

Research Article

Diagnostic Utility of Bedside Lung Ultrasound for Predicting Successful Liberation from Mechanical Ventilation: A Prospective Observational Study

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ABSTRACT

Background: Accurate prediction of successful liberation from mechanical ventilation remains challenging. Bedside lung ultrasound offers a noninvasive method for assessing pulmonary aeration and potentially improving weaning decisions.

Methods: This prospective observational study included 160 mechanically ventilated adults in a tertiary care intensive care unit. A 12-region lung ultrasound score (LUS) was assessed before the first spontaneous breathing trial (SBT). Successful liberation was defined as extubation within 24 hours following successful SBT, without reintubation or unplanned ventilatory support within 48 hours. Diagnostic performance was compared with the rapid shallow breathing index (RSBI) and PaO₂/FiO₂ ratio.

Results: Successful liberation occurred in 118 patients (73.8%). Median LUS was significantly higher in unsuccessful than successful liberation (19.0 versus 13.0; $p < 0.001$). LUS demonstrated an AUROC of 0.687, compared with 0.602 for RSBI and 0.524 for PaO₂/FiO₂. At a cutoff of ≥ 16 , sensitivity and specificity were 69.0% and 69.5%, respectively. Each five-point increase in LUS independently reduced the odds of successful liberation (adjusted OR 0.623; $p = 0.003$).

Conclusion: Pre-SBT lung ultrasound demonstrated moderate predictive accuracy and may complement conventional assessment of readiness for ventilator liberation.

Keywords: Lung Ultrasound, Mechanical Ventilation, Weaning, Spontaneous Breathing Trial, Extubation Success.

INTRODUCTION

Extubation from invasive mechanical ventilation is an important step in the care of the critically ill patient, and a delicate balance must be maintained between providing unnecessary ventilatory support and extubation too early. Longer mechanical ventilation is linked to ventilator-associated pneumonia, respiratory muscle dysfunction, higher cost of healthcare, and longer intensive care unit (ICU) stay. On the other hand, failure to liberate could require reintubation, increase the risk of further complications, and negatively impact clinical outcomes. The international WEAN SAFE study, which recruited 481 ICUs from 50 countries, showed that at 90 days only 65% of the patients included in the study were successfully weaned from mechanical ventilation, indicating

that ventilator liberation in routine critical care practice is complex [1]. While SBTs are the most important bedside test to assess readiness for extubation, successful SBTs do not always guarantee sustained respiratory independence, highlighting the need for other reliable predictors of liberation outcomes [2].

Traditional criteria for weaning readiness include clinical stability, oxygenation indices, respiratory mechanics and the rapid shallow breathing index (RSBI). In their prospective validation cohort, Yang and Tobin showed that RSBI was predictive of weaning outcome with an area under the receiver-operating characteristic curve (AUROC) of 0.89 [3]. However, the performance of conventional indices may differ among critically ill populations, especially in patients with

heterogeneous pulmonary pathology, impaired respiratory muscle function, or residual lung aeration abnormalities. In addition, indices based on either respiratory frequency, tidal volume or arterial oxygenation may not be sensitive enough to describe regional pulmonary abnormalities that become clinically significant when moving from positive-pressure ventilation to spontaneous breathing.

Lung ultrasound at the bedside has become a useful non-invasive tool for evaluating pulmonary aeration and detecting abnormalities, including interstitial involvement, alveolar consolidation and pleural disease. The semi-quantitative lung ultrasound score (LUS), based on the regional sonographic pattern, provides an estimate of the degree of loss of aeration of the lungs and can provide further information on readiness for ventilator liberation. Soummer et al. showed that post extubation respiratory distress was related to changes in lung aeration during a successful SBT. Their study found end-SBT ultrasound scores were significantly higher in patients who went on to develop respiratory distress, with an AUROC of 0.86 for predicting this outcome [4]. These findings provided a physiological basis to use lung ultrasound as a tool for assessing weaning readiness.

Further studies have investigated the predictive value of LUS in mechanically ventilated patients. Tenza-Lozano et al. found AUROCs of 0.80 and 0.78, respectively, for a modified LUS in predicting successful weaning and extubation, indicating that bedside assessment of pulmonary aeration may offer clinically useful prognostic information [5]. In a similar prospective study of 102 critically ill patients, Rajbanshi et al. showed that LUS measured at the start of an SBT predicted successful extubation with an AUROC of 0.786, and improved to 0.841 after 30 minutes [6]. These observations suggest that ultrasound evaluation may be useful prior to and during ventilator liberation.

