Original Article

Anticipation of Succeeded Liberation from Invasive Mechanical Ventilation via Sonographic Pulmonary Scores in Intensive Care Unit Patients; Prospective, Observational Study

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ABSTRACT

Background: Liberation from invasive mechanical ventilation remains a challenge for intensive care physicians. The aim of this study was to ensure that; sonographic pulmonary scores in the form of diaphragmatic thickening indices and modified lung ultrasound scores are reliable and accurate additional tools to anticipate successful liberation from invasive mechanical ventilation in intensive care unit patients.

Methods: This study was a prospective, observational study conducted at Sohag university hospital on 80 patients admitted to intensive care unit and mechanically ventilated invasively for more than 24 hours and they were ready for weaning by standard methods. At the time of spontaneous breathing trials, diaphragm and lung ultrasound were done to obtain diaphragmatic thickening indices and modified lung ultrasound scores. Patients were classified into two groups; failure group (FG) and succeeded group (SG) of liberation from invasive mechanical ventilation.

Results: Only 13 cases (16.25%) were re-intubated within 48 hours after extubation (FG) and 67 cases (83.75%) showed succeeded liberation from invasive mechanical ventilation (SG). The mean diaphragmatic thickening indices were lower in FG (37.2±4.02%) compared to SG of liberation from invasive mechanical ventilation (40.9±6.2%) with significant *p*-value (<0.005) and the mean modified lung ultrasound scores was higher in the FG (16.62±3.223) compared to the SG, (10.69±3.75) with highly significant *p*-value (<0.001).

Conclusions: In our study, sonographic pulmonary scores in the form of diaphragmatic thickening indices and modified ultrasound lung scores provide rapid, bedside, non-invasive, reliable, and accurate, additional methods to anticipate succeeded liberation from invasive mechanical ventilation in critically ill patients.

Key Words: Diaphragm and lung ultrasound, Intensive care unit, Weaning from mechanical ventilation.

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INTRODUCTION

Intensive care unit (ICU) physicians continue to face a challenge in determining the most appropriate time to release a critically ill patient from invasive mechanical ventilation (IMV), as the risk of liberation failure is elevated when IMV is withdrawn prematurely[1]. Conversely, delayed liberation prolongs the duration of MV with additional complications such as barotrauma or ventilator-associated pneumonia[2].

The current guidelines for withdrawal recommend the use of spontaneous breathing trials (SBT) as a method to predict the outcome of weaning. Nevertheless, 13% to 26% of patients who are extubated subsequently to a successful SBT require reintubation within 48 hours[3].

Diaphragm and lung ultrasound is a promising tool in the ICU nowadays due to its bedside, noninvasive, portable, rapid, and safe nature. So, it is currently a hotspot of research in the ICU[4]. Diaphragmatic excursion (DE), diaphragmatic shallow breathing index (DSBI), and diaphragm thickening indices (DTI) are among several diaphragm sonographic predictors that have been proposed. DTI, or the ejection fraction of the diaphragm, is a measure of the diaphragm's thickness during respiratory effort. The lung ultrasound score (LUS) or the modified lung ultrasound score (LUSm) can be used to quantify the aeration and ventilation status of the lung parenchyma. The values of LUSm, which range from 0 to 24 points, are derived from the sum of the grades assigned

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to various ventilation patterns observed in four areas of each lung scan, rather than the six lung areas of LUS (0 to 36 points)[5-8].

The primary outcome was to conclude cut off values for DTI and LUSm with sensitivity and specificity for anticipation of liberation from IMV. The secondary outcomes were to determine the correlations of pulmonary scores (DTI and LUSm) with demographic, clinical and respiratory data including negative and positive correlations in prediction of succeeded liberation from IMV.

PATIENTS AND METHODS

This prospective, observational study was conducted at Suhag University Hospital from September 2022 to October 2023 on 80 patients who were admitted to the ICU and mechanically ventilated invasively for more than 24 hours and ready for weaning. The study was approved by the local Ethical Committee under IRB registration number: Soh-Med-22-09-20, clinical trial number of NCT06461754 and written informed consent was obtained from the nearest relative for each patient. Inclusion criteria: over 18 years of age, more than 24 hours on IMV, and prepared for weaning. Exclusion criteria included spinal cord injury that exceeded T8, arrhythmias, heart failure, hemodynamic instability, terminal extubation, pregnancy, pneumothorax, pneumomediastinum, COPD, thoracostomy, chest injuries that impeded ultrasound, pleural lesions, or neuromuscular diseases.

