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Comparison of High-Flow Nasal Cannula and Conventional Oxygen Therapy Following Extubation After Pediatric Cardiac Surgery: A Retrospective Study

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ABSTRACT

Introduction: Infants and children with congenital heart disease may develop respiratory failure in association with cardiac surgery or as a result of heart disease. In fact, the postextubation period in this group of patients can be complex and the use of continuous positive airway pressure or non-invasive ventilation may be necessary if conventional oxygen therapy is not sufficient. The aim of our study was to compare efficiency and outcomes of high-flow nasal cannula or conventional oxygen therapy post-extubation after pediatric cardiac surgery.

Patients and Methods: A single centre retrospective study was conducted between January and December 2020 in our 12 beds pediatric cardiac intensive care unit. Patients were divided into two groups. In one group 45 patients (Group I), those who received high-flow nasal cannula after extubation, and in the other group 45 patients (Group II), those who received oxygen therapy with a mask after extubation. The aim of the study was to evaluate the relative efficacy of high flow nasal cannula and conventional oxygen therapy on $PaCO_2$, PaO_2 and PaO_2/FiO_2.

Results: PaO_2 values at 1, 6, 12, 24 and 48 hour post-extubation were significantly higher in high-flow nasal cannula group ($p< 0.05$). $PaCO_2$ values were significantly lower in the high-flow nasal cannula group at 1, 6, 12, 24 and 48 hour post-extubation ($p= 0.01$). PaO_2/FiO_2 values in high-flow nasal cannula group at all-time points post-extubation were significantly higher than in conventional oxygen therapy group ($p= 0.01$).

Conclusion: High-flow nasal cannula is useful in decreasing $PaCO_2$ and improving PaO_2 in children following extubation after cardiac surgery. In addition, the simplicity of and tolerability to high-flow nasal cannula is also important. Although more expensive, the use of high-flow nasal cannula can be considered as a safe and effective alternative to conventional oxygen therapy following pediatric cardiac surgery.

Key Words: Conventional oxygen therapy; high-flow nasal cannula; pediatric cardiac surgery.

Pediatrik Kalp Cerrahisi Sonrası Ekstübasyonu Takiben Yüksek Akışlı Nazal Kanül ve Geleneksel Oksijen Tedavisinin Karşılaştırılması: Bir Retrospektif Çalışma

ÖZ

Giriş: Doğuştan kalp hastalığı olan bebeklerde ve çocuklarda, kalp cerrahisine veya kalp hastalığına bağlı olarak solunum yetmezliği gelişebilir. Aslında, bu grup hastalarda ekstübasyon sonrası dönem karmaşık olabilir ve eğer geleneksel oksijen tedavisi yeterli olmazsa, sürekli pozitif hava yolu basıncı veya noninvaziv ventilasyon gerekli olabilir. Çalışmamızın amacı, pediatrik kalp cerrahisi sonrası ekstübasyon sonrasında yüksek akımlı nazal kanül veya konvansiyonel oksijen tedavisinin etkinlik ve sonuçlarını karşılaştırmaktır.

Hastalar ve Yöntem: Ocak-Aralık ayları arasında 12 yataklı pediatrik kardiyak yoğun bakım ünitesinde tek merkezli retrospektif bir çalışma yapılmıştır. Bir grupta ekstübasyon sonrası yüksek akımlı nazal kanül alan 45 hasta (Grup I), diğer grupta ise ekstübasyon sonrası maske ile oksijen tedavisi alan 45 hasta (Grup II) vardı. Çalışmamızda yüksek akışlı nazal kanülün ve geleneksel oksijen tedavisinin $PaCO_2$, PaO_2 ve PaO_2/FiO_2 üzerindeki göreceli etkinliğini değerlendirmektir.

Bulgular: Ekstübasyon sonrası 1, 6, 12, 24 ve 48. saatlerde PaO_2 değerleri yüksek akışlı nazal kanül uygulanan grupta anlamlı olarak yüksekti ($p< 0.05$). Yüksek akışlı nazal kanül grubunda ekstübasyon sonrası 1, 6, 12, 24, 48. saatlerde $PaCO_2$ değeri anlamlı olarak düşüktü ($p= 0.01$). Ekstübasyon sonrası tüm zamanlarda yüksek akışlı nazal kanül grubunda $PaO_2/PaCO_2$ değerleri geleneksel oksijen tedavisi alan gruba göre anlamlı olarak yüksekti ($p= 0.01$).