However, the best use of LUS is yet to be determined. Lung ultrasound and diaphragmatic assessment were shown to be able to identify patients who were at high risk of weaning failure, but the discriminatory power of each ultrasound parameter was moderate [7]. Zhang et al. performed a systematic review and meta-analysis of 13 studies and 988 patients, and found that the pooled sensitivity and specificity were 86% and 75%, respectively, and the overall AUROC was 0.87 for predicting extubation failure [8]. While

these promising results exist, the variability in ultrasound protocols, timing of measurements, diagnostic criteria, patient characteristics, and the definition of liberation failure restricts the applicability of current evidence. Therefore, LUS should be further evaluated in conjunction with other well-known weaning parameters.

The present prospective observational study aimed to assess the value of pre-SBT bedside lung ultrasound in predicting successful liberation from IMV in critically ill adults admitted to a tertiary care ICU. The objective of the study was to assess the association between LUS and liberation outcomes, to establish a clinically relevant diagnostic threshold and to compare the predictive value of LUS with conventional parameters such as the RSBI and the $\text{PaO}_2/\text{FiO}_2$ ratio. The aim of the study was to elucidate the possible use of LUS as an additional tool to the standard ventilator liberation tests in the assessment of subsequent respiratory independence.

PATIENTS AND METHODS

Study Design and Participants

This was a prospective observational study done in the adult intensive care unit (ICU) of a tertiary care centre in 2025–2026. This study comprised 160 adult patients on invasive mechanical ventilation (IMV) who had their first spontaneous breathing trial (SBT). Patients aged ≥ 18 years who were clinically ready for weaning and had been mechanically ventilated for at least 24 hours were eligible. Readiness was defined as improvement in the underlying cause of respiratory failure, satisfactory spontaneous respiratory effort, acceptable oxygenation ($\text{SpO}_2 \geq 92\%$, $\text{FiO}_2 \leq 0.50$, and positive end-expiratory pressure [PEEP] ≤ 8 cmH_2O), and hemodynamic stability without the need for escalating vasopressor use. Patients who had a pre-existing tracheostomy, previous major pulmonary resection, chest wall abnormalities that precluded adequate ultrasonography, planned terminal extubation, limitations of treatment precluding reintubation, or anticipated continuation of ventilation for a nonrespiratory indication were excluded. The first eligible SBT was used for analysis.

Clinical and Ventilatory Assessment

Baseline data consisted of age, sex, BMI, comorbidities, category of admission to the intensive care unit and duration of invasive mechanical ventilation before the index SBT. The Sequential Organ Failure Assessment

(SOFA) and Acute Physiology and Chronic Health Evaluation II (APACHE II) scores were used to determine the severity of disease. Ventilatory parameters (fraction of inspired oxygen [FiO_2], positive end-expiratory pressure [PEEP], respiratory rate, tidal volume, and peripheral oxygen saturation) were measured immediately prior to the SBT. Arterial blood gas analysis was performed and included arterial pH and the ratio of arterial oxygen tension to inspired oxygen fraction ($\text{PaO}_2/\text{FiO}_2$). The rapid shallow breathing index (RSBI) was determined as the ratio of spontaneous breathing frequency to tidal volume in litres, and expressed as breaths/min/L.

Lung Ultrasound Assessment

Bedside lung ultrasonography was performed prior to the index SBT with a standardized 12-region examination, with 6 regions in each hemithorax. The regions were evaluated for pulmonary aeration and given a score of 0 to 3: 0, normal aeration with predominant A-lines; 1, moderate loss of aeration with separated B-lines; 2, severe loss of aeration with confluent B-lines; and 3, consolidation with a tissue-like pattern. The scores of each region were added together to give the total lung ultrasound score (LUS) (range 0–36). A higher score indicated more loss of lung aeration. Total pre-SBT LUS was used as the main diagnostic predictor of liberation outcome and was compared to the conventional weaning indices.

