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Original article

Can Lung Ultrasound Predict Mechanical Ventilation Weaning Outcomes in Critically Ill Adults?

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Abstract

This study aimed to assess the ability of lung ultrasound (LUS) to predict mechanical ventilation (MV) weaning outcomes in critically ill adults. **Methods:** A prospective observational study that analyzed data collected from 50 adult patients, mechanically ventilated for more than 48 hours and eligible for their first spontaneous breathing trial. A LUS was performed prior to and at the end of a 1-hour SBT. To quantify lung aeration, a LUS score was calculated. Patients were divided into two groups according to their response to weaning trials with group A showing successful weaning while group B showing failed weaning. All included patients were followed up to Intensive Care Unit discharge. **Results:** Weaning failure was observed in 36% of patients. LUS score showed a significant difference between both groups (P < 0.001). Pre- and post-spontaneous breathing trial (post-SBT), LUS scores were significantly higher in the failed weaning group (14.44 ±2.52 and 18.83 ±3.18 respectively) than in the successful weaning group (11.25 ±3.05 and 12.53 ±3.41 respectively). A ROC analysis for the ability of post-SBT LUS score to predict weaning outcomes revealed a significant AUC of 0.911 with a 95% confidence interval ranging from 0.830-0.992 (P < 0.0001). The best cut-off was 14.5, at which sensitivity and specificity were 88.8% and 68.7%, respectively. **Conclusions:** Our data suggest that LUS can be used as a predictor of MV weaning outcomes in critically ill adults. A post-SBT LUS score cut-off value of 14.5 has a sensitivity and a specificity of 88.8% and 68.7%, respectively.

Keywords: Lung ultrasound; Mechanical ventilation; Weaning

Introduction

Determining the optimal moment to extubate a critically ill patient remains a challenge, as premature removal of mechanical ventilation (MV) entails a high risk of weaning failure, prompting reintubation that exposes the patient to unnecessary hemodynamic and respiratory stress.[1] Conversely, delayed extubation increases the duration of MV and carries other risks (e.g. development of ventilator-associated pneumonia, tracheal injury, barotrauma).[2] Thus, both early and delayed weaning is associated with increased mortality, intensive care unit (ICU) length of stay and economic cost.[3]

Current weaning guidelines recommend the implementation of a spontaneous breathing trial (SBT) as a tool to predict weaning outcomes.[4] However, 13% to 26% of patients who are extubated following a successful SBT need to be reintubated within 48 hours.[5] In the last few years, multiple indices and parameters have been proposed as predictors of weaning outcomes, but none has shown more than modest prognostic accuracy.[6]

Ultrasound use in the ICU is an area of growing interest because of its portability, speed, safety, and the encouraging results obtained for managing multiple entities.[7] Lung ultrasound (LUS) is helpful in the diagnostic approach to patients with acute respiratory failure, circulatory shock, or cardiac arrest. Moreover, a semi quantification of lung aeration can be performed at the bedside and used in mechanically ventilated patients to guide positive end-expiratory pressure setting, assess the efficacy of treatments, monitor the evolution of the respiratory disorders, and help the weaning process.[8]

The purpose of this study was to assess the ability of LUS to predict MV weaning outcomes in critically ill adults.

Patient and methods

After approval by the institutional ethics committee, a prospective observational study was conducted on 50 consecutive patients admitted to the Critical Care Medicine Department at Benha University over a period of 12 months from July 2022 to July 2023.

Inclusion Criteria: Patients aged > 18 years, mechanically ventilated for more than 48 hours, and eligible for their first SBT according to the treating physician's judgment.

Exclusion Criteria: Patients with tracheostomy, neuromuscular disorder, pneumonectomy, chronic lung disease, and previous SBT failure.

