

Effectiveness of flow inflating device in providing Continuous Positive Airway Pressure for critically ill children in limited-resource settings: A prospective observational study

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Abstract

Background and Aims: Noninvasive ventilation (NIV) is an emerging popular concept, which includes bi-level positive airway pressure or continuous positive airway pressure (CPAP). In settings with scarce resources for NIV machines, CPAP can be provided through various indigenous means and one such mode is flow inflating device – Jackson-Rees circuit (JR)/Bain circuit. The study analyses the epidemiology, various clinical indications, predictors of CPAP failure, and stresses the usefulness of flow inflating device as an indigenous way of providing CPAP. **Methods:** A prospective observational study was undertaken in the critical care unit of a Government Tertiary Care Hospital, from November 2013 to September 2014. All children who required CPAP in the age group 1 month to 12 years of both sexes were included in this study. They were started on indigenous CPAP through flow inflating device on clinical grounds based on the pediatric assessment triangle, and the duration and outcome were analyzed. **Results:** This study population included 214 children. CPAP through flow inflating device was successful in 89.7% of cases, of which bronchiolitis accounted for 98.3%. A prolonged duration of CPAP support of >96 h was required in pneumonia. CPAP failure was noted in 10.3% of cases, the major risk factors being children <1 year and pneumonia with septic shock. **Conclusion:** We conclude that flow inflating devices – JR/Bain circuit are effective as an indigenous CPAP in limited resource settings. Despite its benefits, CPAP is not a substitute for invasive ventilation, as when the need for intubation arises timely intervention is needed.

Keywords: Bain circuit, Bronchiolitis, Continuous Positive Airway Pressure, Jackson-Rees circuit

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Introduction

Invasive and noninvasive ventilation (NIV) play a major role in any pediatric critical care unit. NIV can be delivered either as bi-level positive airway pressure or continuous positive airway pressure (CPAP). Although

the concept of NIV is emerging, the availability of NIV machines is scarce in the public sector due to the cost factor. Hence, in developing countries, with limited resources, there is a need to resort to indigenous

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ways for providing CPAP. For example, providing bubble CPAP, in an indigenous way, was successful in swine flu pandemic in Pune.^[1] Flow-inflating device – Jackson-Rees (JR) circuit, is also an indigenous way of providing CPAP.^[2] It helps to alleviate the respiratory distress/respiratory failure in many primary pulmonary disorders such as bronchiolitis, bronchopneumonia, aspiration pneumonia, cardiogenic shock associated with sepsis, congestive cardiac failure, and scorpion envenomation. CPAP, when compared to invasive ventilation, helps to avoid the risks associated with intubation, decreases nosocomial pneumonia, the need for sedation, and the duration of Intensive Care Unit (ICU) and hospital stay. JR and pediatric Bain circuit, devised by Mapleson, can be used in intensive care settings, with the benefits of providing 100% oxygen as well as CPAP. This was supported by Sanabria Carretero *et al.* who observed that CPAP with Mapleson D circuit (Bain circuit) could successfully provide NIV for children with acute respiratory failure.^[3]

Bain circuit is a coaxial circuit with inner and outer tubes, hence there is no mixing of fresh gas and expired air.^[4] JR circuit-Mapleson F is used in children of age <6 years and weight <20 kg; whereas Bain circuit is used for older children. There is an adjustable expiratory valve at the end of the bag. Partial closure of this valve along with simultaneous compression of the bag delivers positive pressure ventilation. During spontaneous ventilation, partial closure of this valve provides CPAP^[5] [Figures 1 and 2].

We designed a study to find out the usefulness of flow inflating device (Mapleson D and F circuits) as an indigenous way of providing CPAP. The clinical conditions which can be exclusively managed by providing indigenous CPAP and the predictive factors of CPAP failure were also studied.



