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Original Research Article

PREDICTORS OF EARLY CPAP FAILURE IN NEONATES WITH MECONIUM ASPIRATION SYNDROME: A PROSPECTIVE OBSERVATIONAL STUDY

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ABSTRACT

Background: Meconium aspiration syndrome (MAS) is a leading cause of neonatal respiratory distress. Continuous positive airway pressure (CPAP) is a less invasive alternative to mechanical ventilation, but fear of air leak has restrained its early use and predictors of failure remain unclear. We evaluated CPAP as initial respiratory support in MAS and identified predictors of failure.
Materials and Methods: This prospective observational study ran in a tertiary neonatal intensive care unit in Kerala, India, from January 2021 to October 2022. Fifty neonates of ≥34 weeks' gestation born through meconium-stained amniotic fluid, admitted within 24 hours with a Downe score ≥3 and preductal SpO_2 <90% in room air, received nasal CPAP. We excluded infants intubated at admission or with severe asphyxia, lethal malformations or pneumothorax. CPAP failure meant need for invasive ventilation. Analysis used the t test, chi-square and Fisher's exact tests.
Results: CPAP succeeded in 41 neonates (82%). Nine (18%) failed and needed invasive ventilation, eight within 12 hours of admission. None developed pneumothorax. Mortality was 14% (n = 7); all deaths occurred among CPAP failures (7 of 9; 77.8%; $p < 0.001$). A Downe score ≥5 ($p < 0.001$), preductal SpO_2 <85% ($p = 0.027$) and bilateral fluffy opacities on chest radiograph ($p = 0.027$) predicted failure. Mean stay was 5.46 ± 2.65 days.
Conclusion: CPAP supported four of every five neonates with moderate to severe MAS, with no air leak. Downe score, preductal saturation and radiographic pattern at admission flag infants at risk of early failure, warranting readiness for timely escalation.
Keywords: Meconium aspiration syndrome; Continuous positive airway pressure; Downe score; Respiratory distress, newborn; Treatment failure; Neonatal intensive care.

INTRODUCTION

Meconium aspiration syndrome (MAS) remains one of the commonest causes of respiratory distress in the newborn. It follows antepartum or intrapartum aspiration of meconium-stained amniotic fluid (MSAF) in term and near-term infants, and the respiratory morbidity it produces ranges from mild tachypnoea to refractory hypoxaemia. MSAF complicates roughly 4–22% of all deliveries.[1] Only a minority of infants born through MSAF go on to develop MAS — between 3% and 12%.[2,3] Wang et al., studying 424 neonates born through meconium-stained fluid, recorded MAS in 12%, with a low amniotic fluid index, severe fluid contamination and a low one-minute Apgar score emerging as independent predictors.[3]

Delivery-room practice has changed over the past decade. Routine endotracheal suctioning of non-vigorous meconium-stained infants is no longer recommended, and a randomised trial found the procedure did not reduce the incidence of MAS.[4] Chiruvolu et al. observed that abandoning routine suctioning left the incidence of MAS unchanged but increased NICU admissions for respiratory problems and the need for oxygen, ventilation and surfactant.[5]

The burden of managing established MAS has therefore moved from the delivery room to the neonatal unit.

Around 30–50% of neonates with MAS develop severe distress and need invasive mechanical ventilation.[6,7] What to offer the remainder is far less settled. Clinicians have conventionally started this subgroup on free-flow oxygen. Continuous positive airway pressure (CPAP), a gentler and non-invasive alternative, has since gained ground as initial support. Pandita et al. randomised 135 infants with MAS to bubble nasal CPAP or hood oxygen and found that CPAP cut the need for mechanical ventilation in the first seven days from 25.0% to 3.0%.[8] A more recent trial reached the opposite conclusion, finding no advantage for CPAP over hood oxygen.[9] The distending pressure splints collapsing airways, recruits partially occluded distal units and improves gas exchange.

