ORIGINAL ARTICLE

Prediction of Successful Spontaneous Breathing Trial and Extubation of Trachea by Lung Ultrasound in Mechanically Ventilated Patients in Intensive Care Unit

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Abstract

Introduction: Spontaneous breathing trial (SBT) is always successful in mechanically ventilated patients. This study was conducted to assess the prediction of successful SBT and extubation of trachea by bedside lung ultrasound in mechanically ventilated patients.

Methodology: This was a prospective observational study for 1 year conducted at a tertiary teaching hospital ICU on 102 patients with age more than 18 years and who were mechanically ventilated for more than 24 hours. Bedside lung ultrasound was used to assess the lung ultrasound score (LUS) and lung profiles in patients who clinically met the criteria for SBT. The LUS at the beginning of SBT and 30 minutes after SBT were used to predict the successful SBT and tracheal extubation.

Result: Spontaneous breathing trial and tracheal extubation were successful in 73 (71.6%) and 57 (55.8%) of the patients. The AUC for lung ultrasound in predicting successful SBT at the beginning and 30 minutes of SBT were 0.781 (CI 95% 0.674–0.888, $p < 0.001$) and 0.841 (CI 95% 0.742–0.941, $p < 0.001$) with a cut-off value of 17.5 and 19.5, respectively. Similarly, AUC for LUS in relation to tracheal extubation was 0.786 (CI 95% 0.694–0.879, $p < 0.001$) and 0.841(CI 95% 0.756–0.925, $p < 0.001$) at 0 and 30 minutes. About 57.5% of the patients with A profiles tolerated successful SBT while 48.3% of the patients having C profile had failed SBT ($p < 0.001$). COPD, lung ultrasound, higher SOFA score, and longer duration of mechanical ventilation had a statistically significant negative correlation with successful SBT.

Conclusion: Lower LUS and A profiles lung ultrasound are associated with more successful weaning and tracheal extubation in mechanically ventilated patients.

Keywords: Lung aeration, Lung ultrasound, Mechanical ventilation, Spontaneous breathing trial, Weaning, Weaning success.

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Highlight

Lung ultrasound can be used to determine the aeration of lung tissue and thus might be useful in determining the successful spontaneous breathing trial (SBT). This study has demonstrated the usefulness of lung ultrasound in mechanically ventilated patients for weaning process and tracheal extubation.

Introduction

The end point of mechanical ventilation is successful weaning and extubation of trachea. Following a successful SBT, approximately 30% of patients may experience respiratory distress within 48 hours of extubation, necessitating respiratory support in the form of noninvasive or invasive ventilation.[1] Apart from prolong mechanical ventilation, critical illness polyneuromyopathy, comorbid conditions, and severity of the disease, it is assumed that the loss of lung aeration after SBT is primarily responsible for the weaning failure.[2] It is essential to assess the mechanically ventilated patients appropriately and precisely for the readiness for SBT.

The lung ultrasound can be one of the important bedside tools to monitor lung abnormalities and has advantages over conventional radiological means in terms of its reliability, accuracy, and high reproducibility.[3,4] The lung ultrasound can be used to describe the aeration of the lung tissue. A pattern in the ultrasound image field is produced by the normal lung. Similarly, the interstitial and alveolar fluid will produce the longitudinal comet-like lines called B lines originating from the pleural line.[5–7] The consolidation in lung tissue will produce a tissue-like structure with dynamic or static air bronchogram.[8] The presence of B lines and consolidation pattern determines the loss of lung aeration. Bouhemad B first described lung ultrasound score (LUS) based on the lung aeration in different parts of the bilateral lung. The LUS described by Bouhemad ranged from 0 to 36.[9] In a study conducted by Soummer et al., it was demonstrated that an LUS score below 13 following an SBT was a reliable predictor of successful extubation. Conversely, an LUS score exceeding 17 was found to be highly indicative of post-extubation distress and failure.[10,11]

The cut-off LUS for determining successful SBT and successful extubation has wide variability in different literature and is thus

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inconclusive. This study aimed to add more precise evidences on the usefulness of lung ultrasound in determining the success of SBT and successful tracheal extubation.

