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Establishing a Prediction Model for Successfully Planned Endotracheal Extubation in Preterm Neonates: An Answer to Many Questions

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[1,6]Substantial contributions to the conception or design of the work; or the acquisition, [3,4]Active participation in active methodology, [4]analysis, or interpretation of data for the work, [2,5,7]Drafting the work or revising it critically for important intellectual content

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ABSTRACT

Objective: To establish the prediction model for successfully planned endotracheal extubation in preterm neonates.

Methodology: This Prospective cohort study was conducted at Neonatal ICUs of Fatima Memorial Hospital Lahore, from February 2023 to October 2024. The study included 255 preterm neonates (28–35 weeks gestation) intubated <7 days and extubated for the first time before 30 days of age. Successful extubation was labeled as no need for reintubation within 72 hours following extubation. Demographics, prenatal, and peri-extubation data were collected analyzed using multivariate logistic regression to identify independent predictors. Receiver operating characteristic (ROC) analysis assessed model discrimination, and a nomogram was constructed for individualized prediction.

Results: Of 255 neonates, 174 (68.2%) achieved successful extubation. Independent predictors included multigravida status (OR = 0.026, 95% CI: 0.002–0.356, p = 0.006), higher serum sodium levels (OR = 1.436, 95% CI: 1.108–1.862, p = 0.006), higher pre-extubation pH (OR<0.001, p = 0.001), lower PIP (OR = 3.530, 95% CI:1.42 – 8.771, p = 0.007), lower MAP (OR = 8.012, 95% CI: 2.21 – 29.03, p = 0.002), and higher SpO_2 before extubation (OR = 0.101, 95% CI: 0.028 – 0.362, p < 0.001), increase in FiO_2 by 10% post-extubation (OR = 0.049, 95% CI: 0.005–0.452, p = 0.008). The final model incorporating $SpO_2 \geq 94\%$, pH ≥ 7.34, and PIP ≤ 13 cm H_2O demonstrated excellent discrimination (AUC = 0.94, 95% CI 0.91–0.97).

Conclusion: $SpO_2 \geq 94\%$, pH ≥ 7.34, and PIP ≤ 13 cm H_2O are strong predictors of successful extubation in preterm neonates. The developed nomogram provides a simple bedside tool for extubation readiness.

Keywords: Endotracheal extubation, Endotracheal intubation, Mechanical ventilation, NICU, Preterm neonates

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Introduction

Prematurity (birth before 37 completed weeks of gestation) affects approximately 1 in 10 newborns worldwide.[1] In Pakistan about every 6th neonate is born preterm.[1]

Preterm neonates are vulnerable to respiratory failure due to poor breathing efforts, developing lungs, immature respiratory centers, along underlying diseased lung pathology. Nasal CPAP is ideal respiratory support for such neonates with self-ventilatory efforts.[2] But if CPAP fails, invasive mechanical ventilation is unavoidable. A multicenter study by Moya reported that 43% of preterm neonates ultimately require mechanical ventilation[2]. Invasive mechanical ventilation is lifesaving, but prolonged ventilation and delay in weaning pose significant morbidity and mortality.[3] Judicious use of mechanical ventilation and timely extubation is critical to optimize neonatal outcomes. Conversely, extubation failure can result in significant pulmonary, systemic, and cerebral hemodynamic fluctuations, increased ventilatory support, and upper airway injury during reintubation attempts.[4] The reported frequency of failed elective extubation ranges from 23% to 42% in preterm neonates.[5-7]

The principal consensus in clinical practice is to plan for an early and timely attempt at successful extubation. Identifying factors associated with successful extubation will help not only to reduce the duration of invasive mechanical ventilation but also its related morbidity and improve outcomes. It also opens the potential for ongoing clinical research aimed at refining respiratory management strategies.[3,5,6]

In clinical practice, while keeping all facts in consideration, neonatologists frequently face challenging questions such as: How long should a neonate continue on invasive mechanical ventilation? What is the optimal time for extubation? Is the neonate physiologically stable enough to sustain extubation? These questions underscore the need for reliable clinical indicators to guide timely and successful weaning from ventilatory support, ultimately reducing the risk of ventilation-associated morbidities.[7,8,9]