SBT were initiated by the patient who was prepared to commence weaning using conventional methods (FiO_2 ≤0.4, SaO_2 ≥92, frequency <30b/m PEEP <6, PaO_2/FiO_2 ≥201, fully conscious, intact cough reflex, metabolically stable, and hemodynamically stable). The patient was initially transitioned to the pressure support (PS) mode of respiration, which involves continuous positive airway pressure (CPAP) with a positive end expiratory pressure (PEEP) of 5cmH2O and a PS of 8cmH2O (GE DATEX-OHMEDA E, USA). The SBT was maintained with 8cm H2O PS and 5 PEEP if no adverse signs were observed in the patient. Patients who successfully completed the SBT were then extubated.

Weaning failure was defined as the patient's failure during; the SBT, PS ventilation period, or extubation. SBT failure was defined as the presence of such features as an increase in respiratory workload (nasal flaring, paradoxical breathing movements, use of accessory respiratory muscles or diaphoresis), hemodynamic instability (heart rate >140, systolic blood pressure ≥180mm/hg and <90mm/hg), and changes in consciousness, sweating, or frequency ≥30 breaths per minute. Extubation failure was defined as the re-intubation of the patients, the implementation of noninvasive mechanical ventilation (NIMV), or death within 48 hours of extubation. The sonographic evaluations were conducted by a physician with extensive experience in this field during the PS ventilation phase, following the completion of approximately 60 minutes of SBT by the patients. The physician who assessed those results was not responsible for making the decision to extubate the patients.

Ultrasound technique:

The diaphragm thickness was measured in the zone of apposition, on the mid-axillary line among the 8^{th} and 10^{th} intercostal spaces, using a 7–10MHz linear probe in (M) mode (MINDRAY DP – 20, CHINA). The patient was in a semi-decubitus position (20-40 degree) and the diaphragm was viewed as a hypo-echoic structure among two echoic lines (the diaphragmatic pleura and the peritoneal membrane). We measured the thickness of the diaphragm at the end of expiration and at the end of inspiration by capturing nearly three images in M-mode during spontaneous patient breathing. The average of three DTI measurements was calculated using the following formula: (end inspiratory diaphragm thickness - end expiratory diaphragm thickness) / (end expiratory diaphragm thickness)x100[9].

In lung ultrasound; (MINDRAY DP – 20, CHINA) 2–4MHz convex ultrasound probe in (B) mode was employed. The scoring system was implemented to differentiate among four ventilation patterns as follows: (1) Normal aeration (N; presence of lung sliding with A lines and fewer than two isolated B lines), (2) Moderate loss of pulmonary ventilation (B1; ≥2 well-defined B lines), (3) Severe loss of pulmonary ventilation (B2; multiple coalescing B lines), and (4) Pulmonary consolidation (C; presence of a tissue pattern). Each region's most obtrusive pattern was documented, and the four categories were assigned scores of 0–3 (0 points for N, 1 point for B1, 2 points for B2, and 3 points for C). We implemented a modified lung ultrasound score (LUSm) in our investigation, which assessed four lung regions on each side. We evaluated the anterior–superior, anterior-inferior, lateral, and postero-basal lung regions[8]. The total LUSm score for all areas ranges from 0 to 24 points.

Measuerments:

Demographic data and basic clinical data in the form of age, sex, cause of ICU admission, associated comorbidities, time of SBT in minutes and time of MV, ICU stay and hospital stay in days were recorded and compared between study groups. Clinical respiratory data in the form of VE (minute volume in liters), Compliance (ml/cm H2O), PIMax in cmH2o (maximum inspiratory pressure), P0.1 in cmH2O (airway occlusion pressure at 0.1 second of inspiration), RSBI breaths/min/L (Rapid shallow Breathing Index), RR (Respiratory Rate) breaths/minute, Tidal Volume (TV ml), FiO2, SpO_2, PaO_2, PaCO2 and pH were reported and compared between both groups. Also comparisons among LUSm and DTI in relation to demographic, clinical and respiratory data were obtained. Negative or positive correlations of DTI and LUSm to demographic, clinical and respiratory data were obtained.