Figure 1: Jackson-Rees circuit

Methods

This prospective observational study was undertaken in the Pediatric Intensive Care Unit (PICU) of a Government Tertiary Care Hospital, from November 2013 to September 2014. The critical care unit is 6 bedded with a step down of 15 beds to care for children poststabilization. The annual PICU admissions are around 600 cases. The ethical clearance for the study was obtained from the institutional ethics committee.

Inclusion criteria

All children who required CPAP in the age group 1 month to 12 years of both sexes were included. CPAP was initiated on clinical grounds based on the pediatric assessment triangle^[2] and the following groups of children were included:

- Children with bronchiolitis, bronchopneumonia, who presented with respiratory distress/failure, with a patent airway and are alert or voice responsive
- Children who presented with respiratory distress/failure and compensated shock due to underlying congenital heart disease (CHD), sepsis
- Myocardial dysfunction due to scorpion envenomation if the child is conscious/voice responsive and had respiratory distress or failure.

Exclusion criteria

- Unmaintainable airway
- Depressed level of consciousness (pain responsive/unresponsive).

Informed consent was obtained from parents of the children included in this study. Children satisfying the inclusion criteria were administered CPAP using the JR circuit or Bain circuit in older children. A reservoir capacity of 500 mL was used for children <3 years and 1000 mL for children >3 years. The mask was placed such

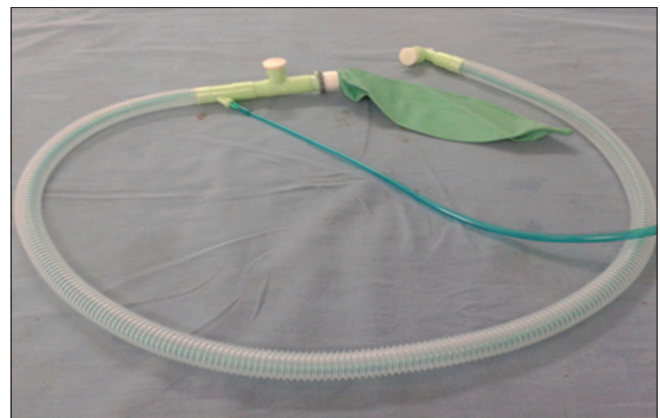


Figure 2: Bain circuit

that it covered the nose and mouth providing an air tight seal. Mother or caretaker was taught to hold the mask and position the head and neck in such a way that the airway was maintained [Figures 3 and 4]. The reservoir was kept completely inflated at all times. The expiratory valve was kept partially open such that the reservoir bag was neither overinflated nor collapsed. The breathing of the patient was confirmed by the inflation and deflation of the reservoir bag. Oxygen flow was calculated as a minimum of three times the minute volume of the patient to prevent rebreathing. Continuous oxygen flow was ensured. Few children with severe hypoxia developed posturing when the mask was initially held. Continuing to hold the mask firmly, helped to resolve hypoxia, and tolerance improved. Children were continuously monitored by clinical assessment of vital signs and regular bedside cardiopulmonary cerebral assessment along with a cardiac monitor and pulse oximeter. An NG tube was used to decompress the stomach if the child developed abdominal distension.

The epidemiological parameters, underlying clinical condition, presence of shock, duration of CPAP, success or failure of CPAP, risk factors for failure of CPAP were analyzed. The duration of CPAP was divided as follows: (a) 24–48 h (b) 48–96 h (c) >96 h. In cases which failed CPAP through flow inflating device, we divided the initial period of CPAP support as (a) <12 h (b) 12–24 h (c) >24 h.

CPAP was considered “successful” when there was a clinical improvement in respiratory distress, with decrease in respiratory rate, work of breathing, heart rate, and improvement in sensorium. CPAP “failure” was considered when children developed worsening of respiratory distress or shallow breathing with apneic spells, hypotensive shock, froth and profuse secretions indicating a worsening of pulmonary edema and

deterioration in sensorium. CPAP was discontinued in these children if they developed any one of the above signs. They were intubated and started on mechanical ventilation. We had a predesigned proforma to record the data, and the cardiopulmonary cerebral assessment was performed for every child on admission, repeated hourly, and after every intervention.