Extubation timing in preterm neonates is usually based on clinical judgment assessing overall cardiorespiratory stability through physical examination, ventilatory support, and blood gas analysis.[8] Successful extubation depends on adequate lung compliance, effective respiratory drive, and sufficient neuromuscular strength to sustain spontaneous ventilation.[9,10] Commonly evaluated factors include gestational age, weight, Apgar score, peak inspiratory pressure (PIP), mean airway pressure (MAP), fraction of inspired oxygen (FiO_2), and pre-extubation pH and partial pressure of carbon dioxide (PCO_2), along with the type of post-extubation respiratory support. [8–11]

These multiple factors work in a strong intricate system. Higher ventilatory pressures and FiO_2 indicate poor pulmonary compliance and ventilation–perfusion mismatch.[12] Similarly, while low pH/ acidosis or elevated PCO_2 reflect respiratory muscle fatigue or inadequate ventilatory drive. In preterm infants, immature respiratory drive and control along with weak diaphragmatic strength further compromise their ability to maintain effective ventilation after extubation.[13] Persistent oxygen requirement or acidosis suggests ongoing alveolar instability and inadequate gas exchange reserve. Recent studies confirm that ventilator and gas-exchange indices like respiratory severity score and FiO_2 trends mirror these underlying pathophysiological limitations and predict extubation outcomes.[12-14] Despite these advances, predictive models vary in sensitivity and specificity, and a universally accepted model with defined clinical cut-offs remains lacking.

To address these research gaps in the context of the local population, this study aimed to explore predictors for successful extubation among preterm neonates. It aims to (1) Establish a prediction model for successfully planned endotracheal extubation in preterm neonates to predict successful extubation and (2) Determine predictors of successful extubation and their cut-off values.

Methodology

Following ethical approval from the Institutional Review Board (IRB) (IRB # FMH-20/10/2022-IRB-1119), from February 2023 to October 2024, we conducted a prospective cohort study in our tertiary care setup. We obtained written informed consent from guardians/parents before participation in our study. The study included only preterm neonates born between 28 and 35 weeks of gestation age (GA) who were intubated during their NICU stay.

The sample size was 255 and calculated with a 95% confidence level, 10% margin of error, and 5% level of significance by taking an average of 32% preterm with extubation failure. Calculations were made with the help of an online sample size calculator (Freely available at https://www.openepi.com).

All intubated preterm neonates of GA 28 – 35 weeks, undergoing first planned extubation before 30 days of chronological age were reviewed for inclusion after seeking consent. All these preterm remained intubated for at least 24 hours but not greater than 7 days.

However, all those neonates having major anomalies, incompatible with life, congenital lung malformations and hypoplasia, congenital heart disease, genetic/metabolic diseases, shock requiring inotropic support, post-extubation surgical intervention, or parental refusal were excluded. Moreover, only neonates with chronological age of > 30 days were also excluded.

Operational definitions

Extubation readiness: Extubation was considered if the neonate met all of the following criteria:

- Clinically and hemodynamically stable with improvement in underlying diagnosis
- PIP ≤ 18 cm of H_2O
- PEEP 5-6 cm of H_2O
- FiO_2 ≤ 40%
- Maintaining a targeted SpO_2 90 – 95%
- Capillary blood gases showing PCO_2 <55 cm of H_2O
- Hemodynamic stability
- Tolerated ETT CPAP trial for 10 minutes

Extubation failure/Reintubation: Neonate may need reintubation if any of the following criteria were met within 72 hours of first extubation:

- Frequent apnea (6 in 12 hours responded to stimulation) or a single episode of apnea requiring positive pressure ventilation (PPV),
- pH <7.25
- PCO_2 >65 mmHg
- FiO_2 > 0.60 is required to maintain oxygen saturation at or above 90%
- Hemodynamic instability with shock

