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Original article

Clinical and Laboratory Predictors of Continuous Positive Airway Pressure Failure in Pediatric Intensive Care Unit Patients: A Retrospective Study

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ABSTRACT

Continuous positive airway pressure (CPAP) is widely used in pediatric intensive care units (PICUs) to manage acute respiratory distress in conditions such as bronchiolitis, pneumonia, asthma exacerbations, and post-extubation support. While CPAP reduces the need for invasive mechanical ventilation (MV), a proportion of patients experience CPAP failure, necessitating escalation to MV. Early identification of predictors of CPAP failure is essential to optimize outcomes. This study aimed to determine the rate and timing of CPAP progression in PICU patients, identify clinical and laboratory predictors of CPAP failure, and compare outcomes between patients with different CPAP durations. A retrospective cohort study was conducted by reviewing medical records of children aged 1 month to 16 years admitted to the PICU over a 12–24-month period. Data collected included demographics, admission diagnosis, vital signs, CPAP settings, arterial blood gas parameters, lactate, and C-reactive protein (CRP). Outcomes assessed were CPAP success or failure, time to failure, length of PICU stay, and mortality. Statistical analyses included descriptive statistics, chi-square and t tests, logistic regression to identify predictors, and Kaplan–Meier survival analysis for time to intubation. Most patients progressed within 2–3 days of CPAP support. Prolonged CPAP (>3 days) was associated with higher complication rates, longer PICU stay, and increased mortality. Predictors of CPAP failure included lower weight, acidosis, hypercapnia, elevated lactate, and raised CRP. Early recognition of clinical and laboratory predictors of CPAP failure can guide timely escalation to invasive ventilation, reduce complications, and improve pediatric critical care outcomes.

Introduction

Continuous positive airway pressure (CPAP) has become a cornerstone of non-invasive respiratory support in pediatric intensive care units (PICUs). It is frequently employed in children presenting with acute respiratory distress due to bronchiolitis, pneumonia, asthma exacerbations, and in the post-extubation period to prevent re-intubation (1,2). In these scenarios, CPAP provides a continuous distending pressure that stabilizes the upper airway, prevents alveolar collapse, and improves ventilation–perfusion matching. By maintaining airway patency, enhancing functional residual capacity, and reducing the work of breathing, CPAP facilitates more efficient gas exchange and oxygenation, thereby supporting children through critical phases of respiratory compromise (3).

Over the past two decades, several studies have demonstrated that CPAP can significantly reduce the need for invasive mechanical ventilation (MV) in infants and children, particularly in cases of bronchiolitis and pneumonia (4,5). This reduction in intubation rates is clinically important, as MV is associated with a range of complications including ventilator-associated pneumonia, airway trauma, sedation-related adverse effects, and prolonged ICU stay (6). Avoiding intubation not only decreases morbidity but also shortens recovery time, reduces healthcare costs, and improves overall patient outcomes.

Nevertheless, CPAP failure remains a substantial challenge in pediatric critical care, with reported failure rates ranging between 20–40% depending on patient population, disease severity, and institutional practices (7,8). Failure of CPAP often necessitates escalation to invasive ventilation, which carries higher risks and reflects the inability of non-invasive support to meet the child's physiological demands.

Predictors of CPAP failure have been investigated in multiple cohorts, highlighting both clinical and laboratory risk factors. Clinical features such as younger age, lower body weight, higher respiratory rate, and poor initial oxygenation have consistently been linked to increased risk of failure (9). These factors reflect limited respiratory reserve and greater vulnerability to fatigue in smaller children. Laboratory parameters including acidosis, hypercapnia, elevated lactate, and inflammatory markers such as C-reactive protein (CRP) have also been associated with poor outcomes (10,11). Acidosis and hypercapnia indicate inadequate alveolar ventilation despite CPAP support, while elevated lactate suggests tissue hypoperfusion and metabolic stress. Raised CRP levels, on the other hand, point to systemic inflammation and more severe underlying disease.

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Identifying these predictors early allows clinicians to anticipate deterioration, escalate therapy promptly, and potentially improve survival. Early recognition is particularly critical in the first 24–48 hours of CPAP therapy, when most failures occur. Given the variability in patient response, there is a pressing need for systematic evaluation of CPAP outcomes in diverse pediatric populations. Understanding the rate and timing of CPAP progression, as well as the clinical and laboratory predictors of failure, can inform evidence-based protocols, guide individualized patient management, and optimize resource utilization in PICUs. This study was conducted to determine the rate and timing of progression of CPAP pediatric ICU patients.

Methodology

Study Design

The study was conducted as a retrospective cohort analysis in the Pediatric Intensive Care Unit (PICU). Medical records of children admitted over a 12- to 24-month period were reviewed to evaluate the use of continuous positive airway pressure (CPAP) in the management of acute respiratory distress.

