Diaphragmatic ultrasound as a predictor for successful weaning from mechanical ventilation

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Background

Diaphragm ultrasound has lately been used in the prediction of successful weaning from mechanical ventilation.

Aim

To assess diaphragm thickening fraction (DTF) and mobility measured by ultrasound as predictors of successful weaning.

Patients and methods

This prospective study included 30 patients who were planned for weaning from invasive mechanical ventilation. Rapid shallow breathing index was measured, and diaphragmatic ultrasound was carried out to assess diaphragmatic excursion (DE) and diaphragm thickening at the time of spontaneous breathing trial. Patients were classified into two groups: group I included patients with successful weaning and group II included patients with failed weaning.

Results

DTF was significantly higher in group I; however, there was no statistically significant difference between the two groups regarding DE. There was a statistically significant difference between the two groups regarding rapid shallow breathing index, as it was higher in group II. The sensitivity, specificity, positive predictive value, and negative predictive value for DTF at a cutoff value more than 0.33% in prediction of successful weaning were 94, 100, 100, and 91.7%, respectively; the corresponding values for DE at a cutoff value more than 0.91 cm were 84, 37, 69.6, and 57.1%, respectively.

Conclusion

DTF may be useful to predict successful weaning during spontaneous breathing trial, and it has better performance than DE.

Keywords:
diaphragm thickening fraction, diaphragm ultrasound, diaphragmatic excursion, mechanical ventilation

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Introduction

It was found that rapid shallow breathing index (RSBI) is one of the most precise predictors of weaning failure [1]. However, RSBI value less than 105 showed inconstant degrees of sensitivity, specificity, and negative predictive values between different studies [2]. Diaphragmatic excursion (DE), its speed of contraction, and diaphragmatic thickening can be measured by ultrasound [3]. The estimation of diaphragm thickening fraction (DTF) may help to evaluate function of the diaphragm and its involvement in respiratory workload. Nevertheless, insufficient studies have evaluated diaphragmatic thickening as a predictor of successful weaning [3].

Aim

The aim was to assess DTF and mobility measured by ultrasound as a predictors of successful weaning.

Patients and methods

This prospective study was carried out on 30 mechanically ventilated patients admitted to Pulmonology ICU in Benha University Hospitals who were planned for weaning during the period between April 2017 and May 2018. Ethical approval of this study was attained from Ethical Committee of Faculty of Medicine, Benha University. Patients were classified into two groups: group I included those with successful weaning and group II included those with failed weaning. Successful weaning is considered when the patient can continue breathing spontaneously for 48 h or more, without any support from ventilator and without developing failure measures of spontaneous

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breathing [4]. All mechanically ventilated patients were subjected to spontaneous breathing trial (SBT) for 1 h using T-piece with oxygen supplementation (FiO_2 of 0.21–0.5) to attain oxygen saturation of at least 94% when all the following criteria were met: FiO_2<50%, PaO_2/FiO_2>200, PEEP≤5 cmH_2O, respiratory rate (RR)<30 breaths/min, fever was absent, and the patient was cooperative, alert, and hemodynamically stable with lacking of any vasoactive therapy support.

If the patient had one or more of the criteria of being unable to breath spontaneously, for example, mental status change, RR more than 35 breaths/min, instability in hemodynamic status (systolic blood pressure<90 or>180 mmHg, heart rate>140/min), or developing signs of increased work of breathing, the trial was disregarded [5]. Patients with diaphragmatic paralysis, neuromuscular diseases, those with altered mental state, hemodynamically instable, or having any vasoactive therapy support were excluded. All enrolled patients were subjected to history taking, clinical examination, routine investigations (kidney function tests, liver function tests, and complete blood count), arterial blood gas analysis (on admission and before SBT), plain chest radiography, computed tomography chest, which was done when indicated, and diaphragmatic ultrasound, which was performed using portable digital color Doppler ultrasound system, model S6 (SonoScape, Shanghai, China). Right hemidiaphragm was assessed by B-mode and M-mode ultrasound, as it was difficult to visualize left hemidiaphragm, as the spleen offers limited acoustic window to obtain pure views on the left hemidiaphragm. Moreover, intestinal or gastric gas may hinder imagining of the left hemi-diaphragmatic dome [6]. All patients were evaluated in a semi-sitting position. The diaphragm was visualized and DTF was calculated as percentage from the following equation [5].

$$\frac{\text{Thickness at end inspiration} - \text{Thickness at end expiration}}{\text{Thickness at end of expiration}} \times 100.$$

DE was measured by using both two-dimensional mode and the M-mode. Detection of DE was done by measurement of the vertical space between upper border of the liver at end of expiration to that at the end of inspiration [7].