Statistical analysis:

The statistical data analysis was conducted using the IBM-SPSS version 25 software, which was developed by IBM in Chicago, USA in August 2017. The data is presented as mean, standard deviation (SD), number, and percentage. Quantitative data were described using the mean and standard deviation, while qualitative data were described using the number and percentage. In the event of non-parametric data, the Mann Whitney test was employed in place of the Student *t* test to compare the means of the two groups. The percentages of qualitative data were compared using Pearson Chi square, while non-parametric data were analyzed using Fisher's exact test. Two quantitative variables were compared using the Pearson correlation test. The following are the explanations for the value of (*r*): Negligible correlation is indicated by $r<0.2$, weak correlation by $r= 0.2-0.4$, moderate correlation by $r= 0.4-0.7$, strong correlation by $r= 0.7-1$, positive correlation by $r= 0$ and negative correlation by $r= -1$. In order to evaluate the predictive value of DTI and LUSm for the risk of weaning failure and to determine the most appropriate cut-off values that achieve the highest level of accuracy (including the highest sensitivity and specificity), a Receiver Operating Characteristics curve (ROC) analysis was conducted. In order to evaluate the potential risk factors of DTI and LUSm for weaning failure, a univariate binary logistic regression analysis was conducted. The variables that exhibited significant univariate regression were incorporated into a multivariate binary logistic regression analysis model to determine whether they could be considered independent risk factors. The level of significance (*P*-value) for all of these tests can be characterized as non-significant (NS) if the *P*-value is greater than or equal to 0.05, significant (S) if the *P*-value is less than 0.05, and highly significant (HS) if the *P*-value is less than or equal to 0.001. After employing the "Power and Sample Size Program" software to determine the minimum sample size required, we determined that a minimum of 52 cases would be required to reject the null hypothesis that the population means of the experimental and control groups are equivalent with a probability (power) of 0.95. This null hypothesis test is associated with a Type I error probability of 0.9. The number of cases was increased to 80 in order to overcome dropout.

RESULTS

Our study enrolled 80 patients; all of them completed the study [Flow chart Figure (1)]. All patients were extubated, only; 13 patients (16.25%) needed reintubation within 48 hours after extubation; failed group (FG) and 67 patients (65.75%) liberated successfully; succeeded group (SG).

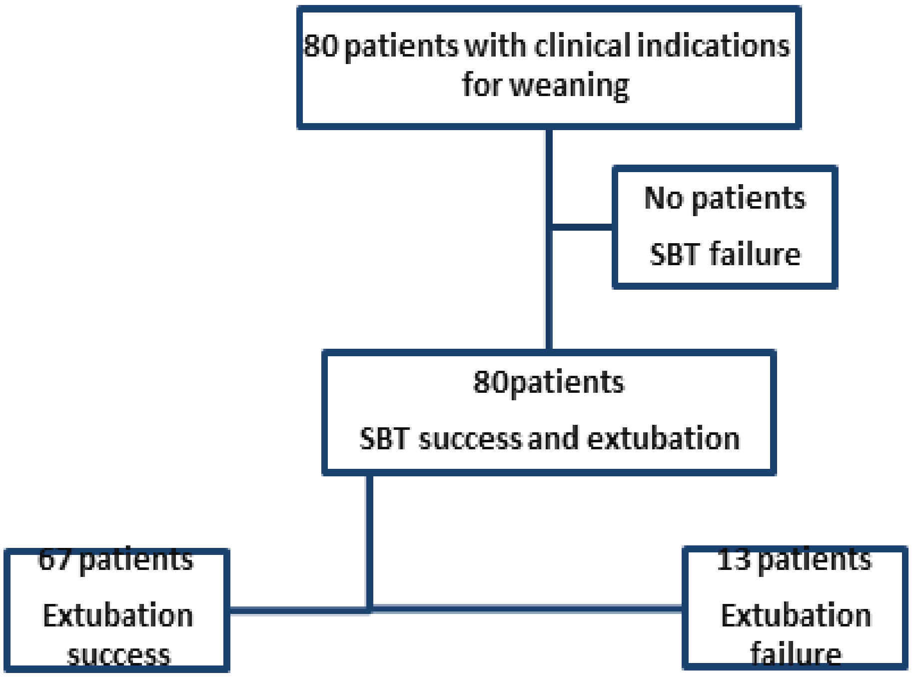

Fig. 1: Flow chart.

A little more than half of the cases were males (57.5%) and the mean age of the study population was around 34±11.8 years. The causes of invasive MV were; septic shock (16.25%), pulmonary edema and impending respiratory failure (15% each), Airway protection during fits (13.75%), disturbed level of consciousness (11.25%), hypoxia (10%), increased intracranial tension (6.25%), post cardiac arrest (3.75%) and hypovolemic shock and organophosphorus poisoning (2.5% each). Nearly all cases had comorbidities (92.5%), in the form of acute kidney injury, diabetes mellitus, Hypertension, chronic kidney disease, ischemic heart disease, acute pneumonia or cancer with single or combined comorbidities.

