Observational Study

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Use of high-flow nasal oxygen in spontaneously breathing pediatric patients undergoing tubeless airway surgery

A prospective observational study

Eun-Hee Kim, MD, PhD[a], Sang-Hwan Ji, MD, PhD[a], Ji-Hyun Lee, MD, PhD[a], Jin-Tae Kim, MD, PhD[a], Young-Eun Jang, MD[a], Seong-Keun Kwon, MD, PhD[b], Hee-Soo Kim, MD, PhD[a,*]

Abstract

The use of high-flow nasal oxygen is gaining popularity in apneic and spontaneously breathing adult patients during anesthesia. This prospective observational study evaluated the effect of high-flow nasal oxygen in maintaining adequate oxygenation and ventilation in spontaneously breathing pediatric patients with dynamic airway obstruction, undergoing tubeless airway surgery.

Oxygenation was provided via an age-appropriate, high-flow nasal cannula at a flow rate of 2 L kg^{-1} min^{-1}. Propofol and remifentanil were used to maintain anesthesia while preserving spontaneous respiration. We sought to determine the incidence and risk factors of rescue ventilation. Rescue ventilation with a face mask was performed when the pulse oximetry oxygen saturation was <90% or transcutaneous carbon dioxide was >80 mm Hg.

In total, 27 patients were included in the final analysis. Median (interquartile range) of pulse oximetry and transcutaneous carbon dioxide were 100% (99%–100%) and 58.4 mm Hg (51.4–70.3 mm Hg), respectively. Altogether, 9 (33.3%) patients needed rescue ventilation during anesthesia. Of these, 7 patients (25.9%) developed oxygen desaturation (<90%) and 2 patients (7.4%) developed hypercarbia. Patients who required rescue ventilation were significantly younger (8.2 vs 28.8 months, P = .02) and required a longer anesthesia time (55.7 vs 41.0 minutes, P = .04) than those who did not.

In conclusion, High-flow nasal oxygen is an alternative technique to maintain oxygenation in children undergoing airway surgeries. However, younger age and longer anesthesia time are significant risk factors leading to the requirement of rescue ventilation in these patients. Further studies with large sample size are required for clinical application of these techniques.

Abbreviations: CI = confidence interval, FiO_2 = fraction of inspired oxygen, IQR = interquartile range, ORI = oxygen reserve index, $TcCO_2$ = transcutaneous carbon dioxide.

Keywords: high flow nasal oxygen, hypercarbia, oxygen reserve index, pediatrics, tubeless airway surgery

1. Introduction

In children with dynamic airway obstruction or narrow airway, as in cases of laryngomalacia, tracheomalacia, or subglottic stenosis, laryngeal microsurgery or suspension examination are challenging but necessary procedures for anesthesiologists. Conventionally, airway management involves repeated intubation and extubation to obtain an appropriate field of view, which makes adequate oxygenation difficult. Alternatively, jet ventilation or maintenance of spontaneous respiration without tracheal intubation is employed.[1] Children have less functional residual capacity[2] and thus, less physiologic reservoir against desaturation. Therefore, more effective strategies are required for oxygenation during airway surgeries.

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The authors have no conflicts of interest to disclose.

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

This study was approved by the institutional Review Board of Seoul National University College of Medicine (Republic of Korea; http://cris.snuh.org/ncris; approval no.: H-1706-204-866) and registered at http://clinicaltrials.gov (NCT03241979; principal investigator: Hee-Soo Kim; date of registration: August 8, 2017). The first patient was registered on August 10, 2017.

Trial registration: registration number: NCT03241979; date of registration: August 8, 2017.

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[a] Department of Anesthesiology and Pain medicine, Seoul National University Hospital, Seoul National University College of Medicine, Seoul, Republic of Korea,

[b] Department of Otorhinolaryngology-Head and Neck Surgery, Seoul National University Hospital, Seoul National University College of Medicine, Seoul, Republic of Korea.