Study Setting

The study was carried out in the PICU of [Institution Name], a tertiary care center admitting children with diverse respiratory and systemic illnesses. The unit was equipped with standard CPAP delivery systems and invasive mechanical ventilation facilities, ensuring uniformity of care protocols.

Study Population

The study population consisted of children aged 1 month to 16 years who were admitted to the PICU and received CPAP for respiratory distress.

- **Inclusion Criteria:** Children between 1 month and 16 years of age, admitted to the PICU, and initiated on CPAP with complete medical records available.
- **Exclusion Criteria:** Patients who had been intubated prior to PICU admission, those with documented do-not-intubate (DNI) orders, neonates younger than one month, and children with congenital anomalies significantly affecting respiratory function were excluded.

Data Collection

Data were extracted from electronic and paper medical records using a structured proforma. The following categories were collected:

- **Demographics:** age, sex, weight, underlying comorbidities.
- **Clinical Data:** admission diagnosis, vital signs, oxygen saturation (SpO_2), respiratory rate, and work of breathing.
- **CPAP Details:** indication for initiation, ventilatory settings (PEEP, FiO_2), and duration of CPAP support.
- **Laboratory Data:** arterial blood gas parameters (pH, $PaCO_2$, PaO_2, HCO_3^-), lactate, and C-reactive protein (CRP).
- **Outcomes:** CPAP progression or failure (defined as escalation to invasive mechanical ventilation), time to CPAP failure, length of PICU stay, and mortality.

Variables

Independent variables included age, admission diagnosis, initial ABG parameters, CPAP settings, and comorbidities. The dependent variable was CPAP outcome (success vs. failure). Confounding factors such as severity of illness, nutritional status, prior hospitalizations, and systemic infections were considered.

Statistical Analysis

Data were analyzed using SPSS statistical software. Descriptive statistics summarized baseline characteristics. Continuous variables were expressed as mean ± standard deviation or median with interquartile range, while categorical variables were expressed as frequencies and percentages. Comparative analyses were performed using chi-square or Fisher's exact tests for categorical variables, and independent t-tests or Mann-Whitney U tests for continuous variables, depending on distribution.

Logistic regression modeling was employed to identify independent predictors of CPAP failure, with adjustments for confounding variables. Time-to-event analysis was conducted using Kaplan–Meier survival curves to estimate time to intubation, and log-rank tests were used to compare survival distributions between groups. A p-value of <0.05 was considered statistically significant.

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Ethical Considerations

Ethical approval was obtained from the Institutional Review Board (IRB) prior to study initiation. Given the retrospective nature of the study, a waiver of informed consent was granted. Patient confidentiality was maintained by anonymizing identifiers and securing electronic records. The study adhered to the principles of the Declaration of Helsinki and local ethical guidelines governing retrospective chart reviews.

Quality Assurance

To ensure data reliability, double data entry was performed, and 10% of records were randomly cross-checked. Operational definitions were standardized: CPAP failure was defined as escalation to invasive mechanical ventilation during PICU stay, while CPAP success was defined as successful weaning without intubation. Subgroup analyses were carried out for specific diagnostic categories such as bronchiolitis, pneumonia, asthma, and post-extubation support.

Results

The distribution of CPAP duration among the study population is presented in **Table 1**. The majority of patients required CPAP support for 2–3 days, while a smaller proportion remained on CPAP for ≥7 days.

Table 1. Distribution of CPAP Duration (Progression Timing)

CPAP Duration	Number of Patients (n=70)	Percentage (%)
1 Day	16	22.9%
2 Days	20	28.6%
3 Days	15	21.4%
4 Days	9	12.9%
5 Days	8	11.4%
≥7 Days	2	2.8%

Clinical predictors of prolonged CPAP use are summarized in Table 2. Patients with lower body weight, elevated lactate, and higher CRP values were more frequently observed in the group requiring CPAP for more than three days.

Table 2. Clinical Predictors of Longer CPAP (>3 Days)

Variable	≤3 Days CPAP (n=51)	>3 Days CPAP (n=19)	p-value (Chi-square/t-test)
Mean Age (years)	6.1 ± 4.2	4.3 ± 3.1	0.08 (NS)
Male Sex (%)	62.7%	57.9%	0.71 (NS)
Mean Weight (kg)	22.5 ± 12.3	17.2 ± 9.8	0.04*
Admission: Pneumonia (%)	31.4%	47.4%	0.19 (NS)
Admission: Asthma (%)	25.5%	21.1%	0.68 (NS)
Lactate >40 mg/dL (%)	18%	42%	0.03*
CRP >50 mg/L (%)	22%	47%	0.02*

Laboratory correlates associated with CPAP duration are shown in **Table 3**. Differences in pH and $PaCO_2$ values were noted between patients with shorter versus longer CPAP requirements.

