Original Article

Application of Lung and Diaphragmatic Ultrasound Score to Predict Weaning Outcomes from Mechanical Ventilation in ICU Patients

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ABSTRACT

Background: Ultrasonography of the lung and diaphragm has emerged as a potentially useful modality for prognosticating patients receiving mechanical ventilation. This novel method may lessen the need for invasive treatments and lessen patient discomfort by providing a non-invasive means of evaluating lung health and responsiveness to ventilation. This research aims to assess the possible advantages of supplementing standard weaning criteria for intensive care unit (ICU) patients with diaphragmatic and lung ultrasonography (US) assessments.

Materials and Methods: At the Madhubani Medical College and Hospital in Madhubani, Bihar, India, a study was conducted on fifty patients admitted to the Department of Anaesthesia, who were on mechanical ventilation and intubation. The study prospectively observed patients who met the traditional criteria for weaning, after undergoing lung and diaphragmatic ultrasonography following extubation. The study measured lung aeration level, diaphragmatic excursion (E), and diaphragmatic thickening fraction (DTF). Arterial blood gases and respiratory mechanics were collected and compared for every ultrasonography result. The data was statistically analyzed using SPSS version 24.0, and for parametric data, we used the student t-test to compare two independent means.

Results: This study involved fifty patients, aged 32 to 77 years, with an average age of 53.42±10.71 years. Group A (SW) consisted of 37 patients who were successfully weaned off of mechanical ventilation, making up 74% of the participants. Group B (FW) consisted of thirteen patients who were unable to complete the weaning procedure and needed to be reintubated within 48 hours. This group made up approximately 26% of the participants. The study found that the average length of time people was on mechanical ventilation was 6.68±2.15 days. To predict successful extubation, the cutoff value for the lung ultrasound score was determined to be 18 points using the ROC curve (AUC: 0.986; 95% confidence interval: 0.9594-1.000), with a sensitivity of 97.30% and a specificity of 92.31%. Similarly, the Diaphragmatic E score had a cutoff value of 19.5 points (AUC: 0.985; 95% confidence interval: 0.9610-1.000) with a sensitivity of 94.59% and a specificity of 92.31%. The DTF score had a cutoff value of 27.5 points for predicting successful extubation, yielding an AUC of 0.999 (95% confidence interval: 0.9947-1.000), a sensitivity of 100%, and a specificity of 92.31%.

Conclusions: When compared to other traditional markers like blood gases and respiratory mechanics, diaphragmatic and lung ultrasonography offer quick, non-invasive markers with very accurate results for the weaning process. They could therefore be applied as predictive parameters to evaluate the weaning process's result.

Keywords: Spontaneous breathing trial, Intensive care unit, Weaning outcomes, Post extubation distress, Lung ultrasound score.

INTRODUCTION

Critically sick patients in intensive care units (ICUs) frequently receive mechanical breathing through the pressure-supported method.[1] Weaning difficulties affect 20% of ICU patients, and 40% of such patients require longer stays during the weaning trial phase.[2] Prolonged use of ventilatory support can lead to impaired diaphragmatic function, which can cause atrophy and prolonged dysfunction that complicates the weaning process. During the weaning process, it is crucial to maintain diaphragmatic function. Nevertheless, there are restrictions and disadvantages to the common methods of diaphragmatic assessment, including trans-diaphragmatic pressure measures, phrenic nerve conduction, and fluoroscopy. These consist of radiation exposure, patient transportation, and restricted availability. In critical care, lung ultrasonography (LUS) and diaphragmatic ultrasound are safe, non-invasive, portable, and radiation-free instruments. It is a quick diagnostic tool since it offers morphologic and functional information in real-time. LUS is necessary to evaluate two important criteria that indicate the likelihood of successful extubation in patients on mechanical ventilation: the lung aeration status and the diaphragm's functional state.[3] Spontaneous breathing trials (SBT) and rapid shallow breathing index (RSBI) are commonly utilized in the ICU to predict patient release from the mechanical ventilator (MV). Predicting extubation failure depends heavily on evaluating patients both before and during SBT.[4] The lung ultrasonography score, developed to evaluate lung abnormalities, has been proposed by Bouhemad to assess lung aeration patterns and predict weaning results. Increased lung fluid may be indicated by the visualization of numerous, diffuse B-lines (more than three per intercostal gap). A B-line is a well-defined, hyperechoic, laser-like comet-tail artifact originating from the pleural line.[5,6] This study aims to assess the predictive ability of

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lung ultrasonography scores as novel additive criteria for weaning process outcomes, compared to current weaning measurements.

