Diaphragm ultrasound as a predictor of successful extubation from mechanical ventilation

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Background Ultrasonography can be used for assessment of diaphragmatic mobility and thickness. Diaphragm is the main muscle of respiration.

Rationale To predict successful extubation from mechanical ventilation.

Patients and methods Forty patients were involved in the present study. They were admitted in the ICU at Abbassia Chest Hospital. They received the conventional measurements for weaning and transdiaphragmatic ultrasonography after extubation. We assessed the diaphragmatic mobility and diaphragmatic thickening fraction. All ultrasonography findings were gathered and compared with some of the usual weaning tools such as arterial blood gas and respiratory mechanics. The findings were statistically analyzed.

Results Thirty-one patients revealed successful liberation from mechanical ventilation. Diaphragmatic mobility and thickening fraction showed high sensitivity and specificity compared with other weaning tools. The cutoff value was 10 mm for mobility and 30% for diaphragmatic thickening fraction.

Conclusion Diaphragmatic ultrasonography can be used as a new tool for prediction of weaning process.
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Introduction

Liberating a patient off a ventilator is a continuous process as with any disease condition, which starts with recognition of patient being ready to be weaned from ventilator by letting the patient breathe on T-piece, and if successful, proceeding to spontaneous breathing trial (SBT) followed by extubation, if it is tolerated well, or else letting the patient on ventilator till next such trial till being successful [1]. Diaphragm is the principal muscle of tidal volume (TV) in normal patients at rest. Studies have appeared that the defect in diaphragmatic motion is probably related to changes in the main respiratory function measurements [2]. Chest ultrasonography has many uses, both diagnostic and interventional. It can be used in the diagnosis of diseases of the chest wall. Chest ultrasonography can also be used in interventional procedures of the pleural space such as thoracocentesis and pleural biopsy [3].

The aim of this work is to evaluate diaphragmatic motion and thickness as a predictor of extubation success or failure.

Diaphragmatic ultrasonography can be used to evaluate diaphragm dysfunction by assessment of diaphragm excursion and thickness to predict weaning outcome.

Diaphragmatic ultrasound has been used successfully to evaluate diaphragm dysfunction, and using excursion, it can discriminate between diaphragmatic paralysis, paradoxical upward movement, or immobility of the diaphragm. Diaphragmatic ultrasound using either excursion or thickening fraction has been demonstrated to perform at least equally or even better to other established weaning indices such as rapid shallow breathing index (RSBI) and maximum inspiratory pressure.

Patients and methods

It is a prospective study. Ethical approval was taken from the head of icu department at abbassia chest hospital.

Nonprobability sampling was done according to inclusion and exclusion criteria.

Patient selection bias was avoided by using random methods when selecting groups from population and ensuring that groups are equivalent.

Consent was taken from the patients.

Our present study was done on 40 patients in the ICU at Abbassia Chest Hospital in the time from July 2016 until

July 2017. The patients were split into two categories regarding their reaction to liberation attempts:

Category A represented successful liberation.
Category B represented unsuccessful liberation, followed by reintubation and mechanically ventilated after 2 days.

Diaphragmatic motion and diaphragmatic thickening fraction (DTF) parameters were gathered for each category and correlated with selected liberation criteria: partial pressure of arterial oxygen (PaO_2), partial pressure of carbon dioxide in the arterial, respiratory rate (RR), maximum inspiratory force pressure, and RSBI.

The following parameters were fulfilled: full history, comorbidities, and thorough clinical examination. All patients in whom clinical status was stable underwent a low-level pressure support liberation from mechanical ventilation attempt or a spontaneous breathing attempt. Arterial blood gas measurements were done 1/2 h after spontaneous breathing trial. Diaphragmatic thickness (DT) was estimated in area of apposition of the diaphragm to the rib cage using a 7–10 MHz ultrasonographic probe. Difference in diaphragm thickness among end-expiration and end-inspiration was measured during either spontaneous breathing or pressure support. Successful extubation was prescribed as spontaneous breathing for more than 48 h after endotracheal extubation was done.

