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EFFICACY OF ULTRASOUND GUIDED EXTRA-VASCULAR LUNG WATER INDEX MEASUREMENT IN PREDICTING DURATION OF MECHANICAL VENTILATION IN CRITICAL CARE UNIT –A PROSPECTIVE OBSERVATIONAL STUDY

Dr. Theyjes Sabesan[1*], Dr. Anand Kuppusamy[2], Dr. Dheepak Kumaran[3]

[1*]Dr. Theyjes Sabesan, Anaesthesia Post-graduate, SRM Medical College Hospital and Research Centre, SRM Nagar, Potheri – 603203, Tamil Nadu, India, E-mail: ts0480@srmist.edu.in, Orcid ID: 0009-0009-6584-0389
[2]Professor, Department of Anaesthesia, SRM Medical College Hospital and Research Centre, SRM Nagar, Potheri – 603203, Tamil Nadu, India, Email: anandk@srmist.edu.in
[3]Assistant Professor, Department of Anaesthesia, SRM Medical College Hospital and Research Centre, SRM Nagar, Potheri – 603203, Tamil Nadu, India

ABSTRACT
Background: Extravascular lung water (EVLW) contributes to respiratory dysfunction and poor outcomes in critically ill patients requiring mechanical ventilation. Lung ultrasound (LUS) is a rapid, non-invasive bedside tool for assessing pulmonary fluid burden using the Total Lung Score (TLS). This study evaluated the utility of LUS-derived TLS in predicting the duration of mechanical ventilation, weaning outcomes, and intensive care unit (ICU) length of stay.
Methods: This prospective observational study included 136 mechanically ventilated adult patients admitted to a tertiary care ICU. Lung ultrasound was performed serially from Day 1 to Day 8 using a standardized four-zone protocol. Total Lung Score and pulmonary fluid burden were categorized as low, moderate, or high. Correlation analysis, one-way ANOVA, multivariable regression, logistic regression, and receiver operating characteristic (ROC) analysis were performed to evaluate the association of baseline TLS with duration of mechanical ventilation, prolonged weaning (>7 days), and ICU length of stay.
Results: The mean age was 46 ± 13 years, and 57% of patients were male. The mean Day 1 TLS was 13.76 ± 3.84, with 69.9% having moderate pulmonary fluid burden. TLS progressively declined to 2.70 ± 3.09 by Day 8, indicating improvement in pulmonary aeration. Day 1 TLS showed weak, non-significant correlations with duration of mechanical ventilation ($r = 0.131$, $p = 0.13$) and ICU stay ($r = 0.157$, $p = 0.069$). Patients with high pulmonary fluid burden required significantly longer mechanical ventilation (5.78 ± 0.97 days) than those with moderate (4.35 ± 1.79 days) or low burden (4.16 ± 1.74 days) ($p = 0.045$). Baseline TLS was not an independent predictor of mechanical ventilation duration, prolonged weaning, or ICU stay. ROC analysis showed poor predictive accuracy for prolonged weaning (AUC = 0.45).
Conclusion: Serial lung ultrasound effectively monitored changes in pulmonary fluid burden during ICU stay. Although higher pulmonary fluid burden was associated with longer mechanical ventilation, baseline Total Lung Score alone was not an independent predictor of mechanical ventilation duration, prolonged weaning, or ICU length of stay. LUS is therefore a valuable bedside monitoring tool when interpreted alongside clinical assessment.

KEYWORDS: Lung ultrasound; Extravascular lung water; Total Lung Score; Mechanical ventilation; Intensive care unit.

INTRODUCTION
Mechanical ventilation (MV) is one of the most frequently employed life-support interventions in intensive care units (ICUs) and plays a crucial role in the management of critically ill patients with acute respiratory failure, severe sepsis, trauma, postoperative complications, and acute respiratory distress syndrome (ARDS). Although mechanical ventilation is lifesaving, prolonged dependence on ventilatory support is associated with several adverse consequences, including ventilator-associated pneumonia, respiratory muscle weakness, prolonged ICU stay, increased healthcare costs, and higher mortality. Therefore, identifying factors associated with the duration of mechanical ventilation and successful weaning remains an important objective in critical care medicine (1,2).
Fluid resuscitation is an essential component of the management of critically ill patients to restore tissue perfusion and maintain hemodynamic stability. However, excessive fluid administration may result in fluid overload, leading to accumulation of extravascular lung water (EVLW) within the pulmonary interstitium and alveolar spaces. Increased EVLW impairs pulmonary compliance, disrupts gas exchange, reduces oxygenation, and may contribute to delayed liberation from mechanical ventilation and other adverse clinical outcomes (3,4). Previous studies have demonstrated an association between increased EVLW and prolonged mechanical ventilation, longer ICU stay, organ dysfunction, and mortality, highlighting the importance of assessing pulmonary fluid status in critically ill patients (5–7).
Transpulmonary thermodilution using the PiCCO system is considered the reference standard for quantitative measurement of EVLW. However, this technique is invasive, requires specialized equipment and vascular catheterization,

and is not routinely available in many intensive care settings, particularly in resource-limited institutions (8,9). Consequently, there has been growing interest in non-invasive bedside methods for evaluating pulmonary fluid burden.

Lung ultrasound (LUS) has emerged as a practical, radiation-free, bedside imaging modality for assessing pulmonary pathology in critically ill patients. The presence and distribution of B-lines correlate with pulmonary interstitial fluid accumulation and provide an indirect estimate of EVLW. Owing to its portability, repeatability, low cost, and ease of use, lung ultrasound has become an attractive alternative to invasive monitoring techniques. Several studies have demonstrated good agreement between lung ultrasound findings and transpulmonary thermodilution-derived EVLW measurements, supporting its role in the assessment of pulmonary edema and lung water content (4,10).

Previous studies have also reported associations between higher lung ultrasound scores and adverse clinical outcomes, including prolonged mechanical ventilation, weaning difficulty, ICU stay, and mortality. Rajpal et al. observed that increased lung ultrasound scores were associated with prolonged weaning and longer ICU stay, while Mayr et al. demonstrated that simplified B-line protocols correlated well with invasively measured EVLW. Zhao et al. also reported that lung ultrasound scores were associated with disease severity in patients with ARDS (10–12). However, these findings have not been entirely consistent across different patient populations, study designs, and lung ultrasound protocols. Whether baseline lung ultrasound measurements independently predict clinically important outcomes in a heterogeneous ICU population remains uncertain.

Furthermore, lung ultrasound has the additional advantage of being easily repeatable, allowing serial assessment of changes in pulmonary fluid burden during the course of treatment. Although serial lung ultrasound is increasingly used to monitor response to fluid management and clinical recovery, evidence regarding the prognostic value of a single baseline examination remains limited, particularly in mixed medical and surgical ICU populations.

Although lung ultrasound has become an established bedside tool for assessing pulmonary fluid burden, whether a baseline lung ultrasound examination independently predicts clinically important outcomes such as duration of mechanical ventilation, prolonged weaning, and ICU length of stay remains uncertain, particularly in heterogeneous ICU populations. Therefore, the present prospective observational study was undertaken to evaluate the association between baseline lung ultrasound-derived Total Lung Score and clinically important outcomes among mechanically ventilated critically ill patients.