Two features of this population complicate that reasoning. Neonates with MAS are relatively mature and often tolerate the nasal interface poorly; the agitation that follows may aggravate pulmonary hypertension. Their lungs are frequently hyperinflated, which raises a theoretical risk of air leak. Either problem can force intubation. This tension — physiological benefit set against a feared complication — remains the central objection to using CPAP in MAS, and data from high-volume, resource-constrained units are scarce. Against that background we evaluated CPAP as the initial mode of respiratory support in neonates with MAS.

Objective: To study the short-term outcome of CPAP in meconium aspiration syndrome and to identify potential predictors of CPAP failure.

MATERIALS AND METHODS

Study design and setting: We carried out a prospective observational study in the Neonatal Intensive Care Unit (NICU) of Government Medical College, Kozhikode, Kerala, from 1 January 2021 to 31 October 2022. The planned sample size was 50. The Institutional Ethics Committee approved the protocol (IEC No. GMCKKD/RP2021/IEC/168). We obtained written informed consent from a parent or guardian of every enrolled neonate. This report follows the STROBE statement for observational studies.

Participants: We enrolled neonates born through meconium-stained amniotic fluid with a gestational age of ≥34 weeks who were admitted to the NICU within the first 24 hours of life with respiratory distress, a Downe score of 3 or more on clinical assessment, and a preductal oxygen saturation below 90% in room air.

We excluded neonates who were intubated at admission and those with severe birth asphyxia, lethal congenital malformations, or a pneumothorax diagnosed before CPAP was started.

Definitions: We defined MAS as respiratory distress in a newborn infant born through MSAF whose symptoms could not be otherwise explained [10]. The Downe score is an objective measure of respiratory distress in neonates; its components are respiratory rate, chest recessions, grunt, air entry and fractional inspired oxygen requirement. Each component scores 0, 1 or 2 with increasing severity, giving a total between 0 and 10.[11] We defined CPAP failure as the need for intubation and invasive mechanical ventilation.

Study procedure: We obtained a chest radiograph in every neonate at admission, both to confirm features of MAS and to exclude air-leak syndromes. The unit delivered CPAP through a ventilator or a bubble CPAP system according to availability, using short binasal prongs as the interface. We began CPAP at a flow of 5 L/min with a PEEP of 5 cm H_2O, titrating FiO_2 against preductal saturation. PEEP and FiO_2 were adjusted to reach a target preductal oxygen saturation of 90–95%, up to a maximum PEEP of 6 cm H_2O and an FiO_2 of 60%.

The clinical team monitored each neonate for cardiorespiratory status using the Downe score, preductal oxygen saturation, non-invasive blood pressure, auscultation for air entry and urine output. We weaned neonates off CPAP once preductal SpO_2 exceeded 90% with no respiratory distress — respiratory rate below 60/min, no or mild retractions — at an FiO_2 requirement of ≤21%. Neonates who required an FiO_2 of 60% or more on CPAP were intubated and mechanically ventilated. We gave surfactant to intubated infants whose chest radiograph showed white-out or low-volume lungs (lung expansion of fewer than seven spaces). We followed all infants for persistent pulmonary hypertension of the newborn (PPHN), shock and multi-organ dysfunction, and collected perinatal and postnatal data prospectively on a structured proforma.

Statistical analysis: We coded all data in a Microsoft Excel sheet, rechecked the entries, and analysed them with SPSS version 25. Quantitative variables are summarised as mean and standard deviation (SD), and categorical variables as frequency and percentage. We used the independent-samples t test to compare means between independent groups, and the Pearson chi-square test and Fisher's exact test to compare categorical variables. A p value below 0.05 was taken as statistically significant. Variables significant on univariate analysis were entered into a multivariate logistic regression model.

RESULTS

The NICU recorded 2730 admissions during the study period. Of these, 152 neonates carried a clinical diagnosis of MAS. Eighty-one had mild disease that did not meet the entry criteria and 19 required invasive ventilation at admission; two were excluded for congenital anomaly or pneumothorax. Fifty neonates therefore satisfied the inclusion criteria and entered the study. [Figure 1] shows the flow of participants.