Methodology

We conducted a prospective observational study at 22-bedded medical and surgical intensive care unit of a tertiary level teaching hospital for a duration of 1 year between 2022 March and 2023 March. Ethical approval was obtained from the institutional review committee. The study enrolled individuals who were over 18 years old and admitted to the intensive care unit (ICU) with surgical or medical diagnoses. These patients had been mechanically ventilated for a duration exceeding 24 hours and were considered ready for the weaning process.

SonoSite II ultrasound system (P24550-03, FusiFilm, Sonosite, Bothell, WA 98021, USA) was used as an ultrasound machine. A curvilinear probe with 2–5 MHz frequency was used for A lines, B lines, and deeper lung tissues, while a linear probe with 8–12 MHz frequency was used to delineate subpleural consolidations. The hemithorax was divided into three sections, namely, the anterior, lateral, and posterior regions using the anterior and posterior axillary lines. Each of these three parts was divided into upper and lower zone by a line passing at the level of both the nipples. In total, 12 zones were scanned with 6 in each hemithorax.

The LUS was calculated based on the following characteristics:

- A pattern – A lines were assigned 0 score and indicates normal aeration.
- B pattern – B lines, which can be observed originating from the pleural line or small consolidations near the pleura, indicate a moderate loss of aeration. These B lines are assigned a score of 1 in the assessment.
- B pattern – When multiple coalescent B lines are observed in several intercostal spaces and appear indistinct, it indicates a severe loss of aeration. This pattern is assigned a score of 2 on the assessment.
- Consolidation – The presence of tissue echogenicity accompanied by a static or dynamic air bronchogram indicates a complete loss of aeration. This particular pattern is assigned a score of 3 in the assessment.

To determine the LUS, the scores of the 12 regions that were examined are summed together. This cumulative score ranges from 0 to 36, reflecting the overall assessment of lung involvement.[9]

The initiation of an SBT was contingent upon confirming that the patient meets specific criteria. These criteria included improvement in the underlying condition, alertness, and ability to communicate effectively. Adequate gas exchange, normal pH levels, low and stable doses of vasoactive drugs, normal electrolyte levels, and a rapid shallow breathing index (RSBI) of 105 breaths per minute per liter or lower were also considered prerequisites for initiating an SBT.[10,12] If subjects participating in the breathing trial exhibited signs of respiratory discomfort, such as a respiratory frequency exceeding 35 breaths per minute, arterial oxyhemoglobin saturation dropping below 90%, utilization of accessory respiratory muscles, or paradoxical thoracoabdominal ventilation, the trial would be interrupted. Additionally, if tachycardia occurred with a heart rate surpassing 140 beats per minute, hemodynamic instability manifested with systolic blood pressure (SBP) below 90 mm Hg or a 20% decrease from baseline levels, or there was a change in mental status, such as drowsiness, coma, or anxiety, the trial would also be halted.

Once the decision to initiate the SBT was made, the lung scan was done in each zone by a clinician who was trained in doing lung ultrasound for the last five years and who was kept blind for the study. The lung score at the time of initiation of SBT was noted and was assigned as time 0 LUS. The lung scanning was repeated 30 minutes after the SBT and was assigned as Time 30 LUS after the SBT. In the lung scan of 12 zones, predominant A, B, and C profiles were noted.

Patients who sustained 2 hours of SBT without any signs of distress were grouped as SBT success group, while those who developed respiratory distress, hemodynamic instability, tachypnea, and desaturation at least 30 minutes after the initiation of SBT were grouped as SBT failed group. Respiratory support with mechanical ventilation was started for failed SBT group.

Patients with successful tracheal extubation did not require any form of invasive or noninvasive respiratory support within 48 hours of extubation.

The objective of the study was to assess the predictive value of the LUS in determining successful SBT and tracheal extubation. The demographic data, comorbid conditions, severity of illness number of successful SBT, number of successful extubation, the requirement of invasive or noninvasive respiratory support after extubation, and number of ventilator-free days were measured in order to meet the objective of the study.

Results

The patient data were recorded using Microsoft Excel, and IBM SPSS version 21 was employed for statistical analysis. The Kolmogorov–Smirnov test was conducted to assess the normal distribution of the various parameters. To compare continuous variables, the Student's *t*-test or the Mann–Whitney *U* test was utilized, while the Chi-square test or the Fisher exact test was used to compare proportions, depending on the appropriateness. Multiple logistic regression analysis was employed to evaluate the impact of various independent factors on the successful SBT. The predictive values of the LUS in determining the success of the SBT and tracheal extubation were assessed using the reciever operating characteristic (ROC) curve for each variable. A *p*-value of less than 0.05 was considered statistically significant.