Statistical analysis

The collected data were tabulated and analyzed by the statistical package for the social sciences (SPSS Inc., Chicago, Illinois, USA). Categorical data were expressed as number and percentage. Continuous variables were expressed as mean and SD for normally distributed variables or median and range for those that were not normally distributed. Suitable tests of significance were calculated. Comparison between groups was done using the unpaired *t*-test, Mann–Whitney *U*-test, and χ^2-test. Correlation analysis to determine the association between DTF, RSBI, DE, and other independent variables was done. Receiver operating characteristic (ROC) curve was used to describe the performance of DTF, RSBI, and DE in prediction of successful weaning. The accepted level of significance in this work was 0.05 (P≤0.05).

Results

This study included 30 patients, of whom 18 (60%) were males and 12 (40%) were females. Their age ranged from 34 to 78 years, with mean±SD of 55.2±11.5. They were classified into two groups: group I included patients with successful weaning (19 patients, comprising eight females and 11 males, with their mean age of 54.11 ±11.07 years) and group II included patients with failed weaning (11 patients comprising four females and seven males, with mean age of 57.09±12.66 years). Causes of respiratory failure are presented in (Table 1). Regarding duration of ventilator treatment, there was a statistically significant difference between the two groups, as it was higher in group II (mean±SD 15.00±7.65) when compared with the group with successful weaning (mean±SD 6.11±3.61); however, there was no statistically significant difference between the studied groups regarding age and sex (Tables 2 and 3). For DTF, there was a statistically significant difference between the studied groups, as it was higher in group I (median=51%) when compared with group II (median=22%). However, regarding diaphragm thickness at total lung capacity (D_{tlc}), DE, and diaphragm thickness at residual volume (DRV), there was no statistically significant difference between the two

Table 1 Cause of respiratory failure in the studied patients

Cause of admission	*N*=30 [*n* (%)]
AECOPD	14 (46.7)
AECOPD and pleural effusion	1 (3.3)
Acute exacerbation of bronchial asthma	3 (10)
Bronchiectasis	3 (10)
Lung cancer and pleural effusion	2 (6.7)
Pneumonia	3 (10)
AE.ILD	3 (10)
Obesity hypoventilation	1 (3.3)

AECOPD, acute exacerbation of COPD; AE.ILD, acute exacerbation of interstitial lung disease.

Table 2 Statistical comparison between studied groups regarding age and duration of ventilator treatment

Variables	Groups	Mean±SD	*t*-Test	*P*
Age (years)	I	54.11±11.07	0.676	0.505
	II	57.09±12.66		
Duration of ventilatory treatment (days)	I	6.11±3.61	3.626	0.003
	II	15.00±7.65		

Table 3 Statistical comparison between studied groups regarding sex

Sex	Groups		FET	*P*
	Group I [*N* (%)]	Group II [*N* (%)]		
Male	11 (57.9)	7 (63.6)	FET	1
Female	8 (42.1)	4 (36.4)		

groups (Table 4). The mean scores of RSBI and RR were significantly higher in group II and that of expiratory tidal volume (Vte) was lower (Table 5). The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for DTF in prediction of successful weaning at cutoff value more than 0.33% were 94, 100, 100, and 91.7%, respectively, and for D excursion at cutoff value more than 0.91 cm were 84, 37, 69.6, and 57.1% respectively, and for RSBI at cutoff value less than 103 were 100, 82, 90.5, and 100%, respectively (Table 6).