** Correspondence: Hee-Soo Kim, Department of Anesthesiology and Pain Medicine, Seoul National University Hospital, Seoul National University College of Medicine, 103 Daehak-ro, Jongno-gu, Seoul 03080, Republic of Korea (e-mail: dami0605@snu.ac.kr).*

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High-flow nasal oxygen, which delivers warm and humidified oxygen to the conducting airways, has several clinical advantages in spontaneous respiration, which include attenuation of the work of breathing by decreasing the inspiratory resistance associated with nasopharynx, improvement of gas exchange by the washout of nasopharyngeal dead space, and provision of distending pressure for lung recruitment.[3–10] Furthermore, high-flow nasal oxygen has an advantage over other techniques in that it allows oxygen delivery with excellent surgical access to the larynx without obstructing the surgical field in smaller infants.[11–13]

High-flow nasal oxygen has been successfully used during perioperative periods, that is, for preoxygenation[14] and apneic oxygenation in patients with difficult airways and in tubeless airway surgeries.[15–17] It increases the margin of safety in spontaneously breathing patients undergoing general anesthesia.[18] In the pediatric population, high-flow nasal oxygen is also known to prolong the apnea time in children without tracheal intubation[15] and is an effective oxygen supplement for patients undergoing anesthesia.[11] Prolongation of apnea time is very desirable for airway surgeries in patients with spontaneous respiration and without intubation. However, some patients develop desaturation and hypercarbia despite the use of high-flow nasal oxygen. We believe that appropriate patient selection is important for providing safe anesthesia.

In this prospective observational study, we administered high-flow nasal oxygen to spontaneously breathing children with dynamic airway obstruction or upper airway narrowing, undergoing tubeless airway surgery. We aimed to define the incidence of rescue ventilation requirement and the risk factors for the rescue ventilation.

Figure 1. Application of high-flow nasal oxygen in pediatric patients.

2. Materials and Methods

2.1. Study design, setting, and participants

This single-arm, prospective observational study was approved by the Institutional Review Board of Seoul National University College of Medicine (Republic of Korea; approval no.: H-1706-204-866) and registered at http://clinicaltrials.gov on August 8, 2017 (registration number: NCT03241979, principal investigator: Hee-Soo Kim). The first patient was registered on August 10, 2017. The study was conducted at a tertiary care children's hospital from August 8, 2017 to June 3, 2018 after trial registration. After obtaining written informed consent from the parents, pediatric patients under 6 years of age, with spontaneous respiration and undergoing laryngeal microsurgery under general anesthesia, were enrolled. Children with severe gastrointestinal reflux disease, neuromuscular disease, central hypoventilation, history of bronchial asthma, anticipated difficult airway (history of difficult airway management, congenital syndrome affecting airways), or history of recent upper airway infection (within 2 weeks) were excluded. This article complies with the STROBE reporting guidelines.

