

# Sonographic measurement of lung aeration versus rapid shallow breathing index as a predictor of successful weaning from mechanical ventilation

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**Background** Lung ultrasonography is a beneficial tool for evaluation of the extent of lung aeration through measurement of the amount of extravascular lung water. Lung ultrasonography offers some advantages over other methods of assessment of lung aeration including the lack of ionizing radiation and the possibility of use at patient's bedside. It facilitates dynamic assessment of the lung during mechanical ventilation and during weaning.

**Aim** To assess lung aeration by lung ultrasonography in patients ready for weaning and to validate the significance of its use as a predictor of weaning outcome in comparison with rapid shallow breathing index.

**Patients and methods** A prospective observational study was conducted on 30 critically ill mechanically ventilated patients for 48 h or more, and ready to undergo spontaneous breathing trial (SBT), according to the readiness criteria. It was conducted in Beni-Suef University Hospital from October 2017 to May 2018. Rapid shallow breathing index was measured before initiation of SBT, and lung ultrasound was done, before, during, and after SBT [lung ultrasound score (LUS) 1, 2, and 3] and were used as predictors for SBT outcome. Patients were divided, according to outcome, into successful weaning group (group A) and failed weaning group (group B).

## Introduction

Mechanical ventilation is significant as a life-saving intervention in any sort of respiratory failure. It is a crude intervention that is only used in critically ill patients in life-threatening conditions [1]. Pulmonary complications of mechanical ventilation increase in incidence with the duration of ventilation, so early successful weaning is a cornerstone in prevention of these complications [2,3]. Weaning failure is a major problem that is commonly seen in critically ill patients. Weaning failure includes spontaneous breathing trial (SBT) failure [4] and postextubation distress that requires re-intubation or noninvasive ventilation within 48 h after extubation [5]. Assessment of readiness of weaning and the ideal time for extubation play an important role in determination of predicted hospital stay and prediction of outcome [2]. Many mechanisms are incriminated in weaning failure from mechanical ventilation, for example, alteration of lung resistance or compliance during weaning process, lung derecruitment, spontaneous breathing-induced cardiac dysfunction, and neuromuscular disorders. Most of these factors are associated with decreased lung aeration

**Results** In the failed weaning group, LUS1, LUS2, and LUS3 were significantly higher than those of the successful weaning group. At cutoff value of 8.5, LUS3 could be used for prediction of weaning failure with sensitivity 85% and specificity 100%. Moreover, there was a statistically significant relation between LUS and the other variables including hospital stay, mechanical ventilation duration, and mortality.

**Conclusion** Lung ultrasound is useful as a bedside tool that can help physicians in their weaning decisions.

*Egypt J Bronchol* 2019 13:477–483

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*Egyptian Journal of Bronchology* 2019 13:477–483

**Keywords:** extravascular lung water, lung ultrasound score, rapid shallow breathing index, spontaneous breathing trial

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**Received:** 15 January 2019 **Revised:** 26 March 2019

**Accepted:** 14 July 2019 **Published:** 25 October 2019

during SBT and lead to weaning failure [6]. Derecruitment, which could be a possible cause of weaning failure, needs to be directly studied to predict and early diagnose failure of the weaning process [7]. Different variables are used as predictors of weaning; the rapid shallow breathing index (RSBI) is the most widely used predictor of weaning success [8]. Visualization of the lungs was not possible by ultrasound for a long time. However, nowadays we can use the artefacts produced at the interface between the lungs and other substances, for example, fluids, to identify specific pathologies in the lung [9]. Lung ultrasound could be used as a predictor of weaning failure by detection of lung aeration loss before weaning and during the SBT [10]. Being a bedside, noninvasive, radiation free, quickly performed procedure and able to perform a dynamic assessment of changes of lung aeration makes it superior to other procedures that

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can be used to assess lung aeration and to predict success of weaning process, so it needs further research and studies to prove its efficacy and accuracy [11].

