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ORIGINAL RESEARCH PAPER

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DEVELOPMENT OF A COMPREHENSIVE EXTUBATION OUTCOME PREDICTION SCORE BASED ON ULTRASOUND AND CLINICAL PARAMETERS: A PROSPECTIVE ANALYTICAL STUDY

KEY WORDS: Extubation failure, Extubation prediction score, Mechanical ventilation, Point of care ultrasound (POCUS), Weaning predictors, Extubation outcome

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ABSTRACT

Purpose: Despite best efforts, extubation failure rates in mechanically ventilated patients remain high in critically ill patients. None of the clinical or ultrasound-based parameters are accurate enough for predicting extubation outcomes when used individually. This study aimed to identify clinical and ultrasound-based parameters significantly associated with extubation outcomes and to use these parameters to develop a score for predicting extubation outcomes. **Methods:** This study analyzed patients receiving invasive mechanical ventilation for over 24 hours. After a successful spontaneous breathing trial, clinical and ultrasound parameters were recorded, and the patients were monitored following extubation. A predictive score was developed using Area Under the Curve (AUC) values and evaluated using univariable logistic regression and Receiver Operating Characteristic (ROC) analysis. **Results:** A total of 101 patients were extubated, with 90 (89.1%) succeeding and 11 (10.9%) failing. RSBI (Rapid Shallow Breathing Index) (AUC 0.972), APACHE II (Acute Physiology and Chronic Health Evaluation II) score (AUC 0.655), duration of mechanical ventilation (AUC 0.845), E/e' (AUC 0.969), Lung Ultrasound Score (AUC 0.901), and serum creatinine (AUC 0.703) were significantly associated with extubation outcomes. **Conclusion:** The comprehensive extubation outcome prediction score, based on RSBI, APACHE II score, duration of mechanical ventilation, E/e', Lung Ultrasound Score, and serum creatinine, demonstrated better predictive capability than individual parameters. Patients with scores below 17.5 had a low probability of success, those with scores between 17.5 and 55 had intermediate success probabilities, and those with scores above 55 points had a high probability of success.

INTRODUCTION

Intubation is a common procedure in critical intensive care units (ICUs) for respiratory failure and airway protection. Withdrawing mechanical ventilation as soon as possible is essential due to the well-known risks of infection, airway trauma, and diaphragmatic dysfunction.[1,2] Determining the most appropriate time to remove mechanical ventilation (MV) in a critically ill patient remains difficult, as premature removal increases the risk of failure, necessitating reintubation, which exposes the patient to unnecessary hemodynamic and respiratory stress; further failure of extubation is associated with a high mortality.[3] Guidelines suggest spontaneous breathing trial (SBT) for predicting weaning outcomes. SBT involves measuring clinical parameters to assess patient's tolerability, and once the patient is tolerating an SBT, the patient is extubated. However, 13%-26% of extubated patients following a successful SBT developed respiratory distress within 48 hours.[4,5] Recent guidelines recommend implementing weaning protocols because they result in shorter weaning times and mechanical ventilation durations compared to traditional physician-directed weaning methods.[4,6] Several weaning indices and scoring systems have been developed and tested, but none of them include any of the new ultrasound-based parameters. This study aims to identify clinical and ultrasound-based parameters associated with extubation outcome and then use these parameters to create a score that predicts extubation outcome.

MATERIALS & METHODS

Study Design And Setting:

This prospective analytical cross-sectional study was conducted at a multi-specialty, tertiary care 600- bed hospital. Study was conducted in the multidisciplinary intensive care unit (MDICU) over a period of 2 years after the approval of the institutional ethics committee, and after obtaining written informed consent from the close relatives of patients.

Inclusion And Exclusion Criteria:

Patients aged >18 years who were admitted to ICU, on invasive mechanical ventilation through an endotracheal tube for more than 24 hours and considered ready for extubation by the treating intensivist after a successful spontaneous breathing trial (SBT) were selected for study and multiple parameters are collected. Participants with post extubation stridor, terminal extubation, pregnancy, having accidental extubation or self-extubation or extubated to NIV were excluded from the study.

Sample Size:

Baptistella et al found the rate of extubation failure to be 8.18%[7] which was taken as proportion of outcome, 1% alpha error and 7.5% desired precision, sample size was calculated to be 89 using the formula, $n = (Z_{1- /2})^2 PQ/d^2$ **(**z = Co-efficient of Significance , = Level of Significance =1%, P = Rate of Extubation Failure =8.18%, Q = 1- P =91.82%, d = Desired Precision =7.5%). The minimum required sample size for the study was calculated to be 89.