2.2. Anesthesia

After the patient's arrival in the operating room, preoxygenation was provided via Airvo™ 2, a humidified Nasal High Flow system (Fisher & Paykel Healthcare, Auckland, New Zealand), using an age-appropriate nasal cannula at a flow rate of 2 L kg^{-1} min^{-1} and fraction of inspired oxygen (FiO_2) of 1.0 for 3 minutes (Fig. 1). During the procedure, oxygenation was provided only using high-flow nasal oxygen at a flow rate of 2 L kg^{-1} min^{-1} and FiO_2 of 1.0. FiO_2 was set to 0.3 in cases where laser was used. General anesthesia was induced using an intravenous injection of 0.02 mg kg^{-1} of glycopyrrolate, 1.5 mg kg^{-1} of 1% lidocaine, and 2 mg kg^{-1} of 1% propofol. Anesthesia was maintained at an infusion rate of 100–200 μg kg^{-1} min^{-1} for propofol (based on dose recommendation by McFarlan et al[19] and Steur et al[20]) and 0.01–0.1 μg kg^{-1} min^{-1} for remifentanil using a bispectral index monitor (BIS™; Medtronic, Minneapolis, MN) with target range of 40 to 60. The infusion rate of propofol was titrated to preserve the patient's spontaneous respiration and to avoid undesired reflex movements (laryngospasm, bronchospasm, and patient movement) due to pharyngo-laryngeal stimulation, which may in turn result in iatrogenic injuries. After the patient attained a stable plane of anesthesia, the endoscopist often placed a tooth guard followed by a laryngoscope into the mouth to view the glottis and periglottic structures. A maximum of 3 mL of lidocaine 2% viscous solution was applied by the surgeon under suspension laryngoscope on the supraglottic airway for prevention of laryngospasm. This, together with an intravenous bolus injection of propofol 1.5 mg kg^{-1} was used to prevent and treat laryngospasm during surgical manipulation of the airway. In case of laryngospasm during surgical manipulation of the airway, 1.5 mg kg^{-1} bolus dose of propofol was intravenously injected as treatment. If the laryngospasm was refractory to propofol, we have done endotracheal intubation for rescue ventilation.

2.3. Monitoring

Monitoring using noninvasive blood pressure, pulse oximetry, and electrocardiogram was performed via a patient monitor, Solar™ 8000 (GE Healthcare, Milwaukee, WI). Since end-tidal carbon dioxide monitoring system was unavailable, transcutaneous carbon dioxide ($TcCO_2$) monitoring system was applied to the patients' right chest via SenTec V-sign™ system (SenTec AG; Therwil, Switzerland). We also monitored the oxygen reserve index (ORI)[21] using Radical-7® and Rainbow® Pulse CO-Oximeter sensors (Masimo, Neuchâtel, Switzerland).

2.4. Outcomes

We set the incidence of rescue ventilation requirements as the primary outcome. Rescue ventilation with a face mask was performed when the pulse oximetry SpO_2 was <90% or $TcCO_2$ was >80 mm Hg. We also evaluated the risk factors for inadequate oxygenation and ventilation.

2.5. Statistical analysis

As this was an investigative study regarding the physiology of oxygenation and ventilation while using high-flow nasal oxygen, we used a previous study[18] for reference and decided that a sample size of 30 patients would be adequate. The normality of data distribution was tested using Shapiro-Wilk test. The data were presented as mean (standard deviation) or median (interquartile range [IQR]), as appropriate. We used independent *t* test for variables that passed normality test, Mann–Whitney *U* test for those did not pass normality test, and χ^2 test for types of procedure to compare perioperative factors between patients who needed rescue ventilation and who did not. Statistical analysis was performed using IBM SPSS Statistics Ver. 22.0 (IBM, Armonk, NY).

3. Results

After excluding 3 patients due to poor airway exposure, 27 patients were included in the final analysis (Fig. 2). Patients' characteristics are shown in Table 1. Excluded patients were adequately sedated, had spontaneous respiration, and were given high-flow nasal oxygen; however, due to the limited mouth opening, both the Benjamin–Lindholm and Kleinsasser laryngoscopes failed to advance into the oral cavity.

Median (IQR) of age, weight, and height of patients who underwent the surgical procedure were 13.0 months (3.0–35.7 months), 8.8 kg (5.2–12.8 kg), and 72.0 cm (57.3–94.0 cm), respectively. The types of procedures performed were diagnostic examination (n = 18), supraglottoplasty (n = 7), and ballooning (n = 2). Duration of anesthesia and operation were 45.0 minutes (31.2–52.2 minutes) and 30.0 minutes (18.2–40.5 minutes), respectively. Bispectral index monitor, heart rate, and mean blood pressure were 44 (40–57.5), 142 bpm (121–163 bpm), and 39 mm Hg (34–46 mm Hg), respectively. Intraoperatively, the median (IQR) of pulse oximetry, $TcCO_2$, and ORI were 100% (99%–100%), 58.4 mm Hg (51.4–70.3 mm Hg), and 0.26 (0–0.41), respectively. Figure 3 shows the ORI changes with different FiO_2 values.