MATERIALS AND METHODS

In this study, fifty patients who were admitted to the Department of Anaesthesia at the Madhubani Medical College and Hospital in Madhubani, Bihar, India, and were on mechanical ventilation and intubation were prospectively observed. The patient's guardians or family members provided written consent to participate in this study in compliance with the ethics committee's standards.

Inclusion Criteria: We selected the patients who were going to be extubated and who were at least eighteen years old and had spent more than forty-eight hours in the critical care unit on mechanical ventilation and intubation for this study.

Exclusion criteria: Individuals who were 18 years of age or younger, those who had undergone post-esophageal or thoracic surgeries in which the intra-operative manipulation of the diaphragm was done, patients with a history of neuromuscular disorders, patients with unilateral or bilateral absent diaphragmatic mobility shown on primary ultrasound, and patients with pulmonary hypertension, aortic valve disease, hyperthyroidism, or any other diagnoses were excluded from this study. We conducted a thorough physical examination, reviewed the patient's medical records, and performed routine laboratory tests, including Arterial Blood Gas (ABG) analysis, for all participants. Upon admission, we calculated the Acute Physiology and Chronic Health Evaluation (APACHE) II score for every patient.[7] Additionally, we assessed the Sequential Organ Failure Assessment (SOFA) score for those admitted to the critical care unit.[8] Furthermore, we used the electrochemiluminescence detection method to determine the serum level of NT-pro BNP after a spontaneous breathing experiment for the participants.[9] Using either a T-tube or 8 cm H2O of pressure support, patients who met the criteria listed in Table 1 were selected to begin the weaning process. Their ventilators were turned off for a 30 to 120-minute spontaneous breath trial (SBT). Each patient's diaphragm was assessed to make sure there was movement on both sides. If there was no movement, the patient was removed from the study. After that, a comprehensive lung and diaphragmatic ultrasound was conducted.

Diaphragmatic Ultrasound:

The linear US probe is positioned in the eighth or ninth intercostal gap, perpendicular to the chest wall, between the anterior and mid-axillary lines, to measure the diaphragm's thickness. Semi-recumbent was the position of the patient during ultrasonography. The diaphragm was seen as a three-layered structure with a central hypoechoic space signifying the diaphragmatic muscle and two parallel echogenic lines representing the peritoneum and pleura. There was muscle in the diaphragmatic thickness. The diaphragmatic thickness was measured between the middles of the pleural and peritoneal lines. The thickness was measured using the end-expiration and end-inspiration. To calculate the average, this was done again, and then we calculated the diaphragmatic muscle thickening fraction (DTF) as follows:

Diaphragmatic excursion (E): To measure the diaphragmatic movement range, the convex probe was placed subcostally parallel to the intercostal space using the M-mode technique and a cursor that spanned the diaphragm. The diaphragmatic mobility range was determined by evaluating the high and low peak points.

Table 1: Demonstrating the criteria for weaning of intensive care unit (ICU) patients.

Parameters	Criteria
Respiratory rate (RR)	• Less than 30-35 breaths per minute
Arterial blood gases (ABG)	• Arterial pH more than 7.35 • PaO_2 more than 60 mmHg • Pa CO_2 less than 50 mmHg • FiO_2 less than 0.5 • PaO_2/FiO_2 more than 200 mg • PEEP less than 5 Cm of water
Respiratory mechanics	• Rapid shallow breath index (RSBI): less than 100 breaths per minute per liter • Tidal volume (TV): more than 5 ml per kg • Vital capacity (VC): more than 10 ml per kg • PI max: less than -15 to -30 Cm H_2O • Minute Volume [VE]: 4-10 L/min • Airway occlusion pressure [$P_{0.1}$]: less than 2 Cm of water
Clinical features	• Heart rate less than 100 beats per minute; haemoglobin level more than 8 g/dL; temperature less than 38°C; absence of sedatives; respiratory stimulation; and appropriate spontaneous cough. Absence of electrocardiographic evidence of myocardial ischemia.