2. METHODOLOGY

2.1. Study Design

The study was conducted as a prospective observational study to evaluate the efficacy of ultrasound-guided Extravascular Lung Water Index (EVLWI) measurement in predicting the duration of mechanical ventilation among critically ill patients admitted to the Critical Care Unit (CCU). The study aimed to determine whether lung ultrasound-derived EVLWI could serve as a reliable bedside predictor of prolonged mechanical ventilation and assess its association with weaning outcome, length of ICU stay, and in-hospital mortality. Since no therapeutic intervention was introduced beyond routine clinical care, an observational design was considered appropriate for evaluating the prognostic value of lung ultrasound in critically ill patients.

2.2. Study Setting

The study was carried out in the Department of Anaesthesiology and Critical Care Unit of the participating tertiary care teaching hospital. The CCU manages a large number of mechanically ventilated patients with diverse medical and surgical illnesses requiring intensive monitoring and respiratory support. The unit is equipped with bedside ultrasonography facilities, advanced mechanical ventilators, and trained intensivists, making it an appropriate setting for serial assessment of extravascular lung water using lung ultrasound.

2.3. Study Duration

The study was conducted over a period approved by the Institutional Ethics Committee. Eligible patients admitted to the Critical Care Unit during the study period were enrolled consecutively. Lung ultrasound examinations, clinical monitoring, and follow-up were performed daily until successful weaning from mechanical ventilation, discharge from the ICU, or death.

2.4. Participants

Patients admitted to the Critical Care Unit and requiring invasive mechanical ventilation were screened for eligibility.

Inclusion Criteria

- Mechanically ventilated patients of either sex.
- Age more than 18 years.
- Patients admitted to the Critical Care Unit requiring invasive mechanical ventilation.

Exclusion Criteria

- Pre-existing lung pathology such as pulmonary fibrosis.
- Persistent pleural effusion.
- Haemothorax.
- Pneumothorax.
- Fracture of ribs interfering with lung ultrasound examination.
- Neurosurgical patients.

- Cardiothoracic surgical patients.

2.5. Study Sampling
A consecutive sampling technique was employed. All eligible mechanically ventilated patients satisfying the inclusion and exclusion criteria and admitted to the Critical Care Unit during the study period were enrolled consecutively until the required sample size was achieved. This method minimized selection bias and ensured that every eligible patient had an equal opportunity to participate during the recruitment period.

2.6. Study Sample Size
The sample size was calculated using the formula for estimating a single population proportion based on the sensitivity of lung ultrasound in estimating extravascular lung water reported by Rajpal M et al. (2024). A 99% confidence level (Z = 2.576), an expected sensitivity (P) of 36% (0.36), and an absolute precision (d) of 7.2% (0.072) were considered for the calculation. The calculated minimum sample size was 136 participants. Therefore, a minimum of 136 mechanically ventilated adult patients fulfilling the inclusion and exclusion criteria were enrolled in the study to evaluate the efficacy of ultrasound-guided Extravascular Lung Water Index (EVLWI) measurement in predicting the duration of mechanical ventilation among critically ill patients admitted to the Critical Care Unit.

2.7. Study Groups
Since this was a prospective observational study, no intervention groups were created. Following daily lung ultrasound assessment, patients were categorized according to pulmonary fluid burden based on the Total Lung Score:

- Low pulmonary fluid burden: Total Lung Score 1–10
- Moderate pulmonary fluid burden: Total Lung Score 11–20
- High pulmonary fluid burden: Total Lung Score 21–32

These categories were used for subsequent analysis of clinical outcomes.

2.8. Study Parameters
The primary study parameter was the Extravascular Lung Water Index (EVLWI) estimated using lung ultrasound-derived Total Lung Score. Secondary parameters included duration of mechanical ventilation, weaning outcome, duration of ICU stay, and in-hospital mortality. Baseline demographic variables including age, sex, diagnosis, pulse rate, blood pressure, and oxygen saturation were also recorded.

2.9. Study Procedure
After obtaining Scientific and Institutional Ethics Committee approval, written informed consent was obtained from the patient's legally authorized representative before enrolment. Eligible patients admitted to the Critical Care Unit were recruited according to the predefined inclusion and exclusion criteria.

Daily bedside lung ultrasound examinations were performed using a 2–5 MHz linear/convex ultrasound probe. Patients were examined in the supine or semi-recumbent position. A simplified four-zone lung ultrasound protocol, adopted from the parent study because of its feasibility for bedside assessment in critically ill patients, was used. Four intercostal spaces, comprising the bilateral third and sixth intercostal spaces extending from the parasternal region to the midclavicular line, were systematically scanned.

Each intercostal space was evaluated for the presence of single and confluent B-lines. Lung water content was graded using a scoring system ranging from 0 to 8 for each scanned region according to the number and extent of B-lines. The individual scores from all four lung regions were summed to obtain the Total Lung Score (TLS), ranging from 0 to 32.

Based on the Total Lung Score, pulmonary fluid burden was categorized as Low (1–10), Moderate (11–20), and High (21–32). Lung ultrasound examinations were repeated daily throughout the period of mechanical ventilation to monitor changes in pulmonary fluid burden and response to treatment.

Patients were followed until successful extubation, ICU discharge, or death. The duration of mechanical ventilation, weaning outcome, ICU length of stay, and mortality were recorded. For analysis, patients were classified into early/normal weaning (≤7 days) and prolonged weaning (>7 days). A cut-off of 7 days was selected because patients requiring mechanical ventilation beyond one week are routinely evaluated for tracheostomy in our intensive care unit as part of standard clinical practice. Following tracheostomy, the clinical course and weaning strategy differ substantially from those undergoing conventional extubation. Therefore, the primary outcome of the present study was limited to the pre-tracheostomy period to enable a uniform evaluation of the relationship between baseline lung ultrasound findings and weaning outcomes.

2.10. Study Data Collection
Data were collected using a structured case record proforma. Baseline demographic characteristics, primary diagnosis, vital parameters, and oxygen saturation were recorded at enrolment. Daily lung ultrasound findings, Total Lung Score, pulmonary fluid burden category, duration of mechanical ventilation, number of weaning attempts, ICU length of stay, weaning outcome, and in-hospital mortality were documented prospectively. All observations were verified for completeness before statistical analysis.

2.11. Data Analysis

The collected data were entered into Microsoft Excel and analysed using Statistical Package for the Social Sciences (SPSS) software. Continuous variables were expressed as mean ± standard deviation, whereas categorical variables were presented as frequency and percentage. Correlation analysis and regression analysis were performed to evaluate the relationship between ultrasound-derived Extravascular Lung Water Index and duration of mechanical ventilation. Logistic regression analysis was used to assess predictors of prolonged weaning where appropriate. Receiver Operating Characteristic (ROC) curve analysis was performed to evaluate the diagnostic performance of Total Lung Score in predicting prolonged mechanical ventilation. A p-value <0.05 was considered statistically significant.