Spontaneous Breathing Trial and Outcome Assessment

The index SBT was performed after clinical evaluation for ventilator liberation. The duration of SBT, the outcome of the trial, and the outcome of extubation were documented. The primary outcome was successful liberation from invasive mechanical ventilation (IMV), defined as successful completion of the index SBT and extubation within 24 hours, with survival and no unplanned reinstitution of ventilatory support or reintubation during the following 48 hours. Unsuccessful liberation was defined as failure to extubate within 24 hours, SBT failure, reintubation, unplanned rescue ventilatory support or death during the observation period. Prophylactic noninvasive respiratory support was separated from rescue ventilation. Patients were divided into two groups: successful and unsuccessful liberation.

Statistical Analysis

The continuous variables were expressed as mean $\pm$ SD or median [IQR] and the categorical variables were expressed as frequencies and percentages. The Mann–Whitney U test was used for continuous variables and Fisher's exact test or Pearson's chi-square test for categorical variables for between-group comparisons.

Receiver-operating characteristic (ROC) curve analysis was used to assess the diagnostic performance of LUS, RSBI and $\text{PaO}_2/\text{FiO}_2$. The area under the ROC curve (AUROC) was used to quantify discrimination, and 95% confidence intervals were calculated using 1,800 stratified bootstrap resamples. Candidate diagnostic thresholds were determined using Youden's index. Sensitivity, specificity, positive predictive value, negative predictive value, and positive and negative likelihood ratios were computed with 95% confidence intervals. Exact binomial intervals were used for sensitivity and specificity, Wilson intervals for predictive values, and log-scale approximations for likelihood ratios. Stratified bootstrap resampling was used to test for differences between paired AUROCs.

Multivariable logistic regression was used to evaluate the independent relationship between LUS and successful liberation, while controlling for RSBI, $\text{PaO}_2/\text{FiO}_2$ and admission SOFA score. Predictors were entered as continuous variables, with LUS expressed per 5-point increase, RSBI per 10 breaths/min/L increase, $\text{PaO}_2/\text{FiO}_2$ per 50-mmHg increase, and SOFA per 1-point increase. Odds ratios, 95% confidence intervals, and Wald p values were reported. The evaluation of model discrimination was performed by apparent AUROC, and optimism correction was performed based on 450 bootstrap samples. Available-case analysis was used for individual comparisons and complete-case analysis for regression, without imputation. All statistical tests were two-tailed and p-values <0.05 were regarded as statistically significant.

RESULTS

Participants and clinical characteristics

Of 160 patients included at their first spontaneous breathing trial (SBT), 118 (73.8%) achieved successful liberation and 42 (26.3%) did not. Overall, 140 (87.5%) completed the index SBT successfully, and 135 (84.4%) underwent extubation within 24 hours. Within the specified observation window, reintubation, unplanned rescue ventilatory support and death occurred in 7 (4.4%), 9 (5.6%) and 1

(0.6%) patients, respectively. Baseline characteristics are summarized in Table 1.

Table 1. Baseline demographic and clinical characteristics according to liberation outcome

Characteristic	Overall (n=160)	Successful (n=118)	Unsuccessful (n=42)	Test statistic	p value
Age, years	55.0 [45.0–66.0]	55.5 [45.0–68.0]	53.0 [38.5–63.8]	U = 2848	0.152
Male sex	95 (59.4)	71 (60.2)	24 (57.1)	Fisher OR = 1.13	0.855
BMI, kg/m ²	25.4 ± 5.1	25.5 ± 4.8	25.0 ± 5.8	U = 2680	0.433
Diabetes mellitus	51 (31.9)	37 (31.4)	14 (33.3)	Fisher OR = 0.91	0.848
Hypertension	57 (35.6)	41 (34.7)	16 (38.1)	Fisher OR = 0.87	0.711
COPD	35 (21.9)	24 (20.3)	11 (26.2)	Fisher OR = 0.72	0.515
Chronic kidney disease	21 (13.1)	17 (14.4)	4 (9.5)	Fisher OR = 1.60	0.596
ICU admission category				$\chi^2(2) = 1.65$	0.439
Medical	102 (63.8)	75 (63.6)	27 (64.3)		
Surgical	43 (26.9)	30 (25.4)	13 (31.0)		
Neurological	15 (9.4)	13 (11.0)	2 (4.8)		
Admission SOFA score	7.0 [5.0–9.0]	6.0 [5.0–9.0]	8.0 [5.2–10.0]	U = 1966	0.046
APACHE II score	18.0 [15.0–23.0]	18.0 [15.0–22.5]	20.0 [16.8–24.0]	U = 1854	0.068
Mechanical ventilation before SBT, hours	104.6 [70.3–147.8]	100.5 [66.9–144.0]	112.8 [74.6–168.7]	U = 2217	0.312

Continuous measures are mean ± SD or median [IQR]; categorical measures are n (%). Test statistics are Mann–Whitney U, Fisher exact odds ratio, or Pearson χ^2 as labelled. APACHE II was available in 155 patients.