Using a curved array ultrasonography probe operating at a 2.5–5 MHz frequency, a highly skilled lung ultrasonographer evaluated the lung ultrasound score (LUS) following the spontaneous breath trial (SBT). Either supine or lateral decubitus should be the patient's position. Each lung was split into three zones, each subjected to anterior and posterior B-mode analysis to

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assess the level of lung aeration. Twelve zones in all were examined. According to Table 2, the image analysis and lung ultrasonography score were computed.[10]

When reintubation or non-invasive ventilation was needed within 48 hours of extubation, post-extubation failure was taken into consideration. Hospital stays, critical care unit stays, and patient fatalities were all monitored. The patients were split into two groups according to how they handled the weaning trials.

Table 2: Demonstrating the criteria for the lung ultrasonography score to identify the level of lung aeration

Points for each lung zone (12 zones)	Degree of lung aeration	Pattern
Zero Point (0)	Normal aeration	Horizontal A-line (no more than two B-line)
One Point (1)	Moderate loss of aeration	Multiple B-lines either regularly spaced or irregularly spaced
Two Point (2)	Severe loss of aeration	Multiple coalescent B lines
Three Point (3)	Complete loss of aeration	Lung consolidation
Total Scores	From zero to thirty-six (0 to 36)	

Group A experienced successful weaning (SW) and was transferred to the ward, whereas Group B experienced failure weaning (FW) and required machine ventilation and re-intubation after 48 hours. The diaphragmatic excursion (E) during inspiration, lung ultrasonography measurements, and diaphragmatic muscle thickening fraction (DTF) were associated with weaning criteria, which included PaO_2, $PaCO_2$, respiratory rate (RR), maximal inspiratory force (MiP), and rapid shallow breath index (RSBI). The patient who was the subject of the study had the following indications for reintubation:

- Respiratory rate more than 40 or less than 6.
- Hypoxemia in the form of PO_2 less than 50 on room air or less than 200 on FiO_2 100%.
- Excessive secretions, hemodynamic instability, and impaired conscious level.

The data was given as mean and standard deviation (SD) [mean ± SD] for quantitative parametric measurements. SPSS version 24.0 was used to statistically analyze the data. For parametric data, the student t-test was used to compare two independent means. The Pearson correlation test was also performed to look into any possible links between each pair of variables within each group for parametric data. A p-value of less than 0.05 was seen as noteworthy.

RESULTS

Fifty patients, whose ages ranged from 32 to 77 years old, with a mean age of 53.42±10.71 years, participated in this study. Group A (SW) consisted of thirty-seven patients who completed the weaning process, accounting for 74% of the participants. Group B (FW) consisted of thirteen patients who were re-intubated 48 hours following the trial due to failures in the weaning procedure. This represents 26% of the participants. In our study, the mean length of time that patients received mechanical ventilation was 6.68±2.15. Table 3 provides specifics on the participants' demographic profiles of the patients.

Table 3: Showing the different demographic profiles and clinical data of the patients

Parameters		Number of Patients (%)
Age (years)		53.42±10.71
Sex	Male	36 (72%)
	Female	14 (28%)
Causes of mechanical ventilation	COPD	5 (10%)
	Shock	15 (30%)
	Pneumonia	14 (28%)
	Coma	16 (32%)
Fluid Balance	Positive Fluid Balance	23 (46%)
	Negative Fluid Balance	27 (54%)

In Table 4, we displayed the results of several ultrasonography parameters, blood gases, and respiratory mechanics, along with the mean, t-value, and significance.