2.12. Ethical Considerations

Prior to commencement of the study, approval was obtained from the Institutional Scientific Committee and Institutional Ethics Committee. Written informed consent was obtained from the legally authorized representatives of all eligible patients before enrolment. The study involved only bedside lung ultrasound, which is a non-invasive, radiation-free, and safe imaging modality without additional risk to the patient. Participants continued to receive standard intensive care management throughout the study period. Confidentiality of patient information was strictly maintained by assigning unique study identification numbers, and all collected data were used solely for research purposes. Participants or their representatives were informed that refusal to participate or withdrawal from the study at any stage would not affect the quality of medical care provided. This methodology is consistent with the study protocol and sample size described in your uploaded synopsis.

RESULTS

Phase 1: Baseline Descriptive Statistics

Table 1: Baseline Demographic and Clinical Characteristics

Variable	**N = 136**
Age (years), Mean (SD)	46 (13)
Gender, n (%)	
F	58 (43%)
M	78 (57%)
Diagnosis, n (%)	
Ards	19 (14%)
Ca Mandible	1 (0.7%)
Ckd	2 (1.5%)
Ckd/Sepsis	30 (22%)
Post-Op/Sepsis	15 (11%)
Pulmonary Edema	4 (2.9%)
Rta	51 (38%)
Rta/Omfs	2 (1.5%)
Trauma	12 (8.8%)
Systolic BP (mmHg), Mean (SD)	136 (14)
Diastolic BP (mmHg), Mean (SD)	80 (10)
Pulse Rate (bpm), Mean (SD)	111 (12)
SpO2 (%), n (%)	
94	8 (5.9%)
95	12 (8.8%)
96	14 (10%)
97	22 (16%)
98	31 (23%)
99	21 (15%)
100	28 (21%)
Day 1 Total Lung Score, Mean (SD)	14 (4)
Day 1 Pulmonary Fluid Burden, n (%)	
Low	32 (24%)
Moderate	95 (70%)
High	9 (6.6%)

A total of 136 mechanically ventilated patients were included in the study, with a mean age of 46 ± 13 years. Males constituted the majority (57%), while females accounted for 43% of the study population. The most common clinical diagnosis was road traffic accident (RTA) (38%), followed by CKD with sepsis (22%), ARDS (14%), post-operative sepsis (11%), and trauma (8.8%). The mean systolic blood pressure, diastolic blood pressure, and pulse rate at admission were 136 ± 14 mmHg, 80 ± 10 mmHg, and 111 ± 12 bpm, respectively. Most patients had an oxygen saturation (SpO_2) of 98% (23%), followed by 100% (21%) and 97% (16%). The mean Day 1 Total Lung Score was 14 ± 4, and the majority of patients had moderate pulmonary fluid burden (70%), while 24% had low and 6.6% had high pulmonary fluid burden, indicating that most patients had moderate extravascular lung water accumulation at baseline.

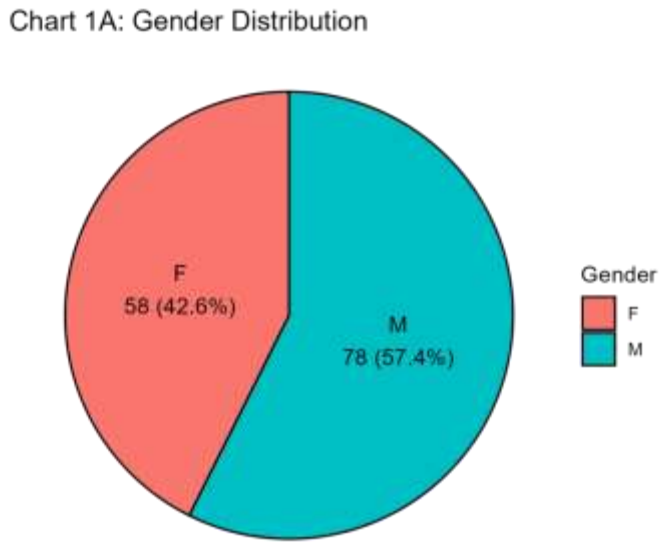

Chart 1A: Gender Distribution

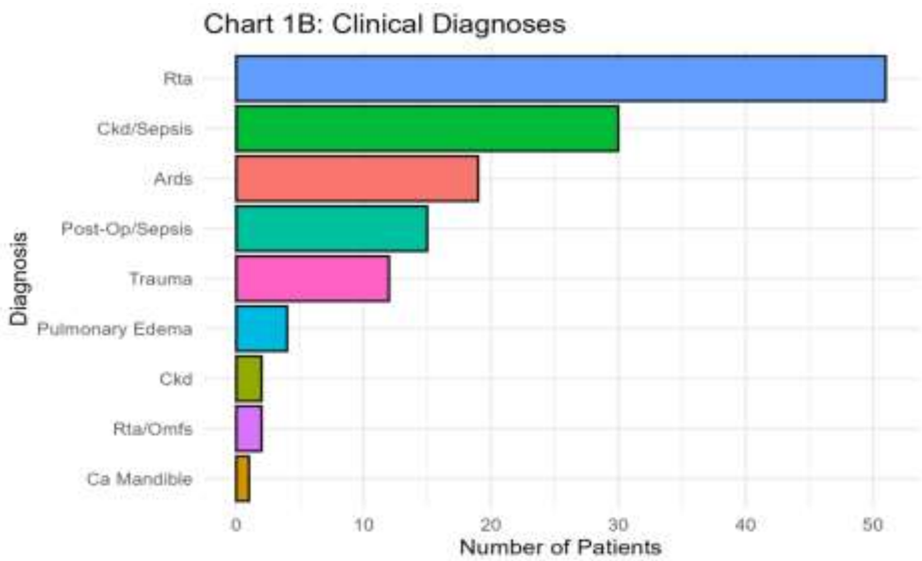

Chart 1B: Clinical Diagnoses

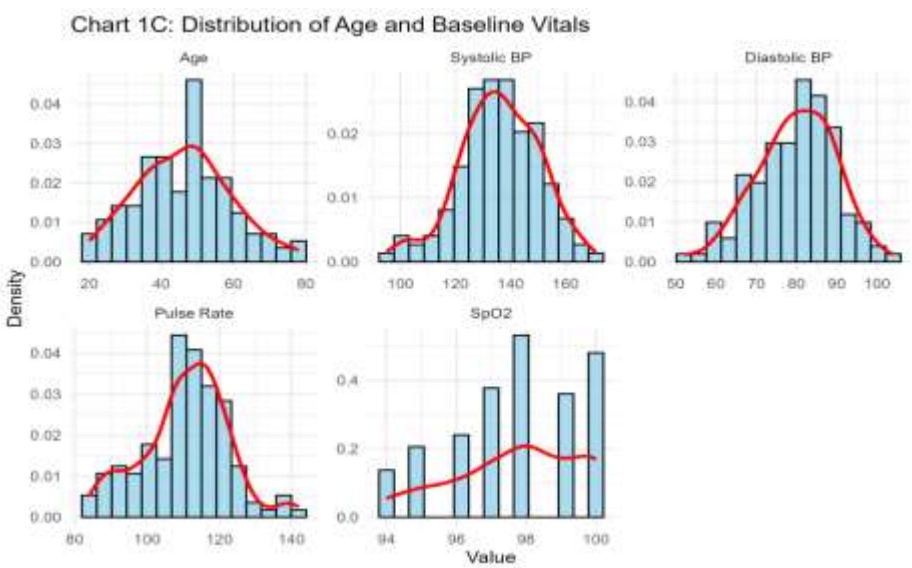

Chart 1C: Distribution of Age and Vitals

Phase 2: Trend Analysis of Extravascular Lung Water

Table 2: Daily Trend of Total Lung Score and Pulmonary Fluid Burden (Day 1 to 8)