### Patients and methods

Thirty critically ill ventilated patients admitted to Beni-Suef University Hospital from October 2017 to May 2018 were enrolled in the study. The study protocol was approved by the research ethical committee of Beni-Suef University. A written consent was taken from the patients' close relatives for agreement of enrollment in the study.

### Inclusion criteria

Patients invasively ventilated for 48 h or more and ready to undergo a SBT according to the traditional readiness criteria were included [12].

### Exclusion criteria

Patients less than 18 years old; patients with traumatic lung injury or pneumothorax; patients with interstitial lung disease, bullous lung lesion, or extensive bronchiectasis; patients with chest wall lesion that impairs the use of chest ultrasound, for example, burn and open wound; morbid obese patients with BMI of at least 40 kg/m<sup>2</sup>; and patients with a previously failed SBT were excluded.

### Study design

RSBI was measured, and lung ultrasonography was done just before initiation of SBT [lung ultrasound score (LUS) 1]. Included patients were then subjected to an SBT using (PSV) with pressure support less than or equal to 10 cmH<sub>2</sub>O and PEEP up to 5 cmH<sub>2</sub>O. During this phase, clinical, laboratory, ABG, and ventilator data were recorded. Lung ultrasonography was done at the end of SBT (LUS2) [1]. According to weaning outcome, patients were divided into two groups: successful weaning group (group A), which included patients who successfully passed an SBT and were weaned from mechanical ventilation with no need for re-intubation or noninvasive ventilation in the subsequent 48 h, and failed weaning group (group B), which included patients who failed during SBT and were brought back to assist ventilation and patients who required re-intubation or noninvasive ventilation within 48 h after extubation. Lung ultrasonography was done 4–6 h after extubation (LUS3), and patients were observed for 48 h to assess the need of re-intubation or noninvasive ventilation, indicating failed weaning. In group B patients, LUS3 was done on failure of the weaning process or just after reinstitution of mechanical ventilation.

### Study outcomes

The primary outcome measures were respiratory distress requiring reintubation or noninvasive ventilation within 48 h after weaning.

The secondary outcome measures were hospital mortality and length of ICU stay within 28 days.

### Methods

Lung ultrasonography was done using LOGIC PRO 100 (KPI Health care company, India) and EDAN DUS 60 (Global health company, China) ultrasound devices by applying B-Mode, with the use of a convex probe (5.5 MHz). The probe was applied vertically over the examined intercostal spaces in each region, with the patients lying flat or in the semi-recumbent position. Lung ultrasonography was done before, during, and after SBT. Lung ultrasound was used to assess the degree of lung aeration loss according to LUS score [13], according to which the chest wall is divided into 12 zones (six zones per side). Each hemithorax is divided into three zones by the parasternal line, anterior axillary line (AAL), posterior axillary line (PAL) and the paravertebral line, and then each zone is divided into upper and lower zones, above and below fifth intercostal space [13]. One of four patterns of aeration was recognized for each region (Table 1 and Fig. 1).

### Statistical analysis

The software used in analysis was the version 15 of the statistical package SPSS (self-propelled semi-submersible, Microsoft, USA). Mean and SD values were compared using simple *t*-test. Pearson's correlation test was used to study the association between each two variables among each group for numerical data. The probability of error (*P* value) up to 0.05 was considered significant. Receiver operating characteristic (ROC) curve analysis was done to predict the cutoff points of the test variables (RSBI, LUS1, LUS2, and LUS3) that best predict the binary state of another variable.