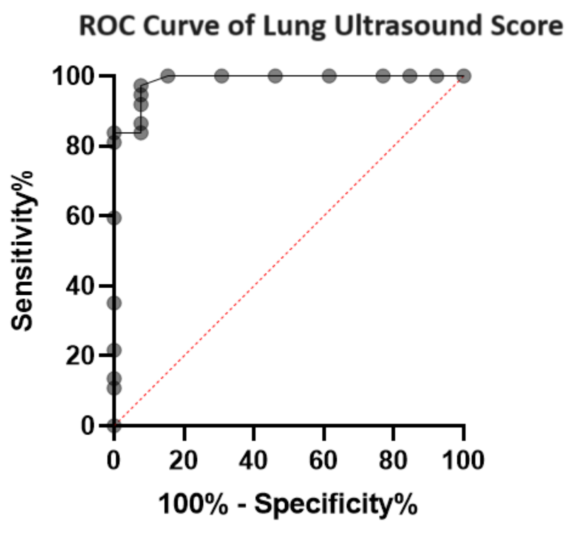

Figure 1: ROC Curve for lung ultrasound score

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Table 4: Comparing the results of respiratory mechanics, blood gases, and several ultrasonography parameters between the two groups

Sr. No.	Parameters		Group A (SW) [Success Weaning]		Group B (FW) [Failed Weaning]		t-value	P Value
			Min - Max	Mean±SD	Min - Max	Mean±SD		
1.	Ultrasound parameters	Lung US score	2-19	7.78±4.16	13-33	24.62±5.06	11.85	<0.0001
		Diaphragm E (mm)	13-32	24.30±3.12	3-22	10.46±5.44	11.20	<0.0001
		DTF (%)	29-36	33.49±1.50	16-29	23.38±2.96	15.90	<0.0001
2.	Blood gases	PaO_2 (mmHg)	62-78	69.46±2.10	32-62	46.46±6.16	19.54	<0.0001
		$PaCO_2$ (mmHg)	15-40	29.30±3.33	50-74	60.92±5.62	24.35	<0.0001
3.	Respiratory mechanics	RR (breath/min)	18-30	25.22±2.10	38-55	42.92±6.03	16.88	<0.0001
		MiP (Cm H_2O)	(-78)- (20)	-50.16± 9.28	(-12)-(-4)	-9.00±1.96	15.76	<0.0001
		RSBI (breath/min/L)	52-96	72.95±7.31	105-126	113.69±5.75	18.18	<0.0001

Table 5: Showing the sensitivity and specificity of different parameters for prediction of the weaning outcome of mechanically ventilated patients

Parameters	Area under the ROC Curve (AUC)	P - value	95% confidence interval				
			Cuff off Value	Lower Bound	Upper Bound	% Sensitivity	% Specificity
Lung ultrasound score	0.986	<0.0001	18	0.9594	1.000	97.30	92.31
Diaphragmatic E score	0.985	<0.0001	19.50	0.9610	1.000	94.59	92.31
DTF score	0.999	<0.0001	27.50	0.9947	1.000	100	92.31

ROC Curve for lung ultrasound score:

Table 5 and Figure 1 illustrate how the ROC curve was used to calculate the cutoff value of the lung ultrasound score for successful extubation prediction. The cut-off value was 18 points (the area under the curve: 0.986; 95% confidence interval: 0.9594 – 1.000), with corresponding sensitivity and specificity of 97.30% and 92.31%.

ROC Curve for Diaphragmatic E score:

In Table 5 and Figure 2, the ROC curve was employed to determine the cutoff value of the Diaphragmatic E score for predicting successful extubation. The determined value was 19.5 points (with the area under the curve being 0.985 and a 95% confidence interval of 0.9610 – 1.000), yielding a sensitivity of 94.59% and specificity of 92.31%.