Statistical analysis

The sample size was calculated based on the assumption that the level of confidence is 95% and success rate of CPAP from previous studies to be 70%.

The categorical variables were expressed as frequency and percentage. The quantity variables were expressed as mean \pm standard deviation. Descriptive statistics were used to evaluate baseline characteristics. The group comparisons for the categorical variables were analyzed using Chi-square test and within the group, comparison of quantitative variables were analyzed using independent *t*-test. $P < 0.05$ was considered statistically significant. The statistical analysis was carried out using statistical software SPSS 19 (Provo, UT).

Results

This study included 214 children managed with CPAP. Infants constituted the majority of the study population of around 169 cases (78.9%) [Figure 5]. Male children (122 cases) were marginally more than female (92 cases). Children with grade 2 malnutrition as per IAP classification contributed to 5.6% of the study population. Grades 3 and 4 malnutrition were not noted in this study population. Majority of the children were from upper lower socioeconomic status 66.4%, with illiterate parents 59.8%, and from rural areas 64.5%. Only a small proportion of the study population (10.3%) reached tertiary care within 1 h and there were no deaths in this group.



Figure 3: An infant with bronchiolitis on Jackson-Rees circuit



Figure 4: Scorpion sting-myocardial dysfunction-pulmonary edema-on Bain circuit

The most common indication for CPAP in our study was bronchopneumonia in 49% followed by bronchiolitis in 30.7% of cases [Figure 6]. In this study, CPAP was successful in 89.7% of the study population. Majority of the bronchiolitis cases (98.3%) could be successfully managed with CPAP; only one case failed CPAP and required mechanical ventilation. There were 10 children with aspiration pneumonia following kerosene ingestion; 6 with scorpion envenomation-induced myocardial dysfunction. Only one case failed CPAP in each of these groups and required intubation, the success rate being (90.0%) and (83.3%), respectively. All children with scorpion sting had pulmonary edema which dramatically improved with CPAP support [Figures 7 and 8]. Children with pneumonia required prolonged duration of CPAP support compared to bronchiolitis. Two children with pneumonia required CPAP of >96 h and survived. Hypoxic ischemic encephalopathy sequelae/cerebral palsy and CHD were the major comorbid conditions in our study.

In this study, CPAP failure was noted in 10.3% of the population (22 children) and infants contributed to 86.4% of the failure cases. In the majority of the cases, bronchopneumonia was the initial indication for initiating CPAP contributing to 72.7%. Sixteen cases (72.7%) needed a short duration of initial CPAP support of <12 h, and 86.7% of them (13 cases) survived. Five children required initial CPAP support of 12–24 h of which only 1 survived, and 1 child required >24 h of CPAP prior to intubation and improved. Thus, the group which required a shorter duration of CPAP prior to intubation had a statistically better outcome when compared to those who required a longer CPAP support [Table 1]. The major underlying etiology for CPAP failure was bronchopneumonia associated with septic shock in 54.5% of the cases.

Out of the 214 study population, 46 children (21.5%) had compensated shock, of which 39 recovered and 7 children expired. It was observed that out of the 22 children who failed CPAP, 72.7% had compensated shock. In the CPAP

