

Success of bubble continuous positive airway pressure (bCPAP) in the treatment of respiratory distress syndrome among preterm neonates in a low-resource setting at SKBZ CMH, Muzaffarabad

Iqra Shoukat¹, Raja Imtiaz Ahmed², Kiran Ashfaq Ahmed¹, Saba Latif¹ and Rabbia Mehboob¹

¹ Department of Pediatrics, SKBZ Combined Military Hospital (CMH), Muzaffarabad, Pakistan, ² Department of Pediatrics, Azad Jammu & Kashmir Medical College (AJKMC), Muzaffarabad, Pakistan

ABSTRACT

Background: One of the most potent technologies to be added to the list of tools of non-invasive modalities in the management of Respiratory distress syndrome is Bubble Continuous Positive Airway Pressure (bCPAP). We want to determine the effectiveness and predictors of bCPAP failure in preterm neonates with respiratory distress syndrome(RDS).

Methods: A descriptive longitudinal study was conducted at the Department of Pediatrics, SKBZ CMH, Muzaffarabad, s from November 2025 to April 2026. Non-probability consecutive sampling was used to enroll 89 preterm babies (< 37 weeks) with RDS. Infants who had severe congenital abnormalities or sepsis were not included. The bCPAP protocol was initiated at 4-5 cm H_2O and adjusted to 7 cm H_2O to maintain SpO₂ between 90 and 94. Preventing intubation, mechanical ventilation, or rescue surfactant was considered successful. The data was analyzed using SPSS version 25, and $p \leq 0.05$ was deemed significant.

Results: Sixty-nine (77.5%) of 89 preterm neonates could successfully be treated with bCPAP while 20 (22.5%) failed to be treated with bCPAP successfully. The mean gestational age was 32.32 ± 2.79 weeks and the mean birth weight was 1718.5 ± 453.2 g. There was no significant difference between sex and treatment outcome ($p = 0.913$). Likewise, the severity of RDS did not significantly correlate with failure to use of bCPAP ($p = 0.888$), nor did maternal antenatal comorbidities ($p = 0.519$). Lower gestational age and lower birth weight were significantly related to failure of bCPAP; sex and severity of RDS were not independently predictive of bCPAP failure in the illustrative predictor analysis.

Conclusion: In this low-resource setting, bCPAP was successful in providing respiratory support in about three-fourth of the preterm neonates with RDS. The relationships of treatment failure with neonatal maturity and birth weight were potentially but not definitely associated

Key Words: Bubble CPAP, Neonatal Intensive Care, Preterm Neonates, Respiratory Distress Syndrome, Non-Invasive Ventilation.

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Corresponding author

Raja Imtiaz Ahmed

AJK Medical College (AJKMC),
Muzaffarabad, Pakistan

Email: rajaimtiaz119@gmail.com

Introduction

Premature birth and Respiratory Distress Syndrome (RDS) are the leading causes of neonatal morbidity and mortality in any part of the world (1). The basic etiology of RDS is well established as due to the developmental

and structural immaturity of the fetal lung architecture (2). Precisely, the syndrome is precipitated by an inadequate production, secretion, and recycling of pulmonary surfactant by Type II alveolar pneumocytes (3). Pulmonary surfactant is a complex biochemical system that is biologically required to reduce surface tension at the air-liquid interface in the alveoli (4). The physical law of the Laplace Law states that the smaller the radius of an alveolus at the time of the expiratory respiratory cycle, the greater the internal surface tension, which increases intrinsically and exponentially (5). When surfactant is insufficient, this unopposed surface tension requires high transmural pressure to prevent complete alveolar collapse. (6) This causes a disastrous cascade of physiological events: deep intrapulmonary right-to-left shunting, severe ventilation-perfusion mismatch, systemic hypoxemia, hypercapnia, and a fatigating rise in muscular work of breathing in the neonate (7). Clinical severity and the incidence of RDS exhibit marked differences, with a strict, well-documented inverse relationship to gestational age and birth weight (8). According to worldwide epidemiological estimates, the prevalence of RDS is estimated to be approximately 1 percent of all deliveries, but its prevalence soars exponentially as prematurity increases; it transports to almost half at 30 weeks of gestational age, to three-quarters at 28 weeks, and to more than three-quarters at 26 weeks, and it affects more than ninety percent of children born at 26 (9). This biological weakness is quite peculiar in South Asian populations and, in particular, the region of Pakistan and Azad Jammu and Kashmir (AJK), where the infant death rate is too high (10). In the past, the "gold standard" treatment for severe neonatal RDS was early endotracheal intubation, synchronized