Data Collection:

Data Collection were done after obtaining ethical committee clearance. Relevant information was obtained using validated proforma and secondary information was obtained from the patient information system. Potential parameters are divided into ultrasound-based and clinical parameters. Ultrasound-based parameters include ultrasound assessment of lungs, heart, and diaphragm. Ultrasound assessment, performed with an M-Turbo (Fujifilm SonoSite Inc., Bothell, WA, USA) with patients in a semi-recumbent position, included transthoracic echocardiography (ejection fraction and E/e'(Ratio between early mitral inflow velocity and mitral annular early diastolic velocity)), LUS score (Lung Ultrasound score), and diaphragm evaluation (diaphragm thickness fraction and excursion). Clinical parameters are subdivided into five categories. The first comprised epidemiological and clinical condition variables: age (years), sex(male/female), APACHE score at admission, muscle strength using MRC (medical research council) score, last 24-hour fluid balance and the admission diagnosis. The second comprised ventilatory variables: duration of mechanical ventilation (days), oxygenation index ($PaO2/FiO2$) and rapid shallow breathing index. The third comprised airway protection variables: level of consciousness; according to the cough strength (0 = no cough; 1 = audible movement of air through the airways; 2 = cough audible, but weak; 3 = clearly audible cough; 4 = strong cough; 5 = multiple sequential strong coughs) and GCS. The fourth category comprised laboratory variables: haematocrit (%), Creatinine, and the fifth comprised hemodynamic variables: mean arterial pressure (mm Hg) and heart rate (HR).

Statistical Analysis:
After data collection, the data were entered in the MS excel 10. As results contained both Categorical and Continuous variables, for Categorical variables Chi square or Fischer test and for Continuous variables unpaired t test or Anova test were done. The Analysis was done using SPSS software version 16 for Windows. A p value less than 0.05 was considered statistically significant.

RESULTS

A total of 101 participants were enrolled in the study. Age distribution of the study population showed that 70.2% of the cases belong to the age group 61-80 years and 28.7% of the cases belong to the group 41-60 years. Majority of study subjects were males (61.4%). Majority of admissions were found with respiratory disease (39.6%) followed by sepsis (16.8%), post-surgery (13.9%) and cardiac diseases (10.9%) (Table 1).

Table 1: General Characteristics Of Study Population

Variables	Frequency	Percentage
Age (Years)		
21 - 40	1	0.01%
41 - 60	29	28.7%
61 - 80	71	70.2%
Sex		
Female	39	38.6%
Male	62	61.4%
Admission diagnosis		
Cardiac disease	11	10.9
Neurologic disease	5	5.0
Post surgery	14	13.9
Respiratory disease	40	39.6
Sepsis/septic shock	17	16.8
Trauma	7	6.9
Others	7	6.9

This study observed that among the participants, 10.9% had post extubation failure, and it was successful among the 89.1% of the participants. Various scores and other parameters were compared among the extubation success and failure cases (Table 2).

Table 2: Comparison Of Various Parameters With Extubation Outcome

Variable		Extubation outcome		p value
		Success	Failure	
APACHE II score		17 (13-20)	19 (17-21)	0.09#
Muscle strength using MRC score		51.1 ±3.8	33.5±7.3	<0.01
Last 24-hour fluid balance		571.5 (430-905)	570 (110-644)	0.21
Duration of MV		4±1.5	6.8±2.1	<0.01
PF RATIO		283.4±47	310.2±52.0	0.08
RSBI		46.8±6.4	69.7±11.1	<0.01
GCS		10 (9-10)	9 (8-10)	0.48#
Volume of pulmonary secretions	Absent	32 (94.1%)	2(5.9%)	0.06
	Mild	41(93.2%)	3(6.8%)	
	Mod	9(75%)	3(25%)	
	Severe	8(72.7%)	2(27.3%)	
SCSS (semi quantitative cough strength score)		4(3-5)	2(1-3)	<0.01#
S Creatinine		1.1±0.4	1.5±0.5	0.01
Hematocrit		27.8±2.9	25.6±4.1	0.03
Mean Arterial Pressure		110.2±14.3	104.9±6.5	0.23
Heart Rate		97.0±12.8	90.8±9.4	0.21
LV ejection fraction		57.4±6.8	46.8±5.4	<0.01
E/e'		8.0±0.8	12.0±3	<0.01
LUS Score		14.1±3.3	21.6±4.7	<0.01
Diaphragmatic thickness fraction (%)		55.8±10.9	38.5±20.8	<0.01
Diaphragmatic excursion(mm)		15.5±2.8	9.6±1.7	<0.01