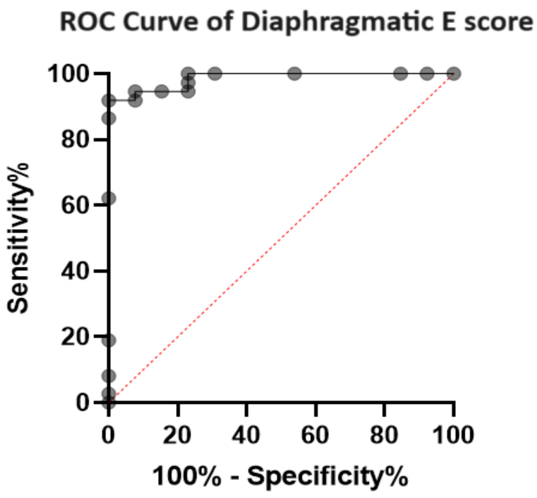

Figure 2: ROC Curve for Diaphragmatic E score

ROC Curve for DTF score:

Table 5 and Figure 3 illustrate how the ROC curve was used to calculate the cutoff value of the DTF score for successful extubation prediction. This value was 27.5 points (the area under the curve: 0.999; 95% confidence interval: 0.9947 – 1.000), with corresponding sensitivity and specificity of 100% and 92.31%.

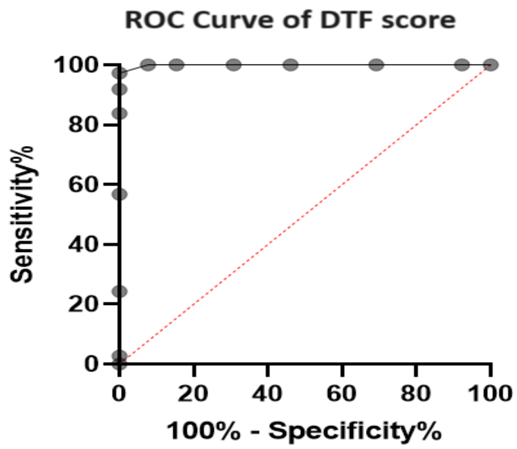

Figure 3: ROC Curve for DTF score

DISCUSSIONS

Studies have shown that weaning is a difficult process that has a 20% failure rate for ICU patients.[11] The respiratory mechanics and arterial blood gases are the main markers and criteria that determine when to start the weaning process; all of these measures indirectly reflect the diaphragmatic function. A bad weaning decision may lead to a high failure rate, prolonged stays in the intensive care unit, and pain in the cardio-respiratory system. In addition,

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postponing weaning decisions increases the risk of infections associated with ventilator use and diaphragmatic atrophy.[12,13] Ultrasound is commonly available in the critical care unit and can be used to immediately visualize and test the diaphragmatic muscle, the major breathing muscle, at the patient's bedside. It is possible to forecast the weaning process's success using this information. Thirteen patients (or 26% of the study group) in our analysis had a failed weaning trial and, within 48 hours, were put back on mechanical ventilation and intubation. This is almost in line with what Esteban et al. found. Saeed et al. and Baess et al. observed failure rates to be approximately 20%, 26.7%, and 23.3%, respectively.[2,14,15] This is questioned by the 63% failure rate reported by Ferrari et al.[16] This could affect the outcome of the weaning process, which was described by a nonuniform rule in the research population selection. Apart from differentiating the duration of ventilation before the process begins, there are multiple justifications for using mechanical ventilation. We employed the M-mode to measure the diaphragmatic E and estimate the degree of movement, even though it was simpler to use than the B-mode when working with noncooperative ICU patients. Several writers, such as Umbrello et al., also used M-mode. M-mode is used to measure diaphragmatic mobility in 210 healthy individuals, according to research by Baess et al. and Boussuges et al.[1,15,17] Nevertheless, other writers have investigated mobility using B mode; Saeed et al.[14] demonstrated that non-ICU patients could easily assess diaphragmatic movement using B mode.

