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Research Article

Ultrasound Evaluation of Lung and Diaphragm as Predictors of Liberation Success from Mechanical Ventilation

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Abstract
Background: . Mechanical ventilation (MV) is one of the most common interventions in critical care. Weaning from MV is one of the most frequently encountered challenges in modern intensive care units (ICU). Weaning failure from MV occurred in 10-20% of patients .our study is to predict liberation success from mechanical ventilation using noninvasive method as lung and diaphragm ultrasound. The aim is to evaluate and assess the value of lung and diaphragm ultrasound for predicting liberation success, using diaphragmatic thickening index “TI”, modified lung ultrasound score (LUSm) and diaphragmatic rapid shallow breathing index (DRSBI). **Methods:** This a prospective observational study. The study involved 60 patients who were mechanically ventilated and planned for weaning trial on SBT using PSV mode. Ultra-sonographic assessment of lung and diaphragm was performed 30 min after SBT using the following indices; TI, DRSBI, and LUSm a . **Results:** The patients with (TI) below 24, DRSBI more than 1.3 breath/min/mm and LUSm higher than 6 were experienced high risk of failed weaning. **Conclusion:** DRSBI,TI and LUSm are sensitive non- invasive bed side sonographic indices that can predict liberation success in mechanically ventilated patients. DRSBI is the best diagnostic predictor than TI and LUSmm, sensitivity 100% and 98.33% accuracy.

Keywords: Lung, diaphragm, mechanical ventilation and ultrasound.

Introduction
Most patients may be successfully weaned off mechanical breathing after they have recovered, as long as they have adequate gas exchange, excellent neurological and muscle function, and hemodynamic stability. Weaning failure, on the other hand, is highly prevalent, and mechanical breathing may be necessary within 48 hours of extubation. Prolonged mechanical ventilation and ICU stay are linked to weaning failure. Weaning off a mechanical ventilator is delayed, which increases the risks of barotrauma, ventilator-associated infections, and ventilator-induced diaphragmatic atrophy and dysfunction.(1)

The diaphragm is the primary respiratory muscle. The diaphragm produces roughly 75 percent of resting pulmonary ventilation with an excursion of 1-2 cm, while its amplitude varies from 7 to 11 cm during forced breathing. Sepsis, hypotension, and hypoxia can all cause damage to the diaphragm. The use of mechanical ventilation can cause diaphragmatic dysfunction, which can lead to weaning failure and the need for long-term artificial ventilation. Weaning failure can be avoided if diaphragmatic dysfunction is diagnosed early before extubation.(2)

Diaphragm US is a test that can be used to assess diaphragmatic dysfunction. Weaning failure can occur when a patient is shifted from MV to spontaneous breathing because of lung aeration loss (derecruitment). Lung ultrasound is a new and increasingly used method for studying lung aeration during MV in both a semi-quantitative and quantitative manner(3).

The aim of our work was to evaluate and assess the value of lung and diaphragm ultrasound for predicting weaning and extubation outcome, using diaphragmatic thickening index “TI”, modified lung ultrasound score (LUSm) and diaphragmatic rapid shallow breathing index (DRSBI).

Patients and methods

This a prospective observational study. It was conducted at intensive care unit of Minia University Hospital between August 2020 and November 2021 on 60 patients who were mechanically ventilated .Informed consent was obtained from the patients or their next of kin.

The selected patients were over age of 18 years old, of both genders males and females who had been mechanically ventilated for more than 24 hours and planned to undergo spontaneous breathing trial and met **the criteria for weaning**: (FiO_2 <0.5, PEEP ≤5cm H_20, PO_2 >60 mmHg, $PaCo_2$ <50 mmHg, P/F ratio > 200 and RR 30 breath/min).

Patients were excluded if they were under the age of 18, had diaphragmatic problems or paralysis, had a spinal cord injury above T8, had a pneumothorax, fracture ribs, had an early burn over the chest wall, had hepato-splenomegaly or tense ascites. Pregnancy, patients with muscular diseases such as Myasthenia gravis or Guillain- Barre syndrome and individuals who have chosen to be intubated to preserve their upper air way.