Patients who did not achieve liberation had higher pre-SBT lung ultrasound scores (LUS), whereas differences in conventional oxygenation and respiratory-mechanics indices were smaller (Table 2). The individual LUS distributions are shown in Figure 2.

Ventilatory findings and lung ultrasound

Table 2. Ventilatory parameters and ultrasound findings by liberation outcome

Characteristic	Overall (n=160)	Successful (n=118)	Unsuccessful (n=42)	Test statistic	p value
FiO ₂ fraction	0.4 [0.3–0.4]	0.4 [0.3–0.4]	0.4 [0.3–0.4]	U = 2453	0.924
PEEP, cmH ₂ O	6.0 [5.0–6.0]	6.0 [5.0–6.0]	6.0 [5.0–6.8]	U = 2126	0.155
Respiratory rate, breaths/min	19.0 [18.0–22.0]	19.0 [17.0–22.0]	20.0 [18.0–22.8]	U = 2133	0.179
Tidal volume, mL	418.9 ± 59.5	414.1 ± 52.4	432.4 ± 75.0	U = 2168	0.230
SpO ₂ , %	95.7 [94.4–96.5]	95.7 [94.5–96.5]	95.5 [94.3–96.5]	U = 2643	0.523
Arterial pH	7.4 [7.4–7.4]	7.4 [7.4–7.4]	7.4 [7.4–7.4]	U = 2622	0.410
PaO ₂ /FiO ₂ , mmHg	299.7 [234.2–346.9]	297.0 [231.9–350.0]	302.9 [238.2–338.1]	U = 2530	0.648
RSBI, breaths/min/L	73.7 [58.5–89.5]	71.2 [57.4–86.0]	75.8 [64.4–99.2]	U = 1847	0.055
Lung ultrasound score (0–36)	14.0 [9.0–20.2]	13.0 [8.0–17.0]	19.0 [13.0–26.8]	U = 1550	<0.001

SBT duration, minutes	60.0 [45.0–90.0]	60.0 [60.0–90.0]	60.0 [45.0–60.0]	U = 2942	0.058
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Values are median [IQR] or mean $\pm$ SD. LUS range 0–36; higher values denote poorer lung aeration. ABG-derived variables were available in 157 and RSBI in 156 patients.

Diagnostic discrimination and candidate thresholds

LUS demonstrated moderate discrimination for unsuccessful liberation, with an AUROC of

0.687 (95% CI 0.585–0.778), compared with 0.602 for RSBI and 0.524 for PaO₂/FiO₂ (Figure 1). The exploratory Youden-derived LUS threshold was ≥ 16.0 . At this threshold, sensitivity was 69.0% and specificity was 69.5% (Table 3).

Table 3. Diagnostic accuracy for identifying unsuccessful liberation

Test	Evaluable n	AUROC (95% CI)	Candidate cutoff for failure	Sensitivity (95% CI)	Specificity (95% CI)
LUS total	160	0.687 (0.585–0.778)	≥ 16.0	69.0% (52.9–82.4)	69.5% (60.3–77.6)
RSBI	156	0.602 (0.502–0.704)	≥ 88.3	42.5% (27.0–59.1)	77.6% (68.9–84.8)
PaO ₂ /FiO ₂	157	0.524 (0.428–0.619)	≤ 384.0	97.6% (87.4–99.9)	15.7% (9.5–23.6)

Test	PPV (95% CI)	NPV (95% CI)	LR+ (95% CI)	LR– (95% CI)
LUS total	44.6% (33.2–56.7)	86.3% (78.0–91.8)	2.26 (1.61–3.18)	0.45 (0.28–0.71)
RSBI	39.5% (26.4–54.4)	79.6% (71.3–86.0)	1.90 (1.16–3.11)	0.74 (0.56–0.98)
PaO ₂ /FiO ₂	29.7% (22.7–37.8)	94.7% (75.4–99.1)	1.16 (1.06–1.27)	0.15 (0.02–1.10)

AUROC 95% CIs use 1,800 stratified bootstrap resamples. Cutoffs maximize Youden's index in these same records and are unvalidated. PPV and NPV depend on failure prevalence. Positive

test: elevated LUS/RSBI or reduced PaO₂/FiO₂. Sensitivity/specificity CIs are exact binomial; PPV/NPV CIs use Wilson intervals; likelihood ratio CIs use log-scale approximations.