Methods:

The SBT was performed by applying a low level of pressure support (5-8 cm H_2O) for one hour. Patients who successfully pass the SBT were extubated and followed up for 48 hours. Failure of SBT was defined by: 1) objective indices, such as tachypnoea, tachycardia, hypertension, hypotension, hypoxemia, acidosis, and arrhythmia; and 2) subjective indices, such as agitation or distress, depressed mental status, diaphoresis and evidence of increasing effort.[10]

LUS was performed by a trained investigator using a 1.7-4 MHz probe of a GE Logiq F8 ultrasound machine prior to and at the end of the SBT. The patient was preferably examined in the sitting position. When this position could not be maintained due to clinical deterioration or poor compliance, the examination was performed in the supine or semirecumbent position. The LUS protocol involved the examination of 12 lung regions: the upper and lower parts of the anterior, lateral, and posterior aspects of the left and right chest wall. Each was scored according to four ultrasound aeration patterns (score 0: A-lines or two or fewer well-spaced B-lines; score 1: three or more well-spaced B-lines; score 2: coalescent B-lines; score 3: tissue-like pattern). For a given region of interest, we allocated points according to the worst ultrasound pattern observed. The final LUS is the sum of points in all 12 regions and ranges from 0 to 36.[9]

The patients were divided into two groups according to their response to weaning trials with group A showing successful weaning while group B showing failed weaning.

Primary outcome measures: Weaning Failure, defined as either the failure of SBT or the need for reintubation within 48 hours following extubation.[10]

Secondary outcome measures: MV duration, ICU length of stay, and ICU mortality.

Sample size calculation:

Using the Med Calc program, set the alpha error at 5% and the power at 80%. The result from a previous study showed that LUS has an area under the curve of 0.78 for prediction of successful weaning which was present in 75% of cases. Based on this, the needed sample was 50 cases taking into consideration a 10% dropout rate.

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Statistical Methods:

Data management and statistical analysis were done using SPSS version 26 (IBM, Armonk, New York, United States). Quantitative data were summarized as means and standard deviations. Categorical data were summarized as numbers and percentages. Comparison between two independent mean groups for parametric data was done using Student t test. ROC analysis was done for the ability of LUS score to predict weaning outcome. Areas Under Curve (AUC) with 95% confidence intervals, best cutoff points, and diagnostic indices were calculated. All statistical tests were two-sided. P values less than 0.05 were considered significant.

Results

Clinical characteristics (Table 1):

Fifty consecutive patients were included in the study and were classified into 2 groups according to their weaning outcome; with group A showing successful weaning while group B showing failed weaning.

The mean age of the study population was 63.56 ±10.88 years. There was a slight female predominance (56%). The mean body mass index (BMI) was 26.5 ±2.67 kg/m^2. About three-quarters (74%) of the patients were admitted due to medical causes. MV was instituted due to respiratory failure in about half (48%) of the patients, altered mental state in about one-third (30%), and hemodynamic instability in the remaining patients (22%). The mean of prior MV duration and ICU length of stay was 6.2 ±2.79 and 17.24 ±6.6 respectively. The ICU mortality and weaning failure rates of the study population were 24% and 36% respectively.

A significant association was reported between increasing age and weaning failure (P = 0.041); mean age was higher in the failed weaning group compared to the successful weaning group. Additionally, increasing MV duration showed a significant association with weaning failure (P = 0.04);

No significant differences were reported regarding gender (P = 0.254), BMI (P = 0.69), admission cause (P = 0.119), APACHE II score (P = 0.546), ICU Length of Stay (P = 0.436), and ICU Mortality (P = 0.639). There were also no significant differences between the two groups regarding their MV indication; the P values for altered mental state, respiratory failure, and hemodynamic instability as an indication were 0.797, 0.705, and 0.459 respectively.

SBT Parameters (Table 2):

Respiratory rate (RR), both prior to SBT and at the end of SBT, significantly differed between the two groups with a P value of 0.033 and < 0.001 respectively. It was significantly higher in the failed weaning group than in those in the successful weaning group. Rapid shallow breathing index (RSBI) showed a significant difference between both groups (P < 0.001). It was significantly higher in the failed weaning group than in the successful weaning group.

Pre-SBT PH revealed a significant difference between both groups (P < 0.02). It was significantly lower in the failed weaning group than in in the successful weaning group (7.39 ±.055). Pre-SBT PaO2/FiO2 ratio significantly differed between both groups (P < 0.019). It was significantly lower in the failed weaning group than in in the successful weaning group.