Respiratory Severity Score (RSS) is the mean airway pressure (MAP) x FiO_2 (0.21 – 1.0). The outcome was measured as successful extubation and no need for reintubation till 72 hours. Oxygen saturation index (OSI) was calculated as (MAP) x FiO_2(0.21 – 1.0) x 100 / SpO_2. The mean FiO_2 in the 2 hours before the extubation attempt was Pre-extubation FiO_2, while Post-extubation FiO_2 was the maximum FiO_2 during the first 24 hours after the extubation attempt. Neonatal Sepsis was diagnosed by the presence of leukocytosis (total leukocyte count $>30\times10^3$) or leukopenia (total leukocyte count $<5\times10^3$) or absolute neutrophilic count $<150 \times 10^3$ along with raised CRP and platelets $<100 \times 10^9$ and or positive blood culture).

All neonates admitted to our NICU who met the inclusion criteria, regardless of their clinical diagnosis, were enrolled in the study and managed according to departmental protocols. All preterm neonates receiving invasive mechanical ventilation were assessed for extubation readiness as per protocol.

Maternal demographic and perinatal statistics including age, diabetes mellitus (DM), hypertensive disorders of pregnancy (PIH & Pre-eclampsia), antepartum hemorrhage (APH), premature prelabour rupture of membranes (PPROM), chorioamnionitis, parity (primigravida/multigravida), maternal anemia, multifetal gestation (MFG), and complete antenatal corticosteroids (ANS) during pregnancy were collected.

Neonatal demographic statistics include gestation age (GA), birth weight, gender, weight for gestation age (AGA / SGA / LGA), mode of delivery, and surfactant administration. Neonatal peri-extubation characteristics include mechanical ventilation support-related parameters including median Oxygen saturation index (OSI), respiratory severity score (RSS), FiO_2, SpO_2, MAP, heart rate (HR), and duration during IMV. Pre-extubation characteristics (within 2 hours before extubation) pH, PIP, PCO_2, MAP, SPO_2, Ventilator rate, FiO_2, and steroids. The post-extubation parameters noted were post-extubation increase FiO_2 ≤10 % and type of respiratory support (n-CPAP vs oxygen). Neonatal clinical characteristics noted were the use of caffeine, comorbid conditions including sepsis, presence of hemodynamically significant patent ductus arteriosus (hsPDA), intraventricular hemorrhage (IVH all grades), and necrotizing enterocolitis (NEC, modified Bell's scoring all stages), and duration of stay.

Data was analyzed using the Statistical Package for the Social Sciences (SPSS 20.0) package. The descriptive statistics and tests of significance were calculated for all the variables. The Shapiro-Wilk test was used to assess the normality of the distribution of investigated continuous variables. All continuous variables if distributed normally were expressed as mean ± SD otherwise the median and interquartile range (IQR) if not normally distributed. In addition, the differences in baseline characteristics and clinical variables between the successful and failed extubation groups were evaluated using a Student t-test for continuous variables and a Pearson chi-square test for categorical variables. Maternal and neonatal characteristics of all preterm neonates were compared based on extubation outcome as successful vs failure and $p<0.05$ was considered statistically significant. Logistic regression analysis was performed on all factors with a p-value < 0.05 in the univariate analysis to identify predictors of extubation success and to calculate the corresponding odds ratios (ORs) and 95% confidence intervals (CIs).

Receiver operating characteristic (ROC) curves were plotted for the pre-extubation SPO2, pH, and post-extubation increase in FiO2 ≤ 10% values to identify the factors determining successful extubation, and the area under the curve was calculated. The Youden index score was used to identify the appropriate pre-extubation SPO2, pH, and post-extubation increase in FiO2 ≤ 10% value with the best-predicted performance. Using a forward model selection procedure, the final prediction model was conducted. Based on the final model, the estimated probability of successful extubation was calculated.

A nomogram was used in which the regression coefficients representing the strengths of correlation were proportionately transferred to the distances on a graph. In turn, the distances were linked to corresponding points and summed up. ROC curve analysis was used to analyze the cut-off point and to examine the prediction effectiveness of the extubation outcome.