As regard demographic data, cause of ICU admission and presence or absence of comorbidities there was no statistical significant difference between the studied groups (Table 1).

As regard clinical data, FG had longer time of SBT 238.5±106.6 minutes compared to 171.9±85.8 minutes for SG with *p*-value of 0.016, which is significant and also hospital stay in days was more in FG, 14.3±2.63 compared to 12.3±5.21 in SC with significant p-value of 0.045. Other demographic and clinical data showed non significant relation between both groups (Table 1).

In relation to pulmonary scores; the mean DTI was lower among FG (37.2±4.02%) compared to SG (40.9±6.2%) with significant *P* value <0.05. On the other hand the mean LUSm was significantly higher among FG (16.6±3.2) compared to SG (10.7±3.8) with highly significant *p*-value <0.001 (Table 1).

According to the clinical respiratory data; FG had lower mean values of; VE (minute volume), Compliance, SpO2, PaO_2 with *P* value <0.001 (HS), lower mean FiO_2 with *P* value <0.05 (S) and higher mean RSBI with *P* value <0.001(HS) compared to SG (Table 1).

Table 1: Comparison between FG and SG regarding demographic, basic clinical, respiratory data, pulmonary scores and mortality:

Variables		**SG**	**FG**	***P* value**
Sex	Male	39(58.2%)	7(53.8%)	0.771(NS)
	Female	28(41.8%)	6(46.2%)	
Age	Mean±SD	34.4±12.4	28.3±5.21	0.084 (NS)
Comorbidities	No	6(9%)	0	0.262(NS)
	Yes	61(91%)	13(100%)	
Time on MV (days)	Mean±SD	6.0±3.86	5.6±1.33	0.445(NS)
Time SBT (minutes)	Mean±SD	171.9±85.8	238.5±106.6	0.016(S)
Hospital stay (days)	Mean±SD	12.3±5.21	14.3±2.63	0.045(S)
ICU stay (days)	Mean±SD	9.0±4.76	9.3±3.18	0.781(NS)
LUSm	Mean±SD	10.6±3.75	16.6±3.223	<0.001(HS)
DTI	Mean±SD	40.9±6.2%	37.2±4.02%	0.040 (S)
VE (l/m)	Mean±SD	8.8±1.406	6.7±1.363	<0.001(HS)
Compliance (mL/cmH_2O)	Mean±SD	72.9±22.09	44.3±5.27	<0.001(HS)
PI Max (cm H_2O)	Mean±SD	-16.8±2.6	-16.0±1.63	0.244(NS)
P0.1	Mean±SD	1.6±1.093	1.1±0.689	0.105(NS)
RSBI (breath/min/l)	Mean±SD	40.1±10.6	52.6±13.38	<0.001(HS)
RR (breaths/min)	Mean±SD	18.6±2.24	19.7±2.35	0.103(NS)
TV(ml)	Mean±SD	479.3±99.9	451.2±73.71	0.339(NS)
FiO_2	Mean±SD	39.6±1.3%	38.0±2.65%	0.049(S)
SpO_2	Mean±SD	96.6±1.7%	93.8±1.9%	<0.001(HS)
PaO_2	Mean±SD	123.3±25.5	94.7±3.6	<0.001(HS)
$PaCO_2$	Mean±SD	40.1±3.07	40.0±1.55	0.907(NS)
pH	Mean±SD	7.3±0.02	7.3±0.02	0.419(NS)
ICU mortality	no(%)	1(1.5%)	6(46%)	<0.001(HS)

FG: Failed Group; SC: Succeeded Group; SD: Standard Deviation; LUSm: Modified Lung Ultrasound Score; DTI: Diaphragmatic Thickening Index; SBT: Spontaneous Breathing Trials; VE: Minute Volume; l/m: liter/minute; PIMax: Maximum Inspiratory Pressure; P0.1: Airway Occlusion Pressure at 0.1 second of inspiration; RSBI: Rapid shallow Breathing Index; RR: Respiratory Rate; TV: Tidal Volume; FiO_2: Fractional inspired Oxygen; SpO_2: Arterial Oxygen Saturation; PaO_2: Arterial Oxygen Tension; $PaCO_2$: Arterial CO_2 tension; ICU: Intensive Care Unit; %: Percent; no: number; NS: None significant; HS: Highly significant; S: Significant.