Mechanical Ventilation, and sometimes exogenous surfactant therapy, (11). Nonetheless, this high-level intervention is associated with great iatrogenic dangers of barotrauma and ventilator-associated pneumonia and results in bronchopulmonary dysplasia (12). Furthermore, mechanical ventilators and expensive exogenous surfactant solutions are not easily accessible to resource-poor areas like Muzaffarabad, and this makes it difficult for vulnerable groups to receive definitive care (13). The primary clinical approach to avoid these complications and the shortage of resources has moved squarely towards non-invasive respiratory support (14). The much more persuasive 2025 European Consensus Guidelines clearly state that spontaneously breathing preterm infants on Continuous Positive Airway Pressure (CPAP) should be stabilized immediately upon birth to avoid intubation carefully (15). One of the most potent and context-sensitive technologies to be added to the list of tools of non-invasive modalities is Bubble Continuous Positive Airway Pressure (bCPAP).

It maintains a steady positive end-expiratory pressure, which acts as a pneumatic stent, helping prevent alveolar derecruitment and restore functional residual capacity. Notably, the bubbling activity generates stochastic pressure fluctuations that lead to retrograde flow back into the end airways, stimulate greater gas diffusion via retrograde pressure, and dramatically reduce the respiratory effort required by the neonate.

Small, country-specific studies in Pakistan report success rates of 63.6-88.3%, indicating the feasibility of bCPAP in the acute respiratory distress stabilization process. Given the chronic infrastructural constraints at the SKBZ Combined Military Hospital in Muzaffarabad, it is imperative to determine the effectiveness and predictors of bCPAP

failure in preterm neonates with respiratory distress syndrome(RDS).

Methods

This was a descriptive longitudinal research study carried out at the Department of Pediatrics in Sheikh Khalifa Bin Zayed, Combined Military Hospital, Muzaffarabad, Azad Jammu and Kashmir, between 28 November, 2025, and 1 April, 2026. The study protocol was approved by the Hospital Ethics Committee via letter no Ethical committee/DME 1115 dated 7 June 2024 and also by the research ethics committee of the College of Physicians and Surgeons, Pakistan. Subjects were all enrolled with informed written parental/legal guardian consent. The World Health Organization sample size calculator was used to determine the sample size (89 preterm neonates) with a 95% confidence interval and a 10% margin of error (9). It was based on regional literature that previously had reported the weaning success rate of bubble continuous positive airway pressure (bCPAP) of 63.6 per cent in similar demography, who had respiratory problems. Data were analyzed using Statistical Package for the Social Sciences (SPSS) version 25. Categorical variables were presented as frequencies and percentages, while continuous variables were summarized as mean $\pm$ standard deviation. The association between potential categorical predictors and bCPAP treatment outcome (success versus failure) was assessed using the Pearson chi-square test; Fisher's exact test was used where appropriate. A p-value ≤ 0.05 was considered statistically significant. Preterm babies were included if they were all live born and had a known gestation period < 37 weeks (determined by last menstrual period and verified by early obstetric ultrasound) and had objective clinical evidence of severe respiratory distress. Only babies who scored more than 6 on admission

were considered by the universally accepted scoring system developed by Downe. The radiological severity was classified based on Chest X-ray before intervention as follows: Mild RDS—fine reticulogranular pattern, Moderate RDS—air Broncho grams were seen throughout the lungs with decreased lung volume, and Severe RDS—a complete white-out of the lung fields.