**Table 1 Lung aeration patterns as detected during lung ultrasonography**

Aeration pattern	Score	Description
Normal	0	Lung sliding, A lines, and $\leq 3$ B lines
Moderate loss	1	Multiple regularly and irregularly spaced B lines
Severe loss	2	Multiple and coalescent B lines
Complete loss	3	Lung consolidation

Figure 1

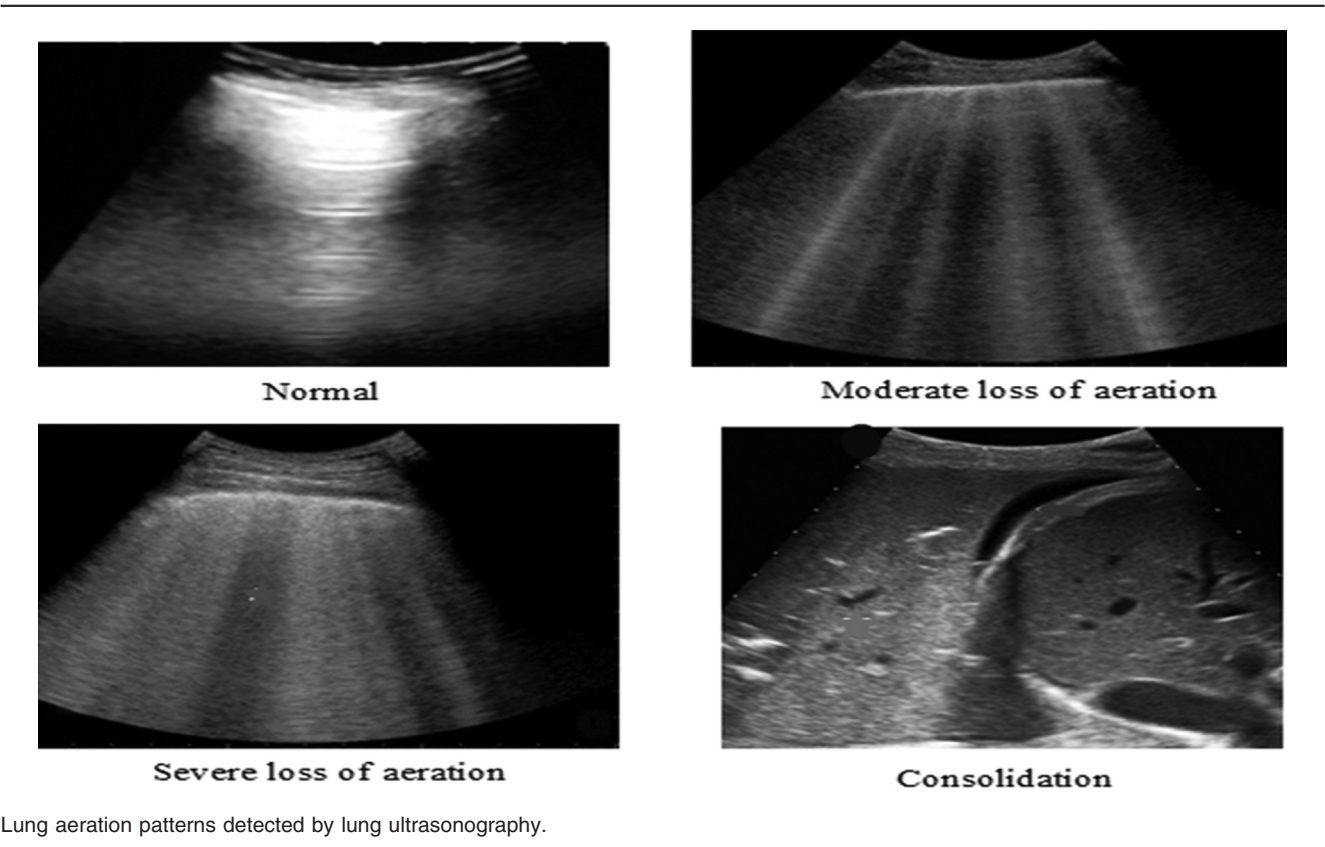
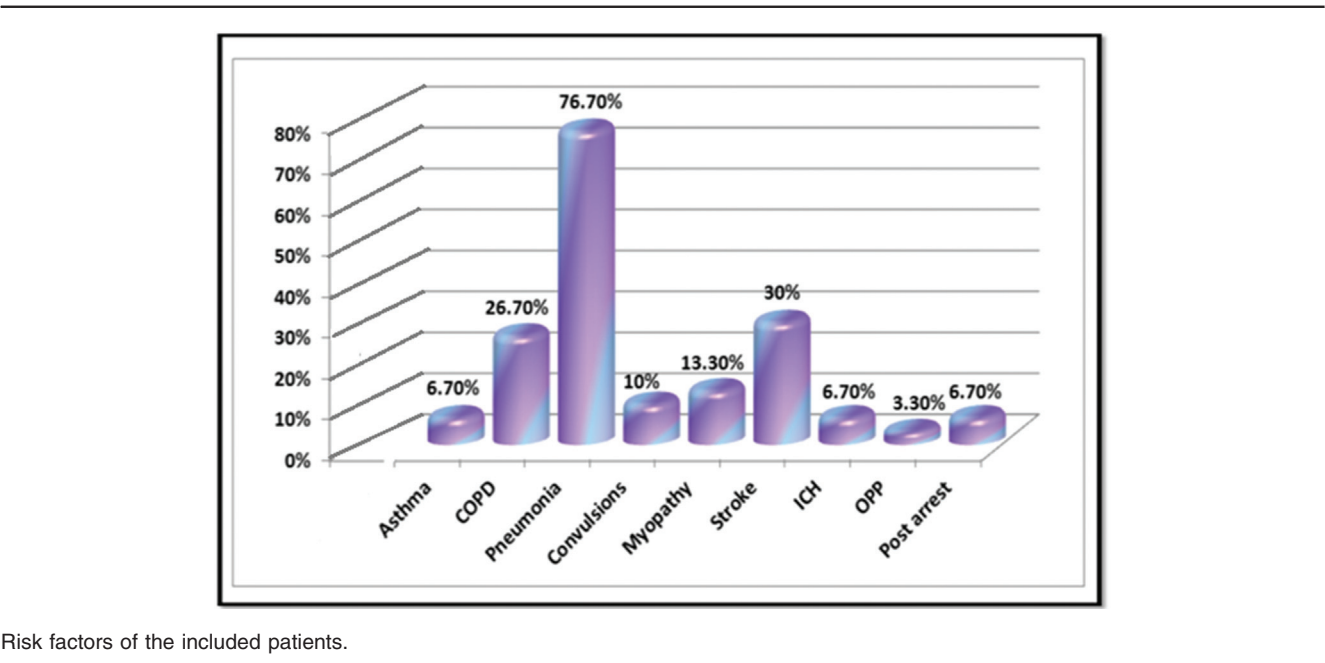