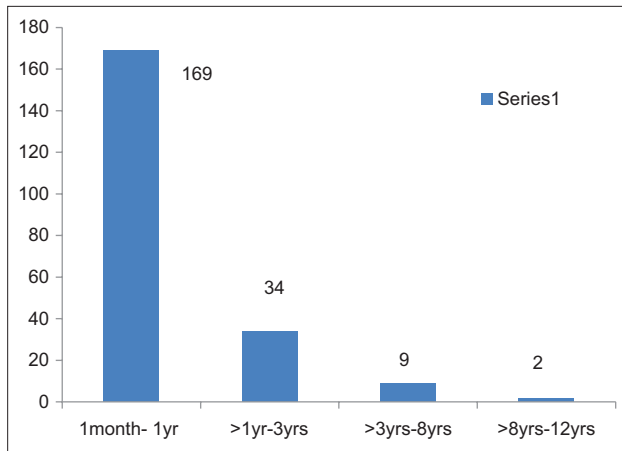


Figure 5: Age distribution with respiratory support

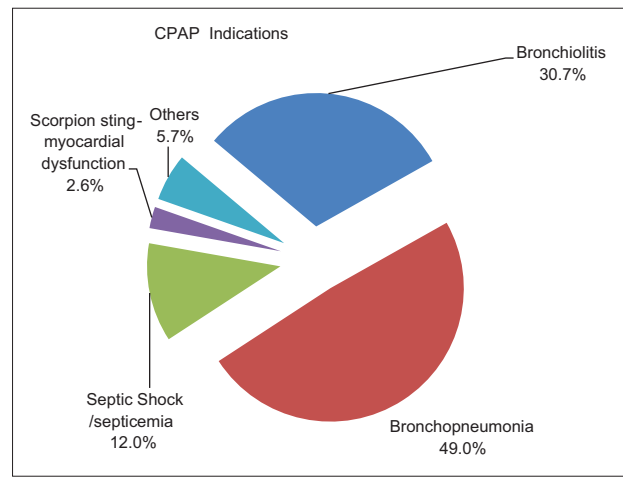


Figure 6: Indications of continuous positive airway pressure support

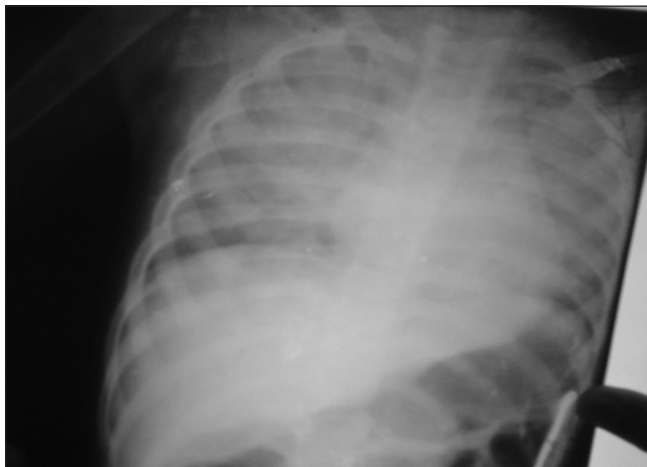


Figure 7: Scorpion sting-myocardial dysfunction-pulmonary edema-initial X-ray



Figure 8: Improvement in pulmonary edema after 24 h of continuous positive airway pressure through Jackson-Rees circuit

success group, 84.4% were hemodynamically stable. Thus, associated shock was found to be a risk factor for failure of CPAP [Figure 9].

The complications among the CPAP group were estimated to be 7.8%. The complications included pressure sores due to tight fitting mask, abdominal distension, dryness of oral and pharyngeal mucosa. Barotrauma was not present in this study. Out of the 214 study population, 7 children expired.

Discussion

This study utilized a novel method of administering CPAP to critically ill children using Mapleson D and F circuit with mask as an interface. Sanabria Carretero *et al.* used Mapleson D circuit to provide CPAP to children with respiratory failure; however, they used nasopharyngeal tube as an interface.^[3]

Infants contributed to the majority of the study population 78.9%. Infants and toddlers required CPAP for primary respiratory illness, whereas older children required CPAP for cardiac conditions such as myocardial dysfunction due to scorpion envenomation and CCF from congenital or acquired heart diseases. All children were continuously monitored by clinical assessment of vital signs, regular bedside cardiopulmonary cerebral assessment, cardiac monitor, and pulse oximeter, which is also supported by the study done by Lum *et al.* in an ICU in Malaysia.^[6] We

did not perform blood gas analysis in our patients. This was also supported by Bernet *et al.* in their study, as they did not find alterations in blood gas analysis as a factor to predict failure of CPAP.^[7] Our study also indicates that critically ill children can be effectively managed in limited resource settings with vigilant monitoring of their clinical status even in the absence of arterial blood gas analysis.