Inclusion criteria

All patients with respiratory failure who required mechanical ventilation were included. All patients had fraction of inspired oxygen (FiO_2) of less than 50%, were hemodynamically stable in the absence of vasopressors, and were fully conscious.

Exclusion criteria

Pregnant women, surgical dressings over the right lower rib cage which would preclude ultrasound examination, unstable hemodynamics, disturbed conscious level of the patients, uncontrolled comorbid disease affecting the weaning of the patients, intubated patients owing to surgical cause, presence of ascitis, colonic distension, presence of lung collapse, fibrosis or pleural effusion, and presence of any mass or mechanical factor in chest or abdomen interfering with the diaphragmatic mobility were the exclusion criteria.

Chest ultrasound examination methodology

Philips ultrasound machine, USA (ClearVue 350) with serial number 453561480681, with double probe, was used for examination of the patients during SBT. Examination was done using a 3.5C (bandwidth 2–5 MHz) convex phased array probe (low-frequency probe with greater depth and allows to assess excursion).

Moreover, Siemens ultrasound machine was used using model: MCmD01AA, serial-No: SN160525010102, made in Italy for Siemens Medical Solutions, USA, Inc. (Issaquah, Washington, USA).

Arterial blood gas machine had the following specifications:

Instrumentation Laboratory Company, Bedford, Massachusetts, USA.

Instrumentation Laboratory SpA, V.le Monza 338, Milano, Italy.

Model:GEM-PREMIER-3000.

RE-F Type.

Made in USA.

Statistical methods

The data were coded, put in tables, and statistically analyzed using statistical package for the social sciences, version 17, statistics software.

Explanation of quantitative variables was done as mean, SD, and range. Explanation of qualitative variables was done as number and percentage. Receiver operator characteristic curve was used to get the best cutoff value, and the validity of predestined variable. Positive predictive value=(true positive test/total positive test)×100=% of true positive cases to all positive. Negative predictive value=(true negative test/total negative test) ×100=% of the true negative to all negative cases. P value more than 0.05 was insignificant, P value less than 0.05 was significant, P value less than 0.01 was highly significant. Diagnostic accuracy = ([true positive test +true negative test]/total cases)×100.

Results were then put in tables and statistically analyzed using SPSS.

Results

The study was conducted on 40 patients. Their age ranged between 18 and 82 years old, and their mean age was 53 years. Thirty-one (77.5%) patients demonstrated successful weaning process and were declared as category A, whereas nine (22.5%)

patients failed weaning and were re-intubated after 2 days from the attempt and were declared as category B.

There was important statistical difference before and after liberation from mechanical ventilation in both categories according to diaphragmatic excursion (DE) alone (P=0.02) (Table 1).

There was a positive relationship between DE before weaning and the other parameter after weaning (DE, DT, and DTF%). Moreover, there was a positive relationship between DT before weaning and DE and DT after weaning, but there was no correlation between DTF% before weaning and the other parameter after weaning, except DTF%, which had a positive relationship (Table 2).

There was a negative relationship between the DE, DT, and DTF% before the weaning and diaphragmatic excursion difference (DED), diaphragmatic thickening difference (DDT), and diaphragmatic thickening fraction difference (DDTF%), correspondingly; however, it became positive following liberation from mechanical ventilation (Table 3).

Table 1 Comparison of ultrasound diaphragmatic parameters before and after weaning

Variables	Mean	Median	*P*
DE (cm) (before)	2.4	2.3	0.002*
DE (cm) (after)	2.9	2.9	
DT (cm) (before)	0.24	0.25	0.21#
DT (cm) (after)	0.25	0.25	
DTF (%) (before)	54	55	0.34#
DTF (%) (after)	56	56	

DE, diaphragmatic excursion; DT, diaphragmatic thickness; DTF, diaphragm thickening fraction. *Significant.