Discussion

Mechanical ventilation is a lifesaving measure in cases presenting with acute respiratory failure [8]. Development of new interventions that decrease the duration of mechanical ventilation is so important to avoid medical and economic consequences [9]. Occurrence of respiratory muscle fatigue will lead to disparity between respiratory body need and supply with subsequent failure to wean, so evaluating the strength of muscles of respiration is extremely important [10]. As the diaphragmatic movement plays an important role in spontaneous breathing, monitoring of its kinetics is crucial [8]. Currently, diaphragmatic function can be evaluated by ultrasound [10]. In this study, there was no statistically significant difference between the two groups regarding patient age. This goes on hand with Adel *et al.* [10], who found that age was matching between the successfully weaned and the failed-to-be-weaned groups, as the mean±SD of their age was 59±6 and 56.2±7.1, respectively, with *P* value 0.18, which is nearly close to the age mean±SD in this study. Of 34 patients enrolled in the study by Pirompanich and Romsaiyut [11], there was also no statistically significant difference between the successfully weaned and the failed-to-be-weaned groups regarding their age, with *P* value 0.333; the mean age was 66.5±13.5 years. According to the results of this study, regarding duration of ventilator treatment, it was significantly higher in the group that failed SBT. This result agrees with Adel *et al.* [10], who found that the number of days of mechanical

Table 4 Statistical comparison between studied groups regarding diaphragmatic ultrasound findings

Variables	Group	Mean±SD	*t*-Test	*P*
D_{tlc} (mm)	I	4.97±2.27	0.794	0.434
	II	4.38±1.06		
DE (cm)	I	1.53±0.84	0.941	0.355
	II	1.24±0.72		
DRV (mm)	I	Median=3.04	*U*=4.087	0.328
	II	Median=3.40		
DTF (%)	I	Median=51	*U*=6.225	0.000
	II	Median=22		

DE, diaphragmatic .excursion; DRV, diaphragm thickness at residual volume; DTF, diaphragm thickening fraction; D_{tlc}, diaphragm thickness at total lung capacity.

Table 5 Statistical comparison between studied groups regarding rapid shallow breathing index, respiratory rate, and expiratory tidal volume

Variables	Groups	Mean±SD	*t*-Test	*P*
RSBI (breath/min/l)	I	75.71±19.55	4.087	0.000
	II	107.53±22.22		
RR (breath/min)	I	24.36±2.65	6.225	0.000
	II	28.45±0.82		
Vte (ml)	I	Median=301	*U*=40.5	0.005
	II	Median=250		

RR, respiratory rate; RSBI, rapid shallow breathing index; Vte, expiratory tidal volume.

Table 6 Performance of diaphragm thickening fraction, diaphragmatic excursion, and rapid shallow breathing index in prediction of successful weaning

	Cutoff	AUC	SN %	SP %	NPV %	PPV %	Efficacy %
DTF	33% (best cutoff)	0.995	94	100	91.7	100	96.6
DE	0.91 cm (best cutoff)	0.591	84	37	57.1	69.6	66.6
RSBI	103 (best cutoff)	0.871	100	82	100	90.5	93.3

AUC, area under the curve; DE, diaphragmatic .excursion; DTF, diaphragm thickening fraction; NPV, negative predictive value; PPV, positive predictive value; RSBI, rapid shallow breathing index; SN, sensitivity; SP, specificity.