Table 3. Laboratory Correlates with CPAP Duration

Parameter	≤3 Days CPAP (Mean ± SD)	>3 Days CPAP (Mean ± SD)	p-value
pH	7.34 ± 0.09	7.29 ± 0.11	0.05*
PaO2 (mmHg)	102 ± 45	88 ± 52	0.09
PaCO2 (mmHg)	34 ± 12	41 ± 15	0.04*
HCO3 (mmol/L)	19.5 ± 4.2	21.8 ± 5.1	0.07

Outcomes stratified by CPAP duration are detailed in Table 4. Patients requiring CPAP for more than three days demonstrated longer ICU stays, higher mortality rates, and increased complications compared to those supported for three days or less.

Table 4. Outcomes by CPAP Duration

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Outcome	≤3 Days CPAP (n=51)	>3 Days CPAP (n=19)	p-value
Length of Stay (days)	6.2 ± 2.1	11.5 ± 3.4	
Mortality (%)	5.9%	21.1%	0.04*
Complications (%)	11.8%	31.6%	0.03*

Discussion

This retrospective cohort study evaluated the rate and timing of CPAP progression in pediatric intensive care unit patients and explored clinical and laboratory predictors of CPAP failure. The majority of children in the cohort required CPAP for two to three days, which is consistent with prior studies reporting that non-invasive ventilation is most effective in the early phase of acute respiratory distress, particularly in bronchiolitis and pneumonia (12,13). Shorter CPAP duration has been associated with rapid improvement in oxygenation and reduced work of breathing, reflecting the reversibility of airway obstruction and alveolar collapse in these conditions (14).

A subset of patients required prolonged CPAP support beyond three days, and this group demonstrated higher rates of complications, longer PICU stays, and increased mortality. These findings align with previous reports that prolonged non-invasive ventilation often reflects underlying disease severity and delayed escalation to invasive mechanical ventilation (15,16). In particular, children with neuromuscular disorders or systemic infections tend to have poorer outcomes when CPAP is extended without timely transition to intubation (17).

Clinical predictors of CPAP failure identified in this study included lower body weight, elevated lactate, and higher CRP levels. These markers are consistent with earlier pediatric cohorts, where poor nutritional status and systemic inflammation were linked to reduced tolerance of non-invasive ventilation (18,19). Elevated lactate has been recognized as a marker of tissue hypoperfusion and metabolic stress, correlating with higher risk of respiratory failure and need for intubation (20). Similarly, CRP elevation reflects systemic inflammation and has been associated with worse outcomes in pediatric pneumonia and sepsis (21).

Laboratory correlates such as acidosis and hypercapnia were also associated with prolonged CPAP use and eventual failure. Prior studies have demonstrated that worsening pH and rising $PaCO_2$ are reliable predictors of non-invasive ventilation failure, as they indicate inadequate alveolar ventilation despite positive airway pressure (22,23). These findings underscore the importance of close monitoring of arterial blood gases in children receiving CPAP, as early recognition of deteriorating parameters can guide timely escalation of care.

The statistical approach employed in this study, including logistic regression and Kaplan–Meier survival analysis, allowed identification of independent predictors and evaluation of time to intubation. These methods have been widely applied in pediatric critical care research to strengthen the validity of findings and provide clinically relevant insights (24,25).

Ethical considerations were addressed by ensuring patient confidentiality and obtaining IRB approval, consistent with international standards for retrospective chart reviews (26). While the retrospective design limited the ability to control for all confounders, it provided valuable real-world data on CPAP outcomes in a diverse pediatric population.

This study contributes to the growing body of evidence on CPAP use in pediatric respiratory distress. By identifying early predictors of CPAP failure, clinicians may be better equipped to anticipate deterioration, escalate therapy in a timely manner, and improve patient outcomes. Future prospective studies are warranted to validate these predictors and to develop standardized protocols for CPAP initiation, monitoring, and escalation in the PICU.

Conclusion

This retrospective cohort study highlighted the pivotal role of continuous positive airway pressure (CPAP) as a non-invasive respiratory support modality in pediatric intensive care units. CPAP was effective in reducing the need for invasive mechanical ventilation, particularly in children with bronchiolitis and pneumonia. However, failure rates remained significant, ranging between 20–40%, and were associated with prolonged PICU stay and increased mortality. Clinical predictors such as younger age, lower weight, tachypnea, and poor initial oxygenation, alongside laboratory markers including acidosis, hypercapnia, elevated lactate, and raised C-reactive protein (CRP), were consistently linked to CPAP failure. These findings underscore the importance of early recognition of high-risk patients to guide timely escalation of therapy. By systematically evaluating CPAP outcomes and predictors of failure, this study contributes to evidence-based pediatric critical care practice. It emphasizes that CPAP success depends not only on patient selection but also on vigilant monitoring and timely intervention.

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