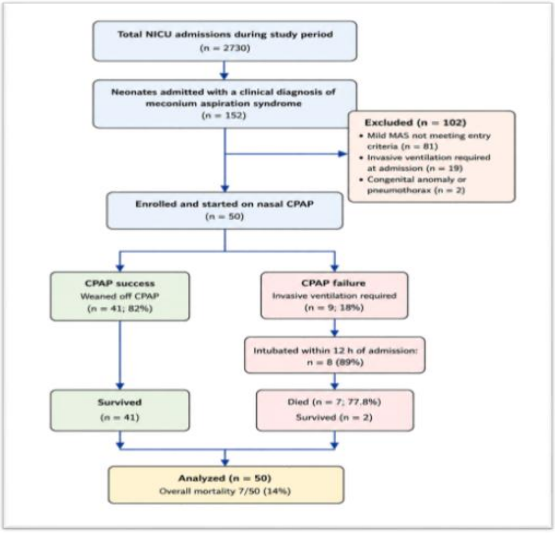

Figure 1: Flow of participants through the study (STROBE diagram). CPAP, continuous positive airway pressure; MAS, meconium aspiration syndrome; NICU, neonatal intensive care unit.

Baseline characteristics: Thirty-three neonates (66%) were male and 28 (56%) were delivered vaginally. Thirty-two (64%) were inborn. Most were term (42; 84%); the remaining 8 (16%) were late preterm at 34–36 weeks. None was post-term. Mean birth weight was 2900 ± 534 g and mean gestational age 38 ± 3 weeks. Gestational hypertension and preeclampsia were the commonest antenatal risk factors (22; 44%), followed by gestational diabetes mellitus (10; 20%).

Ten neonates (20%) required resuscitation at birth. Eight of them showed no features of hypoxic–ischaemic encephalopathy (HIE); two had mild HIE. Respiratory distress was moderate to severe in most infants: 37 (74%) presented with a Downe score of 4 or more. Preductal saturation before CPAP was 85–90% in 22 neonates (44%), 80–85% in 22 (44%) and below 80% in 6 (12%). Hyperinflation was the commonest radiological finding (31; 62%), followed by bilateral heterogeneous fluffy opacities (15; 30%). [Table 1] summarises these characteristics.

Table 1: Baseline and clinical characteristics of the study population (N = 50).

Characteristic	n (%) or mean ± SD
Gestational age (weeks)	38 ± 3
Term (≥37 weeks)	42 (84)
Late preterm (34–36 weeks)	8 (16)
Birth weight (g)	2900 ± 534
Intrauterine growth restriction	5 (10)
Birth weight >4000 g	2 (4)
Male sex	33 (66)
Vaginal delivery	28 (56)
Inborn	32 (64)
Outborn	18 (36)
Gestational hypertension / preeclampsia	22 (44)
Gestational diabetes mellitus	10 (20)
Resuscitation at birth	10 (20)
Mild hypoxic–ischaemic encephalopathy	2 (4)
Downe score at admission	
3	13 (26)
4	24 (48)
5	8 (16)
6	5 (10)
Preductal SpO_2 before CPAP	
85–90%	22 (44)
80–85%	22 (44)
70–80%	6 (12)
Admission chest radiograph	
Hyperinflation	31 (62)
Bilateral fluffy opacities	15 (30)
Patchy consolidation	4 (8)

SD, standard deviation; SpO_2, peripheral oxygen saturation; CPAP, continuous positive airway pressure.

CPAP outcomes: Forty-one of the 50 neonates (82%) were weaned successfully from CPAP. CPAP failed in 9 (18%), in every case because of a rising FiO_2 requirement with worsening respiratory status, and these infants went on to invasive ventilation. Weaning was rapid in most survivors: 40 neonates (80%) came off CPAP by 48 hours of life and only one (2%) needed CPAP beyond 48 hours. Failure, when it occurred, occurred early — 8 of the 9 infants (89%) were intubated within 12 hours of NICU admission.

Nine neonates (18%) developed PPHN during the clinical course and 6 (12%) developed shock requiring inotropic support. No neonate developed a pneumothorax. Mean duration of hospital stay was 5.46 ± 2.65 days.

