Progressing Aspects in Pediatrics and Neonatology
DOI: 10.32474/PAPN.2025.05.000201
ISSN: 2637-4722
Research Article

Feasibility Study of High Flow Oxygen for Airway Management of Recurrent and Severe Upper Respiratory Obstruction in Children with Laryngeal Papillomas: An Observational Study

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Received: May 29, 2025 **Published:** June 03, 2025

Abstract

Background

The incidence rate of recurrent laryngeal papilloma in children is 4.3 cases per 100000 people. It is a rare disease, but it is also the most critical benign tumor affecting children's respiratory tract. Its clinical manifestations are hoarseness and upper respiratory tract obstruction of different degrees; Severe cases can directly endanger the life of the child due to upper respiratory obstruction, difficulty breathing, and subsequent suffocation. In recent years, high flow nasal cannula oxygen therapy (HFNO) has been shown to provide better oxygenation, ventilation, and maintain upper airway patency in adult patients with difficult airways. However, there is currently no reported experience in airway management of recurrent laryngeal papillomas in children with severe upper airway obstruction.

Objective:

TO evaluate the safety and effectiveness of airway management during laryngoscopy in pediatric patients with recurrent laryngeal papillomatosis and severe upper respiratory obstruction using high flow nasal oxygen therapy

Methods

A retrospective observation study was conducted on 27 children with recurrent and severe upper respiratory obstruction and laryngeal papilloma admitted to our institution. They were all underwent carbon dioxide laser microsurgical resection of laryngeal papillomas under laryngoscopy in our hospital. The main outcome measures are: spontaneous ventilation time (defined as the non-mechanical support ventilation time before successful endotracheal intubation or tracheotomy), intraoperative minimum oxygen saturation, rate of secondary and above intubation, whether airway rescue is needed, incidence of intraoperative airway adverse events (including laryngeal edema, laryngeal spasm, bronchial spasm, decreased pulse oxygen saturation ($SpO2<90\%$), and surgical site bleeding). The secondary outcome measures are: postoperative ICU transfer rate and length of hospital stay.

Results

Compared with the traditional self-breathing sevoflurane slow induction group, high oxygen flow can reduce the incidence of secondary and multiple intubation, adverse airway events, airway salvage rate, and postoperative ICU transfer. It can also reduce the spontaneous ventilation time before airway establishment, the length of hospital stay for children, and the duration of resuscitation; There was no statistically significant difference in intraoperative fluid replacement between the two groups, as the end tidal carbon dioxide was reduced and the minimum oxygen saturation was increased during spontaneous ventilation. There is a positive correlation between the incidence of airway adverse events and the postoperative ICU transfer rate.There is a correlation between the duration of spontaneous ventilation, the lowest oxygen saturation during spontaneous ventilation, and the end tidal carbon dioxide during spontaneous ventilation. In children with pre-existing upper respiratory obstruction, the longer the spontaneous ventilation time, the lower the minimum oxygen saturation and the higher the end tidal carbon dioxide during spontaneous ventilation.

Conclusions

High flow nasal oxygen can be successfully used for airway management in pediatric patients with recurrent laryngeal papillomatosis and severe upper respiratory obstruction.

Keywords: Recurrent Laryngeal Papilloma in Children; High Flow Nasal Cannula Oxygen Therapy; Severe Upper Respiratory Obstruction; Airway Management; Anesthesia

Introduction

Laryngeal papilloma in children is a rare and dangerous benign tumor that affects the airway. The incidence rate is about 4.3 cases per 100000 people. It is characterized by multiple, rapid growth, and easy recurrence. The tumor is mainly located in the vocal cords, laryngeal chambers, and subglotta. The clinical manifestations are hoarseness, wheezing, and upper airway obstruction of varying degrees [1]. Due to severe upper respiratory obstruction, these cases often present with difficulty breathing, leading to suffocation, and even directly endangering the child's life. Carbon dioxide (CO_2) laser microsurgery under laryngoscopy is the preferred treatment for recurrent laryngeal papillomas in children. However, pediatric laryngeal papillomas have the characteristic of frequent recurrence, and children usually have undergone multiple surgical treatments. The history of multiple airway surgeries combined with the pathological and physiological changes of pediatric laryngeal papillomas creates an exceptionally complex and difficult airway for children [2]. This means that in this type of child, both mask ventilation and tracheal intubation difficulties often coexist, which poses great challenges to anesthesia airway management during surgery. Poor management of anesthesia airway during surgery can lead to various adverse airway events in children with laryngeal papillomas, such as hypoxemia ($SpO_2<90\%$), airway spasms, laryngeal edema, secondary or multiple endotracheal intubation, surgical site bleeding, emergency tracheotomy, and even death [3].

The preservation of spontaneous breathing sevoflurane inhalation induction intubation is a commonly used method for treating difficult airways in children. Traditionally, this technique is considered safe because in the event of airway obstruction, inhaled anesthetics will no longer be absorbed and the child can quickly recover. However, due to difficulty in ventilation through the face mask and insufficient intake of inhaled anesthetics, sufficient anesthesia depth is usually not achieved; Instead, it leads to laryngeal spasms, respiratory pauses, and airway collapse in the affected children. When necessary, conscious intubation can be chosen for adult difficult airways. The 2022 ASA Difficult Airway Guidelines emphasize that cooperative difficulties or pediatric patients may limit the choice of difficult airway management, especially when it comes to conscious intubation [5] [4]. Tracheostomy, jet ventilation, and direct tracheal intubation are also commonly used methods for children with difficult airways, but these methods also have drawbacks, such as damaging the airway, airway bleeding, multiple intubation leading to airway injury, as well as pressure trauma caused by jet ventilation, interference with surgical procedures, and obstruction of granulation tissue [5].