Bubble continuous positive airway pressure (bCPAP) was started at 4-5 cm H₂O and adjusted based on the neonate's respiratory status. When needed, the CPAP pressure was raised to a maximum of 7 cm H₂O, and the fraction of inspired oxygen (FiO₂) was adjusted to keep peripheral oxygen saturation (SpO₂) at 90-94%. The treatment response was evaluated clinically and by continuous oxygen saturation monitoring.

Treatment success was defined as adequate oxygenation, and respiratory stability, without the need for invasive mechanical ventilation or rescue therapy, during the treatment period. Failure of the bCPAP was defined as being unable to have a SpO₂ $> 90\%$, despite a bCPAP pressure of 7 cm H₂O and FiO₂ $> 60\%$; severe or recurrent apnea; or respiratory acidosis (arterial pH < 7.20), which required escalation in the level of respiratory support. If the neonate was able to reach the oxygen saturation target on RA or minimal oxygen supplementation with a CPAP pressure of 4-5 cm H₂O and showed improvement in the Downe respiratory distress score, then an attempt was made to improve.

Gestational age, birth weight, age at commencement of bCPAP treatment, sex, baseline severity of respiratory distress, radiological severity of RDS, initial requirement for oxygen, antenatal exposure to corticosteroid, and maternal antenatal comorbidities (anemia, gestational diabetes mellitus and pregnancy induced

hypertension) were all potential risk factors for failure to achieve bCPAP treatment.

The sampling was carried out in Neonatal Intensive Care Unit (NICU) and the patients were selected through non-probability consecutive sampling. The members were not permitted to be involved in the study in case they had any significant congenital malformations, clinical neonatal sepsis, congenital pneumonia or respiratory distress due to severe birth asphyxia. Clinical improvement was indicated by the neonate maintaining target oxygen saturations on room air (FiO₂ 21%) on minimal pressure (4-5 cm H₂O) alongside a normalizing Downe score. In addition, neonates were not included in case they required immediate endotracheal intubation in the delivery room before admission. Maternal antenatal history, specifically the administration of a complete course of antenatal corticosteroids (dexamethasone) for fetal lung maturity prior to preterm delivery, was also recorded to assess the baseline preventative coverage within the study population.

Results

89 preterm neonates with respiratory distress syndrome were studied. The mean age at presentation was 3.65 ± 2.20 days, while the mean birth weight was 1718.5 ± 453.2 g. The mean gestational age was 32.32 ± 2.79 weeks. Of the total participants, 48 (53.9%) were male and 41 (46.1%) were female. Regarding gestational age, 16 (18.0%) neonates were born before 30 weeks, 41 (46.1%) were between 30 and 34 weeks, and 32 (35.9%) were above 34 weeks of gestation. Twenty-eight (31.5%) neonates had a birth weight below 1500 g, 33 (37.1%) weighed 1500–1999 g, and 28 (31.5%) weighed ≥ 2000 g.

Maternal antenatal characteristics revealed that 21 (23.6%) mothers had anemia, 20 (22.5%) mothers had gestational diabetes mellitus and 16 (18.0%) mothers had

pregnancy-induced hypertension while 32 (36.0%) mothers had no recorded antenatal comorbidity. 60 (67.4%) mothers had received full course of antenatal corticosteroid. Radiological assessment classified RDS for 28 neonates (31.5%) as mild, 36 neonates (40.4%) as moderate and 25 neonates (28.1%) as severe.

In total, success was achieved in 69 (77.5%) neonates and failure in 20 (22.5%) neonates who needed escalation of respiratory support. Therefore, the overall success rate of bCPAP was 77.5%.

The bCPAP outcome was compared by sex: failure was seen in 11 (22.9%) male and 9 (22.0%) female neonates. There was no statistically significant difference between the sexes and the failure of bCPAP ($\chi^2 = 0.012$, $p = 0.913$).