*Chi square test, @Fisher exact, #Mann-Whitney test & others are unpaired t test

APACHE II: Acute Physiology and Chronic Health Evaluation II, MRC: Medical Research Council, MV: Mechanical Ventilation, PF: PaO2/FiO2, RSBI: Rapid Shallow Breathing Index, GCS: Glasgow Coma Scale, E/e' : Ratio between early mitral inflow velocity and mitral annular early diastolic velocity, LUS: Lung Ultrasound

The median APACHE II score was comparable among both groups (p=0.09). Mean duration of MV and mean RSBI of extubation failure group was significantly higher than that of success group. Median Last 24-hour fluid balance, mean PF Ratio and median GCS showed no significant difference between the two groups. Mean Creatinine, mean E/e', and LUS score of extubation success group was significantly less than that of failure group, while mean MRC score, mean Haematocrit, mean MAP, mean HR, mean LV ejection fraction, mean Diaphragmatic thickness fraction and mean Diaphragmatic excursion of extubation success group was significantly higher than that of failure group.

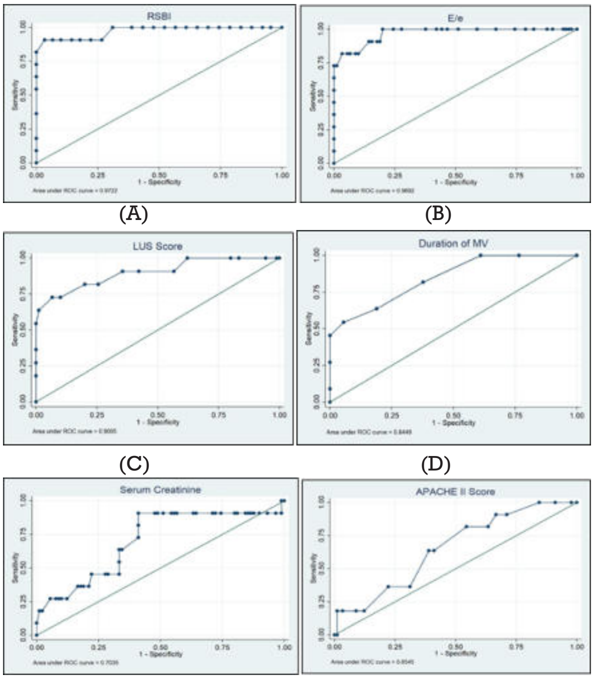
All parameters with p value lower than 0.05 when in the analyses comparing mean or median values between the extubation success and failure groups were investigated with univariable logistic regression analysis to evaluate their association with extubation outcome; the odds ratios (OR) and 95% confidence intervals (CI) were calculated. Muscle strength (MRC) score, duration of MV, mean RSBI, S Creatinine, Hematocrit, LV ejection fraction, E/e', LUS Score, Diaphragmatic thickness fraction, and mean diaphragmatic excursion were found to be potential predictors of extubation failure (Table 3).

Table 3: Potential Predictors Of Extubation Failure Based In An Univariable Logistic Regression Analysis

Variable	OR	95% CI	p-value
APACHE II score	1.15	0.99-1.34	0.06
Muscle strength (MRC)	.50	0.29-0.85	0.01
Duration of MV	2.57	1.56-4.25	<0.01
PF RATIO	1.01	.99-1.02	0.08
RSBI	1.68	1.16-2.42	<0.01
SCSS (semi-quantitative cough strength score)	0.33	0.1766489-0.62	
S Creatinine	6.20	1.37-27.90	0.01
Hematocrit	0.74	0.57-0.97	0.03
LV ejection fraction	0.82	0.75-0 .91	<0.01
E/e'	8.10	2.51-26.12	<0.01
LUS Score	1.75	1.28-2.38	<0.01
Diaphragmatic thickness fraction (%)	0.88	0.82-0.94	<0.01
Diaphragmatic excursion(mm)	0.12	0.02-0.57	<0.01

APACHE II: Acute Physiology and Chronic Health Evaluation II, MRC: Medical Research Council, MV: Mechanical Ventilation, PF: PaO2/FiO2, RSBI: Rapid Shallow Breathing Index, E/e' : Ratio between early mitral inflow velocity and mitral annular early diastolic velocity LUS: Lung Ultrasound.

There are 6 parameters with AUC higher than 0.5 and selected for development of score. They are APACHE II score, duration of MV, RSBI, S. Creatinine, E/e' and LUS score (Figure 1).