Seven neonates died, an overall mortality of 14%. All seven deaths occurred among the nine infants who failed CPAP, giving a mortality of 77.8% in that group against none among those weaned successfully ($p < 0.001$); the remaining two CPAP failures survived.

Predictors of CPAP failure: On univariate analysis, three admission variables were associated with CPAP outcome: the Downe score, preductal SpO_2 before CPAP, and chest radiograph findings [Table 2].

Every neonate with a Downe score of 3 or 4 was weaned successfully, whereas failure rose steeply above that threshold — 4 of 8 infants scoring 5 and all 5 scoring 6 required ventilation ($p < 0.001$). Failure occurred in 1 of 22 neonates (4.5%) with a saturation of 85–90%, 5 of 22 (22.7%) at 80–85% and 3 of 6 (50.0%) at 70–80% ($p = 0.027$). Bilateral fluffy opacities carried a failure rate of 40.0%, against 9.7% for hyperinflation and none among the four infants with patchy consolidation ($p = 0.027$).

Table 2: Association of admission variables with CPAP failure.

Variable	CPAP failure (n = 9)	CPAP success (n = 41)	P value
Downe score at admission			
3	0	13 (100)	<0.001*
4	0	24 (100)	
5	4 (50.0)	4 (50.0)	
6	5 (100)	0	
Preductal SpO_2 before CPAP			
85–90%	1 (4.5)	21 (95.5)	0.027*
80–85%	5 (22.7)	17 (77.3)	
70–80%	3 (50.0)	3 (50.0)	
Admission chest radiograph			
Hyperinflation	3 (9.7)	28 (90.3)	0.027*
Bilateral fluffy opacities	6 (40.0)	9 (60.0)	
Patchy consolidation	0	4 (100)	

Values are n (%) of neonates within each category. *Statistically significant at $p < 0.05$. CPAP, continuous positive airway pressure; SpO_2, peripheral oxygen saturation.

Factors associated with mortality: Mortality was significantly associated with CPAP failure, PPHN, shock and the need for surfactant [Table 3].

Table 3: Factors associated with mortality among neonates with MAS supported on CPAP (N = 50).

Factor	Neonates affected (n)	Deaths, n (%)	P value
CPAP failure	9	7 (77.8)	<0.001*
Persistent pulmonary hypertension	9	7 (78)	<0.001*
Shock requiring inotropes	6	5 (83)	<0.001*
Surfactant administration	7	4 (57)	0.005*

*Statistically significant at $p < 0.05$. CPAP, continuous positive airway pressure.

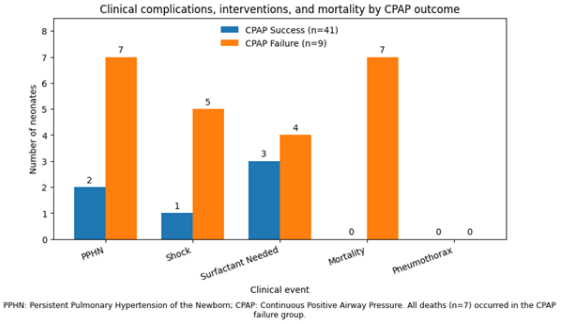

Figure 2: Clinical Outcomes by CPAP Success and Failure in Meconium Aspiration Syndrome

DISCUSSION

In this cohort of neonates with MAS and moderate to severe respiratory distress, 82% were managed effectively with early CPAP. Failure requiring invasive ventilation occurred in 18%. That figure sits comfortably within the 14.5–24% range reported by comparable observational series.[7,12,13].

Every failure in our study followed the same course: worsening respiratory distress with an escalating oxygen requirement. Bhagwat et al. described much the same pattern, with rising oxygen need driven by progressive PPHN and multi-organ dysfunction as the commonest reason for abandoning CPAP.[13].

A presumed risk of pneumothorax in these mature, often hyperinflated lungs has been the main deterrent to early CPAP in MAS. No neonate in our cohort developed one. This is consistent with the low incidence — 0–5% — reported in previous series.[12,14].