After history taking, general examination and routine lab investigation were done, Patients who met the weaning criteria as before were preform SBT using invasive Pressure support ventilation mode on the following parameters:
PEEP ≤ 5cm H_2O, pressure support ≤ 8 cm H_2O and FiO_2 ≤40% for 30-120 min. After 30 min patients were assessed for tolerance of SBT and assessment of sonographic indices were performed.

Patients were classified into two groups;
Group (S): successful spontaneous breathing trial (SBT) with no need for re-intubation within 48 hours of extubation.
Group (F): SBT failed or re-intubation was required within 48 hours of extubation.

▪ Diaphragm ultrasound

With the patient in a semi-decubitus posture (20o–40o), the right hemi-diaphragm was seen in the zone of apposition, on the mid-axillary line between the 8th and 10th intercostal spaces, using the 7-10 linear probe an of Sonosite Turbo™**.** The diaphragm was regarded as a hypoechoic structure between two echoic lines (the diaphragmatic pleura and the peritoneal membrane), and its thickness was assessed. After 30 minutes of spontaneous patient breathing, diaphragm thickness was measured at the end of expiration and the end of inspiration. We calculate diaphragmatic thickening index **(TI)** by taking the mean of the readings and calculate it using the equation (end inspiratory diaphragm thickness minus end expiratory diaphragm thickness)/end inspiratory diaphragm thickness.

Ultrasonography for diaphragmatic displacement will be performed in the semi-setting position with the head of the bed elevated (30-45 degrees). The right hemi- diaphragm will be examined with a 3-5 MHz probe placed immediately below the right costal margin in the midclavicular line in longitudinal plane using M mode. The liver was used as an acoustic window to the right hemi-diaphragm while patients were scanned along the long axis of the intercostal spaces. The typical diaphragm moved caudally toward the ultrasonic transducer during inspiration, resulting in an upward motion of the M-mode trace. From the beginning to the end of inspiration, diaphragmmatic displacement upward and downward will be measured in (cm) in the vertical axis. Diaphragmatic rapid shallow breathing index **DRSBI** will be measured 30 minutes after SBT using this equation; (respiratory rate/ diaphragmatic displacement in mm

Lung ultrasound:
For modified lung ultra sound score **(LUSm)**, B mode, 2-4 MHz convex probe is employed. As a result of the garding methodology, four ventilation patterns were identified:

- ▪ normal aeration (N; presence of lung sliding with A lines and fewer than two isolated B lines)
- ▪ moderate loss of pulmonary ventilation (B1; more than two well defined B lines)
- ▪ severe loss of pulmonary ventilation (B2; multiple coalescing B lines)
- ▪ pulmonary consolidation (C; presence of a tissue pattern).

The four categories were given scores of 0–3 (0 point for N, 1 point for B1, 2 points for B2, and 3 points for C), and the worst visible pattern in each location was noted. We used a modified approach (LUSm) instead of the original LUS score in our investigation, examining four lung regions on each side instead of the conventional six. The goal of this improvement was to avoid having to move the critical patient, hence avoiding difficulties and making the exami-nation process easier. The anterior–superior, anterior–inferior, lateral, and posterobasal zones were all evaluated. The overall LUSm score for both lungs ranged from 0 to 24 points in all categories.

Sample size calculation:

Sample size was calculated by EPI info program at power of test 80% and confidence interval 95% after a conduction of a pilot study which revealed that the mean of TI in weaning success was 28.3±3 while in failure was 23±1.4, DRSBI in weaning success patients was 1.1±0.1, while in weaning failure patients was 1.7±0.3 and LUSm in successful group 5.6±1 while in failed group 9.2±2.5, so the sample size was 60 patients, 30 patients in each group.