Figure 2



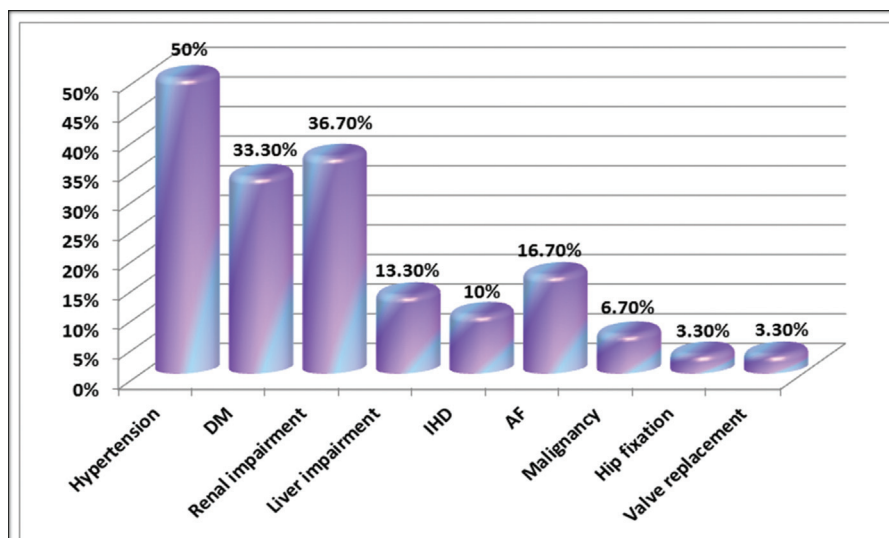
**Results**

The study included 30 patients; the age of the studied patients ranged from 19 to 84 years, with a median age of 66.5 years and mean±SD was 60.8±20.1 years. Of the studied patients, 18 (60%) were males and 12 (40%) were females. Included patients had multiple risk factors and comorbidities; 76.7% had pneumonia,

and 50% were hypertensive. Risk factors and comorbidities of included patients are presented in Figs 2 and 3 [2].

Length of hospital stay ranged from 3 to 28 days, with mean±SD of 16.1±8.3 days. Ventilation days of included patients ranged from 2 to 25 days, with

Figure 3



Comorbidities of the included patients.

mean $\pm$ SD of 9.7 $\pm$ 6.6 days. Of the included patients, 10 (33.3%) were successfully weaned; however, the remaining 20 (66.7%) were classified as failed weaning patients owing to either failure of SBT or owing to the need of re-ventilation within 48 h after weaning. Of the included patients, 16 (53.3%) were survivors, whereas 14 (46.7%) patients were nonsurvivors. Demographic data and clinical criteria of the included patients are described in Table 2.

Statistical results of included patients were correlated with the study outcomes; a statistically significant difference was found between mean pressure of arterial oxygen (PaO<sub>2</sub>)/fraction of inspired oxygen ratio for patients who failed weaning (213 $\pm$ 70) and that for who were successfully weaned (306.2 $\pm$ 128.3), with *P* value 0.015. Moreover, a statistically significant difference was found between mean LUS1, LUS2, and LUS3 for patients who failed to be weaned and that for who were successfully weaned, with *P* value less than 0.05. Correlative data between different variables and study outcomes are illustrated in Tables 3–5.

Receiver operator characteristic curves were used to test the LUS1, LUS2, and LUS3 and RSBI as predictors of failure of weaning from mechanical ventilation. The positive actual state is failed weaning (Table 6 and Fig. 4). ROC curve illustrates the potential of RSBI, LUS1, LUS2, and LUS3 as predictors of weaning failure as follows: At a cutoff value of 34.5 (25–94) the sensitivity of RSBI was 80% and the specificity was 30% [area under the curve (AUC)=0.590], positive predictive value (PPV)=69.6%, and negative predictive value (NPV)=42.8%. At a cutoff value of 11.5

**Table 2** Demographic data and clinical criteria of the included patients

Item	Range/N (%)	Mean $\pm$ SD
Age	19–48	60.8 $\pm$ 20.1
Sex		
Male	18 (60)	
Female	12 (40)	
GCS	10–15	14.1 $\pm$ 1.58
MAP	55–78	66.6 $\pm$ 6.7
RR	12–30	20.7 $\pm$ 5.9
Temperature	36.5–39.5	37.5 $\pm$ 0.9
Pulse	61–102	83.1 $\pm$ 11.9
BMI	20–40	31.03 $\pm$ 4.9
PaO <sub>2</sub> /FiO <sub>2</sub>	150–570	244.2 $\pm$ 101.5
Peak pressure	19.1–38	25.5 $\pm$ 4.4
Plateau pressure	11–28	17.3 $\pm$ 4.6
Mean airway pressure	4–23	10.07 $\pm$ 3.2
Static compliance	20.2–62.1	39.8 $\pm$ 13.2
Ventilator days	2–25	9.7 $\pm$ 6.6
Length of ICU stay	3–28	16.1 $\pm$ 8.3
Failed weaning	20 (66.7)	
Successful weaning	10 (33.3)	
Survivors	16 (53.3)	
Nonsurvivors	14 (46.7)	

FiO<sub>2</sub>, fraction of inspired oxygen; GCS, Glasgow coma scale; MAP, mean arterial pressure; PaO<sub>2</sub>, pressure of arterial oxygen; RR, respiratory rate.