Day	Patients Remaining (N)	Mean TLS ± SD	Low PFB n(%)	Moderate PFB n(%)	High PFB n(%)
1	136	13.76 ± 3.84	32 (23.5%)	95 (69.9%)	9 (6.6%)
2	136	11.68 ± 3.87	63 (46.3%)	68 (50%)	5 (3.7%)
3	114	9.99 ± 4.06	63 (55.3%)	49 (43%)	2 (1.8%)
4	89	8.43 ± 4.31	65 (73%)	23 (25.8%)	1 (1.1%)
5	58	7.64 ± 4.56	46 (79.3%)	12 (20.7%)	0 (0%)
6	36	6.67 ± 4.64	30 (83.3%)	6 (16.7%)	0 (0%)
7	19	4.84 ± 4.27	17 (89.5%)	2 (10.5%)	0 (0%)
8	10	2.7 ± 3.09	10 (100%)	0 (0%)	0 (0%)

The mean Total Lung Score (TLS) declined progressively from 13.76 ± 3.84 on Day 1 to 2.70 ± 3.09 on Day 8. The proportion of patients with low pulmonary fluid burden increased from 23.5% on Day 1 to 100% by Day 8, whereas the proportions with moderate and high pulmonary fluid burden decreased over the same period. The number of patients under observation decreased from 136 on Day 1 to 10 on Day 8 because of extubation, ICU discharge, or death during the follow-up period.

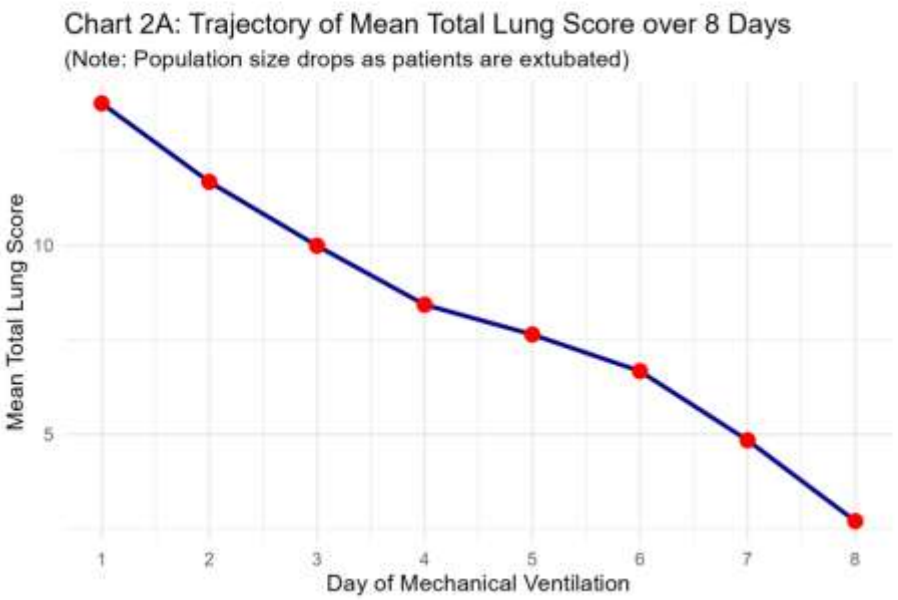

Chart 2A: Line Chart for Mean Total Lung Score

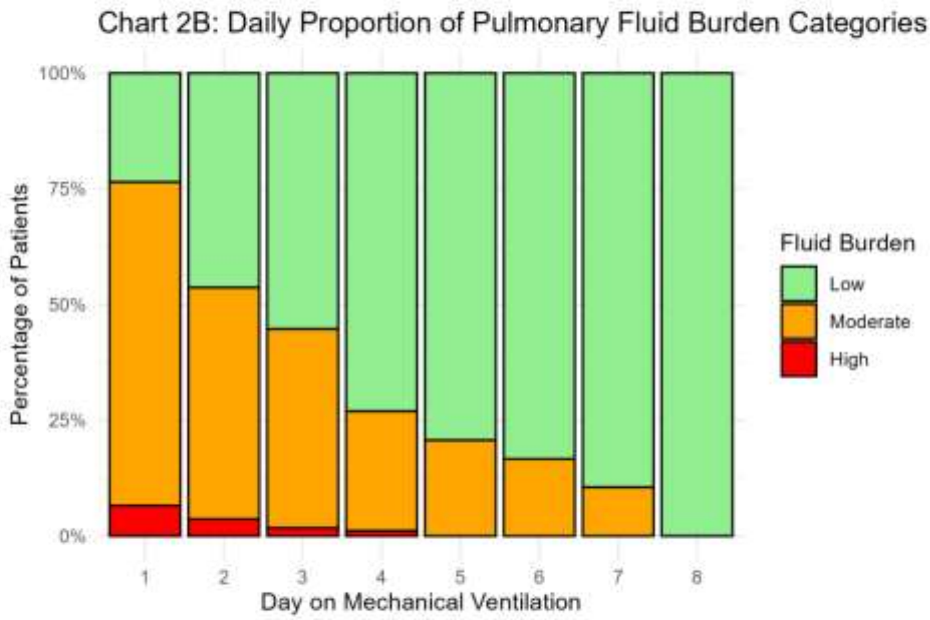

Chart 2B: Daily Pulmonary Fluid Burden Trend

Statistical Analysis Report: Phase 3 & Phase 4 (Survivor Cohort)

Table 3. Association Between Baseline Lung Ultrasound Findings and Duration of Mechanical Ventilation

Table 3A. Correlation Between Day 1 Total Lung Score and Duration of Mechanical Ventilation

Variable	**Pearson's correlation coefficient (r)**	**p-value**
Day 1 Total Lung Score vs. Duration of Mechanical Ventilation (days)	0.131	0.130

A weak positive correlation was observed between baseline Total Lung Score and duration of mechanical ventilation; however, the association was not statistically significant ($r = 0.131$, $p = 0.130$).

Table 3B. Duration of Mechanical Ventilation According to Baseline Pulmonary Fluid Burden

Baseline Pulmonary Fluid Burden	**n**	**Duration of Mechanical Ventilation (Days), Mean ± SD**
Low	32	4.16 ± 1.74
Moderate	95	4.35 ± 1.79
High	9	5.78 ± 0.97

One-way ANOVA: $p = 0.045$

The mean duration of mechanical ventilation was 5.78 ± 0.97 days in patients with high pulmonary fluid burden, compared with 4.35 ± 1.79 days in the moderate group and 4.16 ± 1.74 days in the low group (ANOVA, $p=0.045$).