Statistical analysis

The collected data were coded, tabulated, and statistically analyzed using SPSS program (Statistical Package for Social Sciences) software version 25. Descriptive statistics were done for parametric (normally distributed) quantitative data by mean, Standard deviation (SD) and minimum and maximum of range and for non-parametric quantitative data by median and interquartile range (IQR), while for qualitative data by frequency and percentage. Distribution of the data was done by Shapiro Wilk test. Analyses were done between the two groups for parametric quantitative data using Independent Samples T test and for non-parametric quantitative data using Mann Whitney test, while Analyses between the two times within each group for parametric quantitative data were done using Paired Samples T test. Analyses were done between the two groups for Qualitative data using Chi square test. Simple logistic regression analysis was done for prediction of success weaning, followed by ROC curve analysis to calculate area under the curve, optimal cutoff point, sensitivity, specificity, positive predictive value, negative predictive value and accuracy of variables predicting successful weaning. Pearson's correlation coefficient was done to assess correlation between duration of ventilation and sonographic indices. Mann Whitney test for non-parametric quantitative data between duration of ventilation and weaning outcome.

Results:

The study enrolled a total of 60 patients who were prepared for weaning. Flow chart in showed weaning outcome in (fig. 1).

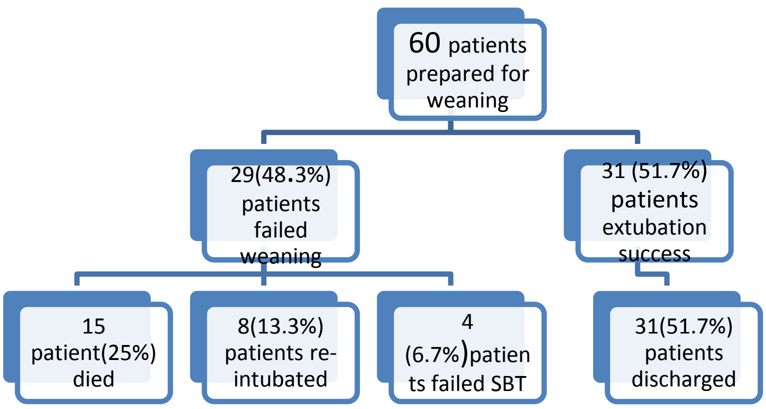

Figure (1) flow chart showing weaning outcome

Table 1 showing the patients characteristics; the majority of cases admitted to ICU was due to trauma. The most common cause of weaning failure among the studied population was disturbed conscious level. The duration of ventilation and length of stay in ICU was shorter in patients with weaning success as compared to weaning failure.

Table (1): Patients characteristic (data are expressed as a mean ±SD or number and percentage

variables	Group S Success (31)	Group F Failed (29)	P value
●age	32.5±12.3	43.9±10.8	<0.001*
●sex Male	22(71%)	19(65%)	
female	9(29%)	10(34)	
Comorbidities (N %)			
Diabetes	1	3	
Hypertension	2	3	0.090
Ischemic heart disease	1	1	
Cause of ICU admission: N(%)			
●Trauma	12(20%)	24(40%)	<0.001
●Hemodynamic unstability	1 (1.6%)	-	
●Post operative	7(11.6%)	1(1.6%)	0.002*
●Post ictal	7(11.6%)	-	
●chest cause	4(6.6%)	1(1.6%)	0.272
●sepsis		1(1.6%)	
Cause of filure of weaning:			
●DCL		16(26.6%)	
●hemodynamic unstability		2(3.3%)	<0.001
●respiratory problem		11(18.3%)	
Durationof mechanical ventilation (days)	1±2	3±3.5	<0.001
Length of stay in ICU (days)	4±2	5±2	<0.001
Mortality rate	-	15 (25%)	<0.001

Table 2 illustrated the sonographic indices**;** diaphragmatic thickening index **(TI)** measured 30min after SBT was significantly high in successful group it ranged between (22-35%) with mean ±SD (28.3%±3) and ranged between (20-25%) with mean ± SD (23%±1.4) in the successful and failed group respectively with (p value <0.001) .

