Cardiology in the Young

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Impact of high-flow nasal oxygen therapy on postoperative atelectasis and reintubation rate after paediatric cardiac surgery

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Abstract

Introduction: Airway problems emerging after congenital cardiac surgery operations may have an impact on mortality and morbidity. Recently, to improve alveolar gas exchange and reduce respiratory effort, high-flow nasal cannula (HFNC) has started to be used in paediatric cases. This study aimed to evaluate the potential effects of high-flow nasal oxygen therapy on postoperative atelectasis development and reintubation rate in paediatric cardiac surgery patients. *Methods:* This study was conducted retrospectively in term newborns and infants younger than six months of age who underwent congenital cardiac surgery operation from 1 November 2022 to 1 November 2023 and were followed in the paediatric cardiac ICU. Patients who were receiving mechanical ventilator support at least 12 hours postoperatively were evaluated for the development of postoperative atelectasis and reintubation in the first 3 days of extubation. The patients were grouped as HFNC and non-HFNC users. Demographic characteristics, surgery type, and ICU clinical follow-up data were obtained from medical records. The results were statistically evaluated. *Results:* A total of 40 patients who did not use HFNC in the early postoperative period and 40 patients with HFNC in the late period during the study period were included in the study. The median age was 1 month (IQR 15 days–2 months) with equal gender distribution. Among patients, 70% of them were in the neonatal age group. Reintubation rates in the first 72 hours in HFNC users and non-HFNC users were 2.5% and 12.5%, respectively ($p < 0.05$). The median postoperative atelectasis scores at 24, 48, and 72 hours of extubation were 2 versus 2.5 ($p > 0.05$), 1.5 versus 3.5 ($p < 0.05$), and 1 versus 3 ($p < 0.05$) in HFNC users and non-HFNC users, respectively. *Conclusion:* HFNC therapy may have a positive effect on preventing atelectasis and reducing the reintubation rate in the early postoperative period.

Introduction

The incidence of CHD varies between 4 and 8 per thousand in all live births. Approximately 25% of these cases are critical CHD that require treatment in the first year of life.[1] Various complications may develop postoperatively in ICUs following surgical procedures.[2] Postoperative pulmonary complications may be associated with increased morbidity and mortality due to prolonged mechanical ventilator and ICU time after congenital cardiac surgery.

Many factors such as pulmonary oedema, muscle weakness, diaphragm paralysis, and postoperative atelectasis may cause pulmonary complications and adversely affect gas exchange and finally haemodynamics. Factors such as age, weight, complexity of cardiac pathology, duration of operation, surgical risk category, accompanying genetic syndrome, and anaesthesia management may affect this process.[3–5]

Various medical drugs and treatment methods are used to prevent pulmonary complications. High-flow nasal cannula (HFNC) is increasingly used as a form of respiratory support. HFNC delivers oxygen at the desired flow rate and fraction of inspiratory oxygen (FiO_2) through a humidified circuit. In this method, the airway pressure is variable and cannot be controlled. It gives positive expiratory pressure, which helps in alveolar recruitment, greater wash-out of dead space favouring the elimination of CO_2, and better oxygenation. HFNC has been shown to be well tolerated by patients.[5,6]

HFNC has been used in children with bronchiolitis, in interhospital transport of critically ill children, and in the early postextubation period in neonates.[7] However, data on postoperative atelectasis prevention following congenital cardiac surgery are limited.

The aim of this study was to evaluate the potential positive effects of HFNC treatment on the prevention of postoperative atelectasis and reintubation in paediatric cardiac surgery patients.

Material and methods

This study was conducted retrospectively in term newborns and infants younger than 6 months of age who underwent congenital cardiac surgery operation from 1 November 2022 to 1 November 2023 and were followed in the paediatric cardiac ICU (PCICU). Patients with known neurological diseases, premature infants, and patients without cardiopulmonary bypass (CPB) were excluded from the study. The work was planned in accordance with the Declaration of Helsinki after obtaining permission from the local ethics committee.

CPB was maintained according to an institutional protocol. At the end of the surgical procedure, children were transferred to the PCICU for postoperative monitoring and ventilator weaning. All patients were ventilated using a volume-guaranteed modality with the aim of maintaining tidal volumes in the range of 6–10 ml/kg; positive end-expiratory pressure values ranged from 3 to 5 mmHg, and they were sedated with a continuous infusion of midazolam (0.05–0.1 mg/kg/h), dexemetedine (0.5 µg/kg/h), and morphine (0.1 µg/kg) according to an institutional protocol. Once haemodynamic stability was achieved (heart rate, arterial blood pressure, and central venous pressure within normal values) for 12–24 hours, sedation with midazolam was discontinued, and weaning from mechanical ventilation was started.