Model validation was performed using cross-tabulation of predicted versus actual extubation outcomes at the optimal probability threshold identified by the ROC analysis (Youden Index). Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy were calculated from a 2×2 contingency table based on the complete cohort (n = 255), reflecting the model's sensitivity and specificity.

Results

During the study period, 379 preterm neonates were intubated in our NICU but 314 fulfilled the inclusion criteria. Further 59 were excluded and consequently, 255 neonates (83.9%) were included in the final analysis and 174 patients (68.2%) were successfully extubated.

Table 1 summarizes the baseline maternal and neonatal characteristics stratified by extubation outcome. In univariate analysis, maternal diabetes, anemia, multigravida status, and antenatal corticosteroid (ANS) use were statistically significant risk factors associated with extubation outcome ($p < 0.05$). The median birth weight with successful extubation was 1700 (1200 – 2390) grams. The statistically significant neonatal factors were higher gestational age and birth weight, caffeine therapy, absence of sepsis, frequent intubation, HsPDA, surfactant instillation, and serum sodium ($p < 0.05$). Among 81 neonates who faced extubation failure, about two-thirds (61.7%), were reintubated within 24 hrs.

No significant differences were observed during mechanical ventilation in median OSI, RSS, MAP, or FiO_2 except duration of IMV. However, pre-extubation parameters like higher pH, lower peak inspiratory pressure (PIP), lower mean airway pressure (MAP), lower FiO_2, and higher oxygen saturation were associated with successful extubation ($p < 0.05$). Similarly, neonates requiring a post-extubation increase in FiO2 by 10% remained successfully extubated 33 (52.5% vs 30 47.6%) (p<0.001), and the use of n-CPAP 136 (65.5%) vs 72 (34.6%) (p 0.04), as shown in table II.

Table I: The maternal and neonatal demographic characteristics.

Characteristics		Successful extubation n=174 (68.2%)	Failed extubation n= 81 (31.8%)	p value
Maternal				
Maternal age (years)	Median (IQR)	30 (26 – 35)	33 (27 – 39)	0.066
	<25	27 (75%)	9 (25.0%)	0.514
	26 – 30	69 (74.2%)	24 (25.8%)	
	31 – 35	38 (65.5%)	20 (34.5%)	
	>35	40 (58.8%)	28 (41.2%)	
Diabetes mellitus		53 (60.2%)	35 (39.8%)	0.038
Antepartum hemorrhage		34 (64.2%)	19 (35.8%)	0.288
PIH & Pre Eclampsia		84 (69.4%)	37 (30.6%)	0.401
ANS		117 (76.0%)	37 (24.0%)	<0.001
PPROM		34 (73.9%)	12 (26.1%)	0.232
Chorioamnionitis		16 (69.6%)	7 (30.4%)	0.546
Parity (multigravida)		124 (72.1)	48 (27.9%)	0.040
Maternal Anemia		68 (76.4%)	21 (23.6%)	0.027
Multifetal gestation		11 (64.7%)	6 (35.3%)	0.467
Neonatal				
Birth weight (kg)	Median (IQR)	1700 (1200 – 2390)	1320 (1000 – 1900)	0.001
	< 1	30 (56.6%)	23 (43.4%)	0.016
	1.1 – 1.5	38 (59.4%)	26 (40.6%)	
	1.6 – 2.5	71 (76.3%)	22 (23.7%)	
	>2.5	35 (77.8%)	10 (22.2%)	
Gestational age (weeks)	28 – 30	35 (50.0%)	35 (50.0%)	<0.001
	30+1 – 32	25 (62.5%)	15 (37.5%)	
	32+1 – 35	114 (78.6%)	31 (21.4%)	
Weight for GA (SGA)		68 (63.6%)	39 (36.4%)	0.326
Gender (male)		100 (67.1%)	49 (32.9%)	0.376
Frequent intubation		91 (74.0%)	32 (26.0%)	0.038
HsPDA		66 (62.3%)	40 (27.7%)	0.056
NEC		22 (68.8%)	10 (31.3%)	0.561
Mode of delivery (LSCS)		53 (67.9%)	25 (32.1%)	0.529
Surfactant		84 (60.9%)	54 (39.1%)	0.004
Sepsis		90 (59.2%)	62 (40.8%)	< 0.001
Caffeine		91 (74.0%)	32 (26.0%)	0.038
IVH		38 (61.3%)	24 (38.7%)	0.117
JNN		143 (66.5%)	72 (33.5%)	0.116
Median Na (mmol/L)		136 (134 – 138)	138 (134 – 144)	0.000
Median K (mmol/L)		5.04 (4.50 – 6.00)	5.20 (4.50 – 5.60)	0.531
Median ionized Ca (mmol/L)		1.09 (0.990 – 1.22)	1.11 (1.00 – 1.27)	0.139
Duration of stay (days)		8 (6 – 10)	9 (6 – 12)	0.410
Reintubation duration (hours)	< 24	0	50 (100%)	<0.001
	24 – 72	0	19 (100%)	
	>72 - 120	0	12 (100%)	
	None	173	0	