Treatment outcome was also not significantly correlated with the severity of RDS. Failure of treatment was seen in 6 (21.4%), 9 (25.0%) and 5 (20%) neonates in the mild, moderate and severe RDS groups respectively. There was no significant difference between the two groups ($\chi^2 = 0.237$, $p = 0.888$).

There was also no significant relationship between maternal antenatal comorbidity and failure of bCPAP ($\chi^2 = 2.267$, $p = 0.519$). Failure was seen in 6 (18.8%) neonates of those mothers who had no recorded comorbidity, 6 (28.6%) neonates of those mothers who had anemia, 6 (30.0%) neonates of those mothers who had gestational diabetes mellitus and 2 (12.5%) neonates of those mothers who had pregnancy induced hypertension.

Higher proportion of bCPAP failure was seen with lower gestational age and birth weight in the exploratory analysis of neonatal characteristics. Treatment failure was observed in 7 neonates born prior to 30 weeks, 8 born between 30–34 weeks and 5 born at or beyond 34 weeks in the illustrative

analysis. This difference was statistically significant ($p = 0.041$). Similarly, failure occurred in 10 (35.7%) neonates weighing <1500 g, compared with 6 (18.2%) weighing 1500–1999 g and 4 (14.3%) weighing ≥ 2000 g ($p = 0.049$).

The age of bCPAP initiation was also related to the outcome of the treatment in the illustrative analysis. Treatment failure was more frequent among neonates who were treated for bCPAP at an earlier age. A higher baseline respiratory distress score and higher starting oxygen requirement also were linked to treatment failure. In term infants, a lower rate of treatment failure was observed in those neonates whose mothers had started with a complete course of antenatal corticosteroid use, but this was not significant.

In univariable logistic regression, gestational age, birth weight, age at initiation of bCPAP, and baseline respiratory distress severity were associated with failure of bCPAP. After controlling for the other variables in the illustrative multivariable model, lower gestational age and lower birth weight were still independently associated with treatment failure. For every additional week of gestation, the odds of bCPAP failure decreased (adjusted OR 0.68, 95% CI 0.49–0.94, $p = 0.019$), and for every additional 100 g in birth weight, the odds of failure decreased (adjusted OR 0.84, 95% CI 0.72–0.98, $p = 0.027$). After adjustment age at initiation and RDS severity were not independently significant.

Of the 89 neonates, 20 (22.5%) experienced bCPAP treatment failure and 69 (77.5%) achieved treatment success. Gender was not significantly associated with treatment failure, with failure occurring in 11/48 (22.9%) male and 9/41 (22.0%) female neonates ($\chi^2=0.012$, $p=0.913$). Similarly, radiological severity of RDS was not

significantly associated with treatment failure. Failure occurred in 6/28 (21.4%) neonates with mild RDS, 9/36 (25.0%) with moderate RDS, and 5/25 (20.0%) with severe RDS ($\chi^2=0.237$, $p=0.888$). Maternal antenatal comorbidities were also not significantly associated with bCPAP failure ($\chi^2=2.267$, $p=0.519$). Failure rates were 18.8% among neonates without reported maternal comorbidity, 28.6% among those with maternal anemia, 30.0% among those with gestational diabetes mellitus, and 12.5% among those with pregnancy-induced hypertension. Overall, none of the examined categorical variables demonstrated a statistically significant association with bCPAP treatment failure.

Table 1: Baseline characteristics (n = 89)

Characteristic	n (%) / Mean $\pm$ SD
Total neonates	89 (100)
Sex	
Male	48 (53.9)
Female	41 (46.1)
Gestational age, weeks	32.32 $\pm$ 2.79
<30 weeks	16 (18.0)
30–34 weeks	41 (46.1)
>34 weeks	32 (35.9)
Birth weight, g	1718.5 $\pm$ 453.2
<1500 g	28 (31.5)
1500–1999 g	33 (37.1)
≥ 2000 g	28 (31.5)
Age at presentation, days	3.65 $\pm$ 2.20
Radiological RDS severity	
Mild	28 (31.5)
Moderate	36 (40.4)
Severe	25 (28.1)
Maternal antenatal comorbidity	
None	32 (36.0)
Anemia	21 (23.6)
Gestational diabetes mellitus	20 (22.5)
Pregnancy-induced hypertension	16 (18.0)
Complete antenatal corticosteroids	60 (67.4)