Regarding the relationship between the whole criteria of weaning [TV (ml/kg), PiO_2/FiO_2, RR (min), minute ventilation (l/min), and RSBI] and the DE (cm) before and after weaning and DDE (cm), there were an important positive correlation appeared among TV (ml/kg) and DE (cm) before weaning (P=0.02). Similar significant positive correlation appeared between RR (min) and DED (cm) (P=0.05). Moreover, rapid shallow breathing index (RSBI) index had significant correlation with DT (cm), and it was negative in direction before weaning and positive in direction with DDT (cm) (P=0.049 and 0.024, respectively). Finally, there were a significant correlation between the TV (ml/kg) and DTF% after weaning and DDTF%, and it was positive in direction (P=0.012 and 0.007, respectively) (Table 4).

Discussion

This study was conducted on 40 patients admitted to Abbassia Chest Disease Hospital at ICU to estimate diaphragm thickening and diaphragm mobility, which can be used as a predictor of weaning success or failure.

Liberation from mechanical ventilation of ICU patients is a complex process with an evaluated 20% failure rate [4]. This process decision depends on many factors and tools, mainly the arterial blood gases and the respiratory mechanics, with all tools representing diaphragmatic function [5].

In this study, nine patients went through failed weaning process, representing 22.5% of the studied patients. This is nearly coordinated with Osman and

Table 2 Correlation between the ultrasound diaphragmatic parameters before and after weaning

Diaphragmatic parameter	DE (cm) (after)		DT (cm) (after)		DTF (%) (after)	
	*r**	*P*	*r**	*P*	*r**	*P*
DE (cm) (before)	0.553	<0.0001*	0.308	0.053*	0.399	0.012*
DT (cm) (before)	0.359	0.023*	0.363	0.021*	–0.163	0.322
DTF (%) (before)	0.206	0.202	–0.215	0.182	0.584	<0.0001*

DE, diaphragmatic excursion; DT, diaphragmatic thickness; DTF, diaphragm thickening fraction.

Table 3 Correlation between the ultrasound diaphragmatic parameters before and after weaning and the difference in between

Diaphragmatic parameter	DED (cm)		DDT (cm)		DDTF (%)	
	*r**	*P*	*r**	*P*	*r**	*P*
DE (cm) (before)	–0.328	0.039*	0.089	0.584	0.156	0.343
DE (cm) (after)	0.606	<0.0001*	–0.213	0.187	0.153	0.352
DT (cm) (before)	0.201	0.213	–0.545	<0.001*	0.183	0.264
DT (cm) (after)	–0.168	0.3	0.583	<0.001*	–0.1	0.545
DTF (%) (before)	–0.04	0.806	0.15	0.356	–0.342	0.033*
DTF (%) (after)	–0.022	0.895	–0.092	0.578	0.563	<0.001*

DDT, diaphragmatic thickening difference; DDTF, diaphragmatic thickening fraction difference; DE, diaphragmatic excursion; DED, diaphragmatic excursion difference; DT, diaphragm thickness; DTF, diaphragmatic thickening fraction.

Table 4 Relation between criteria of weaning and the ultrasound diaphragmatic parameter before and after weaning

Diaphragmatic measurement	TV (ml)		PaO_2/FiO_2		RR (cycle/m)		MV (l/min)		RSB index	
	*r**	*P*	*r**	*P*	*r**	*P*	*r**	*P*	*r**	*P*
DE (cm) (before)	0.368	0.02*	0.234	0.147	−0.125	0.443	0.058	0.723	−0.305	0.056
DE (cm) (after)	0.285	0.074	0.305	0.056	0.169	0.296	0.291	0.069	−0.054	0.739
DED (cm)	−0.028	0.866	0.123	0.451	0.311	0.051*	0.275	0.086	0.229	0.154
DT (cm) (before)	0.247	0.124	0.237	0.14	−0.229	0.155	−0.038	0.814	−0.314	0.049*
DT (cm) (after)	−0.029	0.86	−0.08	0.622	0.113	0.486	0.128	0.433	0.091	0.577
DDT (cm)	−0.242	0.133	−0.279	0.081	0.302	0.058	0.148	0.361	0.355	0.024*
DTF (%) (before)	0.034	0.837	0.102	0.531	0.236	0.143	0.207	0.2	0.166	0.307
DTF (%) (after)	0.401	0.012*	0.02	0.905	0.104	0.53	0.268	0.099	−0.133	0.419
DDTF (%)	0.423	0.007*	−0.109	0.51	−0.075	0.649	0.136	0.411	−0.289	0.075