There were positive weak and significant correlations among DTI and each of VE, compliance, Po.1, SpO_2 and PaO_2. negative moderate and significant correlation among LUSm and each of VE and compliance, negative weak correlations among LUSm and each of SpO_2 and PaO_2 and positive weak correlation among LUSm and RSBI. Also, we found negative moderate and significant correlation among LUSm and each of VE and compliance, negative weak correlations with SpO_2 and PaO_2 and positive weak correlation with RSBI. All other correlations were none significant (Table 2).

Table 2: Correlation between pulmonary scores and clinical data:

Variable		LUSm	DTI%
VE (l/m)	Pearson Correlation (r)	-0.420	0.346
	P value	<0.001	0.002
Compliance (ml/cm H_2O)	Pearson Correlation (r)	-0.445	0.310
	P value	<0.001	0.005
PI Max (cm H_2O)	Pearson Correlation (r)	0.071	-0.054
	P value	0.531	0.634
P0.1 (cm H_2O)	Pearson Correlation (r)	-0.072	0.369
	P value	0.525	0.001
RSBI (breaths/min/l)	Pearson Correlation (r)	0.346	-0.132
	P value	0.002	0.244
RR (breaths/min)	Pearson Correlation (r)	0.150	0.002
	P value	0.185	0.987
TV (ml)	Pearson Correlation (r)	-0.213	0.102
	P value	0.058	0.368
FiO_2	Pearson Correlation (r)	-0.166	0.172
	P value	0.142	0.127
SpO_2	Pearson Correlation (r)	-0.294	0.293
	P value	0.008	0.008
PaO_2	Pearson Correlation (r)	-0.315	0.304
	P value	0.004	0.006
$PaCO_2$	Pearson Correlation (r)	-0.123	-0.156
	P value	0.278	0.166
pH	Pearson Correlation (r)	0.022	0.161
	P value	0.847	0.153

LUSm: Modified Lung Ultrasound Score; DTI: Diaphragmatic Thickening Index; VE: Minute Volume; l/m: liter/minute; PIMax: Maximum Inspiratory Pressure; P0.1: Airway Occlusion Pressure; RSBI: Rapid shallow Breathing Index; RR: Respiratory Rate; TV: Tidal Volume; FiO_2: Fractional inspired Oxygen; SpO_2: Arterial Oxygen Saturation; PaO_2: Partial Oxygen Tension; $PaCO_2$: Partial CO_2 tension; %: percent.

Factors which showed significant relation between the FG and SG in the univariate regression analysis (Table 3) were included in the multivariate regression analysis model table to detect the independent risk factors and we found that none of these factors showed significant results which means that all of them are affecting each other and none of them could be a single independent predictive factor for the risk of failure of weaning (Table 4).

By analysis of the ROC curve Figure (2) and table of the area under the ROC curve (Table 5), we found that both DTI and LUSm can be used to predict the risk for failure of weaning, with a significant difference regarding DTI and a highly significant difference regarding LUSm. Using the coordinate points of the curve, we found that the most suitable cut-off point of DTI was 35%, below which the risk for failure of weaning can be predicted with a sensitivity of 69.2% and a specificity of 76.1%. Also, we found that the most suitable cut-off point of LUSm was 14.5, above which the risk for failure of weaning can be predicted with a sensitivity of 76.9% and a specificity of 82.1%.

Mortality rate was higher in FG than SG (6 patients 46% versus 1 patient 1.5%) respectively with highly significant *P* value <0.001. Time of death of all cases was after more than 48 hours of extubation (Table 1).

Table 3: Univariate regression analysis for the possible risk factors for weaning failure among the study population:

Variables	*P* value	Odd's ratio	CI of Odd's ratio
Sex	0.771	1.194	0.362-3.939
Age	0.098	0.941	0.876-1.011
Time on MV	0.670	0.961	0.798-1.156
Presence of comorbidities	0.999	0.978	0.344-2.346
Time of SBT-extubating	0.032	1.007	1.001-1.013
Hospital stay	0.190	1.074	0.965-1.195
ICU stay	0.778	1.018	0.898-1.154
LUSm	0.001(Hs)	1.719	1.274-2.320
(DTI)%	0.044(s)	0.882	0.780-0.997
VE	<0.001(s)	0.418	0.261-0.670
Compliance	0.001(Hs)	0.899	0.842-0.959
PI max	0.242	1.166	0.901-1.507
Po	0.107	0.608	0.331-1.114
RSBI	0.001(Hs)	1.097	1.037-1.161
RR	0.110	1.287	0.945-1.753
Tidal volume	0.339	0.997	0.991-1.003
FiO_2	0.004(s)	0.664	0.500-0.881
SpO_2	0.001(Hs)	0.464	0.313-0.689
PaO_2	0.003(s)	0.920	0.872-0.971
$PaCO_2$	0.906	0.988	0.803-1.215
pH	0.415	1.001	0.998-1.013