According to diaphragmatic rapid shallow breathing index **(DRSBI)** measured 30 min after SBT was also statistically significant with mean±SD (1.1 breath/min/mm±0.1) in successful and (1.7 breath/min/mm ±0.3) in failed group and p value <0.001 respectively. Modified lung ultrasound score (**LUSm)** 30 min after SBT was significantly lower in successful group than the failed one with mean (5.6±1) and (9.2±2.5) in successful and failed group respectively and with p value <0.001

Table (2): Sonographic indices of lung and diaphragm among studied groups.
Data are expressed as range or mean ± standard deviation (SD)

		Success N=31	Failed N=29	P value
TI 30 min after SBT(%)	*Range* *Mean ± SD*	(22-35) 28.3±3	(20-25) 23±1.4	***<0.001****
DRSBI 30 min after SBT (breath/min/mm)	*Range* *Mean ± SD*	(0.9-1.3) # 1.1±0.1	(1.3-2.5) # 1.7±0.3	***<0.001****
LUSm 30 min after SBT	*Range* *Mean ± SD*	(4-8) 5.6±1	(6-14) 9.2±2.5	***<0.001****

TI: diaphragmatic thickening index **LUSm:** modified lung ultrasound score.

DRSBI: diaphragmatic rapid shallow breathing index Cut off value of **TI** 30 min after SBT in patients who had successful weaning was **>24%** with sensitivity, specificity, PPV, NPV and accuracy (90.3%, 89.7%, 90.3%, 89.7%, 90%) respectively. AUC was 0.952 as **illustrated in table 3**.
Cut off value of **DRSBI** 30 min after SBT in patient who weaned successfully was ≤1.3 breath/min/mm with sensitivity 100%, specificity 96.55%, PPV, NPV and accuracy (96.9%, 100% .98.33) respectively. The AUC 0.999 as **shown in table 3.**

LUSm 30 min after SBT in the successfully weaned patient had optimal cut off value ≤6 with sensitivity 83.9% and specificity 93.1%. PPV, NPV, and accuracy (92.9%, 84.4%, and 88.3% respectively). AUC was 0.940 as **shown in table 3.** patients with a value of **TI** lower than 24%, **DRSBI** more than 1.3 breath/min/mm and **LUSm** more than 6 weaning failure will be expected in them and **DRSBI** was the most sensitive and accurate sonographic index of prediction the waning out come with sensitivity 100% and 98.33% accuracy**.**

Table (3): Receiver operating characteristic curve (ROC) analysis in studied population.
Data are expressed as mean ± standard deviation (SD) or Number and percentage.

	Optimal cutoff point	AUC	95% CI	P value	Sensitivity	Specificity	PPV	NPV	accuracy
TI 30 min	>24	0.952	0.863-0.99	<0.001	90.32%	89.66%	90.3%	89.7%	90%
DSRBI 30 min	≤1.3breath/ min/mm	0.999	0.938-1	<0.001	100%	96.55%	96.9%	100%	98.3%
LUSm 30 min	≤6	0.940	0.848-0.985	<0.001	83.87%	93.1%	92.9%	84.4%	88.3%

Simple logistic regression analysis for prediction of success of weaning revealed that increase the TI 30 min after SBT will increase the possibility of success weaning (OR=3.85, P= 0.002), while increase in LUSM 30 min will decrease the possibility of success weaning (OR=0.17, P < 0.001)as shown in **table (3).**

Table (3): Simple logistic regression for prediction of success weaning.
Data are expressed as number.

	OR	95% CI	P value
DSRBI 30 min	NA	NA	NA
TI 30 min after SBT	3.85	1.66-8.92	0.002*
LUSM 30 min after SBT	0.17	0.07-0.45	<0.001*

- *OR: Odds Ratio* *CI: Confidence Interval*

There was a negative correlation between duration of mechanical ventilation and diaphragmatic thickening index (rho -0.577), while diaphragmatic rapid shallow breathing index and modified lung ultrasound score were positively correlated (rho 0.573, 0.425) respectively with p value< 0.001 as illustrated in table (4).