DDT, diaphragmatic thickening difference; DDTF, diaphragmatic thickening fraction difference; DE, diaphragmatic excursion; DED, diaphragmatic excursion difference; DT, diaphragmatic thickness; DTF, diaphragmatic thickening fraction; MV, minute ventilation; PaO_2, partial pressure of arterial oxygen; RR, respiratory rate; RSBI, rapid shallow breathing index; TV, tidal volume.

Hashim, Esteban and colleagues, Saeed and colleagues and Baess and colleagues [4–8], who showed failure rates of approximately 26.5, 20, 26.7, and 23.3%, respectively. This is in contrast to Ferrari and colleagues who reported 63% failure rate.

False decision in liberation from mechanical ventilation associated with elevated failure rate results in cardiorespiratory distress, increased stay time in ICU, and elevated mortality rates. Moreover, being too late in liberation decision increases the risk of ventilator associated pneumonia (VAP) and diaphragmatic atrophy [9].

Ultrasonography, which is excessively present in the ICU, gives direct, bed side, and quick visualization and measurement of diaphragmatic motion and diaphragmatic function, as it is a cornerstone of respiratory muscle, which could be used an index for the liberation result [5].

Two studies (with different methodologies) have recently evaluated the concept of using DT (a surrogate for diaphragmatic strength) as a predictor index for weaning outcome. DiNino et al. [10] examined 63 intubated patients with ultrasonography before their first weaning trial and determined the degree of DT during tidal breathing. They found that a cutoff of 30% or more for DT was a good predictor for weaning success. However, Ferrari et al. [11], in their study on 46 tracheostomized patients who failed weaning at least once and underwent sonographic evaluation of DT during maximal inspiration during a trial for liberation from mechanical ventilation, found that a cutoff value of 36% was related to successful weaning. Despite the different cutoff values, the two groups agreed that DT is more accurate compared with the RSBI in predicting successful extubation. They held a similar argument that the RSBI is a result of the work of diaphragm and accessory muscles, where DT reveals the grade of the more potential power.

Ferrari and colleagues revealed important difference in DTF% among patients with successful and failed weaning. SBT-determined DTF% more than or equal to 36% was associated with a successful SBT with a sensitivity of 0.82 and specificity of 0.88. Agmy et al. [12] specified that DTF% more than 40% was associated with a successful SBT and had a sensitivity of 88% and a specificity of 92%.

Ferrari et al. [11] revealed that a DTF value more than 36% is related with successful weaning and suggested DTF has the potential in predicting patients who may not make the process of liberation from mechanical ventilation, similarly to other already settled weaning measurements and tests.

There was a significant statistical difference before and after weaning in both groups regarding DE only ($P=0.02$). There was a positive correlation among DE before weaning and the other parameters after weaning (DE, DT, and DTF%).

There was a positive relation between DT before weaning and DE and DT after weaning, but there was no correlation between DTF% before weaning and the other parameter after weaning, except DTF%, which had a positive correlation.

There was a negative relationship between the DE, DT, and DTF% before the weaning and DED, DDT, and DDTF%, correspondingly, which became positive after weaning.

Conclusion

Diaphragmatic ultrasound parameters provide rapid and noninvasive indices for weaning process with high accurate results in comparison with other traditional indices such as blood gases and the respiratory mechanics. Therefore, they can be used as predictive parameters to assess the weaning process outcome.

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Conflicts of interest

There are no conflicts of interest.

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