The patients were grouped as those who used HFNC and those who did not use HFNC (using conventional oxygen therapy (COT)).

The use of the HFNC (Optiflow^{TM} Nasal High Flow; Fisher & Paykel Healthcare, Tokyo, Japan) was prophylactically commenced just after extubation at a flow rate of 2 L/kg/min, at 37 °C with a humidifier, and with an adequate FiO_2 to achieve target oxygen saturation (SpO_2) ≥90%. The nasal cannula size was selected based on the patient's weight and nasal size. The use of the HFNC was continued for 48 hours after extubation if intolerance did not occur. If the patient was not tolerant to the HFNC with a flow rate of 2 L/kg/min, we reduced the flow rate to 1 L/kg/min. If intolerance occurred at the flow rate of 1 L/kg/min, we reduced the flow rate to <1 L/kg/min or changed the HFNC to COT such as therapy using a facemask and a nasal cannula.[8]

The selection criteria for noninvasive ventilation (NIV) or reintubation during the 72-hour intervention period are the physician's clinical judgement based on the observation of clinical signs of an increased respiratory rate (RR), worsening gas exchange, or patient intolerance. There was no limitation of oxygen therapy after the 72-hour intervention period.

A study form was created for each patient. In this form, preoperative data (demographic characteristics, preoperative clinical status, cardiac pathology, echocardiography, presence of genetic syndrome, reoperation status), operative data (presence of CPB, duration of operation, risk adjustment in congenital heart surgery data, postoperative data (extubation time, duration of stay in ICU, atelectasis score, blood gas analysis, reintubation status) were divided into three subheadings. The presence of nasal ulcers, need for supplemental sedation, and gastric distension were recorded every 12 hours. Each component of the surgical procedure was evaluated separately. According to the echocardiographic findings, the patients were divided into groups as Technical Performance Score (TPS) 1 (optimal, no residual defect), TPS-2 (adequate, minimal residual defect), and TPS-3 (inadequate, haemodynamically significant residual defect).[9]

Patients who were receiving mechanical ventilator support at least 12 hours postoperatively were evaluated for the development of postoperative atelectasis and reintubation in the first 3 days of extubation.

Reintubation was determined as a reimplementation of mechanical ventilation within 72 hours. The criteria for reintubation were (a) worsened acute respiratory failure (increased respiratory rate, increased partial pressure of arterial carbon dioxide, decreased SpO2), (b) decreased consciousness, (c) deterioration of cardiovascular functions (cardiac arrest, arrhythmia, and heart failure), and (d) clinical judgement of the attending clinicians.

Daily chest X-ray was performed in accordance with the clinical protocol. The chest X-rays were taken with the patients in the supine position using a portable X-ray machine. Results were scored by two independent clinicians unaware of group assignment using a Radiological Atelectasis Scoring system. This system scored atelectasis, hyperinflation, and mediastinal shift. A partial atelectasis of one pulmonary lobe was scored as 1 point, and complete atelectasis of one lobe was marked as 2 points. The distinction between infiltration and atelectasis was made by the clinician. The presence or absence of hyperinflation was marked as 1 point or 0 points, respectively. The presence or absence of a mediastinal shift was scored as 1 or 0. The scores were then summed for each chest X-ray in each patient.[10]

Statistical analyses were performed using SPSS for Windows (Version 21, SPSS Inc., USA) software package. Median with range was used to describe continuous data, whereas absolute count with percentage was used for categorical data. Data were analysed for correlation between the scores and outcome using Spearman's rho. Fisher's x2 and Mann–Whitney U tests were used for the comparison of groups, and the Wilcoxon test was used for repeated consecutive measurements. Statistical significance was set to $p = 0.05$.

Results

During the study period, 40 patients did not use HFNC in the early postoperative period, and 40 patients used HFNC in the late period. The primary cardiac diagnoses of both groups are shown in Table 1.

The median age of patients was 1 month (IQR 15 days–2 months) with equal gender distribution. Among them, 70% were newborns. Preoperative cardiac diagnoses of patients are presented in Table 2. In two HFNC patients, the therapy was discontinued because of abdominal distension after 24 and 36 hours, respectively: these patients' data were included in the analysis. No other patients showed HFNC-related complications, such as delay the initiation of feeding post-operation, nasal ulcers, or need for supplemental sedation.