Table 3C. Multivariable Linear Regression Analysis for Predicting Duration of Mechanical Ventilation

Variable	**Regression Coefficient (β)**	**95% Confidence Interval**	**p-value**
Day 1 Total Lung Score	0.06	−0.02 to 0.14	0.140
Age (years)	−0.02	−0.04 to 0.00	0.110
SpO_2 (%)	−0.08	−0.24 to 0.09	0.380

Abbreviations: β = Regression coefficient; CI = Confidence Interval.

On multivariable linear regression analysis adjusted for age and baseline SpO_2, Day 1 Total Lung Score was not significantly associated with the duration of mechanical ventilation ($\beta = 0.06$, 95% CI −0.02 to 0.14; $p = 0.140$). Age ($\beta = -0.02$, 95% CI −0.04 to 0.00; $p = 0.110$) and baseline SpO_2 ($\beta = -0.08$, 95% CI −0.24 to 0.09; $p = 0.380$) were also not significantly associated with the duration of mechanical ventilation.

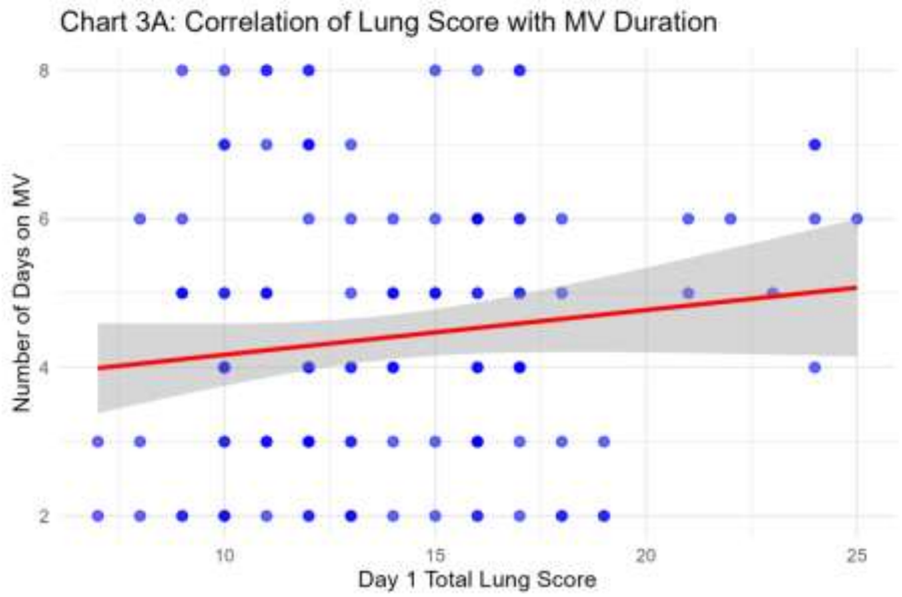

Chart 3A: Scatter Plot

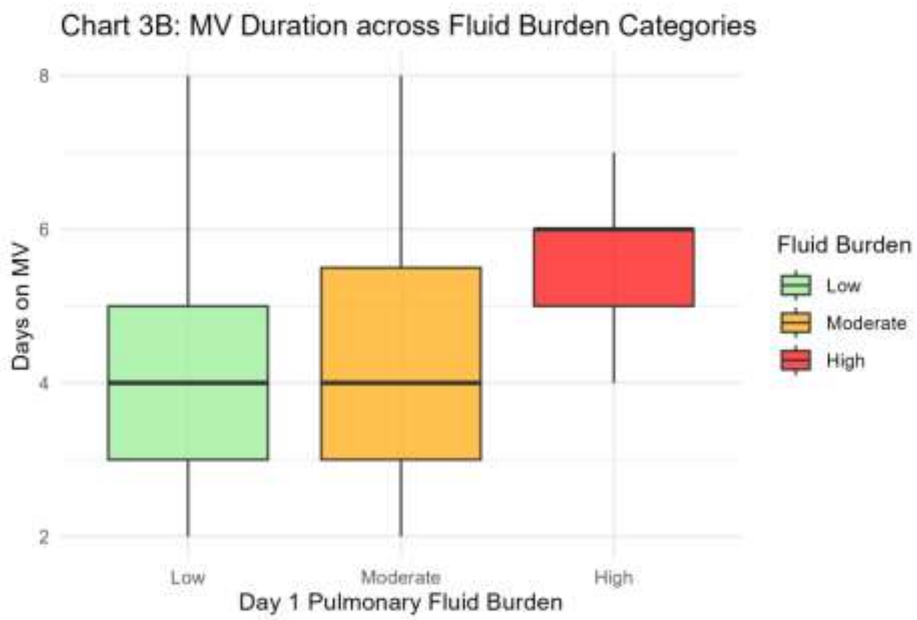

Chart 3B: Box Plot

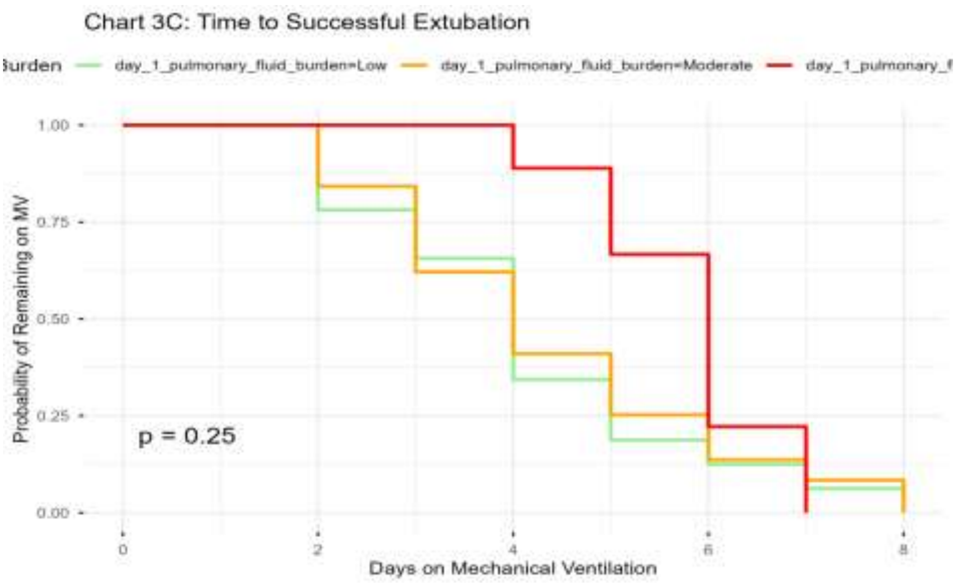

Chart 3C: Kaplan-Meier Curve

Phase 4: Weaning Outcome Analysis (Prolonged vs Normal)

Table 4A: Association between Day 1 PFB and Weaning Category

Characteristic	Early/Normal (≤7 Days) N = 126	Prolonged (>7 Days) N = 10	p-value[1]
Day 1 Pulmonary Fluid Burden, n (%)			0.63
Low	30 (24.0)	2 (20.0)	
Moderate	87 (69.0)	8 (80.0)	
High	9 (7.1)	0 (0.0)	

Among the 136 mechanically ventilated patients, 126 (92.6%) underwent early/normal weaning (≤7 days), whereas 10 (7.4%) experienced prolonged weaning (>7 days). Moderate pulmonary fluid burden on Day 1 was the most frequent category in both the early/normal and prolonged weaning groups (69.0% and 80.0%, respectively), followed by low pulmonary fluid burden (24.0% and 20.0%, respectively). High pulmonary fluid burden was observed in 9 patients (7.1%) in the early/normal weaning group and in none of the patients with prolonged weaning. The distribution of Day 1 pulmonary fluid burden did not differ significantly between the two weaning groups (p = 0.63).