Logistic regression analysis identified several independent predictors of successful extubation in preterm neonates. Multigravida status (parity) was statistically significant and was associated with an increased likelihood of extubation success (OR = 0.026, 95% CI: 0.002–0.356, p = 0.006). Higher serum sodium (Na) levels (OR = 1.436, 95% CI: 1.108–1.862, p = 0.006) were also predictive of success. Among ventilatory parameters, higher pre-extubation pH (OR<0.001, p = 0.001), lower peak inspiratory pressure (OR = 3.530, 95% CI:1.42 – 8.771, p = 0.007), lower mean airway pressure (OR = 8.012, 95% CI: 2.21 – 29.03, p = 0.002), and higher oxygen saturation (SpO_2) before extubation (OR = 0.101, 95% CI: 0.028 – 0.362, p < 0.001) were significant predictors. Additionally, an increase in FiO_2 by 10% post-extubation was strongly associated with extubation failure (OR = 0.049, 95% CI: 0.005–0.452, p = 0.008). Other variables such as maternal anemia, gestational age, caffeine use, and steroid administration showed trends toward significance but did not reach statistical thresholds.

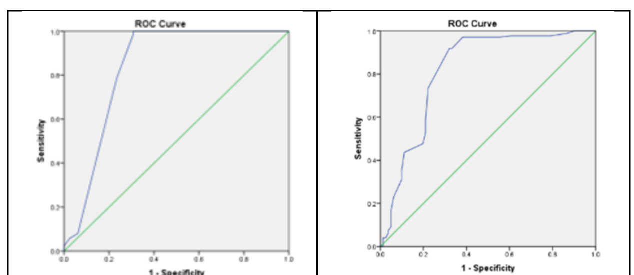
Figure 1 shows the ROC curve predicting successful extubation and it revealed that pre-extubation SpO_2 and pre-extubation pH were the strongest predictors of extubation success with AUC values of 0.836 and 0.818, respectively, indicating excellent discriminatory power. The SPO_2 cut-off ≥94 has a sensitivity: of 98.85%, specificity: of 69.14%, PPV: of 87.31%, NPV: of 96.55%, and Youden's Index: of 0.68 indicating a strong predictor of extubation success. Similarly, pH cut-off ≥7.34 has a sensitivity: of of 91.95%, specificity: of 66.67%, PPV: of 85.56%, NPV: of 79.41%, and Youden's Index: of 0.59. AUC for the post-extubation increase in FiO_2, parity, and mean sodium are 0.603, 0.560, and 0.389, respectively.

The regression model identifies these factors as key predictors, with pH ≥7.34 and SPO_2 ≥94 showing particularly strong associations with extubation success.

A peak inspiratory pressure (PIP) cutoff of ≤13 cm H_2O was significantly associated with higher odds of successful extubation in preterm neonates, with an estimated fivefold increase in the likelihood of success compared to those with higher PIP values (OR = 4.967, 95% CI: 1.435–17.194, p = 0.011). However, despite the statistical significance, the discriminative performance of this cutoff was poor, as evidenced by an area under the receiver operating characteristic curve (AUC) of 0.152. This suggests that while lower PIP may be associated with successful extubation, it lacks sufficient predictive accuracy to be used in isolation for clinical decision-making.