We had a success of 89.7% with CPAP delivered by Mapleson D or F circuits. This was similar to the other studies though the method of delivery of CPAP was different. They used either bubble CPAP/NIV. Abadesso *et al.* in their study in an ICU in Portugal reported a success of 77.5% among children managed with NIV.^[8] Antonelli *et al.* reported a success of 69–79%.^[9] Essouri *et al.* in their 5-year observational study estimated the success to be around 77%.^[10] A study done by Mayordomo-Colunga *et al.* observed a success in NIV to be 84%.^[11]

Primary respiratory illness contributed to the majority of the cases successfully managed with CPAP, which was also observed in the study done by James *et al.*^[12] The common indications for CPAP in our study were pneumonia (49%) followed by bronchiolitis (30.7%). Although the majority of the CPAP indications were due to pneumonia, bronchiolitis had the most successful outcome with CPAP, the success rate being around 98.3% [Figure 10]. This success with CPAP is because

Table 1: Comparison of initial continuous positive airway pressure duration and outcome in continuous positive airway pressure failure cases

Initial CPAP duration (h)	Recovered (%)	Expired (%)
<12	13 (86.7)	3 (42.9)
12-24	1 (6.7)	4 (57.1)
>24	1 (6.7)	0
Total	15	7

P=0.029. CPAP: Continuous positive airway pressure

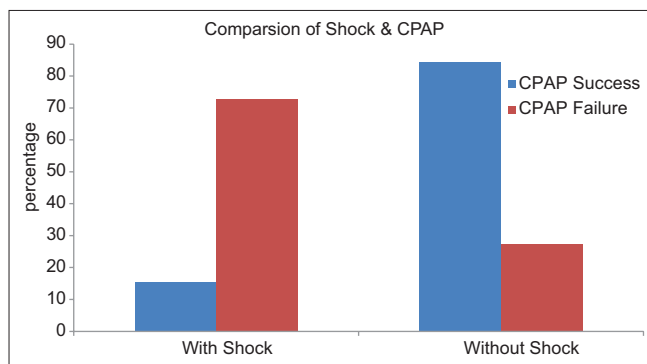


Figure 9: Outcome of continuous positive airway pressure support in children with shock

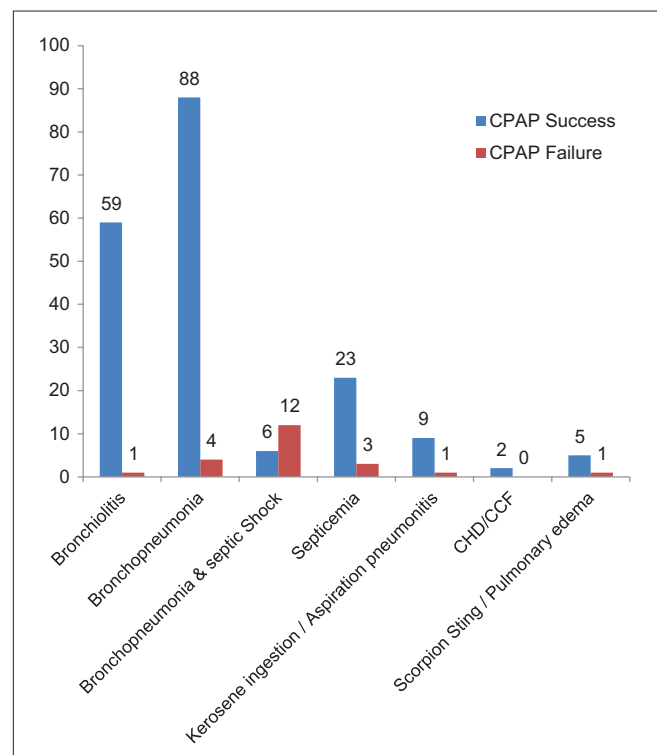


Figure 10: Final diagnosis and respiratory support (etiology wise)