Sonuç: Yüksek akışlı nazal kanül, kalp cerrahisi sonrası ekstübasyonu takiben çocuklarda $PaCO_2$'yi düşürmede ve PaO_2'yi iyileştirmede faydalıdır. Ek olarak, yüksek akışlı nazal kanül kullanımının basitliği ve tolere edilebilirliği de önemlidir. Daha pahalı olmasına rağmen, yüksek akışlı nazal kanül kullanımı pediatrik kalp cerrahisini takiben geleneksel oksijen tedavisine güvenli ve etkili bir alternatif olarak düşünülebilir.

Anahtar Kelimeler: Geleneksel oksijen tedavisi; pediatrik kardiyak cerrahi; yüksek akışlı nazal kanül.

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INTRODUCTION

Infants and children with congenital heart disease (CHD) may develop respiratory failure in association with cardiac surgery or as a result of heart disease. After cardiac surgery requiring cardiopulmonary bypass (CPB), respiratory failure due to fluid accumulation, inceased pulmonary vascular resistance, muscular weakness, diaphragmatic fatigue and edema can be seen in patients[1]. The most common causes of morbidity and mortality in cardiac surgeries are pulmonary complications with wide variation of incidence, from 6% to 76%[2]. It is believed that factors such as general anesthesia, surgical incision, CPB, ischemia time, intensity of surgical manipulation and number of drains may predispose patients to pulmonary function changes, that are highly related to the onset of respiratory complications after cardiac surgery[3-5]. Among the various postoperative complications of cardiac surgery in children, the most common are respiratory stridor secondary to glottal edema, atelectasis, pulmonary edema, pleural effusion, chylothorax, diaphragmatic dysfunction, and pneumonia associated with mechanical ventilation. These and other complications can lead to respiratory failure[6,7]. In fact, the postextubation period in this group of patients can be complex and the use of continuous positive airway pressure (CPAP) or non-invasive ventilation (NIV) may be necessary if conventional oxygen therapy (COT) is not sufficient.

Oxygen therapy with HFNC is currently a popular modality of respiratory support in pediatric care. HFNC ventilation refers to the delivery of a mixture of air and oxygen through a humidified circuit with very high flows, which exceed the patient's spontaneous inspiratory demand. HFNC delivers heated and humidified gases and provides some level of CPAP, yet the exact amount cannot be predicted[8,9].

The use of HFCN has been shown to reduce airway resistance and to flush nasopharyngeal dead space, thus contributing to reduction of respiratory work favouring the elimination of CO_2 and bronchial secretions[10,11].

Despite the widespread use of HFNC in the pediatric intensive care unit, the physiological and clinical effect of HFNC therapy on pediatric patients with respiratory distress after cardiac surgery has not been thoroughly investigated[12,13].

The aim of our study was to evaluate CO_2 elimination, improve O_2 and effect on PaO_2/FiO_2 ratios postextubation after pediatric cardiac surgery using HFNC or COT.

PATIENTS and METHODS

A single centre retrospective study was conducted between January and December 2020 in our 12 beds pediatric cardiac intensive care unit. The study was approved by local ethic committee (2021/3/470). In our study, it was divided into two groups. In one group there were 45 patients (Group I), those who received HFNC after extubation, and in the other group there were 45 patients (Group II), those who received oxygen therapy with a mask after extubation. The aim of the study was to evaluate the relative efficacy of HFNC and COT on $PaCO_2$, PaO_2 and PaO_2/FiO_2.

Children younger than two years undergoing elective cardiac surgery under CPB with a Risk Adjustment for Congenital Heart Surgery (RACHS) score of 2 and more were included in the study. Children with major congenital malformations or neuromuscular diseases, on ventilator support before surgery and cyanotic children undergoing palliative surgeries were excluded from this study.