Paired AUROC comparisons:

Comparison	Paired n	AUROC difference (95% CI)	Bootstrap p
LUS versus RSBI	156	0.084 (-0.039 to 0.206)	0.179
LUS versus PaO ₂ /FiO ₂	157	0.165 (0.060 to 0.273)	0.001

Differences are LUS minus the comparator; paired stratified bootstrap (1,800 replicates) uses only observations with both measurements.

Adjusted association and internal validation

On complete-case analysis, a five-point increase in LUS was independently associated with reduced odds of successful liberation

(adjusted OR 0.623, 95% CI 0.457–0.851; p = 0.003). The adjusted associations for RSBI, PaO₂/FiO₂ and admission SOFA were not statistically significant (Table 4). The four-predictor model was fitted in 153 patients and had an apparent AUROC of 0.698; the bootstrap optimism-corrected AUROC was 0.663.

Table 4. Multivariable logistic regression for successful liberation

Predictor	Adjusted OR (95% CI)	Wald z	p value
LUS (per 5-point increase)	0.623 (0.457–0.851)	-2.98	0.003
RSBI (per 10 breaths/min/L increase)	0.905 (0.747–1.095)	-1.03	0.304
PaO ₂ /FiO ₂ (per 50-mmHg increase)	0.810 (0.596–1.102)	-1.34	0.18
Admission SOFA (per 1-point increase)	0.951 (0.816–1.108)	-0.64	0.522

Outcome coded as successful liberation. The model includes four prespecified continuous predictors and an intercept, with 153 complete records (the SOFA score is untransformed).

Wald z and two-sided p values are shown. Optimism correction used 450 bootstrap samples.

Figures

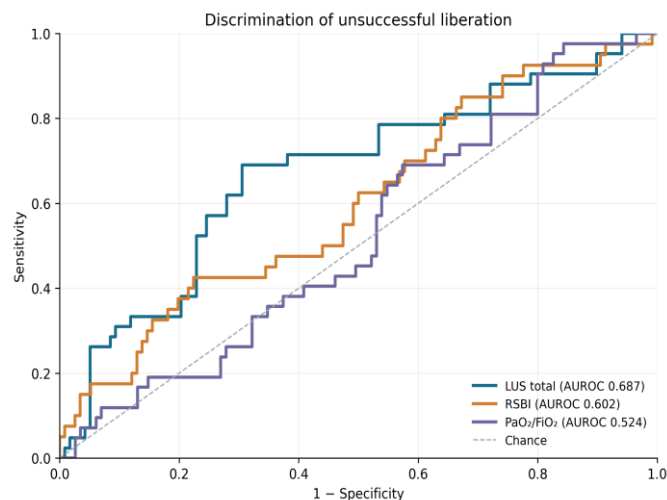


Figure 1. Receiver-operating characteristic curves of pre-SBT LUS, RSBI and $\text{PaO}_2/\text{FiO}_2$ for identifying unsuccessful liberation. A higher LUS or RSBI and a lower $\text{PaO}_2/\text{FiO}_2$ indicate greater predicted risk.

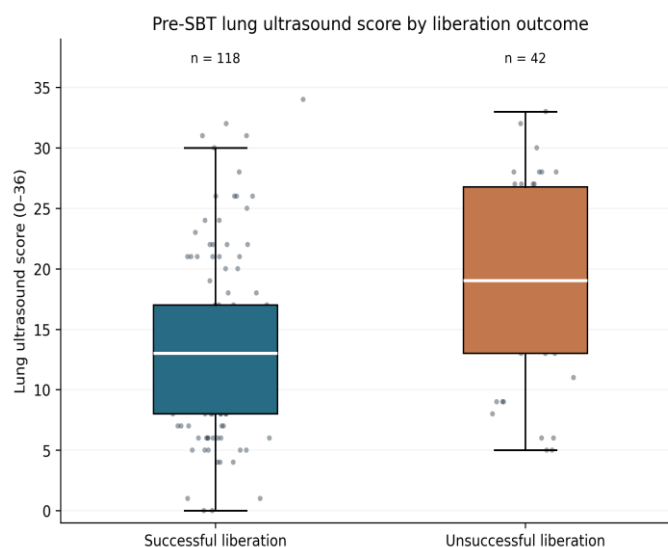


Figure 2. Pre-SBT lung ultrasound scores according to liberation outcome. Boxes show interquartile ranges and the median; points represent individual records.