LUSm: Modified Lung Ultrasound Score; DTI: Diaphragmatic Thickening Index; MV: Mechanical ventilation; SBT: Spontaneous Breathing Trials; VE: Minute Volume; L/m: liter/minute; PIMax: Maximum Inspiratory Pressure; P0.1: Airway Occlusion Pressure at 0.1 second of inspiration; RSBI: Rapid shallow Breathing Index; RR: Respiratory Rate; TV: Tidal Volume; FiO_2: Fractional inspired Oxygen; SpO_2: Arterial Oxygen Saturation; PaO_2: Arterial Oxygen Tension; PaCO2: Arterial CO_2 tension; ICU: Intensive Care Unit; %: Percent; no: number; NS: None significant; HS: Highly significant; S: Significant.

Table 4: Multivariate regression analysis for the possible risk factors for Prediction of failure of weaning among the study population:

Variables	*P* value	Odd's ratio	CI of Odd's ratio
Time of SBT-extubating	0.999	0.987	0.871-1.228
Time of Hospital stay			
LUSm	0.273	90.122	0.029-282.33
(DTI)	0.297	9.989	0.132-757.22
VE	0.330	11.959	0.081-176.13
Compliance	0.257	0.219	0.016-3.028
RSBI	0.541	1.159	0.723-1.856
FiO_2	0.362	0.020	0.001-91.339
SpO_2	0.263	0.001	0.001-344.98
PaO_2	0.478	0.637	0.183-2.215

LUSm: Modified Lung Ultrasound Score; DTI: Diaphragmatic Thickening Index; CI: Confidence Interval; SBT: Spontaneous Breathing Trials; VE: Minute Volume; RSBI: Rapid shallow Breathing Index; FiO_2: Fractional inspired Oxygen; SpO2: Arterial Oxygen Saturation; PaO_2: Partial Oxygen Tension; PaCO2: Partial CO_2 tension.

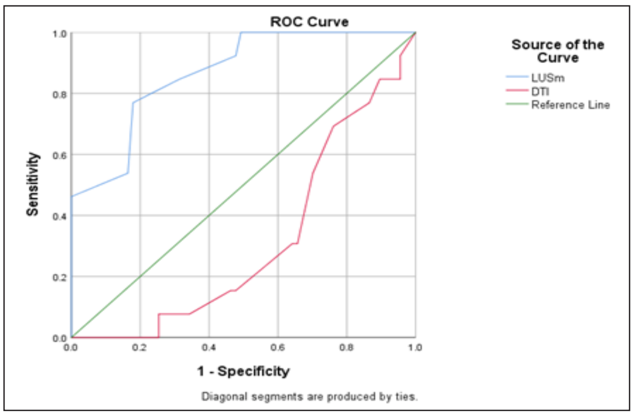

Fig. 2: ROC curve analysis to estimate the predictive value of LUSm and DTI for weaning.

ROC: Receiver Operating Characteristics; LUSm: Modified Lung Ultrasound Score; DTI: Diaphragmatic Thickening Index.

Table 5: Area under the curve:

Test Result Variable(s)	Area	Standard error	*P* value	Asymptotic 95% CI	
				Lower Bound	Upper Bound
LUSm	0.867	0.050	<0.001	0.770	0.965
DTI %	0.315	0.069	0.036	0.180	0.450

LUSm: Modified Lung Ultrasound Score; DTI: Diaphragmatic Thickening Index; %: percent; CI: Confidence Interval.

DISCUSSION

In the present study modified sonographic lung scores(ULSm) and diaphragmatic thickening indices (DTI) were obtained at the PS ventilation period after the patients completed approximately 60 minutes of SBT and then patients extubated under conventional methods.