Demographic data (age, weight) and baseline data such as CPB time, cross-clamp time, duration of mechanical ventilation, including heart rate (HR), invasive blood pressure, respiratory rate (RR) were recorded. Arterial blood gases were checked and collected with the child receiving CPAP before extubation and 1, 6, 12, 24 and 48 hours after extubation.

Outcomes

The primary outcomes were the changes of respiratory and hemodynamic changes in both groups. Basal variables including PaO_2, $PaCO_2$ and PaO_2/FiO_2 were initially obtained. These variables were recorded at 1, 6, 12, 24 and 48 hours after extubation period. Secondary outcome was reintubation rate. The decision of reintubation was made by the clinician. Efficacy was determined by normal CO_2 levels (35-40 mmHg) and higher PaO_2 levels with better PaO_2/FiO_2 values.

For HFNC therapy, the appropriate-sized nasal cannula was selected, and the gas mixture was set at 1-2 L/kg/min. For COT, cannulas delivering maximum flow rate of 5-6 L/min were used. COT was delivered by face mask with the same target SpO_2. In this group, oxygen was delivered with a flowmeter from wall oxygen and humidification with a closed sterile water system at room temperature. The FiO_2 in the COT group was calculated using Finer's formula for low-flow COT[14].

No complications related to HFNC such as nasal ulcers, gastric distension were seen in children who were applied HFNC.

Statistical Analysis

Continuous data were expressed as mean ± standard deviation and compared by an independent samples t-test or the Mann-Whitney U test as appropriate for comparison of continuous variables between the two groups. Chi-square test was used for categorical parameters. $p< 0.05$ was considered stastically significant.

RESULTS

Ninety children were enrolled for the study (45 in Group I and 45 in Group II). Demographic data and baseline parameters (PaO_2, $PaCO_2$ and PaO_2/FiO_2) were comparable between Group I and II (Table 1). RACHS catagories were not significantly different between two groups (p= 0.12). The mean duration of

Table 1. Demographic characteristics and baseline parameters

Variables	Group I	Group II	p
Weight (kg)	5.32 ± 1.54	5.67 ± 1.73	0.17
Age (month)	10.31 ± 3.42	11.62 ± 4.87	0.62
Male (%)	25 (55%)	23 (51%)	0.52
CPB time (min)	134.6 ± 69	130.4 ± 63.5	0.55
Cross-clamp time (min)	90.3 ± 33.2	84.7 ± 28.7	0.34
Duration of mechanical ventilation (hours)	17.6 ± 9.2	17.1 ± 7.3	0.84
CPAP			
Baseline PaO_2(mmHg)	123.5 ± 57.4	127.4 ± 45.2	0.76
Baseline $PaCO_2$(mmHg)	32.8 ± 8.5	34.5 ± 5.7	0.63
PaO_2/FiO_2 (mmHg)	245.3 ± 115.4	240.7 ± 121.2	0.54
RACHS (n)			0.12
2	15	19	
3	20	18	
4	10	8	
Cyanotic, N (%)	13 (29%)	10 (22%)	0.25
Reentubation, N (%)	5 (11%)	6 (13%)	0.48

mechanical ventilation was not significantly different between HFNC and COT groups (p= 0.84).

Primary Outcomes

PaO_2 values at 1, 6, 12, 24 and 48 hours post-extubation were significantly higher in HFNC group (p< 0.05) (Table 2). $PaCO_2$ values were significantly lower in the HFNC group at 1, 6, 12, 24 and 48 hour post-extubation (p= 0.01) (Table 3). And PaO_2/FiO_2 values in HFNC group at all-time points post-extubation were significantly higher than in COT group (p= 0.01) (Table 4).

Secondary Outcomes

After the extubation, 5 patients (11%) in the HFNC group and 6 patients (13%) were reintubated. There were also no statistically significant differences between two groups (p= 0.48). However, There were no significant differences in systolic, diastolic blood pressure and HR levels during the extubation period in both groups (Table 5). During the extubation period, RR at all time were significantly lower in the HFNC group compared to COT group (respectively, p= 0.003, p= 0.004, p= 0.004, p= 0.005 and p= 0.005) (Table 5).