No significant differences were reported regarding SBP (pre and post-SBT) (P = 0.751 and 0.995 respectively), HR (pre and post-SBT) (P = 0.897 and 0.906 respectively), PH (post-SBT) (P = 0.237), PaCO2 (pre and post-SBT) (P = 0.869 and 0.376 respectively), and PaO2/FiO2 (post-SBT) (P = 0.329).

LUS Score (Table 3):

LUS score showed a significant difference between both groups (P < 0.001). Pre- and post-SBT LUS scores were significantly higher in the failed weaning group than in the successful weaning group. Additionally, LUS score variation differed significantly between both groups (P < 0.001); the mean variation was significantly higher in the failed weaning group than in the successful weaning group.

ROC analysis was done for post-SBT LUS score in predicting weaning outcomes. It revealed a significant AUC of 0.911 with a 95% confidence interval ranging from 0.830-0.992 (P < 0.0001). The best cut-off was 14.5, at which sensitivity and specificity were 88.8% and 68.7% respectively (Figure 1)

Table 1: Clinical Characteristics**.**

	Total (n = 50)	**Group A (n = 32)**	**Group B (n = 18)**	**P value**
Age (years), Mean ±SD	63.56 ±10.88	61.22 ±11.92	67.72 ±7.33	**0.041**
Gender		16 (50)	6 (33.3)	
Male, n (%)	22 (44)	16 (50)	12 (66.7)	0.254
Female, n (%)	28 (56)			0.254
BMI (kg/m^2), Mean ±SD	26.5 ±2.67	26.63 ±2.37	26.28 ±3.19	0.69
Cause of Admission	37 (74)	26 (81.25)	11 (61.1)	
Medical, n (%)	13 (26)	6 (18.75)	7 (38.9)	0.119
Surgical, n (%)				0.119
APACHE II, Mean ±SD	23.16 ±11.02	23.88 ±10.93	21.89 ±11.37	0.546
Indication for mechanical ventilation				
Altered mental state, n (%)	15 (30)	10 (31.25)	5 (27.78)	0.797
Respiratory failure, n (%)	24 (48)	16 (50)	8 (44.44)	0.705
Hemodynamic instability, n (%)	11 (22)	6 (18.75)	5 (27.78)	0.459
Prior MV Duration (days), Mean ±SD	6.2 ±2.79	5.59 ±2.83	7.28 ±2.44	**0.04**
ICU Length of Stay (days), Mean ±SD	17.24 ±6.6	16.69 ±7	18.22 ±5.9	0.436
ICU Mortality, n (%)	12 (24)	7 (21.9)	5 (27.8)	0.639

group A: successful weaning group; group B: failed weaning group; n: number; SD: standard deviation; BMI: body mass index; MV: mechanical ventilation; APACHE II: acute physiology and chronic health evaluation.

Table 2: SBT Parameters.

	Group A (n = 32)	**Group B (n = 18)**	**P value**
SBP (mmHg)			
prior to SBT, Mean ±SD	119.56 ±14.54	121.28 ±19.9	0.751
at end of SBT, Mean ±SD	121.53 ±14.14	121.50 ±17.23	0.995
HR (beats/min)			
prior to SBT, Mean ±SD	90.59 ±12.27	91.06 ±11.64	0.897
at end of SBT, Mean ±SD	94.31 ±11.28	93.94 ±8.98	0.906
RR (breaths/min)			
prior to SBT, Mean ±SD	15.75 ±1.81	17.00 ±2.14	**0.033**
at end of SBT, Mean ±SD	16.91 ±2.08	26.89 ±3.47	**< 0.001**
RSBI (breaths/min/L), Mean ±SD	68.72 ±12.16	118.67 ±5.35	**< 0.001**
PH			
prior to SBT, Mean ±SD	7.39 ±.055	7.35 ±.048	**0.02**
at end of SBT, Mean ±SD	7.36 ±.047	7.34 ±.044	0.237
$PaCO_2$ (mmHg)			
prior to SBT, Mean ±SD	37.88 ±6.45	38.22 ±8.15	0.869
at end of SBT, Mean ±SD	37.06 ±7.63	39.33 ±10.16	0.376
PaO_2/FiO_2			
prior to SBT, Mean ±SD	184.88 ±14.8	174.5 ±14.1	**0.019**
at end of SBT, Mean ±SD	186.63 ±12.13	179 ±31	0.329