Table (4): Correlation between duration of ventilation and sonographic indices.
Data are expressed as number.

All cases (n=60)	Duration of ventilation	
	r	**P value**
TI 30 min after SBT	-0.577	<0.001*
DRSBI 30 min after SBT	0.573	<0.001*
LUS m /24 30 min after SBT	0.425	0.001*

Discussion

The number of tools available for selecting the best time to wean and predicting the success of weaning is limited. Subjective decisions are frequently incorrect. The US is well-known as a noninvasive, widely available, and simple to use method that can be used by an intensivist to evaluate and manage mechanically ventilated patients, as well as guide weaning from it. The lungs and diaphragm should be examined during a chest ultrasound. LUS can detect extravascular lung water and measure the degree of regional lung aeration loss with pinpoint accuracy[3]

Because the diaphragm is the major muscle of breathing, accounting for roughly 70% of tidal volume during inspiration in healthy people, diaphragmatic dysfunction is not uncommon in patients with weaning problems[4]

The results of the present study demonestrated that, 31 patients experienced successful weaning (51.7%), while 29 patients experienced failed weaning(48.3%) and re- intubated and mechanically ventilated within 48 hours.
The current study revealed that, patients with (TI) below 24, DRSBI more than 1.3 breath/ min/mm and LUSm higher than 6 were experienced high risk of failed weaning.

The diaphragmatic thickening index (TI) 30 min after SBT with cut off value > 24% with a sensitivity 90.32%, specificity 89.88%, PPV 90.3% and NPV 89.7%. The diaphragmatic rapid shallow breathing index (DRSBI) with cut of value ≤1.3 breath/min/mm with sensitivity 100%, specificity 96.55%, PPV 96.9, NPV 100%. Modified lung ultrasound score (LUSm) with optimal cut off value ≤ 6, sensitivity 83.9% and specificity 93.1%, (92.9%, 84.4%, 88.3%) for PPV, NPV, accuracy respectively indicated that patients had high risk of successful weaning.

Our findings matched with those of (Tenza-lozano, et al., 2018)[5] study which use lung and diaphragm ultrasound as predictors of success in weaning from mechanical ventilation. They evaluate diaphragmatic thickening index and lung aeration on 4 lung areas 30 min after SBT and found that optimal cut off point of TI was 24%, with a sensitivity 93%, specificity 58% and LUSm is greater than 7 points, the patient has a high risk of weaning failure.

In collaboration with our results (Zaytoun et al., 2021)[6],who studied the role of diaphragmmatic rapid shallow breathing index and maximum inspiratory pressure in predicting outcome of weaning from mechanical ventilation. They found that DRSBI less than 1.6 breaths/min/mm was a very good tool to predict successful weaning.

(Spadaro et al., 2016) investigated the role of the diaphragmatic rapid shallow breathing index (DRSBI) in predicting weaning failure during T-tube trials and discovered that DRSBI was the measure with the highest diagnostic accuracy[7]. A cutoff of D-RSBI >1.3 breaths/min/mm yielded 94.1% sensitivity, 64.7% specificity this was in accordance with our results.

Our results were in agreement with (Bouhemad et al., 2020)[8] who used combined cardiac and lung ultrasound to predict weaning failure in elderly high risk cardiac patients. They assess the lung aeration in 6 areas for each lung, the condition has been reported to be associated with extubation failure if the anterolateral LUS score is ≥5 and matched with the results of (Gok et al., 2021)[9] who found that for the success of extubation, the cut-off value for LUS obtained during the T-tube stage was 6.5 as a total of eight areas.

Conclusion

DRSBI, TI and LUSm are sensitive non-invasive bed side sonographic indices that can predict weaning out come in mechanically ventilated patients. **DRSBI** is the best diagnostic accuracy than TI and LUSmm, sensitivity 100% and 98.33% accuracy.

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