DISCUSSION

The current study aimed to assess the value of bedside lung ultrasound in predicting successful liberation from invasive mechanical ventilation in 160 critically ill patients. Successful liberation was accomplished in 118 patients (73.8%) and unsuccessful liberation in 42 (26.3%). Patients who failed to be liberated from the ventilator had significantly higher pre-SBT lung ultrasound scores (LUS) (median 19.0 versus 13.0; $p < 0.001$). The discriminatory ability of

LUS for unsuccessful liberation was moderate (AUROC = 0.687, 95% CI 0.585–0.778). Sensitivity and specificity were 69.0% and 69.5% at a threshold of ≥ 16 . In addition, for each 5-point increase in LUS, the odds of successful liberation were independently decreased (adjusted odds ratio [OR] 0.623; 95% CI 0.457–0.851; $p = 0.003$). These results indicate that residual pulmonary aeration abnormalities are associated with liberation outcomes and that bedside ultrasonography

can help to complement conventional respiratory indices.

The association of higher LUS with failed liberation is similar to that of Jousselein et al. [9], who studied pulmonary aeration by lung ultrasound and electrical impedance tomography in 40 patients undergoing extubation. Twelve patients (30%) experienced extubation failure, and the pre-extubation LUS was significantly higher in the extubation failure group compared to the successful extubation group (19 vs. 10; $p = 0.003$). Patients with failure also had a smaller number of pixels available for ventilation in the lungs (352 vs. 406; $p = 0.042$). These results support the physiological relevance of residual aeration loss, but were obtained in patients who had already undergone an SBT. In a similar study, Rathish et al. [10] assessed 100 patients at high risk of extubation failure, and found that 35% failed to wean successfully. In the failure group, median LUS was significantly higher (16 vs. 10), with an AUROC of 0.831. A threshold of ≥ 13 had 86.2% sensitivity and 80.0% specificity. While these results suggest greater discrimination than was seen in the present study, differences in diagnostic performance may be due to the enrollment of a selected high-risk population.

LUS has also been shown to be predictive in larger ICU populations. Kedia et al. [11] studied 124 mechanically ventilated adults and found a significantly higher pre-SBT LUS in unsuccessful weaning patients (10 versus 8; $p = 0.008$). The post-SBT assessment yielded an AUROC of 0.797, 95% sensitivity and 66% specificity at a threshold of 9. The results indicate that ultrasound measurements taken during the physiological stress of spontaneous breathing could be more effective in identifying risk than a single baseline measurement. Wang et al. [12] evaluated 35 elderly COVID-19 patients who were intubated and mechanically ventilated, with 12 of them developing weaning failure in a different clinical population. LUS demonstrated an AUROC of 0.885 (95% CI 0.770–0.999), while a threshold of 10 provided 92.3% sensitivity and 72.7% specificity. The higher discriminatory performance and lower threshold reported in that study might be attributed to differences in the characteristics of pulmonary disease, patient selection, and distribution of aeration abnormalities. These comparisons suggest that LUS thresholds need to be considered in the context of the clinical population and measurement protocol, and not universally.

However, some studies have not shown any significant link between LUS and extubation success. Rabuske et al. [13] assessed 128 patients who were planned for extubation, and achieved successful extubation in 92.2%. Neither modified LUS nor diaphragmatic excursion was significantly different between outcome groups, although diaphragmatic thickening fraction was significantly larger among successfully extubated patients (42.1% versus 20.9%; $p = 0.042$). Their findings are different from the present results and indicate that in some patient groups, respiratory muscle performance might be more useful than pulmonary aeration. The relatively low failure rate (7.8%) and assessment during the SBT, rather than exclusively before it, may also have had an impact on the ability to detect differences. These discrepancies suggest that weaning failure is a multifactorial process involving pulmonary, neuromuscular, cardiovascular and airway mechanisms.