Our results showed that; all patients were successfully liberated from IMV but 13 patients (16.25%) needed reintubation within 48 hours after extubation; failed group (FG) and 67 patients (83.75%) showed succeeded liberation from IMV; succeeded group (SG). The causes of reintubation in this study were hypoxemia, chest secretions, Co2 retention or disturbed level of consciousness. In harmony with our results; Tenza-Lozano *et al.,*[9] study who recorded failure rate of 24.6% and Farghaly *et al.,*[10] study that reported 25.9% failure rate. In comparison; other far studies recorded high failure rate of 32%, 36%, 35%, 63%, 38% and 48.3% consecutively[11-16]. Only Gok *et al.,*[11] mentioned the causes for re-intubation in FG as tracheobronchitis, mucous plugging and lack of good cough reflex. The management of FG varied among these studies as; re-intubation and IMV, none invasive pressure support ventilation or high frequency nasal ventilation (HFNV)[9-16]. These variations in failure rate and in methods of management of FG might be due to many factors which will be mentioned later.

In relation to pulmonary scores; in this study: the mean DTI was lower among FG (37.2) compared to SG

(40.9) with significant *p*-value (<0.05). All far researches stated that; the mean DTI was significantly lower among FG compared to SG, which is in line with this work but with comparable mean values of DTI for FG (22.94-30.8) and different values from each other's in SG (28.3-58.9)[9-17]. However, Abdel Rahman *et al.,*[18] who studied DTF in pediatric different age groups, reported that; the mean DTF was significantly lower among FG compared to SG in infants (20.4 for FG and 31.75 for SG) and children (15.83 for FG and 28.7 for SG) which is in line with the present and all previous studies (in adults) but stated that no significant difference among FG and SG in adolescents which is in disagreement with the present study and also with previous studies. In the present study the cut-off point of DTI was 35%, below which the risk for failure of weaning can be predicted with a sensitivity of 69.2% and a specificity of 76.1%. The corresponding results in the previous studies reported variable cutoff values (24% - 36%) for prediction of liberation success or failure with variable sensitivity (48%-94%) and variable specificity (64%-100) which is in harmony with our results[9-17]. In line with our results in adults also, Abdel Rahman *et al.,*[18] who studied DTF in pediatric different age groups, reported that; the best cut-off value of DTF for predicting weaning success was ≥23 with a sensitivity of 100% and a specificity of 76.2% for infants and children. On the other hand, in our results the mean LUSm was significantly higher among FG (16.6) compared to SG (10.6) with highly significant *p*-value (<0.001). We reported that the cut-off point of LUSm was 14.5 above which the risk for failure of weaning can be predicted with a sensitivity of 76.9% and a specificity of 82.1%. Other studies also stated that the mean LUSm was significantly higher among FG compared to SG in agreement with our results but all studies recorded different values from our study and from each other's both in mean values and cutoff values. As Tenza-Lozano *et al.,*[9] who found the mean LUSm was 8 for FG and 5 for SG, and the cut-off point was 7 with specificity and sensitivity of 76% and 73% in order. Esraa *et al.,*[16] revealed significantly more mean LUSm in FG than SG, as it was 9.2 and 5.6 respectively and cut off value of ≤6 with specificity 93.1% and sensitivity 83.9%.

Also researches which studied the mean original LUS reported higher significant mean values among FG compared to SG[13,17,18].

DTI and LUSm in relation to clinical respiratory data; our study reported that DTI had significant positive correlation with VE, compliance, P0.1, SpO_2 and PaO_2. All other correlations were none significant including correlations with RSBI. Gok *et al.,*[11] found positive correlation among DTF and RSBI. Ferrari *et al.,*[14] DTF was positively correlated only with expiratory TV. In Esraa *et al.,* work there was a negative correlation among DTI and periods of MV[16]. In Osman *et al.,* study, DTI revealed significant positive correlation with RSBI and PIMax[17]. Also this study reported that LUSm had significant negative correlations with VE, compliance, SpO_2 and PaO_2 and positive correlation with RSBI. In agreement with our study Esraa et al. and Osman *et al.,* concluded that LUSm and RSBI were positively correlated[16,17].

As regard the demographic and clinical data, in our research FG had significant longer time of SBT and hospital stay than SG with significant *p*-value of 0.016 and 0.045 consecutively and all other patients demographic and clinical data showed non significant relation among the two groups. In contrary Tenza-Lozano *et al.,*[9] and Elgazzar *et al.,*[12] studies reported more time on MV for FG than SG with non significant difference in other demographic and clinical data. Gok *et al.,*[11], results who reported that FG had longer duration of MV, ICU stay time and hospital stay duration (in line with our result) than SG. Li *et al.,* stated that no significant difference in demographic and clinical data among the two groups[13], Ferrari *et al.,* the mean duration of MV and time of hospital stay (in line with our result) were significantly higher in FG than SG[14] Esraa *et al.,* study concluded significant older age, longer ICU stay time, more period of MV in FG, also recorded trauma and postoperative cases as causes of MV were significantly more in FG[16]. Abdel Rahman *et al.,* study on pediatric age groups revealed that there were statistically significant differences among FG and SG regarding their age, morbidity and duration of MV[18]. The causes of these variable results among researches in demographic and clinical data in relation among FG and SG will be mentioned soonly.