(1.5–20), the sensitivity of LUS1 was 90% and the specificity was 50% (AUC=0.773, PPV=78.3%, and NPV=71.4%). At a cutoff value of 8.5 (0.5–18.5), the sensitivity of LUS2 was 80% and the specificity was 70% (AUC=0.830, PPV=84.2%, and NPV=63.6%). At a cutoff value of 8.5 (2–21), the sensitivity of LUS3 was 85% and the specificity was 100% (AUC=0.903, PPV=100%, and NPV=76.9%).



**Table 3 Correlative data between successful and failed weaning groups**

Item	Failed weaning	Successful weaning	<i>P</i> value
Age (years)	62±18.7	58.3±23.3	0.854
Sex			
Female	8 (40)	4 (40)	0.456
Male	12 (60)	6 (60)	
GCS	14±1.7	14.3±1.2	0.457
MAP	59.6±2.3	71.9±6.1	0.564
RR	27.6±2.3	22.6±2.3	0.745
Temperature	37.8±0.6	37.8±0.3	0.986
Pulse	92.4±3.2	85.1±11.6	0.365
BMI	30.1±3.1	33±7	0.765
PaO <sub>2</sub> /FiO <sub>2</sub>	213.3±70	306.2±128.3	0.015
RSBI	57.8±23.65	49.8±18.2	0.390
LUS1	14.3±5.3	10.2±4.4	0.044
LUS2	10.7±4.8	6.3±2.7	0.012
LUS3	13.5±5.5	5.7±2.1	<0.001
Duration of ventilation	12.7±6	3.7±2.4	<0.001
Length of ICU stay	19.7±7.1	8.9±5.2	<0.001

FiO<sub>2</sub>, fraction of inspired oxygen; GCS, Glasgow coma scale; LUS1, lung ultrasound score during positive pressure ventilation; LUS2, lung ultrasound score during spontaneous breathing trial; LUS3, lung ultrasound score after weaning from mechanical ventilation; MAP, mean arterial pressure; PaO<sub>2</sub>, pressure of arterial oxygen; RR, respiratory rate; RSBI, rapid shallow breathing index.

**Table 4 Correlative data between survivors and nonsurvivors**

Items	Survivors	Nonsurvivors	<i>P</i> value
Duration of ventilation	9.1±7.9	10.2±4.9	0.545
Length of ICU stay	15.5±9.8	16.8±6.3	0.634
LUS1	11.25±5.25	14.85±4.81	0.061
LUS2	7.87±5.14	10.86±3.65	0.082
LUS3	8.06±5.09	14.14±5.28	0.003

LUS1, lung ultrasound score during positive pressure ventilation; LUS2, lung ultrasound score during spontaneous breathing trial; LUS3, lung ultrasound score after weaning from mechanical ventilation.

## Discussion

Chest ultrasound is a quick bedside test and a noninvasive reliable technique for the assessment of pulmonary congestion [14]. This study hypothesis was built on the assumption that LUS can accurately detect extravascular lung water and quantify for the degree of aeration loss. Hence, it can be used to detect SBT-associated lung derecruitment and can significantly predict the results of weaning before and during initiation of the weaning process. This study showed a statistically significant difference between mean PaO<sub>2</sub>/fraction of inspired oxygen ratio of patients who failed to be weaned and that of who were successfully weaned, with *P* value 0.015. Similar to these results, Osman and Hashim [15] stated that the mean value PaO<sub>2</sub> was higher in the successful weaning

**Table 5 Correlation between lung ultrasound score during spontaneous breathing trial and length of ICU stay**

Length of ICU stay	LUS2
Pearson correlation ( <i>r</i> )	0.364
<i>P</i> value	0.048

LUS2, lung ultrasound score during spontaneous breathing trial.