A total of 729 patients were admitted in 1 year in the intensive care unit of a teaching hospital, out of which 318 patients were mechanically ventilated and 113 patients were eligible for recruitment in the study. Only 102 patients were finally included for data analysis. Eleven patients were excluded because of consent denial (4), hemodynamic instability immediately after the onset of SBT (5), and self-extubation of the trachea (2).

Demographic and Clinical Profile of the Patients

The study population had a mean age of 43.52 ± 19.50 years, with a higher proportion of males (60.8%) compared with females (39.2%). About 67.6% of the total population were admitted to ICU with a medical diagnosis, and the rest (32.4%) with a surgical diagnosis. The incidences of hypertension, diabetes, ischemic heart disease (IHD), chronic obstructive pulmonary disease (COPD), and the use of inotropes were 30.4%, 36.3%, 24.5%, 21.6%, and 20.6%, respectively. There was a predominance of A, B, and C profiles in lung ultrasound in 47.1%, 32.4%, and 20.6% of patients, respectively. Spontaneous breathing trial (SBT) was successful in the first attempt in 73 (71.6%) of the patients out of which only 57 (55.8%) had successful tracheal

Table 1: Demographic and clinical profiles of patients

Variables	*Values*
Age	43.52 ± 19.50
Sex	
Male	62 (60.8%)
Female	40 (39.2%)
Patient type	
Medical	69 (67.6%)
Surgical	33 (32.4%)
Hypertension	31 (30.4%)
Diabetes	37 (36.3%)
IHD	25 (24.5%)
COPD	22 (21.6%)
Inotropes	21 (20.6%)
Lung profile	
A	48 (47.1%)
B	33 (32.4%)
C	21 (20.6%)
SBT successful	73 (71.6%)
Tracheal extubation	57 (55.8%)
SOFA	10.88 ± 5.69
SBP	115.17 ± 15.76
PO_2	307.62 ± 95.37
RSBI	60.64 ± 24.45
Duration MV	5.79 ± 3.26
Type of respiratory support in failed extubation	
Noninvasive	11 (68.7%)
Invasive	5 (31.3%)

COPD, chronic obstructive pulmonary disease; IHD, ischemic heart disease; LUS, lung ultrasound score; MV, mechanical ventilation; PO_2, arterial partial pressure of oxygen; RSBI, rapid shallow breathing index; SBP, systolic blood pressure; SOFA, sequential organ failure assessment

extubation. Of those who failed tracheal extubation (total 16), 11 patients required noninvasive form of respiratory support, while 5 patients were reintubated and required invasive mechanical ventilation. The mean duration of mechanical ventilation was 5.79 ± 3.26 days (Table 1).

Table 2 presents the comparison of lung profiles and LUSs for tolerance to SBTs. Patients with A profile are more likely to tolerate SBTs successfully as compared with B and C profiles ($p < 0.0001$) Patients having lower lung scores both at the beginning and 30 minutes of SBT were more likely to have successful SBT as compared with higher score level (11.91 ± 4.96 *vs* 17.82 ± 6.26 $p < 0.001$ at 0 minutes, 13.67 ± 5.82 *vs* 22.97 ± 6.77, $p < 0.001$, respectively). Similarly, patients with higher sequential organ failure assessment (SOFA) levels and longer duration of mechanical ventilation had less chance of successful SBT ($p < 0.001$ and $p = 0.018$, respectively).

The predictive value of LUS at the beginning of SBT (LUS0) and after 30 minutes of initiation of SBT (LUS30) in determining successful SBT was assessed by plotting the LUSs in the ROC curve (Fig. 1). The area under the curve (AUC) for predicting successful SBT for LUS at the beginning of initiation of SBT was 0.781 (CI 95% 0.674–0.888, $p < 0.001$) with cut-off value of 17.5 having a sensitivity of 83.6% and specificity of 59.6%, while the AUC for LUS at