group A: successful weaning group; group B: failed weaning group; n: number; SD: standard deviation; SBT: spontaneous breathing trial; SBP: systolic blood pressure; HR: heart rate; RR: respiratory rate; RSBI: rapid shallow breathing index; PH: potential of hydrogen; $PaCO_2$: partial pressure of carbon dioxide in arterial blood; PaO_2/FiO_2: ratio of partial pressure of oxygen in arterial blood to the fraction of inspiratory oxygen concentration

Table 3: LUS Score.

	Group A (n = 32)	Group B (n = 18)	P value
LUS Score			
Prior to SBT, Mean ±SD	11.25 ±3.05	14.44 ±2.52	**< 0.001**
At end of SBT, Mean ±SD.	12.53 ±3.41	18.83 ±3.18	**< 0.001**
Variation, Mean ±SD	1.31 ±1.12	4.39 ±1.65	**< 0.001**

group A: successful weaning group; group B: failed weaning group; n: number; SD: standard deviation; SBT: spontaneous breathing trial; LUS: lung ultrasound.

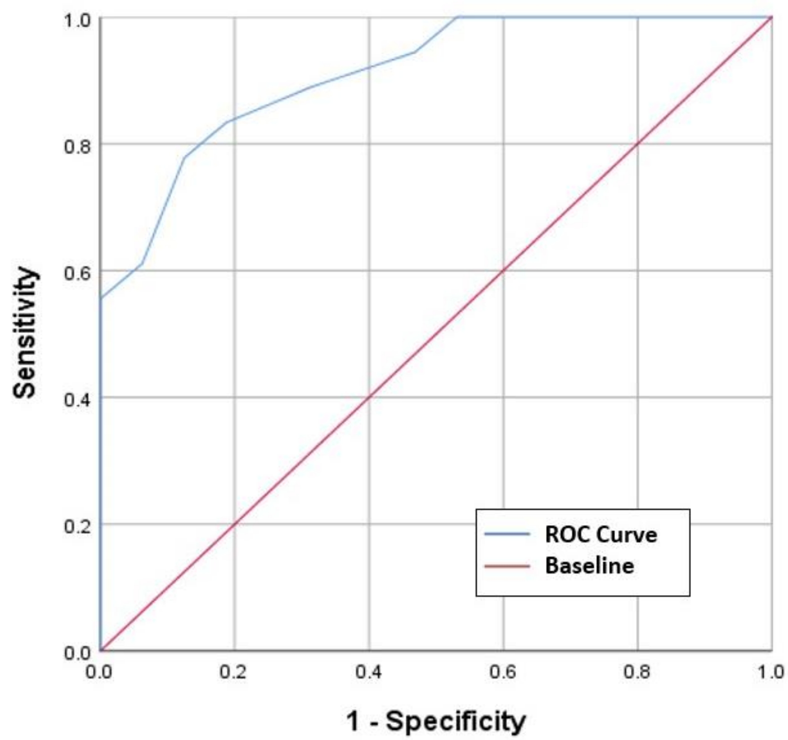

Figure 1: ROC analysis of post-SBT LUS to predict weaning outcomes.

Discussion

The weaning process represents about 40–50% of the total duration of MV. It is a complex process with an estimated failure rate of about 20-30%. Premature weaning may lead to the necessity of reintubation with an associated increase in the risk of ventilator-associated pneumonia and airway trauma. A delay in weaning can increase the risk of ventilator-related complications such as pneumonia, tracheobronchitis, or barotrauma, and may lead to prolonged ICU stay which is also associated with increased costs and mortality rates in healthcare systems. Thus, a reliable prediction of weaning failure and the identification of its underlying mechanism is of great importance.[11]

Tools available for determining the optimal timing of weaning and the prediction of its outcome are not always precise. In addition, subjective decisions are usually wrong. Therefore, a precise prediction of successful extubation for patients is an important issue and worthy of study.[12]