Table 4B: Logistic Regression predicting Prolonged Weaning > 7 Days (Odds Ratios)

Characteristic	OR (95% CI)	p-value
Day 1 Total Lung Score	0.95 (0.78 to 1.13)	0.62
Age	0.98 (0.92 to 1.03)	0.34
Sex		
Female	Reference	—
Male	1.75 (0.46 to 8.51)	0.43

Multivariable logistic regression analysis was performed to evaluate factors associated with prolonged weaning (>7 days). Day 1 Total Lung Score was not significantly associated with prolonged weaning (OR = 0.95, 95% CI 0.78–1.13; p = 0.62). Age was also not significantly associated with prolonged weaning (OR = 0.98, 95% CI 0.92–1.03; p = 0.34). Compared with females, male patients had higher odds of prolonged weaning (OR = 1.75, 95% CI 0.46–8.51; p = 0.43), although this association was not statistically significant. None of the variables included in the model showed a statistically significant association with prolonged weaning.

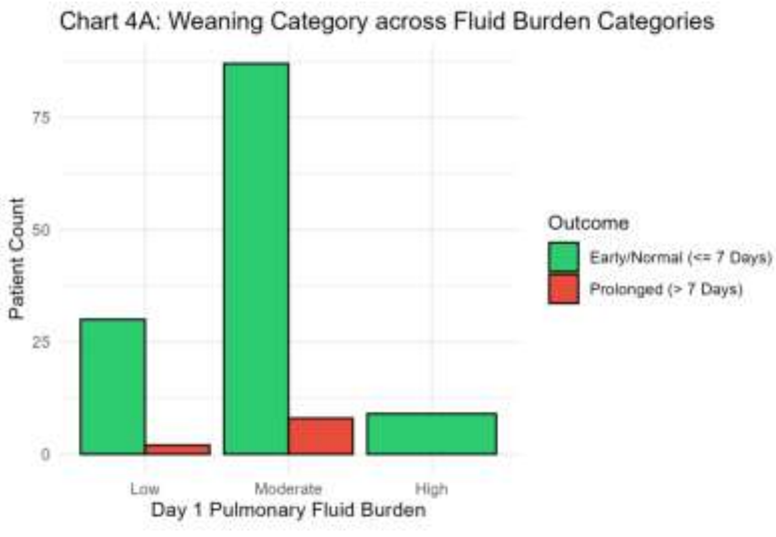

Chart 4A: Clustered Bar Chart

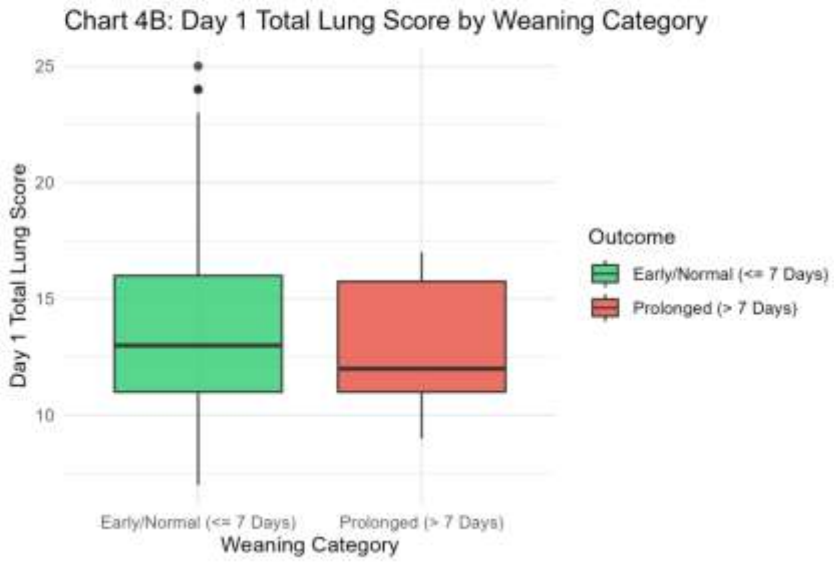

Chart 4B: Box Plot

Statistical Analysis Report: Phase 5 & Phase 6 (Survivor Cohort)
Phase 5: Length of Stay in ICU Analysis

Table 5A: Correlation between Total Lung Score and Length of Stay in ICU

Variables	**Pearson_r**	**p_value**
Day 1 Total Lung Score vs. Length of Stay in ICU	0.157	0.069

A weak positive correlation was observed between Day 1 Total Lung Score and length of ICU stay ($r = 0.157$); however, the association was not statistically significant ($p = 0.069$). This indicates that baseline lung ultrasound score was not significantly correlated with ICU length of stay.

Table 5B: Multivariable Regression Model Predicting ICU Length of Stay

Characteristic	**β (95% CI)**	**p-value**
Day 1 Total Lung Score	0.08 (−0.01 to 0.18)	0.094
Age (years)	−0.03 (−0.06 to 0.00)	0.050
Baseline SpO_2 (%)	−0.21 (−0.43 to 0.00)	0.053

Multivariable linear regression analysis was performed to evaluate factors associated with length of ICU stay. Day 1 Total Lung Score was not significantly associated with ICU length of stay ($\beta = 0.08$, 95% CI −0.01 to 0.18; $p = 0.094$). Age was not significantly associated with ICU length of stay ($\beta = -0.03$, 95% CI −0.06 to 0.00; $p = 0.050$). Similarly, baseline SpO_2 was not significantly associated with ICU length of stay ($\beta = -0.21$, 95% CI −0.43 to 0.00; $p = 0.053$).