Reintubation rates in the first 72 hours in HFNC users and non-HFNC users were 2.5% and 12.5%, respectively ($p < 0.05$). The median postoperative atelectasis scores at 24, 48, and 72 hours of extubation were 2 versus 2.5 ($p > 0.05$), 1.5 versus 3.5 ($p < 0.05$), and 1 versus 3 ($p < 0.05$) in HFNC users and non-HFNC users, respectively. Reintubation and atelectasis scores are shown in Table 3.

Discussion

The aim of this study was to evaluate the potential positive effects of HFNC treatment on the prevention of postoperative atelectasis and reintubation compared to COT in paediatric cardiac surgery

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Table 1. Primary cardiac diagnoses

Diagnosis	HFNC (+) $n = 40$	Conventional oxygen therapy (+) $n = 40$
TGA	7	5
TOF	5	4
AVSD	2	2
HLHS	5	4
TAPVD	4	4
VSD	2	4
DORV	1	2
VSD + PA	2	3
CoA or IAA or hypoplastic aortic arch	7	6
DILV	2	2
Other	3	4

DILV = double inlet left ventricle; DORV = double outlet right ventricle; HLHS = hypoplastic left heart syndrome; IAA = interrupted aortic arch TGA = transposition of the great arteries; TAPVD = total anomalous pulmonary venous drainage; PA = pulmonary atresia; VSD = ventricular septal defect; AVSD = atrioventricular septal defect; CoA = coarctation; HFNC = high-flow nasal cannula.

Table 2. Main clinical characteristics and baseline vital signs of the HFNC and conventional oxygen therapy groups

Variable	HFNC (+)	Conventional oxygen therapy (+)	p
Male	20 (50)	20 (50)	NS
Age, month	1 (0.5–2)	1.5 (1–2)	NS
Newborn	30 (75)	26 (65)	NS
Weight	3.5 (3–4.5)	3.8 (3.2–5)	NS
Acyanotic heart disease	16 (40)	20 (50)	NS
Syndrome	3 (7.5)	2 (5)	NS
Cardiopulmonary bypass time	95 (80–110)	90 (75–105)	NS
Cross-clamp time	40 (35–50)	45 (40–50)	NS
RACHS-1 category	3 (2–4)	3 (2–4)	NS
RACHS-1 category ≥4	20 (50)	20 (50)	NS
Technical Performance Score			
TPS-1 TPS-2 TPS-3	26 (65) 10 (25) 4 (10)	29 (72.5) 8 (20) 3 (7.5)	NS
Mechanical ventilation time, hour	36 (24–60)	40 (30–48)	NS
Respiratory rate minutes	45 (40–50)	40 (35–50)	NS
$PaCO_2$, mmHg	40 (35–45)	42 (36–48)	NS
Lactate, mmol/litre	2.1 (1.5–3)	2.4 (2–3.2)	NS
Arterial oxygen saturation %	90 (85–95)	88 (82–94)	NS
Systolic blood pressure, mmHg	80 (70–90)	85 (80–95)	NS
Heart rate minutes	130 (120–140)	125 (115–135)	NS
Complications Nasal ulcers Need of supplemental sedation Gastric distension	- - 2 (5)	- 1 2 (5)	NS
Stay ICU, day	8 (6–10)	11 (7–14)	**0.001**

n(%) Median (IQR).
HFNC = high-flow nasal cannula; NS = non-significant; IQR = interquartile range; RACHS-1 = risk adjustment for congenital heart surgery 1.

patients. Patients with HFNC had better reintubation rates and lower atelectasis scores. Our study is one of the limited studies reported in the literature with these features.

Paediatric patients undergoing cardiac surgery with CPB are at increased risk for postoperative pulmonary complications. These complications might be exacerbated by pneumonia and atelectasis. Factors such as decreased chest wall compliance, mucus plug, small airways, weakened cough reflex, low birth weight, plastic bronchitis, pulmonary hypertension, genetic abnormalities, and immunosuppression may aggravate pulmonary complications. Studies have shown that approximately 6.2–25.0% of all patients have varying degrees of pulmonary complications after cardiac surgery.[11,12]