Switching a patient from a controlled ventilation mode to a spontaneous breath trial (SBT) is a stress test for the patient and induces changes in lung aeration. If significant, these changes can be detected using LUS. The best way to semi-quantify aeration changes at the bedside is by using a LUS rating system, the LUS score. The decrease in lung aeration quantified by the LUS score is the final common pathway of different mechanisms inducing weaning failure, namely derecruitment and cardiogenic pulmonary edema.[8]

MV was instituted due to respiratory failure in about half (48%) of the patients, altered mental state in about one-third (30%), and hemodynamic instability in the remaining patients (22%). The mean of prior MV duration and ICU length of stay was 6.2 ±2.79 and 17.24 ±6.6 days respectively. The weaning failure rate in our study was 36%.

Previous Studies reported varying weaning failure rates between 15-45%. This may be related to different weaning failure definitions used and different study populations; as many studies reported that surgical ICU patients are easier to be weaned from MV.[9,14,15,16] In our study, the majority of the patients (74%) were admitted due to medical causes, and this may explain the relatively higher (36%) weaning failure rate in our study.

We found a significant association was reported between increasing age and weaning failure (P = 0.041); mean age was higher in the failed weaning group compared to the successful weaning group.

This finding is consistent with the **WEAN SAFE**, reported that older age is strongly associated with weaning failure (P < 0·0001); the median age was higher in the failed weaning group compared to the successful weaning group (66 (59–76) vs 62 (49–73) years).[14]

Interestingly, a study done in 2015 found that weaning failure increased with age, however the mean values of failure did not show significant differences (P = 0.552*)*.[17]

Additionally, we found that increasing MV duration showed a significant association with weaning failure (P = 0.04); the mean duration for the failed and successful weaning groups was 7.28 ±2.44 and 5.59 ±2.83 days respectively.

The **ENIO**, showed similar results; it reported that patients with weaning failure displayed a longer MV duration (14 (7-21) vs 6 (3-11) days).[16]

However, another study evaluating the LUS as a predictive of post-extubation distress reported no significant difference between weaning success and weaning failure groups regarding their prior duration of MV.[9]

No significant differences were found in our study regarding gender (P = 0.254), or BMI (P = 0.69).

The **ENIO** study showed similar results.[16] Furthermore, the WEAN SAFE study found no association between BMI and weaning failure (P = 0.254). However, the female gender had a higher weaning failure rate (P = 0.9).[14]

Another study, aimed to investigate gender differences in prolonged MV patients, found no differences in weaning status or ventilator dependence.[18]

In the present study, no significant differences were found regarding admission cause (P = 0.119), APACHE II score (P = 0.546), ICU Length of Stay (P = 0.436), and ICU Mortality (P = 0.639).

The respiratory rate has been reported as an effective predictor of weaning failure; the best cut-off point > 24 breaths per minute had a sensitivity of 100%, specificity of 85%, and accuracy of 88%.[19] Furthermore, respiratory rate is incorporated into the more commonly used index to predict weaning failure, the rapid shallow breathing index (RSBI). A rapid shallow breathing index higher than 105 during the SBT is considered highly predictive of weaning failure.[20] **Saeed et al.** reported a lower RSBI (91 breaths/min/ml) in patients with successful weaning than in patients with failed weaning (123.6 breaths/min/ml).[21] Also**,** it was reported that an RSBI of 71.9 and 113.9 were for the successful weaning and failed weaning groups respectively.[22]

In the current study, the respiratory rate (RR), both prior to and at the end of the SBT, significantly differed between the two groups (P = 0.033 and < 0.001 respectively). It was significantly higher in the failed weaning group than in those in the successful weaning group. The rapid shallow breathing index (RSBI) also showed a significant difference between both groups (P < 0.001). It was significantly higher in the failed weaning group (118.67 ±5.35) than in the successful weaning group.

In our study, pre-SBT PH revealed a significant difference between both groups (P < 0.02). It was significantly lower in the failed weaning group than in the successful weaning group. Pre-SBT PaO2/FiO2 ratio significantly differed between both groups (P < 0.019). It was significantly lower in the failed weaning group than in the successful weaning group.