Table 4 displays the relationship between our findings and several weaning parameters, including blood gases and respiratory mechanics. The other authors' most often used measure for comparison was RSBI.[1,14,15] In the present investigation, the average relative breath-by-minute (RSBI) varied between group A (SW) and group B (FW), with an average value of 72.95 and 113.69, respectively. Patients who were able to wean effectively had an average RSBI of 91. In contrast, those who were unable to do so had an average RSBI of 123.6, as reported by Saeed et al.[14] Arterial blood gases and respiratory mechanics, particularly the RSBI and MiP, were found to have a substantial to high significant correlation with diaphragmatic thickening fraction (DTF), diaphragmatic excursion (E), and lung ultrasound score (LUS). This experiment is similar to earlier ones.[14,15,16] 19.50 mm Diaphragmatic E was the cut-off value in the current investigation, with 94.59% sensitivity and 92.31% specificity. This figure is higher than that of other researchers who assessed the weaning outcome using a cut-off value of 10–11 mm Diaphragmatic E and discovered variable levels of sensitivity and specificity. Saeed et al. obtained 86.4% sensitivity and 87.5% specificity in contrast to Baess et al.'s results, which displayed 69.5% sensitivity and 71.4% specificity. Jiang et al. also discovered 84% and 83% of specificity and sensitivity, correspondingly.[17, 18, 19, 20, 21] According to our investigation, the diaphragmatic thickening fraction (DTF) cut-off value of 27.5% demonstrated 100% sensitivity and 92.31% specificity. According to Di Nino et al. and Baess et al., respectively, this corresponds to the 30% diaphragmatic thickening fraction (DTF) cut-off value, with a specificity of roughly 71.43% and 71% and a sensitivity of roughly 69.57% and 88%.[15,20] Ferrari et al.'s findings[16] of a higher cut-off value of 36% with 82% sensitivity and 88% specificity cast doubt on this. A lower cut-off value of 20% was also discovered by Umbrello et al.[1]

Everyone who agreed that E and DTF, despite some minor differences in the diagnostic validity results compared to previous research, are good indicators of weaning outcomes. The DTF performed better in terms of dependability than E, with increased sensitivity, efficacy, and an enhanced AUC score in line with Umbrello et al. and Baess et al.[1,15] With a threshold value of 18 (AUC: 0.986; 95% CI: 0.9594-1.000), the lung ultrasonography score in our study demonstrated high predictive power for the weaning outcome (post-extubation distress), with a sensitivity of 97.30% and specificity of 92.31%. While lung ultrasonography score was also reported by Faris F. M. et al.[21] to be a 90% sensitive and 75% specific predictor of weaning outcome, with a threshold value of 15.5 (AUC: 0.851; 95% CI: 0.721–0.981). According to Soummer et al.[22] who also found that LUS greater than 17 predicted post-extubation distress and less than 12 predicted extubation success, lung ultrasonography score was sensitive and specific for predicting weaning outcome. These findings are consistent with our research.

Furthermore, the lung ultrasonography results agreed with Caltabeloti and Rouby et al.'s observations.[23] Additionally, Ahmed Osman et al.[24] found that an intermediate risk of failure extubation was associated with a lower LUS of 12 to 17, a higher LUS of 17 was associated with a higher risk of unsuccessful extubation, and a lower LUS of 12 to 17 was associated with a better likelihood of successful extubation.

This study investigated the utility of diaphragmatic and lung ultrasonography as prognostic indicators of weaning outcomes. At the threshold value of 12 (AUC: 0.942), 100% sensitivity and 96% specificity were shown. Additionally, Caihong et al.[25] found that lung ultrasound scores can predict post-extubation distress with a cutoff value of 13.5, the sensitivity was 80.0%, and the specificity was 65.2% in a study for the prediction of weaning outcomes using lung ultrasound scores in patients intubated with an intra-abdominal infection. The AUC of the LUS score before extubation for predicting the failure was 0.81 (95% CI:0.69–0.92, P 5 0.001), according to ROC curve analysis. Finally, a high sensitivity and specificity ultrasound score was obtained, which can be helpful in the weaning trials and is comparable to the other weaning features. Ultrasound is one quick, simple, non-invasive diagnostic technique. However, the primary drawbacks were the operator-dependent approach and the ultrasound technology's capabilities, which included the potential for pneumothorax and the inability to use the optimal window for diaphragm visualization due to morbid obesity.

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CONCLUSIONS

When diaphragmatic and lung ultrasonography are compared to other traditional indices like blood gases and respiratory mechanics, these techniques provide quick, non-invasive indicators with very accurate results for the weaning process. Thus, they could be used as predictive factors to assess the weaning process's outcome.

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