HFNC is a novel respiratory support technique that provides a positive end-expiratory pressure by a predetermined gas flow containing a relatively constant oxygen concentration at a given temperature and humidity. In this way, it reduces upper airway resistance and respiratory effort. It has a positive effect on respiration mechanics by improving oxygenation and CO_2 excretion. Although its use is increasing, a limited number of studies have been reported in patients with congenital cardiac surgery.[12–14]

Shioji et al. compared postextubation HFNC and NIV in patients who underwent congenital heart surgery before 48 months old. They observed that the reintubation rate within 48 hours and 28 days tended to be lower in the HFNC group (3% vs. 17%, $p = 0.06$ and 3% vs. 26%, $p = 0.04$).[8]

Kumar et al. compared the effect of HFNC and NIV methods after acyanotic congenital heart surgery in 121 cases. They proposed no difference in CO_2 clearance but better oxygenation with HFNC in the postextubation period. There was no difference between reintubation rates.[6]

Kamerkar compared the effects of HFNC, nasal intermittent mechanical ventilation (NIMV), and nasal continuous positive airway pressure (NCPAP) in 42 postoperative patients younger than 6 months of age. In the infantile age group, they reported that the respiratory effort was similar in HFNC, NIMV, and NCPAP regardless of flow rate or inspiratory pressure. Nevertheless, they proposed that if a high level of synchronisation could be achieved, bi-level NIMV could be superior to other methods.[15]

Iyer and colleagues evaluated the extubation failure (EF) rates of HFNC, CPAP, and COT in newborns and infants through a systematic meta-analysis. Both CPAP and HFNC were found to be more effective than COT in reducing EF and treatment failure (TF) (CPAP: OR for EF, 0.43; 95% credible intervals (CrI), 0.17–1.0 and OR for TF 0.27, 95% CrI 0.11–0.57 and HFNC: OR for EF, 0.64; 95% CrI, 0.24–1.0 and OR for TF, 0.34; 95% CrI, 0.16–0.65).[16]

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Table 3. Comparison of reintubation and atelectasis scores

Variable	HFNC (+)	Conventional oxygen therapy (+)	*p*
Reintubation within 24 h	1 (2.5)	3 (7.5)	0.02
Reintubation within 48 h	1 (2.5)	5 (12.5)	0.001
Reintubation within 72 h	1 (2.5)	5 (12.5)	0.001
Atelectasis score 24 h	2 (1.5–3)	2.5 (2–3)	NS
Atelectasis score 48 h	1.5 (1–2)	3.5 (3–4)	0.003
Atelectasis score 72 h	1 (0.5–1.5)	3 (2-4)	0.01

n(%) Median(IQR); NS = non-significant.

Zhou and colleagues[17] conducted another meta-analysis on this topic in postoperative paediatric cardiac surgery patients. Their search yielded five publications, comprised of one randomised controlled trial and four cohort studies. Meta-analysis revealed a significant reduction in reintubation rates in children post-congenital heart surgery treated with HFNC as compared to NIV (RR = 0.36, 95% CI [0.25 ~ 0.53], $p < 0.00001$).

In our study, atelectasis score and reintubation rates were found to be lower in the HFNC group compared to the COT group.

Unsuccessful extubation is associated with a long ICU length of stay and a high rate of mortality. The reintubation rate after paediatric and neonatal cardiac surgery are approximately 6–9 and 17%, respectively.[6–8]In Pediatric Cardiac Intensive Care Group multicentre study including neonates who underwent cardiac surgery, the reintubation rate was 11% (range 5 to 22%).[18]

In our study, overall reintubation rate was 7.5%. Reintubation rate was significantly lower in the HFNC group than the COT group (2.5% vs. 12.5%, respectively).

Limitation

The study has a number of limitations. It is a single centre, retrospective study with a limited number of cases. In addition, the presence of heterogeneous cardiac pathologies is another limitation. Comparison of HFNC with noninvasive mechanical ventilation would have made the results more valuable.

Conclusion

HFNC may have a positive effect on the prevention of atelectasis and reducing the reintubation rate in the early postoperative period. In this regard, there is a need for multicentre studies involving more patients.

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Authors' contribution. IO: Conception or design of the work, drafting the work, final approval of the version to be published, any part of the work are appropriately investigated and resolved.

EO: Conception or design of the work, drafting the work, final approval of the version to be published, any part of the work are appropriately investigated and resolved.

BZTR: Conception or design of the work, drafting the work, final approval of the version to be published, any part of the work are appropriately investigated and resolved.

ICT: Acquisition and analysis, final approval of the version to be published, any part of the work are appropriately investigated and resolved.

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