of the auto-positive end-expiratory pressure (PEEP) pathophysiology in this condition, where the inflamed airways close prematurely, along with an increase in expiratory time constant. CPAP helps to tide over this auto-PEEP. Ganu *et al.*^[13] and Campion *et al.*^[14] reported a success of 83% in children with bronchiolitis managed with CPAP. A success rate of 81% was observed in the study by Javouhey *et al.*^[15] and 75.5% by Larrar *et al.*^[16] Pneumonia, required a longer duration of CPAP support in our study. We had two children with pneumonia who needed CPAP for more than 96 h and both of them improved. Children who were managed with CPAP for myocardial dysfunction due to scorpion envenomation required a shorter duration of CPAP support of <48 h.

The failure of CPAP in our study was 10.3%. Abadesso *et al.* observed a failure of 22.5% with NIV.^[8] The failure rate was 36% in the study by James *et al.*^[12] and 19.1% in the study by Muñoz-Bonet *et al.*^[17] Bernet *et al.* observed failure rates of 8–43% with NIV.^[7,8] Infants were observed to have a higher rate of CPAP failure which was supported by many other studies.^[11,13,14,17,18]

A higher rate of CPAP failure was observed in pneumonia which was also supported by Abadesso *et al.* and Muñoz-Bonet *et al.*^[8,17] Bronchopneumonia when associated with septic shock, was the major cause of CPAP failure in 54.5%. Our study had the majority of CPAP failure within 12 h of initiation of CPAP significantly, when compared to those who required a longer duration of CPAP prior to intubation. This observation indicates that most of the CPAP failure in our study could be due to underlying disease severity and progression as they could not tolerate CPAP support even for a relatively shorter period. It should also be remembered that CPAP is not a substitute for invasive ventilation, for when the need for intubation arises timely intervention is needed for an improved outcome. The predictive factors for CPAP failure in our study were (a) infancy (b) pneumonia with associated septic shock.

We observed that 75% of children with comorbid conditions could be successfully managed with CPAP. In children with global developmental delay/cerebral palsy where mechanical ventilation is preferably avoided, CPAP could still be used as it was found to be effective in 75% of children with comorbidity in our study. The complication rate in our study was 7.8%. Lum *et al.* observed that 14% of the complications were due to large size mask, and 5.8% due to pressure sores.^[6]

Limitations

- a. Amount of CPAP and FiO₂ could not be titrated as it is an indigenous way of providing CPAP

- b. Due to limited resources, blood gas analysis was not done for our patients.

Conclusion

CPAP is a missing link between conventional forms of oxygen support and invasive ventilation. We observed bronchiolitis to be the most successful condition managed with CPAP. Children with pneumonia required a prolonged duration of CPAP support. Infancy and pneumonia associated with septic shock were observed to be the predictors of CPAP failure. This study reveals that flow inflating devices – JR/Bain circuit are effective in providing CPAP in an indigenous way which is extremely beneficial in settings with limited resources, where there is no access to NIV machines. CPAP through flow inflating device when applied to the properly selected group, helps to avoid invasive ventilation.

What is already known?

Conventional CPAP through NIV machines helps to relieve respiratory distress in bronchiolitis, pneumonia, cardiogenic pulmonary edema.

What this study adds?

Indigenous CPAP through flow inflating device – JR/Bain circuit can also relieve respiratory distress/respiratory failure in an effective manner in resource-poor settings.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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