The Downe score performed well as a bedside discriminator. Every infant admitted with a score of 3 or 4 responded to CPAP, while a score of 5 or above was strongly associated with failure ($p < 0.001$). Dangriwal et al. likewise identified the Downe score as the single most significant predictor of CPAP outcome.[12]. The practical message is straightforward: a high score at admission should prompt closer observation and readiness to escalate without delay.

Admission saturation carried similar prognostic weight. Failure rose from 4.5% at a saturation of 85–90% to 22.7% at 80–85% and 50.0% below 80% ($p = 0.027$). El-Sayed et al. also found a significant association between low admission SpO_2 and CPAP failure, though their threshold was lower, with risk becoming evident below 70%.[14]. The precise cut-off may differ across cohorts; the direction of the association does not. Work in preterm infants points the same way: Gulczyńska et al. showed that the oxygen requirement in the first hours of life predicts CPAP failure, with the risk climbing by 7.5% for every 0.01 rise in FiO_2 in the second hour.[15]. Oxygen need, however measured, appears to be the common thread.

Bilateral diffuse infiltrates on the admission radiograph predicted both CPAP failure and death in

our cohort. This pattern plausibly reflects a greater burden of aspirated meconium, and hence more extensive chemical pneumonitis and surfactant inactivation, which would explain the association we observed. Gestational age, birth weight, out born status and perinatal asphyxia showed no significant relationship with CPAP failure.

Overall mortality was 14%, and every death occurred among neonates whose primary respiratory support failed (7 of 9; $p < 0.001$). Death was also significantly commoner in infants who developed PPHN (7 of 9; $p < 0.001$) and shock (5 of 6; $p < 0.001$). Failure of non-invasive support, in other words, marked a group with a very poor prognosis rather than simply a group needing a different device. Others report the same. Chaudhary et al. recorded mortality of 67.9% among the 28 neonates who failed bubble CPAP in a Nepalese unit.[16], and Gulczyńska et al. found that CPAP failure carried a more than twentyfold rise in the risk of death and pneumothorax.[15]. The excess mortality is plausibly mediated through pulmonary hypertension: MAS is among the commonest causes of PPHN, and infants with PPHN attributable to MAS carry a fourfold higher risk of death or readmission in the first year of life.[17].

Our findings contrast with those of Mustaqeem et al., who found no significant difference in the need for invasive ventilation, PPHN or mortality between infants with MAS managed with early CPAP and those given conventional hood oxygen, and concluded that CPAP conferred no advantage.[9]. The difference is probably one of case mix. Their participants had predominantly mild to moderate respiratory distress; ours had moderate to severe disease. Pandita et al., whose cohort more closely resembles ours in severity, found a marked reduction in the need for ventilation with CPAP.[8]. In moderate and severe MAS, meconium produces widespread airway obstruction, chemical pneumonitis, surfactant inactivation and atelectasis. The resulting loss of compliance and ventilation–perfusion mismatch generate hypoxaemia that supplemental oxygen alone cannot correct, and distending pressure is needed to maintain functional residual capacity. CPAP outcomes therefore need to be read against the severity of disease at admission.

Effective non-invasive support also shortens the time to oxygen independence and, with it, the hospital stays. Mean stay in our cohort was 5.46 ± 2.65 days.

Limitations: The sample was small, which limits statistical power and the generalisability of our estimates. We did not include a randomised control group receiving hood oxygen, so we cannot draw firm conclusions about the comparative efficacy of CPAP. Single-centre recruitment further restricts external validity.

CONCLUSION

Continuous positive airway pressure is a safe and effective form of non-invasive respiratory support in neonates with moderate to severe respiratory distress due to meconium aspiration syndrome. Four of every five infants avoided intubation, and none developed an air leak. A Downe score of 5 or above, a preductal saturation below 85% and bilateral fluffy opacities at admission identify neonates at high risk of early failure, in whom escalation should not be delayed. Randomised trials stratified by disease severity are needed to establish how CPAP compares with conventional hood oxygen across the severity spectrum of MAS.

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