Table 2. Arterial oxygen tension (PaO_2) at different time points

Time point (hr)	Group I	Group II	p
1	143.25 ± 98.8	118.72 ± 77.3	**0.02**
6	135.43 ± 88.7	101.53 ± 68.4	**0.01**
12	138.67 ± 69.5	98.83 ± 57.6	**0.01**
24	131.53 ± 58.9	92.75 ± 62.1	**0.01**
48	132.46 ± 61.3	87.52 ± 57.3	**0.01**

Table 3. Arterial carbon dioxide tension ($PaCO_2$) at different time points

Time point (hr)	Group I	Group II	p
1	34.56 ± 11.8	39.45 ± 6.3	**0.01**
6	35.33 ± 9.8	42.28 ± 8.8	**0.01**
12	36.23 ± 8.2	45.17 ± 9.3	**0.01**
24	35.42 ± 6.4	42.32 ± 7.5	**0.01**
48	38.32 ± 7.2	45.21 ± 8.2	**0.01**

Table 4. PaO_2/FiO_2 ratio at different time points

Time point (hr)	Group I	Group II	p
1	280.75 ± 178.5	194.65 ± 121.6	**0.01**
6	233.65 ± 112.8	188.68 ± 111.9	**0.01**
12	242.52 ± 123.5	192.81 ± 101.7	**0.01**
24	240.2 ± 134.6	190.23 ± 113.5	**0.01**
48	245.5 ± 126.2	181.32 ± 107.6	**0.01**

Table 5. Hemodynamic and respiratory parameters after extubation period

	Hours	Group I	Group II	p
Systolic blood pressure (mmHg)	1	97.1 ± 2.4	95.2 ± 1.9	0.42
	6	99.7 ± 2.3	96.2 ± 2.4	0.22
	12	98.3 ± 2.6	96.8 ± 2.1	0.34
	24	99.2 ± 1.7	97.3 ± 2.3	0.33
	48	98.6 ± 2.5	97.1 ± 2.7	0.53
Diastolic blood pressure (mmHg)	1	57.2 ± 1.5	53.4 ± 1.8	0.12
	6	58.1 ± 2.1	54.5 ± 1.3	0.13
	12	58.4 ± 1.8	55.3 ± 1.5	0.13
	24	57.8 ± 2.3	55.7 ± 2.4	0.33
	48	57.1 ± 1.3	56.2 ± 1.8	0.41
Heart rate (/min)	1	121.3 ± 3.2	123.6 ± 4.7	0.32
	6	120.5 ± 5.2	121.2 ± 1.6	0.43
	12	124.6 ± 5.3	126.9 ± 6.7	0.32
	24	122.4 ± 2.8	125.1 ± 3.8	0.21
	48	124.3 ± 4.2	127.4 ± 4.2	0.12
Respiratory rate (/min)	1	32.1 ± 2.1	38.3 ± 3.1	**0.003**
	6	34.6 ± 4.3	40.2 ± 2.6	**0.004**
	12	32.4 ± 3.5	39.1 ± 4.7	**0.004**
	24	31.6 ± 2.4	38.5 ± 3.2	**0.005**
	48	30.1 ± 1.5	36.1 ± 2.2	**0.005**

DISCUSSION

Oxygen delivery with nasal cannula and face mask is a traditional method used for hypoxemic respiratory failure after extubation period[15,16]. However, the use of HFNC has recently gained increasing acceptance and popularity in the treatment of respiratory conditions[9,17]. HFNC is currently being applied to patients of all groups, from preterm infants to adults[9,18]. Despite the widespread use of HFNC in the pediatric intensive care unit, the physiological and clinical effect of HFNC therapy on the pediatric patients with respiratory distress after cardiac surgery has not been fully investigated[12].

The aim of our study was to compare the efficiency and outcome of oxygen therapy using HFNC and COT after extubation in pediatric cardiac surgery.