A combined ultrasound protocol of the lung, diaphragm and cardiac system was shown to be potentially valuable by Kundu et al. [14], who studied 60 patients after successful SBTs. Twenty-seven patients then needed ventilatory support within 48 hours. The failure group had higher increases in LUS during SBT (2 versus 1; $p < 0.001$), lower diaphragmatic thickening fraction (27.88% versus 30.87%; $p = 0.04$), and lower velocity-time integral response to passive leg raising (9.11% versus 13.63%; $p < 0.001$). Diaphragmatic thickening fraction $< 26\%$ (OR 6.20) and velocity-time integral response $< 10.2\%$ (OR 6.16) were significant predictors of failure in multivariable analysis. The results indicate that a combination of the three parameters (pulmonary aeration, respiratory muscle function and cardiovascular reserve) may be a more complete indicator of readiness for extubation than any single parameter.

One of the most significant findings of the current study was that the predictive accuracy of traditional weaning indices was relatively low. The AUROC of RSBI was 0.602, and that of the $\text{PaO}_2/\text{FiO}_2$ ratio showed very little discrimination (AUROC 0.524). LUS showed a higher AUROC than $\text{PaO}_2/\text{FiO}_2$ (AUROC difference 0.165; $p = 0.001$), but its improvement over RSBI was not statistically significant ($p = 0.179$). Limitation of RSBI was also noted by Saravanan et al. [15] in 200 mechanically ventilated patients, of whom 171 were successfully weaned. The AUROC of diaphragmatic excursion was 0.809, whereas

the AUROC of RSBI was 0.422. The sensitivity and specificity were 94% and 71%, respectively, at an excursion threshold of >1.21 cm, and 94% and 31%, respectively, at an RSBI threshold of <82. Similarly, Song et al. [16] studied 110 patients and found that 37 (33.6%) had weaning failure. The AUROCs of conventional RSBI, diaphragmatic excursion-adjusted RSBI and diaphragmatic thickening fraction-adjusted RSBI were 0.639, 0.813 and 0.859, respectively. Both ultrasound-adjusted indices were significantly better than the traditional RSBI ($p = 0.004$ and $p < 0.001$). These results show the potential role of ultrasound-based physiological measurements in addition to traditional respiratory mechanics. This independent relationship between LUS and liberation outcome was observed in the present multivariable analysis, even after adjusting for RSBI, $\text{PaO}_2/\text{FiO}_2$, and admission Sequential Organ Failure Assessment score. The four-predictor model, however, had only moderate discrimination, an apparent AUROC of 0.698, and an optimism-corrected AUROC of 0.663. In addition, $\text{LUS} \geq 16$ had a positive predictive value of 44.6% and a negative predictive value of 86.3%. While a lower score may be useful to identify patients who have relatively favourable liberation prospects, the positive predictive value is relatively low and therefore LUS alone is not very reliable in identifying patients who will fail. LUS therefore may be more suitable to be used in addition to clinical judgment and SBT assessment rather than as a single factor determining extubation.

The key strengths of this study are the assessment of 160 critically ill adults, the use of standardized 12-region lung ultrasound scoring prior to the index SBT, and the evaluation of clinically relevant liberation outcomes over 48 hours, compared with conventional weaning indices. Diagnostic performance was evaluated with bootstrap confidence intervals, paired AUROC comparisons, and multivariable analysis with internal validation. However, there are a few restrictions to consider. The one-centre design may limit generalizability, and the fact that the underlying causes of respiratory failure may differ could affect pulmonary aeration and liberation outcomes. Lung ultrasound was assessed at one time point before SBT, thus no assessment of dynamic changes in aeration during spontaneous breathing. Other physiological contributors to failure were not included (diaphragmatic and cardiac ultrasound measurements). Precision may have been influenced by the relatively small unsuccessful-

liberation group and available-case analysis. Further, the candidate LUS threshold was calculated from the same cohort and needs to be validated. More multicentre studies with serial lung ultrasound and integrated cardiopulmonary assessment are required to define reproducible thresholds and to assess whether ultrasound-driven liberation strategies have an impact on patient outcome.

CONCLUSION

Bedside lung ultrasound showed moderate diagnostic accuracy for predicting unsuccessful liberation from invasive mechanical ventilation. Successful liberation was independently associated with lower pre-SBT LUS, and LUS was more discriminatory than the $\text{PaO}_2/\text{FiO}_2$ ratio, but its advantage over RSBI was not statistically significant. The exploratory LUS threshold of ≥ 16 had moderate sensitivity and specificity. Lung ultrasound may thus be a useful addition to the traditional weaning process.

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