(A) (B) (C) (D) (E) (F)

Figure 1: ROC curves for parameters with AUC higher than 0.5 and selected for development of score- RSBI (A), E/e' (B), LUS score (C), Duration of MV (D), S. Creatinine (E) and APACHE II score' (F) used to distinguish the extubation success group from the failure group.

APACHE II: Acute Physiology and Chronic Health Evaluation II, MV: Mechanical Ventilation, RSBI: Rapid Shallow Breathing Index, E/e' : Ratio between early mitral inflow velocity and mitral annular early diastolic velocity, LUS: Lung Ultrasound

Total score of our predicted comprehensive extubation outcome prediction score is estimated as 100. Maximum weightage of each parameter was calculated using the odds ratios estimated after logistic regression analysis. Accordingly S.Creatinine & E/e' are the parameters with the highest maximum score (25 points), followed by Duration of MV (20 points) and LUS score, APACHE score & RSBI (10 points each). From Youden's index calculation of ROC curve, the cut off value was calculated for the 6 shortlisted variables (Table 4).

Table 4: Sensitivity And Specificity At The Cut-off Of The Highest Youden Index

	Cut off	Sensitivity	Specificity	Area under the curve
APACHE II score	19	63.64%	61.11%	.6545
Duration of MV	5	81.82%	62.22%	.8449
RSBI	58	90.91%	96.67%	.6919
S Creatinine	1.12	90.91%	58.89%	.7035
E/e'	9.7	81.82%	93.33%	.9692
LUS Score	20	72.73%	93.33%	.9005

APACHE II: Acute Physiology and Chronic Health Evaluation II, MRC: Medical Research Council, MV: Mechanical Ventilation, PF: PaO2/FiO2, RSBI: Rapid Shallow Breathing Index, GCS: Glasgow Coma Scale, E/e' : Ratio between early mitral inflow velocity and mitral annular early diastolic velocity, LUS: Lung Ultrasound

Further for each parameter, three categories were fixed and scoring was given based on the cut-off, median and interquartile values. Thus, 6 parameter comprehensive extubation outcome prediction score is made, with a maximum score of 100 and a minimum score of 0 (Table 5).

Table 5: Comprehensive Extubation Outcome Prediction Score

PARAMETER	VALUE	SCORE
APACHE-II score	<17	10
	17 - 21	5
	>21	0
Duration of MV	<5	20
	5 – 7	10
	>7	0
RSBI	<54	10
	54 – 62	5
	>62	0
S Creatinine	<1.04	25
	1.04-1.2	12.5
	>1.2	0
E/e'	<9.7	25
	9.7 – 10.9	12.5
	>10.9	0
LUS Score	<18	10
	18 – 22	5
	>22	0

APACHE II: Acute Physiology and Chronic Health Evaluation II, MV: Mechanical Ventilation, RSBI: Rapid Shallow Breathing Index, E/e' : Ratio between early mitral inflow velocity (E) and mitral annular early diastolic velocity, LUS: Lung Ultrasound.

Comprehensive extubation outcome prediction score of all patients included in the study was calculated and ROC curve for the score used to distinguish the extubation success group from the failure group was plotted. It showed significant AUC value (0.9404) (Figure 2).

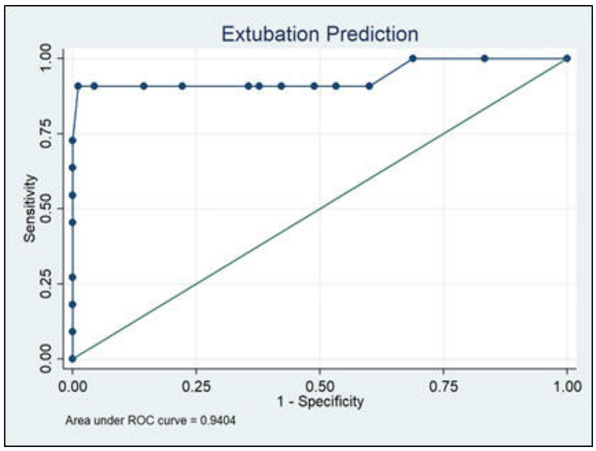


Figure 2: ROC curve for comprehensive extubation outcome prediction score, used to distinguish the extubation success group from the failure group.

The sensitivity, specificity and success probability rate of the final novel scoring system was also presented (Table 6).