**Table 6 ROC curve analysis for lung ultrasound score 1, 2, 3 and rapid shallow breathing index in relation to weaning success**

	RSBI	LUS1	LUS2	LUS3
Cutoff point	34.5	11.5	8.5	8.5
Low probability of failure	<25	<1.5	<0.5	<2
Intermediate probability of failure	25–94	1.5–20	0.5–18.5	2–21
High probability of failure	>94	>20	>18.5	>21
Sensitivity (%)	80	90	80	85
Specificity (%)	30	50	70	100
PPV (%)	69.6	78.3	84.2	100
NPV (%)	42.8	71.4	63.6	76.9
AUC	0.590	0.773	0.830	0.903

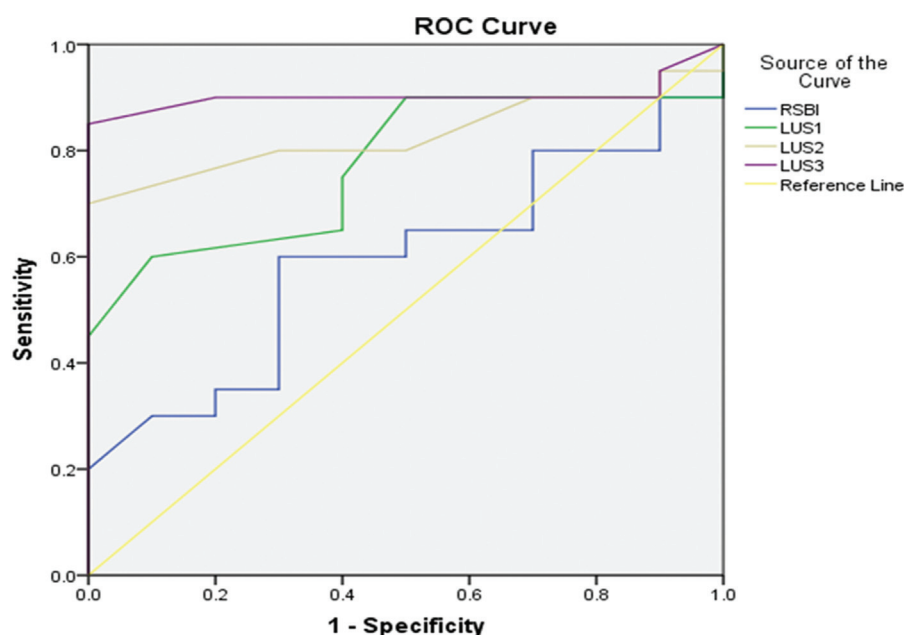
AUC, area under the curve; LUS1, lung ultrasound score during positive pressure ventilation; LUS2, lung ultrasound score during spontaneous breathing trial; LUS3, lung ultrasound score after weaning from mechanical ventilation; NPV, negative predictive value; PPV, positive predictive value; ROC, receiver operating characteristic; RSBI, rapid shallow breathing index.

group than the failed weaning group, with mean values of 69.7 and 46.6, respectively, which was considered statistically significant.

This study could not find a statistically significant difference between failure and successful weaning groups regarding any of the clinical and laboratory data. Similarly, Tenza-Lozano *et al.* [16] performed a prospective cohort study including patients ventilated for more than 24 h and ready to be weaned. No significant relation between hemodynamic monitoring and study outcomes could be detected. Against these results, Haji *et al.* [17] found that there was a significant increase in the respiratory rate for those who failed weaning than those who succeeded, with *P* value of 0.02. This difference from this study can be explained by single measurement of the hemodynamic parameters at initiation of the SBT and were not followed after success or failure of SBT. Moreover, in this study, respiratory rate was estimated on pressure support ventilation not on T-piece.

This study did not find any significant statistical difference in mean values of RSBI between successful weaning group and failed weaning group. Similarly, Tenza-Lozano *et al.* [16] could not detect a statistical significance in the difference of mean values

Figure 4



ROC curve analysis.

of RSBI in the failed group versus that of the successful group. In the contrary, Osman and Hashim [15] found that RSBI was higher in the failure than the success group, with median values of 113.9 and 71.9, respectively, which was considered statistically significant.