Table II: Peri-extubation characteristics.

Characteristics	Successful extubation n=174 (68.2%)	Failed extubation n= 81 (31.8%)	p value
Characteristics during IMV			
Median HR during IMV	135 (115 – 146)	134 (121 – 153)	0.422
Median OSI during IMV	6.27 (5.32 – 8.30)	6.72 (5.32 – 8.30)	0.602
RSS during IMV	5.8 (4.95 – 7.80)	6.25 (5.2 – 7.80)	0.630
Median SpO2 during IMV	93 (92 – 94)	93 (92 – 93)	0.312
Median MAP during IMV	12 (11 – 13)	12 (10 – 13)	0.157
Median FiO2 during IMV	0.50 (0.40 – 0.60)	0.60 (0.42 – 0.65)	0.085
Duration of IMV	3 (3 – 5)	5 (4 – 6)	0.081
Pre extubation Characteristics			
Pre Extubation Ph	7.38 (7.35 – 7.42)	7.30 (7.27 – 7.35)	0.000
Pre Extubation PIP	13 (13 – 13.5)	15 (14 – 15)	0.000
Pre Extubation PCO2	41.6 (35 – 45)	41 (35 – 45.6)	0.684
Pre-Extubation Ventilatory Rate	45 (41 – 46)	45 (40 – 46)	0.517
Pre Extubation FiO2	30 (25 – 31)	30 (25 – 40)	0.000
Pre Extubation MAP	9 (7 - 9.5)	10 (9 – 10)	<0.001
Pre Extubation SpO2	96 (95 – 98)	96 (96 – 98)	<0.001
Peri extubation steroids	59 (56.7%)	45 (43.3%)	0.001
Post extubation Characteristics			
Post Extubation HR	125 (121 – 135)	141 (132 – 147)	0.784
Post extubation increase in FiO2 by 10	33 (52.4%)	30 (47.6%)	<0.001
Post extubation resp support: N CPAP	136 (65.4%)	72 (34.6%)	0.040
Post extubation resp support: Oxygen	38 (80.9%)	9 (19.1%)	



Pre extubation SPO2 | Pre extubation pH

Figure 1. The ROC analysis: predictors of successful extubation.

MAP and Na were found to be statistically insignificant. On the other hand, parity (multigravida) and post-extubation increase in FiO_2 were found to significantly decrease the chances of success. For this cohort, the probability of successful extubation was calculated using three strong positive predictors as SPO_2 ≥ 94%, pH ≥ 7.34, and PIP ≤ 13 each contributing significantly to the total point score with a 96.2% probability of successful extubation (figure 2a).

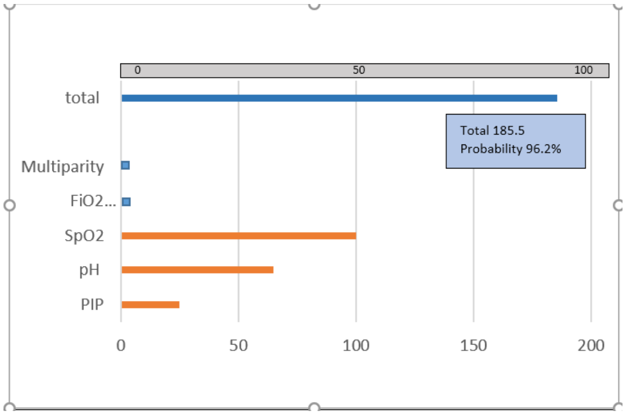


Figure 3a. Nomograms to predict successful extubation.

The ROC analysis demonstrated excellent model performance, with an AUC of 0.940, standard error of 0.016, and $p < 0.001$. The 95% confidence interval (0.908–0.973) confirmed the precision and reliability of the model (Figure 2b).