Rescue ventilation was required for 9 patients (33.3%). Of these, 7 patients (25.9%) needed rescue ventilation for oxygen desaturation and 2 patients (7.4%) for a rise in $TcCO_2$ >80 mm Hg. Patients who required rescue ventilation were significantly younger (*P* = .02; mean difference: 20.6; 95% confidence interval [CI]: 2.3–38.8), had a lower weight (*P* = .04; mean difference: 4.2; 95% CI: 0.1–8.4), and required a longer anesthesia time (*P* = .04; mean difference: 14.7; 95% CI: 4.9–34.3) than those who did not. Patients who were treated with supraglottoplasty frequently required rescue ventilation (relative risk: 12.0; 95% CI: 1.6–85.1; *P* = .01).

4. Discussion

In this observational study, we found that pediatric patients with spontaneous respiration, undergoing laryngeal microsurgery supported by high-flow nasal oxygen, often developed variable degree of oxygen desaturation during surgery. Infants undergoing supraglottoplasty with prolonged anesthesia time frequently required rescue ventilation.

Participants in the group with rescue ventilation were younger and required a longer anesthesia time than those in the group without rescue ventilation. In infants, functional residual capacity under general anesthesia decreases up to 10% to 15% of the vital capacity, which is incompatible with normal gas exchange.[22] Decreased oxygen delivery and higher oxygen demands make infants and young children susceptible to perioperative hypoxemia and tissue hypoxia. When compared to a previous similar study,[11] our study showed a markedly higher incidence of rescue ventilation. Taking into consideration our result that younger age and longer operation time are more likely to result in hypoxia,

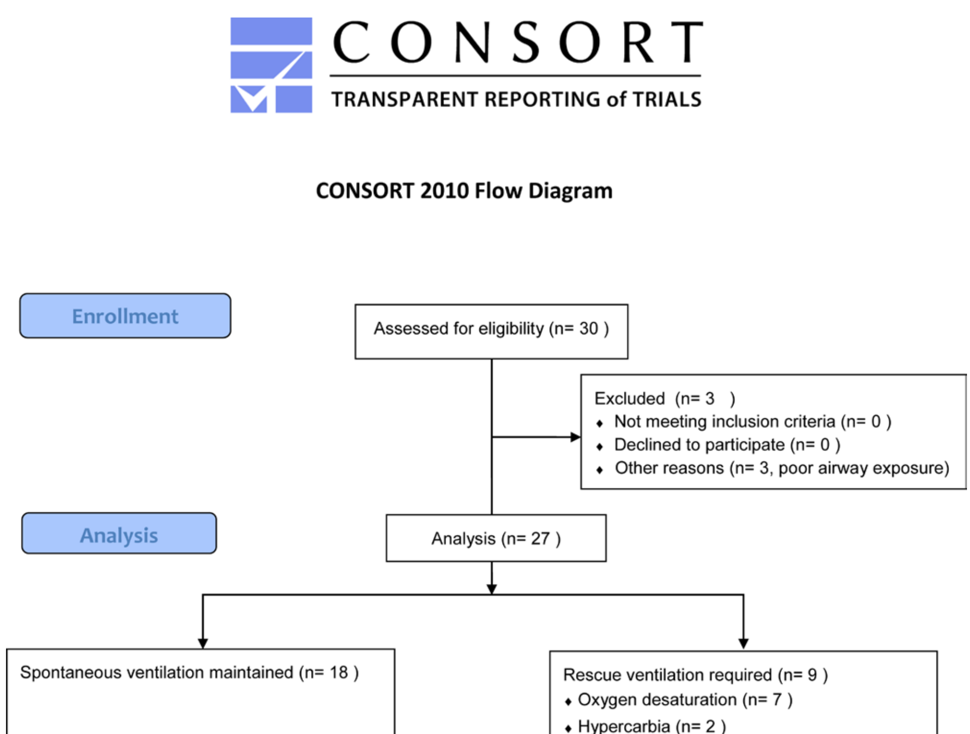

Figure 2. Flow diagram of included patients.