In relation to clinical respiratory data; FG had lower mean values of; VE, Compliance, SpO_2, PaO_2 and FiO_2 and higher mean RSBI compared to SG. In the univariate regression analysis these factors showed significant results, while in the multivariate regression analysis none of these factors showed significant results, which means that all of them are affecting each other and non of them could be a single independent predictive factor for the risk of failure of weaning. In Tenza-Lozano *et al.,*[9] study only Lower SpO_2 in FG than SG which was the same in our study with no significant correlation with other clinical respiratory values. Some studies also showed only that RSBI values were higher in FG than SG with no significant correlation with other clinical respiratory values[12-14,16]. Youssef *et al.,*[15] found that FG had significant lower mean values of; VE (in line with our study) and PImax (not significant in our study) than SG. Also Osman *et al.*,[17] reported that FG had lower mean values of PaO_2 (in harmony with our results) and PImax and higher mean PaCO2, RSBI (in agreement with us) and RR compared to SG.

Mortality rate in our study was higher in FG than SG (6 patients 46% versus 1 patient 1.5%, respectively) with highly significant P value. The time of death was after more than 48 hours of extubation in all cases and the causes of death were circulatory collapse and/or cardiac arrhythmias.

Contrary to our results, Tenza-Lozano *et al.,*[9] mentioned 24% death rate in FG and 2.3% in SG, also Gok *et al.,*[11] recorded 27% mortality in the FG and 5% in the SG and Ferrari *et al.,*[14] reported 11.7% ceased patients in the FG and 3.4% in the SG.

In disagreement with us Esraa *et al.,*[16] reported 50% mortality rate in FG with no mortality in SG. However no study mentioned the time or the cause of death in these patients.

These variations and conflicting results in all these researches might be due to different samples size, different factors of patient's recruitment, variable periods of MV before weaning, variable age groups from infants, children, adolescents, adults and old age, different onset time of sonographic measurement; 30, 60 or 120 minutes after SBT and sonographic attempts before extubation, after extubation or before and after extubation. As regard diaphragmatic sonar some authors did only the right side, others did both sides and even diaphragmatic parameters varied among researchers, some did only one parameter, others did combined parameters as; DTF, DE, at the end of inspiration, at total lung capacity, at the end of expiration or at a residual volume after maximal expiration. Also the stage of SBT varied either in PS or *t*-tube stage. Lung scores also may be the original LUS or LUSm. Added to all these variations the results also depend on the perfection of the sonographer (operator dependent) and the ultrasound equipment[9-18].

CONCLUSION

In our study, sonographic pulmonary scores in the form of diaphragmatic thickening indices and modified ultrasound lung scores, provide rapid, bedside, non-invasive, reliable and accurate additional methods to anticipate succeeded liberation from invasive mechanical ventilation in critically ill patients.

LIMITATIONS

It was a single-center study, small sample size, and related to the operator performance and the ultrasound equipment.

RECOMMENDATIONS

More multi centric studies are required to verify LUSm and DTI reproducibility. More sample size and wider spread parameters for recruitment of patients are required.

ABBREVIATIONS

ICU: Intensive Care Unit; **IMV:** invasive mechanical ventilation; **DTI:** Diaphragmatic Thickening Indeces; **LUSm:** Modified Lung Ultrasound Score; **SBT:** Spontaneous Breathing Trials; **VE:** Minute Volume; **PIMax:** Maximum Inspiratory Pressure; **P0.1:** Airway Occlusion Pressure at 0.1 second of inspiration; **RSBI:** Rapid shallow Breathing Index; **RR:** Respiratory Rate; **TV:** Tidal Volume; **FiO_2:** Fractional inspired Oxygen; **SpO_2:** Arterial Oxygen Saturation; **PaO_2:** Arterial Oxygen Tension; **$PaCO_2$:** Arterial CO_2 tension.

CONFLICT OF INTERESTS

There are no conflicts of interest.

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