Table 2: Comparison of variables between successful SBT and failed SBT group

Variables	*Successful SBT*	*Failed SBT*	*p-value*
Lung profile			
A	42 (57.5%)	6 (20.7%)	<0.0001
B	24 (31.0%)	9 (31.0%)	
C	7 (9.6%)	14 (48.3%)	
LUS at 0 minute	11.91 ± 4.96	17.82 ± 6.26	<0.001
LUS at 30 minute	13.67 ± 5.82	22.97 ± 6.77	<0.001

LUS, lung ultrasound score

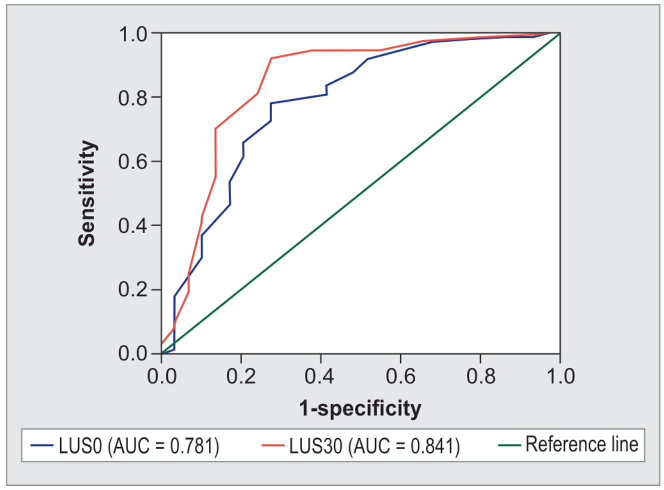

Fig. 1: ROC curve for lung ultrasound score and successful spontaneous breathing trial

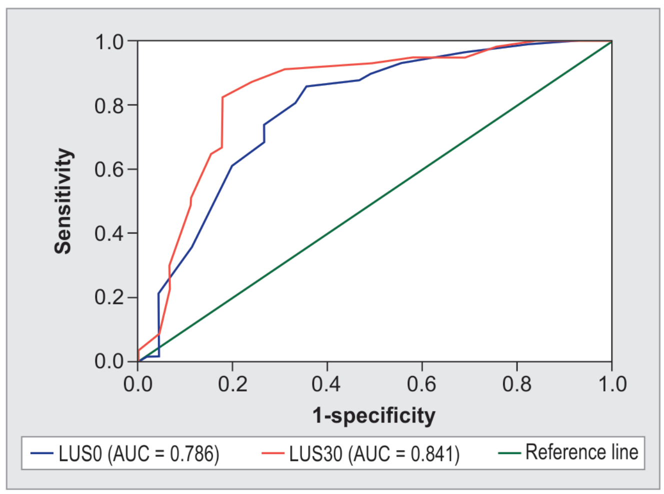

Fig. 2: ROC curve for lung ultrasound score and successful tracheal extubation

30 minutes of SBT was 0.841 (CI 95% 0.742–0.941, $p < 0.001$) with a cut-off value of 19.5 having a sensitivity of 80.6% and specificity of 75.9%.

Out of 73 patients with successful SBT, only 57 patients were successfully extubated and did not require any form of respiratory support apart from oxygen by face mask. Again, LUSs at the beginning and 30 minutes of SBT were assessed for predictability of tracheal extubation (Fig. 2) which showed that at 0 minutes,

Table 3: Multiple logistic regression for the various independent factors on successful spontaneous breathing trial

Variables	B	SE	Sig	OR (ExpB)	95% CI Lower	95% CI Upper
Age	–0.027	0.023	0.249	0.974	0.930	1.019
Sex	–0.013	1.058	0.990	0.124	0.124	7.851
Patient	1.094	1.036	0.291	2.987	0.392	22.77
HTN	1.421	1.159	0.137	1.852	0.857	2.681
IHD	–1.093	0.897	0.223	0.335	0.058	1.943
DM	–1.304	0.847	0.124	0.271	0.052	1.427
COPD	–2.387	1.032	0.021	0.092	0.012	0.694
Inotrope	2.120	1.121	0.059	2.329	0.925	4.014
LUS0	–0.209	0.140	0.136	0.358	0.126	0.841
LUS30	–0.380	0.145	0.009	0.684	0.515	0.908
SOFA	–0.152	0.101	0.032	0.859	0.704	1.047
Duration MV	–0.034	0.124	0.014	0.967	0.758	1.232
SBP	0.047	0.029	0.099	1.048	0.991	1.109
PO_2	0.205	0.110	0.669	2.682	1.095	5.627
RSBI	–0.018	0.016	0.259	0.983	0.953	1.013