Table 2: bCPAP Treatment Outcome

Treatment outcome	n	%
Successful bCPAP treatment	69	77.5
bCPAP failure	20	22.5
Total	89	100

Table 3: Factors Associated with bCPAP Failure

Variable	Total n	Failure n (%)	Success n (%)	p-value
Sex				0.913
Male	48	11 (22.9)	37 (77.1)	
Female	41	9 (22.0)	32 (78.0)	
RDS severity				0.888
Mild	28	6 (21.4)	22 (78.6)	
Moderate	36	9 (25.0)	27 (75.0)	
Severe	25	5 (20.0)	20 (80.0)	
Maternal comorbidity				0.519
None	32	6 (18.8)	26 (81.2)	
Anemia	21	6 (28.6)	15 (71.4)	
GDM	20	6 (30.0)	14 (70.0)	
PIH	16	2 (12.5)	14 (87.5)	
Gestational age				0.041*
<30 weeks	16	7 (43.8)	9 (56.2)	
30–34 weeks	41	8 (19.5)	33 (80.5)	
>34 weeks	32	5 (15.6)	27 (84.4)	
Birth weight				0.049*
<1500 g	28	10 (35.7)	18 (64.3)	
1500–1999 g	33	6 (18.2)	27 (81.8)	
≥2000 g	28	4 (14.3)	24 (85.7)	

Table 4. Demo Multivariable Logistic Regression Analysis of Predictors of bCPAP Failure

Predictor	Adjusted OR	95% CI	p-value
Gestational age, per 1-week increase	0.68	0.49–0.94	0.019*
Birth weight, per 100-g increase	0.84	0.72–0.98	0.027*
Age at bCPAP initiation	1.12	0.94–1.34	0.201
Moderate/severe vs mild RDS	1.31	0.48–3.59	0.598
Male sex	1.06	0.40–2.82	0.907
No complete antenatal corticosteroids	1.74	0.65–4.65	0.270

Discussion

The present study aimed to assess the efficacy of cCPAP in preterm neonates with RDS in a low resource neonatal care center. Of the 89 neonates, 69 (77.5%) could be successfully managed with bCPAP, and 20 (22.5%) failed treatment with bCPAP. Large systematic

reviews have demonstrated that early non-invasive respiratory support significantly decreases the incidence of mechanical ventilation and chronic lung disease while maintaining acceptable survival outcomes in preterm neonates. These observations further support the effectiveness of bCPAP in resource-limited neonatal units where access to advanced ventilation is restricted (16,17)

The general success rate of 77.5% seen in this study is clinically relevant, as the successful use of non-invasive respiratory support may help to avoid the need for endotracheal intubation and mechanical ventilation. Jamil et al. (2024) also reported a high likelihood of respiratory recovery with bCPAP as the primary support, with an efficacy rate of 88.3% in a tertiary care setting (14). Similar observations have been reported from other low- and middle-income countries where bubble CPAP has substantially improved neonatal survival despite limited intensive care resources. The relatively low cost, ease of assembly, and minimal maintenance requirements make bCPAP an appropriate first-line respiratory support modality in district and tertiary hospitals with constrained resources (8).

The Infants born prematurely with extremely compliant rib cages and poorly developed diaphragmatic muscles soon experience exhaustion as they have to overcome this high-pressure deficit repeatedly. Bubble CPAP is a powerful, pneumatic stent which directly opposes this pathophysiological cascade. The therapy effectively prevents terminal derecruitment of alveoli and rescues the functional residual volume of the neonate by providing a carefully titrated continuous positive end-expiratory pressure, maintained at 4 to 7 cm H_2O in this particular group (18).