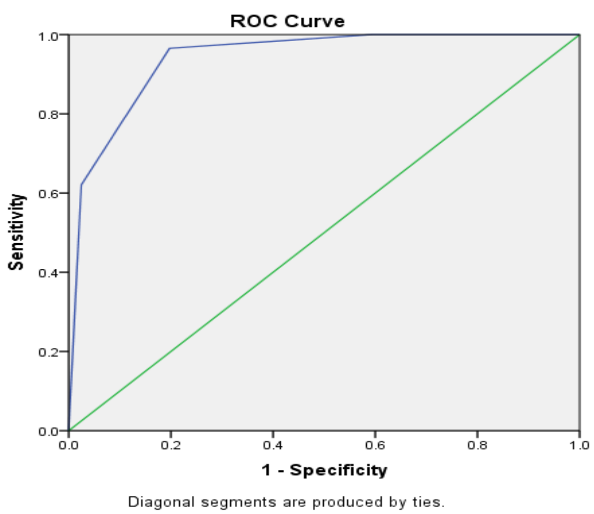


Figure 3b. ROC for prediction effectiveness of the extubation outcome.

For internal validation, diagnostic performance metrics were derived from a 2×2 cross-tabulation comparing predicted and actual extubation outcomes within the study cohort (n = 255). Predicted success was defined as cases meeting all three favorable parameters—$SpO_2 \geq$ 94%, pH ≥ 7.34, and PIP ≤ 13 cmH_2O—while all others were classified as predicted failure. The model correctly identified most successful extubations, yielding a sensitivity of 98.3%, specificity of 75.3%, positive predictive value (PPV) of 89.5%, negative predictive value (NPV) of 95.3%, and an overall accuracy of 91.0%. These findings confirm excellent internal validity, consistent with the high discriminative ability indicated by the ROC curve.

Discussion

Prediction of successful extubation is crucial for defining outcomes in preterm neonates since prolonged mechanical ventilation is associated with increased morbidity and mortality.[3] The decision to ensure “timely and successful extubation” primarily relies on the neonatologist’s clinical judgment, which integrates clinical assessment, blood gas parameters, oxygen requirement, level of ventilatory support, and post-extubation respiratory needs.[3-6] However, strong evidence supporting the use of individual predictors with high precision for assessing extubation readiness in preterm infants remains limited.[11,15] Keeping this gap in view, we aimed to develop a prediction model for the estimation of “successful extubation” within our local NICU setting.

In our prospective cohort of 255 preterm neonates intubated for < 7 days, multivariate analysis identified independent predictors of successful extubation as multigravida status (parity), normal serum sodium levels, lower pre-extubation PIP, higher pH and SpO_2, and post-extubation FiO_2 increase ≤ 10%. Further ROC analysis highlighted three key predictors—$SpO_2 \geq$ 94%, pH ≥ 7.34, and PIP ≤ 13 cm H_2O—as optimal indicators of physiological stability and intrinsic respiratory effort, representing readiness for extubation. These parameters were integrated into a nomogram model to estimate the probability of successful extubation in preterm neonates, similar to recent predictive models proposed for very preterm populations.[15-17]

Reported extubation success (ES) rates in preterm neonates vary across studies. Chawla et al. documented an ES rate of 50–63% among extremely preterm infants, while Wissam et al. observed 53% within 7 days and Mhanna et al. reported 69%. [6,12,13] The 68.2% ES rate in our cohort aligns with these observations. A recent multicenter study by Hoff Calegari et al. similarly showed pooled ES rates of 60–70% in preterm neonates, confirming the global consistency of outcomes despite differences in gestational age and care practices. [15] Our 72-hour definition for extubation success was intentionally selected to reflect “true readiness” while minimizing reintubation from unrelated post-extubation events.[18,19]

Pre-extubation pH remains a crucial determinant of readiness. Cheng et al. reported a median pH of 7.31