COPD, chronic obstructive pulmonary disease, IHD, ischemic heart disease; LUS, lung ultrasound score; MV, mechanical ventilation; PO_2, arterial partial pressure of oxygen; RSBI, rapid shallow breathing index; SOFA, sequential organ failure assessment; SBP, systolic blood pressure

AUC was 0.786 (CI 95% 0.694–0.879, $p < 0.001$), while at 30 minutes, AUC was 0.841 (CI 95% 0.756–0.925, $p < 0.001$). The cut-off values of LUS for trachea extubation at 0 and 30 minutes of SBT were 15.5 (sensitivity 86% specificity 64.4%) and 17.5 (sensitivity 82.5% and specificity 82.2%)

A model was created to determine if various predictors, namely, age, sex, hypertension, diabetes, COPD, use of inotropes, lung score at 0 and at 30 minutes, RSBI, PaO_2, SBP duration of mechanical ventilation and SOFA score could influence the likelihood for successful SBT (Table 3). To test this hypothesis, multivariate logistic regression analysis was used.

The results showed that 86.3% of the variance in the likelihood of successful SBT was accounted for by the measured predictors in the model with the sensitivity of 97.3% and specificity of 75.9% collectively. Looking at the individual contributions of the predictors, the results showed that increasing age, male patients, IHD, COPD, lung score at 30 minutes, higher SOFA score, longer duration of mechanical ventilation, and higher RSBI had a negative likelihood of successful SBT. The statistically significant predictors of successful extubation were COPD (OR 0.092, CI 95% 0.012–0.694, $p = 0.021$), LUS at 30 minutes of SBT (OR 0.684, CI 95% 0.515–0.908, $p = 0.009$), higher SOFA score (OR 0.859, CI 95% 0.704–1.047, $p = 0.032$) and longer duration of mechanical ventilation (OR 0.967, CI 95% 0.758–1.232, $p = 0.014$).

Discussion

The objective of the present study was to examine the predictive value of lung ultrasound in assessing the success of SBTs and tracheal extubation among patients receiving mechanical ventilation in the intensive care unit (ICU).

The findings showed that lung ultrasound had a high predictive value for identifying patients who are likely to succeed in SBTs and those who can be safely extubated.

In the present study, the lung ultrasound done for 12 zones on bilateral chest demonstrated the predominance of A pattern, followed by B and C patterns. Out of 102 patients, 73 (71.6%) patients successfully tolerated SBT, while 57 (55.8%) patients successfully extubated the trachea and did not require any form of noninvasive or invasive respiratory support. The predominant A profile pattern in lung ultrasound led to a greater success rate of SBT, while the patients having predominant B and C profiles in lung ultrasound had a higher probability of failed SBT indicating that the lung profiles could significantly identify the patients under mechanical ventilation who could successfully tolerate the SBT and extubation of the trachea subsequently. In their study, Soummer et al. found that progressive lung derecruitment and potential alveolar fluid infiltration resulting from the loss of positive pressure during an SBT could help identify patients who were more likely to experience extubation failure.[10] Similarly, according to the observations made by Stein Silva, the presence of B lines in lung ultrasound was found to be highly predictive of the development of post-extubation respiratory distress. However, it was important to note that the presence of consolidations (C profile) showed a weak association with the rate of post-extubation distress.[13] Ana Carolina P. Antonio's research revealed that B-predominance was a weak predictor of SBT failure with sensitivity, specificity, positive predictive values, and negative predictive values of 0.47 (95% CI: 0.33–0.61), 0.64 (95% CI: 0.57–0.70), 0.25 (95% CI: 0.17–0.35), and 0.82 (95% CI: 0.75–0.88), respectively.[14] Furthermore, another study by Ana Carolina P. Antonio observed that there is a tendency for the development of B and C profiles at the conclusion of the SBT. Notably, patients with C profiles demonstrated a higher likelihood of SBT failure.[15]