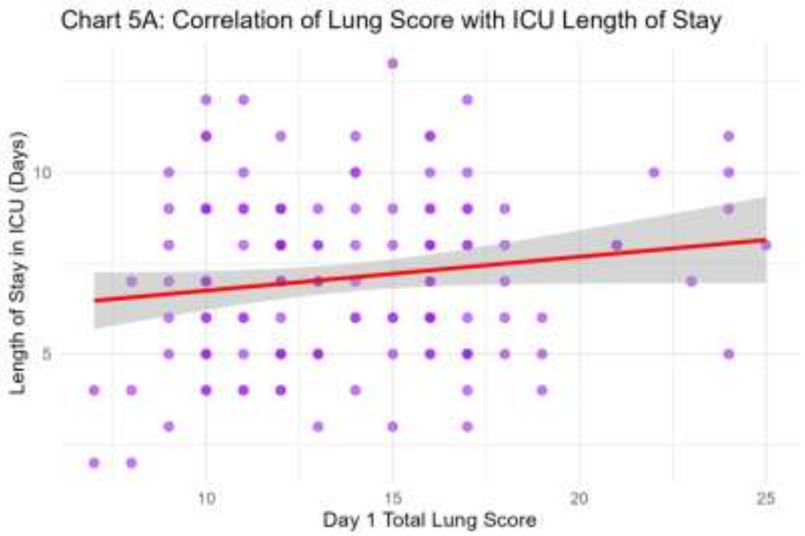

Chart 5A: Scatter Plot

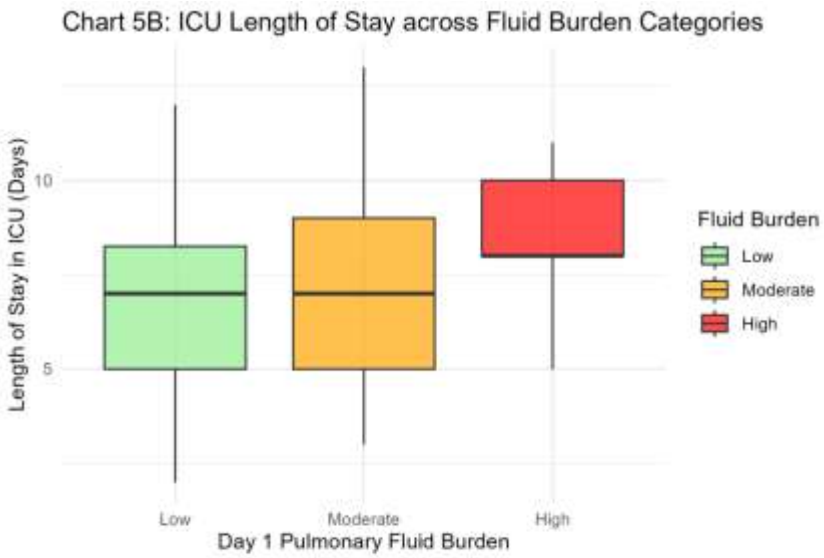

Chart 5B: Box Plot

Phase 6: Diagnostic Accuracy (ROC) for Prolonged Weaning (> 7 Days)

Characteristic	**Early/Normal (≤7 Days) N = 126**	**Prolonged (>7 Days) N = 10**	**p-value[1]**
Day 1 Total Lung Score, Mean (SD)	14 (4)	13 (3)	0.43
Peak Total Lung Score, Mean (SD)	14 (4)	13 (3)	0.46

[1]Welch Two Sample t-test.

The mean Day 1 Total Lung Score was similar between patients who underwent early/normal weaning (14 ± 4) and those with prolonged weaning (13 ± 3), with no statistically significant difference (p = 0.43). Likewise, the mean Peak Total Lung Score did not differ significantly between the two groups (14 ± 4 vs. 13 ± 3; p = 0.46).

Table 6B: Diagnostic Accuracy of Day 1 Total Lung Score in predicting Prolonged Weaning

Metric	**Value**
Area Under the Curve (AUC)	0.45
Optimal Cut-off Score	≥8.5
Sensitivity (%)	100
Specificity (%)	4

Receiver operating characteristic (ROC) analysis was performed to evaluate the performance of the Day 1 Total Lung Score in identifying prolonged weaning (>7 days). The area under the curve (AUC) was 0.45. At the optimal cut-off value of ≥8.5, the sensitivity was 100% and the specificity was 4%.

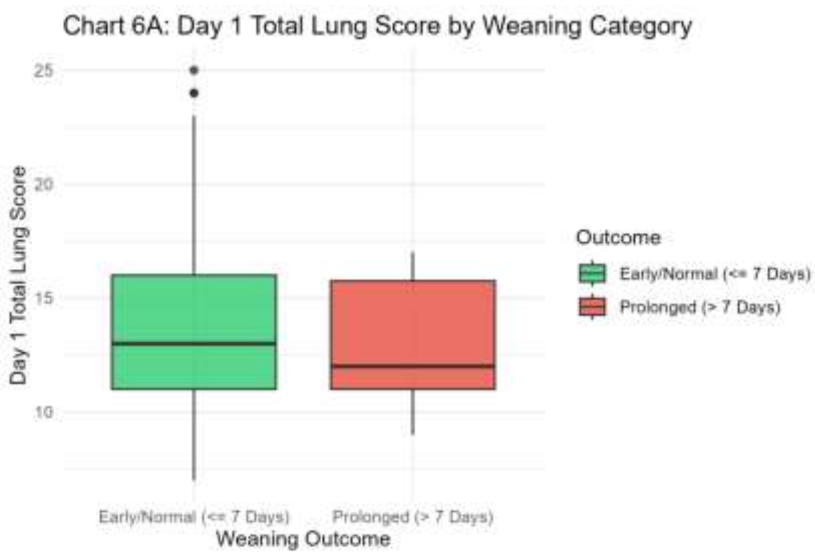

Chart 6A: Box Plot

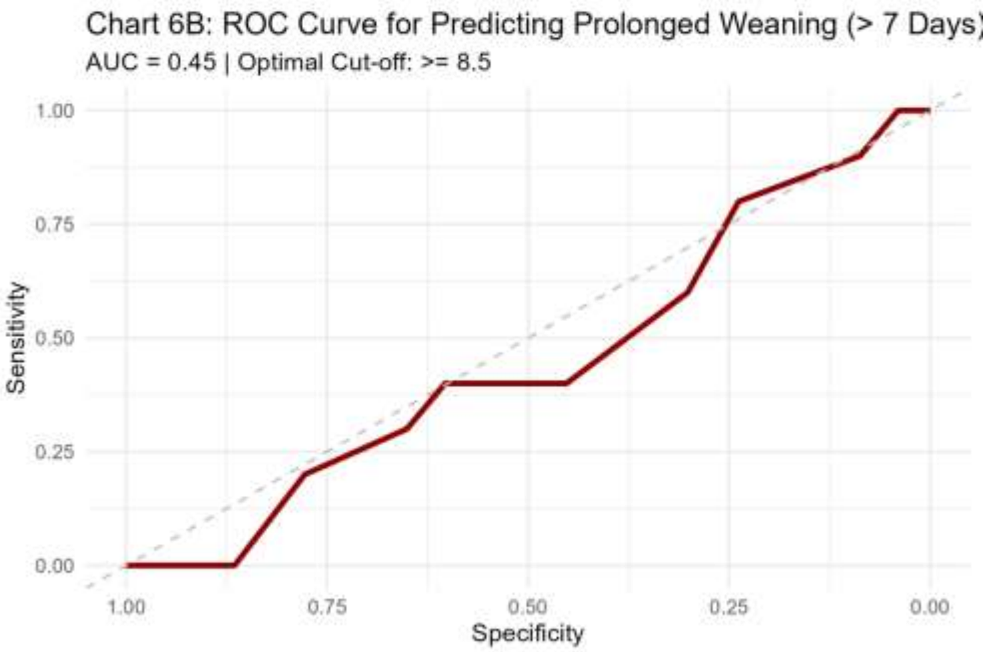

Chart 6B: ROC Curve

DISCUSSION

The present prospective observational study evaluated the association of lung ultrasound-derived Total Lung Score (TLS) and pulmonary fluid burden (PFB) with clinically important outcomes in mechanically ventilated critically ill patients. Most patients had moderate pulmonary fluid burden at admission, with a mean Day 1 TLS of 13.76 ± 3.84, reflecting that pulmonary fluid accumulation was common in this heterogeneous ICU population. However, the study demonstrated that baseline TLS alone was not significantly associated with duration of mechanical ventilation, prolonged weaning, or ICU length of stay after adjustment for relevant clinical variables.