Table 1

Patients' characteristics.

	Rescue ventilation required (n = 9)	Spontaneous ventilation maintained (n = 18)	*P* value
Age (mo)	8.2 ± 10.2	28.8 ± 25.4	.02
Height (cm)	66.1 ± 11.2	82.0 ± 22.9	.06
Weight (kg)	6.7 ± 2.1	11.0 ± 5.8	<.01
Male gender (n, %)	5 (55.5)	11 (61.1)	.88
Anesthesia time (min)	55.7 [41.5–65.0]	41.0 [30.0–45.0]	.04
Diagnosis			.17
Recurrent aspiration		1	
Respiratory difficulty		2	
Laryngeal cleft	1	1	
Laryngomalacia	6	3	
Subglottic stenosis	2	9	
Tracheoesophageal fistula		1	
Laryngeal papilloma		1	
Procedure			<.01
Examination	3	15	
Supraglottoplasty	6	1	
Ballooning		2	

Data presented as mean ± standard deviation, median [interquartile range], or number (%).

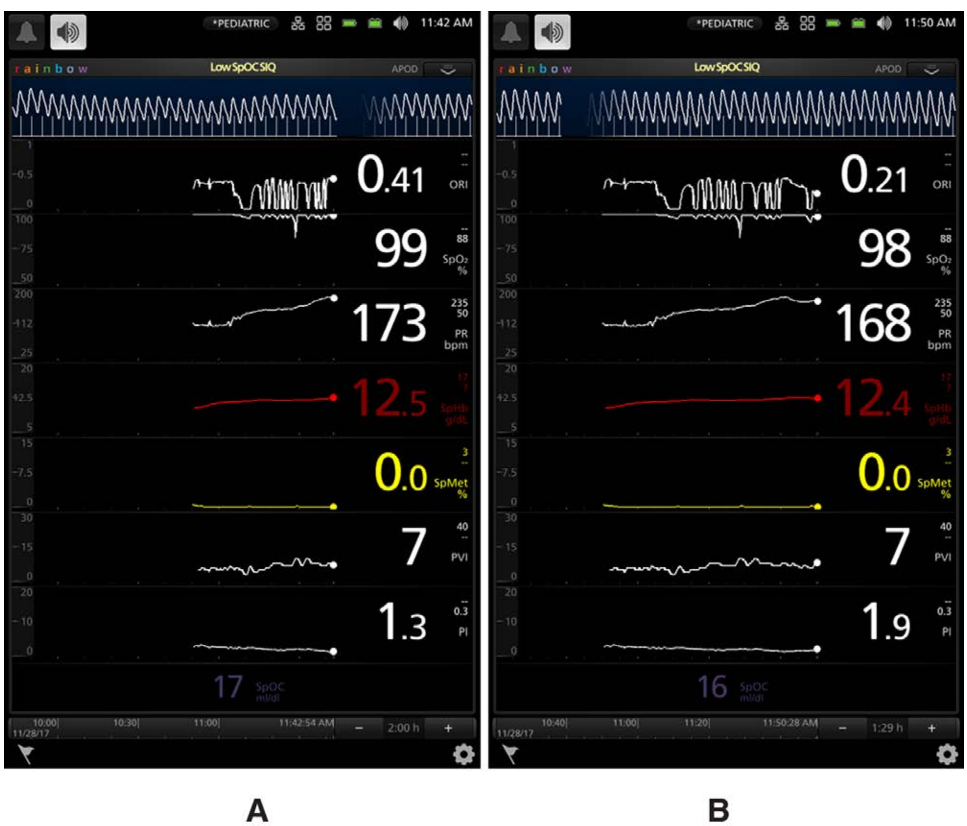

Figure 3. Oxygen reserve index in a patient undergoing laser supraglottoplasty (A) with FiO_2 1.0 and (B) with FiO_2 0.3.