(7.25–7.37) associated with increased EF risk, while He F et al. confirmed that pH < 7.38 significantly predicts EF.[14,3] Dryer et al. suggested a pH cutoff of 7.33 ± 0.06 for failure prediction.[20] Recent data further support these findings, identifying pH ≥ 7.34 as a reliable marker of successful extubation in neonates on volume-targeted ventilation.[21] Higher level of pre-extubation respiratory support, indicated by lower pre-extubation pH and higher pre-extubation mean airway pressure, fraction of inspired oxygen, and Pco2 were associated with extubation failure.[19] In our study, pH > 7.34 was similarly associated with higher odds of success. Acidosis, whether respiratory or metabolic, impairs respiratory drive and muscle contractility, thereby predisposing to extubation failure specially in preterm neonates.[22]

Regarding ventilatory parameters, Mahana et al. and Liu et al. reported that higher pre-extubation PIP values strongly correlated with EF.[13, 23] Liu et al. identified a PIP ≤ 15 cm H_2O as having 91.4% sensitivity and 66.7% specificity for predicting success.[23] Our findings mirror this relationship, with PIP ≤ 13 cm H_2O significantly associated with extubation success (OR = 4.967; p = 0.011). Lower PIP values generally reflect better lung compliance, resolution of underlying disease, and reduced risk of ventilator-induced lung injury.[19] Although lower PIP values are associated with successful extubation, PIP alone does not provide adequate discriminatory ability to serve as a reliable predictor in neonates.[22-24]

Oxygenation metrics have consistently been emphasized as important readiness markers. Pholanun et al. found that SpO_2 > 90% conferred a 6-fold higher likelihood of success versus ≤ 85%.[25] Abu Jawdeh et al. demonstrated that intermittent hypoxemia (SpO_2 < 80%) within 72 hours predicted failure [26] Similarly, our cutoff of SpO_2 ≥ 94% was associated with enhanced success rates, indicating a threshold ensuring respiratory stability and safety. Comparable results were observed in a recent population-based study of infants < 26 weeks GA where FiO_2 ≤ 0.35 and stable SpO_2 predicted extubation success.[6]

Despite multiple predictive efforts, a universally accepted scoring tool for extubation readiness remains elusive. Previous scores—such as the Extubation Readiness Estimation (ERE) score proposed by Bhatia et al. showed limited accuracy (AUC = 0.49; sensitivity 36%; specificity 54%).[27] Recent systematic reviews and nomogram models have further stressed the need for multifactorial approaches combining clinical and physiological predictors (e.g., FiO_2, pH, SpO_2, MAP, and ventilation duration).[21, 28-30] Chawla et al. and Ferguson et al. highlighted that post-extubation support strategies such as CPAP also enhance outcomes.[1, 28] Our findings converge with this evidence and add a validated nomogram-based approach for estimating individualized probability of successful extubation in preterm neonates.

Overall, our model not only supports previously identified physiological predictors of extubation readiness but also strengthens their combined clinical utility through a simple, interpretable prediction tool. This may aid neonatologists in reducing extubation-related morbidity and refining individualized ventilatory strategies for preterm infants in low- and middle-income NICU settings.

LIMITATIONS: This study was conducted at a single tertiary care center with a modest sample size, which may limit generalizability. However, adherence to standardized clinical protocols and consistent data collection minimized bias and ensured methodological rigor. The analysis was restricted to first-attempt extubations within 72 hours, which may not capture delayed or recurrent failures. Despite these constraints, the study provides valuable region-specific evidence on predictors of successful extubation in preterm neonates and establishes a foundation for larger, multicenter validation of the proposed prediction model.

Conclusion

In this prospective cohort of preterm neonates, the overall extubation success rate was 68.2%. The developed prediction model, based on three key physiological parameters—pH ≥ 7.34, SpO_2 ≥ 94%, and PIP ≤ 13 cmH_2O—demonstrated excellent discriminative accuracy (AUC = 0.94). These variables collectively reflect optimal respiratory stability and readiness for spontaneous ventilation. The resulting nomogram offers a practical, bedside tool for estimating the probability of successful extubation in preterm neonates, potentially guiding clinical decision-making and reducing the risk of reintubation in resource-limited NICU settings.

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