An important observation of the present study was the consistent decline in TLS during ICU stay. The mean TLS decreased from 13.76 ± 3.84 on Day 1 to 2.70 ± 3.09 by Day 8, while the proportion of patients with low pulmonary fluid burden increased from 23.5% to 100%. These serial changes suggest that lung ultrasound effectively reflected changes in pulmonary aeration during treatment. Similar observations were reported by Rajpal et al. [13], who demonstrated improvement in lung ultrasound scores during ICU management and reported significant associations between EVLW and duration of mechanical ventilation, ICU stay, and weaning outcomes. The present findings support the usefulness of serial lung ultrasound as a bedside monitoring tool, allowing repeated assessment of pulmonary fluid status and response to therapy without radiation exposure or invasive monitoring. Dynamic assessment may therefore be more clinically informative than reliance on a single baseline examination.

Although patients with high pulmonary fluid burden required significantly longer mechanical ventilation (5.78 ± 0.97 days) than those with moderate (4.35 ± 1.79 days) or low pulmonary fluid burden (4.16 ± 1.74 days; $p = 0.045$), baseline TLS showed only a weak correlation with ventilation duration ($r = 0.131$, $p = 0.13$) and was not significantly associated with ventilation duration on multivariable analysis ($\beta = 0.06$, $p = 0.14$). These findings differ from those reported by Rajpal et al. [13] and Emperador IV et al. [17], who observed significant associations between lung ultrasound findings and duration of mechanical ventilation. Several factors may explain these differences. First, the present study included a heterogeneous ICU population comprising patients with ARDS, trauma, chronic kidney disease with sepsis, postoperative sepsis, pulmonary edema, and road traffic accident-related injuries. These conditions have different mechanisms of pulmonary fluid accumulation, ranging from increased capillary permeability to hydrostatic edema and pulmonary contusion. Consequently, the relationship between pulmonary fluid burden and duration of ventilation may not be uniform across all disease categories.

Second, the present study evaluated only the baseline Day 1 TLS as a predictor of clinical outcomes. Pulmonary edema is a dynamic process that changes during critical illness in response to fluid management, diuretic therapy, ventilatory strategies, and resolution of the underlying disease. A single baseline measurement may therefore inadequately represent the patient's pulmonary status throughout the ICU course, whereas serial assessments are likely to provide greater prognostic information.

With respect to weaning outcomes, 92.6% of patients underwent early or normal weaning, whereas only 10 patients (7.4%) experienced prolonged weaning. Baseline pulmonary fluid burden did not differ significantly between the two groups ($p = 0.63$), and neither TLS ($OR = 0.95$, $p = 0.62$), age ($OR = 0.98$, $p = 0.34$), nor sex ($OR = 1.75$, $p = 0.43$) showed a significant association with prolonged weaning. These findings differ from those reported by Rajpal et al. [13], who found higher weaning failure among patients with increased EVLW. The relatively small number of prolonged weaning events ($n = 10$) in the present study may have reduced the statistical power of the regression model and limited its ability to identify significant associations.

Similarly, only a weak correlation was observed between baseline TLS and ICU length of stay ($r = 0.157$, $p = 0.069$), and multivariable analysis demonstrated no significant association between TLS and ICU stay ($\beta = 0.08$, $p = 0.094$). In contrast, Rajpal et al. [13] reported significantly longer ICU stay among patients with increased EVLW, while Gavelli et al. [15] demonstrated that elevated EVLW was associated with higher mortality and poorer survival in critically ill patients. Differences in study population, outcome measures, disease severity, and imaging protocols may account for these variations.
Receiver operating characteristic analysis showed an AUC of 0.45 for baseline TLS in predicting prolonged weaning. This was lower than the diagnostic performance reported by Atmowihardjo et al. [14] and Mayr et al. [16], who demonstrated stronger correlations between lung ultrasound findings and directly measured EVLW. The present study differed from these investigations because the outcome assessed was prolonged weaning rather than quantitative EVLW, and a simplified four-zone lung ultrasound protocol was used. Although more extensive 8-, 12-, and 28-zone protocols may provide greater anatomical coverage, the four-zone protocol offers important practical advantages in critically ill patients by reducing examination time, minimizing patient repositioning, and facilitating repeated bedside assessment. This simplified approach was adopted from the parent study and was considered appropriate for routine ICU practice.
The present study has several limitations. It was conducted at a single centre with a relatively modest sample size, and only 10 patients experienced prolonged weaning, limiting the statistical power for regression analyses. The study population was heterogeneous, including patients with ARDS, trauma, chronic kidney disease, pulmonary edema, postoperative sepsis, and road traffic accident-related injuries, each with distinct mechanisms of pulmonary fluid accumulation. Furthermore, only baseline TLS was evaluated as a predictor of outcome, whereas serial measurements may provide greater prognostic value. Finally, the four-zone lung ultrasound protocol, although practical for bedside use, may detect fewer regional abnormalities than more comprehensive scanning protocols.
Overall, the present study suggests that serial lung ultrasound is valuable for monitoring changes in pulmonary fluid burden during ICU treatment, whereas a single baseline Total Lung Score alone showed limited association with duration of mechanical ventilation, prolonged weaning, and ICU length of stay in this heterogeneous ICU population. These findings support the role of lung ultrasound primarily as a dynamic bedside monitoring tool, with its prognostic value likely to be enhanced when serial examinations are interpreted alongside the patient's clinical condition and physiological parameters rather than as an isolated baseline measurement.

CONCLUSION

The present study demonstrates that lung ultrasound is a valuable bedside tool for monitoring pulmonary fluid burden and changes in lung aeration among mechanically ventilated critically ill patients. Serial Total Lung Scores showed a progressive decline during the ICU stay, reflecting improvement in pulmonary status. Patients with a higher pulmonary fluid burden required a significantly longer duration of mechanical ventilation; however, baseline Total Lung Score alone was not an independent predictor of mechanical ventilation duration, prolonged weaning, or ICU length of stay after adjustment for clinical variables. Additionally, the Day 1 Total Lung Score showed poor diagnostic accuracy for predicting prolonged weaning. These findings suggest that lung ultrasound is more useful for dynamic monitoring of pulmonary fluid status than as a standalone prognostic tool. Integration of lung ultrasound findings with clinical assessment may enhance decision-making and optimize the management of critically ill mechanically ventilated patients.

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