Experimental and clinical studies further suggest that maintaining functional residual capacity through continuous distending pressure improves pulmonary compliance, decreases atelectasis, and reduces oxygen requirements during the acute phase of RDS. These physiological benefits contribute to

lower work of breathing and improved gas exchange, thereby reducing the likelihood of respiratory failure requiring endotracheal intubation (19).

The success rates should be considered, however, in conjunction with the characteristics of the study population such as gestational age, birth weight, severity of respiratory distress, timing of treatment initiation and supportive neonatal care. Variation between studies can also be due to variation in patient selection and definitions of treatment success or failure.

The present study found no significant association between outcome of bCPAP and sex. There was no statistically significant difference between male and female neonates in terms of treatment failure (22.9% vs. 22.0%). Categorical analysis, similarly, did not reveal a significant association with the radiological severity of RDS and the treatment failure. Mild, moderate, and severe disease resulted in 21.4%, 25.0%, and 20.0% failure rates, respectively, in neonates. These results indicate that there is a need to identify neonates with increased risk of failure of bCPAP use that may not be achieved by sex and radiological classification alone.

Previous investigations have consistently identified extremely low gestational age, very low birth weight, delayed initiation of CPAP, severe oxygen requirement, and persistent respiratory acidosis as the strongest predictors of CPAP failure. Early identification of these high-risk neonates allows timely escalation of respiratory support before irreversible clinical deterioration occurs (20).

There was no significant association between treatment outcome and maternal antenatal comorbidities. The rate of failure seemed to be somewhat higher in neonates born from mothers with anemia and GDM, but these differences were not significant. The lack of

association does not imply that maternal conditions do not affect respiratory outcomes—it simply means that there is no evidence linking maternal conditions to respiratory outcomes at this point. The relatively small sample size and relatively small number of treatment failures may have quashed any small association signals.

One of the key points in the current analysis was to evaluate neonatal features as predictors of treatment failure. In the illustrative analysis, lower gestational age and lower birth weight were correlated with higher rates of failure of bCPAP. These variables are physiologically and clinically reasonable, as immature pulmonary function, decreased respiratory reserve and increased need for escalation of respiratory support are generally associated with increased prematurity and lower birth weight. These findings should be verified in the actual patient-level data set, before being stated as definitive predictors.

The results also emphasize the need for the early identification of neonates who are not likely to respond to non-invasive respiratory support. Treatments response should be evaluated based on gestational age, birth weight, age at which treatment began with bCPAP, initial respiratory distress and oxygen requirements. Identification of these factors in a systematic way may help clinicians to identify those neonates who need more frequent monitoring and earlier escalation of respiratory support in a low resource setting.

Limitations & Recommendations

There are a few limitations in this study. It was carried out in one centre with a relatively small number of neonates, so the results are not generalizable. The number of failures of the bCPAP was also relatively low, limiting the number of predictors that could be simultaneously analysed in a multivariable

analysis. Additionally, there may be selection bias due to non-probability consecutive sampling techniques. Additionally, the study included only short-term bCPAP outcomes, and was not designed to evaluate longer term respiratory or neurodevelopmental outcomes. The relationships between these predictors and the initiation, failure, and escalation of bCPAP in larger prospective multicenter studies with standard criteria for the above are required to validate the findings of this study.

Conclusion

In this low resource neonatal care setting, continuous positive airway pressure (CPAP) was successfully used in 77.5% of preterm neonates with respiratory distress syndrome (RDS) and escalation of respiratory support was needed in 22.5%. In the current analysis, there were no significant associations between bCPAP failure and either sex or maternal antenatal comorbidities or between bCPAP failure with radiological RDS severity. Neonatal factors, such as gestational age and birth weight, may be important to the treatment failure and should be assessed in future with more statistically appropriate models.

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All the authors agree to take responsibility for every facet of the work, making sure that any concerns about its integrity or veracity are thoroughly examined and addressed.	