A statistically significant difference was found between mean LUS1, LUS2, and LUS3 for patients who failed to be weaned and that for who were successfully weaned. In the same context, Shoaier *et al.* [18] performed lung ultrasound for all patients before weaning, during SBT, and 6 h after extubation. LUS score was higher in the failed weaning group than the successful weaning one, with *P* value less than 0.001 [3]. Similarly, Haji *et al.* [17] found that LUS in the anterior and lateral chest wall regions was significantly different between successful and failed group, with median values of 11 and 17, respectively, with *P* value of 0.007. Moreover, it showed a lower significant statistical analysis when comparing the total score by adding the posterior wall score, with the result of weaning with median values of 22 and 18 for the successful and failed groups, respectively, with *P* value of 0.06.

Moreover, Soummer *et al.* [19] proved that LUS before SBT trial was 6–13 in the successful group and 13–17 in the failure group, with *P* value less than 0.001. At the end of SBT, failed weaning group showed LUS 16–21, which is extremely higher than the successful group, 7–13, with *P* value less than 0.001. Following 4–6 h

after extubation, failed weaning group showed significant derecruitment in lung aeration, with LUS ranging from 17 to 23, against the successful group, with LUS ranging from 7 to 15, with *P* value less than 0.001.

Similar to this work, Banerjee and Mehrotra [20] found a significant relation between weaning results and LUS, with mean values of  $7.23 \pm 3.69$  and  $20.77 \pm 5.79$  for successful and failed groups, with *P* value less than 0.0001.

In this study, there was a statistically significant difference in the duration of mechanical ventilation between patients who failed the weaning process and those who were successfully weaned from mechanical ventilation. Similarly, Shoaier *et al.* [18] found a significant relation between days on mechanical ventilation and weaning results, with *P* value less than 0.001. Moreover, Banerjee and Mehrotra [20] found that duration of mechanical ventilation was higher in failed group, with *P* value less than 0.0001.

This study showed a significant difference in the length of ICU stay between failed and succeeded weaning groups of patients. In the same context, Shoaier *et al.* [18] found that the length of stay in ICU was significantly higher in the failed group, with *P* value less than 0.001. Similarly, Tenza-Lozano *et al.* [16] showed with statistically significant values that failed weaning group of patients had a higher duration of

ICU stay than successfully weaned group, with *P* value less than 0.002.

This study showed a significant linear correlation between LUS2 and length of ICU stay, with *P* value of 0.048. In this context, Tierney *et al.* [21] found that higher LUS was positively associated with increased length of ICU stay (*P*=0.003).

ROC curve was plotted to test RSBI, LUS1, LUS2, and LUS3 as predictors of weaning, and results were concomitant with the results of Soummer *et al.* [19] who found that LUS at the end of SBT more than 17 was highly specific for predicting postextubation distress with AUC=0.86, and a LUS score up to 12 was highly sensitive for excluding postextubation distress. Moreover, Osman and Hashim [15] found that SBT-LUS less than 12 has high probability for success, 12–17 for intermediate probability for success, and more than 17 for high probability for failure. In another way, Tenza *et al.* [16] found that the optimal cutoff point for successful weaning was 7, with sensitivity 76% and specificity 73% (AUC=0.80).

## Conclusion

Lung ultrasonography is a useful method in assessment of the degree of lung aeration during positive pressure ventilation, during and after SBT. So, it can be used as a good predictor of the weaning results. The best predictive measurement for LUS is at 4–6 h after a successful weaning trial. Early prediction of weaning failure by LUS can be helpful to prevent re-intubation by early initiation of NIV before actual failure.

## Acknowledgements

This study was supported by Beni-Suef University Hospital.

## Financial support and sponsorship

Nil.

## Conflicts of interest

There are no conflicts of interest.

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