was that diaphragmatic excursion was greater in BIPAP and PS modes of mechanical ventilation in patients with COPD, so the study suggests their usage as preferred modes of mechanical ventilation in patients with COPD when possible and not contraindicated. The secondary outcome was that diaphragmatic excursion was related to other physiological parameters of weaning such as TV and RSBI and also that diaphragmatic displacement assessed by chest ultrasound is a good predictor for weaning from mechanical ventilation in patients with COPD, as it is sensitive, specific, and accurate. Moreover, from this work, we recommend further similar studies with more patients, especially in NIV mechanical ventilation.

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Conflicts of interest
There are no comflicts of interest.

References
1 Kang HW, Kim TO, Lee BR. Influence of diaphragmatic mobility on hypercapnia in patients with chronic obstructive pulmonary disease. *J Korean Med Sci* 2011; **26**:1209–1213.

2 Petrof BJ, Jaber S, Matecki S. Ventilator-induced diaphragmatic dysfunction. *Curr Opin Crit Care* 2010; **16**:19–25.

3 Clinton M, Rebecca G. *Clinical epidemiology and biostatistics*. 3rd ed. Maryland: Williams & Wilkins 1992.

4 Lopez AD, Shibuya K, Rao C, Mathers CD, Hansell AL, Held LS. Chronic obstructive pulmonary disease: current burden and future projections. *Eur Respir J* 2006; **27**:397–412.

5 Osman A, Hashim R. Diaphragmatic and lung ultrasound application as new predictive indices for the weaning process in ICU patients. *Egypt J Radiol Nucl Med* 2017; **48**:61–66.

6 Epstein SK. Putting it all together to predict extubation outcome. *Intensive Care Med* 2004; **30**:1255–1256.

7 Kim SH, Na S, Choi JS. An evaluation of diaphragmatic movement by M-mode ultrasonography as a predictor of pulmonary dysfunction after upper abdominal surgery. *Anesth Analg* 2010; **110**:1349–1354.

8 Saeed AM, El Assal GI, Ali TM, Hendawy MM. Role of ultrasound in assessment of diaphragmatic function in chronic obstructive pulmonary disease patients during weaning from mechanical ventilation. *Egypt J Bronchol* 2016; **10**:167–172.

9 Shaalan MA, Badr GA, Ibrahim AA. Diaphragmatic excursion assessment by ultrasound versus volume associated weaning parameters as a prediction in extubation in critically ill patients. *Egypt J Hosp Med* 2018; **72**:3873–3878.

10 Liu LX, Su D, Hu ZJ. The value of the excursion of diaphragm tested by ultrasonography to predict weaning from mechanical ventilation in ICU patients. *Zhonghua Nei Ke Za Zhi* 2017; **56**:495–499.

11 Nassar YS, Elbanna M, Arafa M, Hussein A. Evaluation of ventilator-induced diaphragmatic dysfunction by diaphragmatic excursion during spontaneous breathing trials. *J Anesth Clin Res* 2018; **9**:824.

12 Saeed AM, Elshahed GS, Osman NM, Gomaa AA, Fahyim SM. Study of diaphragmatic mobility by chest ultrasound and echocardiographic changes in chronic obstructive pulmonary disease patients on different modes of mechanical ventilation. *Egypt J Bronchol* 2018; **12**:399–404.

13 Gerscovich EO, Cronan M, McGahan JP, Jain K, Jones D, McDonald C. Ultrasonographic evaluation of diaphragmatic motion. *J Ultrasound Med* 2001; **20**:597–604.