No significant differences between both groups were reported in the present study regarding SBP (pre and post-SBT) (P = 0.751 and 0.995 respectively), HR (pre and post-SBT) (P = 0.897 and 0.906 respectively), PH (post-SBT) (P = 0.237), PaCO2 (pre and post-SBT) (P = 0.869 and 0.376 respectively), or PaO2/FiO2 (post-SBT) (P = 0.329).

In our study, LUS score showed a significant difference between both groups (P < 0.001). pre- and post-SBT LUS scores were significantly higher in the failed weaning group than in the successful weaning group.

In addition, the LUS score demonstrated significant changes in lung aeration during SBT in the failed weaning group (P < 0.001); the mean variation was significantly higher in the failed weaning group than in the successful weaning group.

Furthermore, a ROC analysis was done for post-SBT LUS score in predicting weaning outcomes. It revealed a significant AUC of 0.911 with a 95% confidence interval ranging from 0.830-0.992 (P < 0.0001). The best cut-off was 14.5, at which sensitivity and specificity were 88.8% and 68.7%, respectively.

These results are similar to the findings reported by others who reported that the patients in the weaning failure group had a significantly higher LUS scores both before and after SBT compared to the weaning success group and patients in the weaning failure group had a significantly higher LUS score change following SBT; 2(1–4) vs 1(0–2) (P = 0.005).[23]

Furthermore, **Rajbanshi et al.** found that patients who have lower LUS scores both at the beginning and 30 minutes of SBT were more likely to have successful SBT as compared with higher scores. He also reported that the AUC for predicting successful weaning for LUS at 30 minutes of SBT was 0.841 (CI 95% 0.756–0.925, P < 0.001) with a cut-off value of 17.5 (sensitivity 82.5% and specificity 82.2%).[24]

Another study investigating the use of the LUS score as a predictor of weaning failure in COVID-19 patients reported higher LUS scores at 30 min after the SBT in the weaning failure group; 15(12-18) vs 8(4-12) (P < 0.001). They also reported an AUC for LUS score to predict weaning failure of 0.885 (95% CI 0.770–0.999, P < 0.001), and a cut-off score of 10 provided specificity of 72.7% and sensitivity of 92.3%.[25]

These results also match with the results published previously which showed that despite similar basal LUS scores in patients with weaning failure (13 (10–17)) and weaning success (12 (8–15)), LUS scores significantly increased during the SBT in both groups.[9]

Several studies reported similar cut-off values of ≤ 14 and <12 respectively as a predictor of weaning success.[22,26]

Considering the results of this study and that LUS is a simple and rapid technique, LUS should be combined with other traditional parameters in the assessment of the patients to be weaned from MV, not only to identify the patients who will fail the weaning process but also to understand the underlying mechanism.

LUS can detect lung derecruitment during the SBT, this derecruitment can be easily reversed and prevented by the use of positive end-expiratory pressure. Therefore, in patients who successfully pass the SBT and whose post-SBT LUS score is ≥ 14.5, the application of noninvasive ventilation after extubation could be proposed to prevent further derecruitment and weaning failure.

limitations: this is a single-center study, with a small sample size; LUS is operator-dependent and there is variability in the results. However, in our study only one trained physician performed the examination; therefore, we avoided personal variability in the results; poor LUS views as in obese patients, since thick thoracic walls stand against the ultrasound beams to be propagated appropriately; the present conclusions were derived from adult, predominantly medical ICU, and should be confirmed in other settings; pulmonary aeration loss is one of the main potential causes of weaning failure. However, it is not the only one, and it is essential to contextualize the information obtained from LUS with clinical and laboratory data, as well as information derived from other imaging techniques such as echocardiography.

Conclusions

Conditions that may affect the weaning process involve alterations in the aeration of pulmonary parenchyma (eg, pulmonary edema, atelectasis). These aeration changes can be assessed by using LUS. Our data suggest that LUS can be used as a predictor of MV weaning outcomes in critically ill adults. A post-SBT LUS score cut-off value of 14.5 has a sensitivity and a specificity of 88.8% and 68.7%, respectively.

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