ventilation was higher in the group that failed to be weaned when compared with the successfully weaned group, with *P* value 0.001. This result also agrees with Ferrari *et al*. [5], who found that the duration of ventilator treatment was statistically higher in the group with failed weaning (37 days) when compared with successfully weaned group (26 days). However, Farghaly and Hasan [12], found that the duration of mechanical ventilation did not vary significantly between the successfully weaned and the failed-to-be-weaned groups. In this study, the patient sex did not vary significantly between the two studied groups. This goes in hand with Pirompanich and Romsaiyut [11], who found that there was no statistical significant difference between the successfully weaned and the failed-to-be-weaned groups regarding their sex. This study showed that there was a statistically significant difference between the two groups regarding DTF, as it was higher in the group with successful weaning; however, there was no statistically significant difference between the studied groups regarding D_{tlc}, DRV, and DE. This agrees with Ferrari *et al.* [5], who found that there was statistically significant difference between the successfully weaned and the failed-to-be-weaned groups regarding DTF but not regarding D_{tlc} and DRV. This also agrees with Eman and Ahmad [8], who found that DTF was significantly higher in the group with successful weaning group when compared with the group with failed weaning group, as it was 56% (35–63%) and 26% (22–33%), respectively. Diaphragm acts as the chief muscle of breathing as it gives ~70% of tidal volume in normal patients, so it is common for diaphragmatic dysfunction to occur in patients with difficult weaning [12]. In this study, there was a statistically significant difference between the two groups regarding RSBI, RR, and Vte as the mean scores of RSBI and RR were higher in the group II. These results are in line with Baess *et al.* [13], who found that the RSBI seems to be a more reliable and accurate tool for predicting successful weaning and should be estimated in every weaning protocol. Like the results of this study, Ferrari *et al*. [5], have reported that RR has a significant difference between the successfully weaned and the failed-to-be-weaned groups; it was 27 (18–32) and 31 (24–58), respectively, with *P* value 0.001. Regarding Vte, the results of the current study are in line with the results published by Adel *et al*. [10], who reported a significant difference in Vte between their studied groups as the mean value of Vte in successfully weaned group (448 ml) was higher than the mean value in weaning failure group (286.8 ml). This study shows that the sensitivity, specificity, PPV, and NPV for DTF in prediction of successful weaning at cutoff value more than 33% were 94, 100, 100, and 91.7%, respectively; and for DE at cutoff value more than 0.91 cm were 84, 37, 69.6, and 57.1% respectively; and for RSBI at cutoff less than 103 were 100, 82, 90.5, and 100%, respectively. Farghaly and Hasan [12], reported that DE at a cutoff value 10.5 mm or less had 87.5% sensitivity and 71.5% specificity in prediction of successful weaning; however DTF% of at least 34.2% had 90% sensitivity and 64.3% specificity on the other hand RSBI less than 105 had 90% sensitivity and 18.7% specificity in predicting successful extubation. Ferrari *et al.* [5], found that DTF more than 36% is a predictor of successful weaning. Eman and Ahmad [8], reported that the cutoff value for DTF more than 30% has sensitivity of 97.3%, specificity of 85.2%, PPV of 94.4%, NPV of 90.6%, and accuracy of 91.9%, and DE at cutoff value more than 1.5 cm showed a sensitivity of 88.7%, specificity of 84.3%, PPV of 92.6%, NPV of 81.3%, and accuracy of 87.9%. A recent study by Pirompanich and Romsaiyut [11], found that RSBI up to 105 has sensitivity of 96.0%, specificity of 44.4%, PPV of 82.8%, NPV of 80.0%, and accuracy of 82.4%, and DTF of at least 26% has sensitivity of 96.0%, specificity of 67.7%, PPV of 88.9%, NPV of 85.7%, and accuracy of 88.2%. They reported that prediction of successful weaning is greatly improved when both the right DTF and RSBI are used together as patients who cannot maintain natural breathing have a tendency to have high respiratory frequency and low tidal volume, which might be attributed to diaphragmatic weakness. The aforementioned results may be explained by the significance of the diaphragm's involvement in tidal volume. The function of all inspiratory muscles is revealed by RSBI which constitutes the integrative function of both inspiratory muscle capacity and respiratory load. If there is diaphragmatic failure, the other inspiratory muscles will pay compensation to reserve tidal volume, and diaphragmatic weakness may be masked by the action of these muscles. However, the rib cage muscles are weaker than the diaphragm and more susceptible to fatigue, and these muscles are unable to maintain sufficient ventilation [14]. Accordingly, weaning failure may occur in spite of an initially adequate tidal volume and RSBI. In this situation, using B-mode in measurement of diaphragmatic function would be a better tool to predict weaning failure. The lower sensitivity and specificity for DE when compared with DTF in predicting weaning failure may be elucidated by the fact that DTF reflects the active diaphragmatic contraction during mechanical ventilation [15], whereas DE is mainly linked to the inspired volume [16], irrespective of whether it depends on the muscle work or the ventilatory support. Therefore, DTF should be used to estimate the diaphragm function during mechanical ventilation, whereas DE is evocative in the absence of the ventilatory support.

Conclusion

DTF may be useful to predict successful weaning during SBT, and it has better performance than DE.

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Conflicts of interest

There are no conflicts of interest.

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