The effect of lung profile on successful SBT was supported by the LUS at the beginning and 30 minutes of SBT. We observed that the higher lung score at both time frame could statistically identify the patients who failed SBT. The LUS score at 30 minutes had better predictability of successful SBT as compared with LUS at the beginning of SBT as described by larger AUC for LUS at 30 minutes in the ROC curve. The cutoff value of LUS for successful SBT was 19.5 at 30 minutes and 17.5 at the beginning of SBT. Ana Carolina P. Antonio's findings indicated that patients who achieved a lung ultrasound (LUS) score of less than 13 after the SBT had a 9% risk of post-extubation failure. In contrast, patients with an LUS score exceeding 17 had a substantially higher risk of 85% for post-extubation failure.[15] Funda Gok observed that LUS had an AUC of 0.760 with the sensitivity of 70% and specificity of 83.3%. In contrast to the present study, the cut-off value of LUS observed by Funda Gok was only 6.5 as they scanned only eight zones of the bilateral chest.[16] There was a significant and strong correlation between the success of extubation and the RSBI, with a correlation coefficient of 0.774 and a p-value of ≤ 0.001. Additionally, a moderate correlation was observed between extubation success and both the LUS and lung profiles. Another study, which examined 12 regions, reported that weaning was considered successful when the LUS score was below 12. Abhinav Banerjee has demonstrated that the LUS of 1–10 has a high probability of weaning success, while the score 16–32 had a high probability of failed weaning.[17] Similarly, a significant difference in the LUS was observed by V Amara et al. between patients with simple weaning and difficult or prolonged weaning.[18]

The findings of the current study revealed a negative correlation between successful SBTs and factors, such as COPD, higher lung scores, increased severity of illness, and longer durations of mechanical ventilation. The elderly population is at an increased risk of weaning failure, and an independent risk factor for this outcome is an elevated LUS.[19,20] In the present study, COPD had a negative correlation with SBT. Nava S et al. had demonstrated that approximately, 60% of COPD patients fail the first SBT trial with 40% experiencing difficulties in weaning.[21] Increased airway resistance, hyperdynamic lung condition, and expiratory flow limitation with increased respiratory drive could lead to respiratory muscle fatigue and thus increase the risk of failed SBT and extubation of the trachea.[22]

In the present study, tracheal extubation was successful at the first attempt after successful SBT in 55.8% of the patients, and in those who did not tolerate tracheal extubation after successful SBT, 16 patients (15.6%) required noninvasive and invasive mode of respiratory support. The incidence of re-intubation within 48 hours following a successful SBT has shown considerable variation in previous studies, ranging from less than 5% to nearly 20%. These discrepancies are likely attributed to differences in patient populations and the criteria utilized to determine the suitability of extubation and subsequent re-intubation.[23]

The findings of this study have important clinical implications in the management of mechanically ventilated patients in the ICU. First, the use of lung ultrasound can assist in identifying patients who are ready for weaning from mechanical ventilation, leading to potential benefits, such as shorter ventilation duration and reduced risks associated with prolonged mechanical ventilation. Secondly, lung ultrasound serves as a valuable tool in predicting the risk of extubation failure, enabling timely intervention and potentially avoiding the need for re-intubation. Additionally, the noninvasive nature, accessibility, and the absence of ionizing radiation make lung ultrasound a safer imaging modality for critically ill patients.

Limitations

While this study provides valuable insights into the use of lung ultrasound in managing mechanically ventilated patients in the ICU, it is important to acknowledge certain limitations. First, the sample size of the study was relatively small, resulting in imprecise results and wide confidence intervals for some variables. Therefore, large-scale studies with a more substantial sample size are needed to validate and confirm these findings more accurately. Another limitation is that the study was conducted at a single center, which may introduce operator-induced variability in the ultrasound findings. Replicating the study across multiple centers would help mitigate this limitation and enhance the generalizability of the results. Furthermore, the study did not consider certain factors that can significantly influence weaning success in mechanically ventilated patients, such as fluid balance and cardiac conditions including diastolic dysfunction and right heart failure. Future research should encompass these variables to provide a more comprehensive understanding of their impact on weaning outcomes.

Conclusion

The LUS can effectively predict the successful SBT in mechanically ventilated patients. The lower LUS and A profiles in lung ultrasound have a higher predictability value of successful SBT and successful tracheal extubation. Additionally, COPD, increased severity of illness, and prolonged mechanical ventilation can lead to a risk of failure of SBT.

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