Table 6: Extubation Success Probability Of Comprehensive Extubation Outcome Prediction Score

	Sensitivity	Specificity	Success rate	Probability
<17.5	90.91%	51.11%	55.45%	Low
17.5-55	90.9-72.73%	51.11-98.89	55.45-98.02%	Intermediate
>55	72.73%	98.89%	98.02%	High

DISCUSSION

All the patients selected for our study were planned for extubation after a successful spontaneous breathing trial (SBT). The extubation failure rate in our study was 10.9%, which is comparable to previous studies.[8]

Two ultrasound-based parameters significantly associated with extubation outcomes and included in our score are E/e' and LUS score. This is comparable to a previous study by Sommer et al., where the mean LUS score after SBT in the extubation failure and success groups was 19 and 10, respectively.[9] The mean E/e' in the extubation failure and success groups in the current study was 12 and 8, respectively. A systematic review and meta-analysis by Sanfilippo et al. showed that the mean E/e' in extubation failure groups in different studies ranged from 7 to 14.7, reflecting differences in weaning outcome and E/e'.[10]

Even though there is a significant relationship between diaphragmatic ultrasound parameters (diaphragmatic thickness fraction and excursion) and extubation outcomes, they were not included in our score since the AUC value after ROC analysis was less than 0.5. Multiple studies have shown that diaphragmatic ultrasound is useful in predicting extubation outcomes[11,12]; but a large multicenter study by Vivier et al. could not replicate the same.[13]

4 clinical parameters significantly associated with extubation outcomes and hence included in our score are RSBI, duration of mechanical ventilation (MV), serum creatinine and APACHE II score. The value of RSBI for predicting weaning and extubation success has been examined by many researchers. RSBI <105 breaths/min/L was widely considered to be predictive of extubation success[14]; however, subsequent studies showed that RSBI around 50 breaths/min/L is associated with extubation success, while RSBI around 80 breaths/min/L is associated with failure[15,16], which are comparable to our values. Tanios et al. studied RSBI as a weaning predictor with a randomized, controlled trial and concluded that RSBI prolonged weaning time and should not be used routinely in weaning decision-making. [17] This concludes that even though RSBI has significant weight as an extubation predictor, it alone cannot accurately determine the extubation outcome. MV duration is another parameter included in our score. The mean duration of MV for the extubation success group and failure group was 4 and 6.8 days, respectively. A previous study by Xie et al showed that a duration of MV longer than 12 hours significantly impacts extubation failure.[5]

Serum creatinine level is the only lab parameter routinely evaluated in the ICU setting, which is included in our score. A similar significant difference in serum creatinine was seen in a previous study to develop an extubation prediction score, and hence it was a component of their score as well.[7] Several multi-parameter scores have been proposed to predict extubation outcome over the years due to conflicting results when different parameters are assessed alone. Recent examples are the CORE index[18], the Integrative Weaning Index (IWI)[19], the Burns Wean Assessment Program (BWAP)[20], the modified-BWAP[21], and the Extubation Predictive Score (ExPreS)[5]. However, these scores have not proven to be very efficient: even with their application, the extubation failure rate remains high. Additionally, some of these scores either included only respiratory parameters or included a large number of parameters, making them difficult to use in daily practice. Moreover, none of the previous studies on extubation prediction scores evaluated any of the ultrasound-based parameters. Since ultrasound is portable, non-invasive, and can detect under-recognized causes of extubation failure (notably cardiac, diaphragm, and lung abnormalities related to extubation failure), it is important to include ultrasound-based parameters in future extubation scoring systems. This further explains why this score may outperform previous scores.

This study has its limitations: it is based on single-centre data, SBT was considered successful based on the evaluation of the treating intensivist and not based on any fixed criteria for success of SBT, has low statistical power in extubation failure prediction due to a small sample of patients with extubation failure in analysis. Like all techniques of ultrasonography, bedside lung, heart, and diaphragm ultrasonography can be operator-dependent, even though a high intra- and inter-observer reproducibility was reported.

CONCLUSION

The comprehensive extubation outcome prediction score, incorporating parameters such as RSBI, APACHE II score, duration of IMV, E/e', LUS score, and serum creatinine, predicts extubation outcomes in mechanically ventilated ICU patients and demonstrates superior predictive capability compared to individual parameters. Patients with a score <17.5 had a low probability of extubation success, those with a score of 17.5–55 had an intermediate probability, and those with a score >55 had a high probability of success. Larger studies are needed to validate the accuracy of this scoring system

Key Messages

This study emphasizes the importance of combining ultrasound-based parameters with traditional measures to improve the prediction of extubation outcomes in critically ill patients. Ultrasound is portable, non-invasive, and capable of identifying subtle factors often overlooked in standard assessments.

By integrating these insights into a comprehensive predictive score, the study provides a more accurate and practical tool to guide extubation decisions, helping to reduce failure rates and enhance patient outcomes.

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