Considering the complex respiratory and cardiac pathophysiology in children with heart disease, several effects on the hemodynamics of patients should be noted after congenital heart surgery. Low cardiac output syndrome (LCOS) is offen seen after congenital heart surgery and contributes to significant postoperative morbidity and mortality[19]. In the presence LCOS, increased work of breathing (WOB) is poorly tolerated; excessively negative intrathoracic pressure increases systemic ventricular afterload, while increased diaphragmatic oxygen consumption reduces oxygen delivery to vital organs[20]. In this stuation, HFNC therapy helps to decrease afterload by providing positive pressure and via unloadi ng of respiratory and cardiovascular work[20,21]. Another, an upper airway obstruction (UOA) is relatively common after pediatric cardiac surgery and has been implicated as an important contributor to extubation failure in this population[22]. UOA increases negative swings of intrathoracic pressure and increases WOB, thereby imposing an undue burden on a recovering myocardium and further complicating LCOS; HFNC therapy could alleviate the WOB and large negative swings of intrathoracic pressure[13].

Our primary aim was to compare postoperative PaO_2 and $PaCO_2$ values in the post-extubation period. Roca et al. showed that significant improvement in respiratory parameters and arterial blood gases in adults as early as 30 min of HFNC in comperison with 30 min of COT with face mask[23]. Another prospective, observational study in adults also compared HFNC with COT in patients with acute respiratory failure. This study concluded that the use of the HFNC significantly reduced respiratory rate and improved PaO_2 values[24]. In our study, we also found comfirmed beneficial effect of HFNC in improving PaO_2 levels at all time post-extubation ($p< 0.05$). Additionally, the HFNC group had better CO_2 elimination compared to the COT group, being statistically significant at all time ($p< 0.05$). PaO_2/FiO_2 ratio was higher in HFNC group than COT group ($p< 0.05$). Frizzola et al. showed that a flow dependent improvement in gas Exchange as evidenced by the $PaCO_2$[25]. Accordingly, we evaluated that the increased flow of HFNC was able to flush the nasopharyngeal space and improve CO_2 elimination in the post-extubation period following pediatric cardiac surgery. We showed that HFNC therapy decreases $PaCO_2$ post-extubation in children. Another study reported better values in SpO_2 levels and no difference in PaO_2/FiO_2 with HFNC therapy after extubation. The authors also showed decreased respiratory rates, and $PaCO_2$ levels after extubation for the HFNC group as compared with noninvasive ventilation group[26]. Similar to our study, we found, improved PaO_2, decreased CO_2 levels and respiratory rates after extubation with HFNC therapy.

Parke et al. found that there was a consistent drop, between subjects, in breathing frequency on initiation of high-flow nasal therapy. The authors speculated that this decrease in breathing frequency might be primarily to a reduction in physiological dead space and the plateau effect seen is consistent with this because the expected benefits of nasopharyngeal washout may reach a ceiling at the flow that provides for no rebreathing of dead space gas[13,21]. An alternative or additional explanation is that, this drop in respiratory rate may have been due to a mild degree of hypoxaemia.

Additionaly, in our study, 11 patients were reintubated after extubation. Five patients were in HFNC group and 6 patients were in COT group. In present study, there was no difference between the two groups regarding incidence of reintubation. Testa et al. reported that there were no significant differences in reintubation in both groups[12,16]. However, in another study, comparing the effects of the venturi mask and HFNC therapy showed less required reintubation following extubation in the HFNC group[27]. We observed no complications such as nasal ulser, gastric distension during HFNC therapy like study of Burra et al.[9]. However, a nasogastric tube was left after extubation in all children.

In conclusion, HFNC is useful in decreasing $PaCO_2$ and improving PaO_2 in children following extubation after cardiac surgery. In addition, the simplicity of and tolerability to HFNC is also important. Although more expensive, the use of HFNC can be considered as a safe and effective alternative to conventional oxygen therapy following pediatric cardiac surgery.

Ethics Committee Approval: This study was approved by Kartal Kosuyolu High Specialization Training and Research Hospital Ethics Committee (2021/3/470).

Informed Consent: Informed consent was obtained.

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Author Contributions: Concept/Design - ÖŞ; Analysis/Interpretation - ÖŞ; Data Collection - YY, FI; Writing - ÖŞ, AY; Critical Revision - BÖ, EA, NÇ; Final Approval - ÖŞ, HC; Statistical Analysis - ÖŞ; Overall Responsibility - ÖŞ.

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