this difference can be explained by the younger age (median: 13 vs 18 months) and lower weight (median: 8.8 vs 11 kg) of the population in our study. Moreover, although the median time of the operation was similar (approximately 30 minutes), the maximum value was higher in our study (115 vs 61 minutes).

A retrospective observational study conducted by Booth et al[18] demonstrated the benefits of using high-flow nasal oxygen in the management of spontaneously breathing adult patients during general anesthesia, especially in those with obstructed airways. In these patients, the high-flow nasal oxygen maintained an adequate SpO_2 and end-tidal carbon dioxide level throughout the surgery. However, the results of our study suggest that pediatric patients differ from adults in many ways with regard to preserving spontaneous respiration during general anesthesia. The most common indication for laryngeal microsurgery in adults is a fixed airway obstruction,[16,18] whereas in pediatric patients, dynamic airflow obstruction (e.g., laryngomalacia, tracheomalacia, or subglottic stenosis) is a common indication for diagnostic laryngoscopy and bronchoscopy. In these patients, dynamic assessment of the native airway movement (functioning of vocal cords, larynx, and trachea) is the most valuable diagnostic tool[12,13] (Video 1, Supplemental Digital Content, http://links.lww.com/MD/G891). However, this is impossible in cases of apnea. Consequently, airway obstruction occurred frequently at the time of induction of anesthesia or during the intervention in these patients.

In our study on pediatric patients, carbon dioxide tended to accumulate despite spontaneous breathing during surgery. In pediatric patients, carbon dioxide elimination during apneic oxygenation is controversial.[15,23,24] Although, hypercarbia is inevitable and generally well tolerated in pediatric patients,[13] care should be taken to monitor and avoid it.

Another finding of this study was the effectiveness of ORI during tubeless airway surgery. To ensure adequate respiration and oxygenation, the most basic method of monitoring is pulse oximetry. However, pulse oximetry desaturation is a late sign of respiratory compromise, especially during administration of supplemental oxygen.[25] Although capnography provides an earlier warning of inadequate ventilation,[26,27] it is unavailable with high-flow nasal oxygen therapy. Monitoring ORI was effective in providing an early warning of impending respiratory compromise (Fig. 3).[28] Further large-scale randomized controlled trials regarding the effectiveness of ORI monitoring during airway surgery are needed.

This study has several limitations. First, this is a prospective observational study. Although our surgeons reported more favorable outcomes for surgery using these techniques as compared to the intermittent intubation technique, which is the conventionally used technique in our hospital, we could not objectively compare the clinical advantages of high-flow nasal oxygen over other techniques. Second, we included only 30 pediatric patients and excluded neonates with significant respiratory symptoms. Hence, generalization of these results to other pediatric populations should be done cautiously. Finally, since it is an initial observational study in pediatric age group, further studies with large sample size are definitely required before applying the method in clinical practice.

In conclusion, high-flow nasal oxygen is an alternative technique to maintain oxygenation in children undergoing airway surgeries; however, younger age and longer anesthesia time are significant risk factors leading to the requirement of rescue ventilation in these patients. Further studies with large sample size are required for clinical application of these techniques.

Author contributions

E-HK and S-HE analyzed and interpreted the patient data regarding the hemodynamic during surgery and were major contributors in the writing of the manuscript. S-KK performed the laryngoscopic examination of the airway. J-HL, J-TK, and Y-EJ recruited patients and collected the data. H-SK planned this study and revised the manuscript. All authors read and approved the final manuscript.

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