Compared with traditional face masks and nasal cannula oxygen inhalation, high flow nasal oxygen can provide a humidified and heated air oxygen mixture of up to 70L/min through a special device, with a stable inhaled oxygen concentration between 20% and 100%; Therefore, it can provide better oxygenation and avoid the need for positive pressure ventilation [6]. In adults with pre-existing upper respiratory obstruction, the combination of HFNO and spontaneous breathing can maintain oxygenation and airway patency [7]. For children with preoperative upper respiratory obstruction, maintaining oxygenation is a major challenge. Currently, there are no reports of using high flow nasal oxygen therapy for airway management in children with recurrent laryngeal papillomatosis complicated by severe upper respiratory obstruction. This study retrospectively analyzed 27 children with laryngeal papillomas to evaluate the safety and effectiveness of high flow nasal oxygen in airway management during laryngoscopy for recurrent laryngeal papillomas in children with severe upper respiratory obstruction before surgery.

Methods

Patient selection

This study was conducted at Sun Yat sen Memorial Hospital of Sun Yat sen University. It is a retrospective study and obtained the review consent and informed consent of the ethics review committee of our research institution on February 17, 2022 ((Approval No: SYSEC-KY-KS-2022-066)). We collected data from the hospital electronic medical record database of the HIS software version 3.0 of our hospital from January 2018 to December 2021. The study subjects were pediatric patients with recurrent laryngeal papilloma complicated with severe upper respiratory obstruction who underwent CO_2 laser microsurgical resection under laryngoscope in our hospital between January 2018 and December 2021. A total of 27 children with recurrent and severe upper respiratory obstruction and laryngeal papilloma were included in this study.

Inclusion and exclusion criteria

The inclusion criteria for this study were children aged 0-14 years, with recurrent laryngeal papilloma, treated with CO_2 laser microsurgery under laryngoscopy, with preoperative upper airway obstruction of grade 3 or above [8,9], and assessed as difficult airway. Exclusion criteria: Children with first-time surgery for laryngeal papilloma who do not have or only have mild upper respiratory obstruction before surgery [8,9]. For children who do not have or only have mild upper respiratory obstruction before surgery, conventional static suction combined with fast induction tracheal intubation can be used, without difficult airway.

Airway management

Twelve pediatric patients (n=12) were treated with HFNO for airway management. The device used to deliver HFNO was ADAPTER (Fisher & Paykel HEALTHCARE), which is an adjustable FiO_2 system that includes a gas regulator that can adjust the inhaled oxygen concentration from 20% to 100%; Simultaneously use Opti flow nasal cannula. The induction protocol is as follows: the induction dose of propofol is 2-2.5mg/kg, the maintenance dose is 0.15-0.3mg/kg/min, remifentanil is 0.2-0.3ug/kg/min, the HFNO oxygen concentration is 100%, and the oxygen flow rate is supplied according to the weight of the child (2L/kg/min for children weighing 0-15KG, 35L/min for children weighing 15-30KG, 40L/min for children weighing 30-50KG, and 50L/min for children weighing>50KG) [9]. Twelve children who received HFNO intravenous anesthesia had their tumors removed by forceps, and after the upper respiratory obstruction was relieved, they underwent selective tracheal intubation under a laryngoscope and continued with the surgery. None of these 12 cases required unplanned termination of HFNO ventilation. The airway management of the remaining 15 children was to preserve spontaneous breathing and induce tracheal intubation with inhalation of sevoflurane. The inhalation concentration of sevoflurane was 6-8%, the oxygen flow rate was 2-4 L/min, and the oxygen concentration was 100%.

Intraoperative management

Continuous monitoring of SpO_2, non-invasive blood pressure (NIBP), ECG, and lead respiratory waveform during surgery. Respiratory and hemodynamic data are automatically entered into anesthesia records. Record the patient's age, gender, American Society of Anesthesiologists (ASA) physical condition grading, relevant comorbidities, and preliminary diagnosis. All patients are intermittently administered dopamine or continuously pumped norepinephrine to maintain hemodynamic stability.

Observation indicators

The main outcome measures are: spontaneous ventilation time (defined as the non-mechanical support ventilation time from anesthesia induction to successful endotracheal intubation or tracheotomy), intraoperative minimum oxygen saturation, number of intubation attempts, rate of second or more intubation attempts, whether airway rescue is needed, incidence of intraoperative airway adverse events (including laryngeal edema, laryngeal spasm, bronchospasm, decreased pulse oxygen saturation ($SpO_2<90\%$), surgical site bleeding), and CO_2 at the end of spontaneous ventilation. Blood oxygen saturation (SpO_2) is measured using pulse oximetry. At the end of the automatic ventilation period, $ETCO_2$ records the final airway (supraglottic airway or tracheal tube) in a closed loop.

The secondary outcome measures are: postoperative ICU transfer rate and length of hospital stay.

Baseline data includes gender, age, weight, and ASA grade of the patient, while surgical data includes minimum SpO_2 records, surgical duration, anesthesia time, resuscitation time, and intraoperative infusion volume.

Statistical analysis

Data was collected using Excel 2007, and statistical analysis was performed using SPSS 23.0. Relevant matrix and forest plots were plotted using R4.3.0 software. Count data: Descriptive analysis is expressed in frequency (n) and percentage (%), and comparison between groups is performed using a chi square test; Measurement data: Normality data is represented by mean ± standard deviation (` x ± s), inter group comparison is performed using two independent sample t-test, and non-normality quantitative data is performed using two independent sample rank sum tests. Using generalized estimation equations to calculate the impact of different airway treatment methods on various clinical indicators. Pearson correlation was used for correlation analysis. P<0.05 is considered statistically significant.

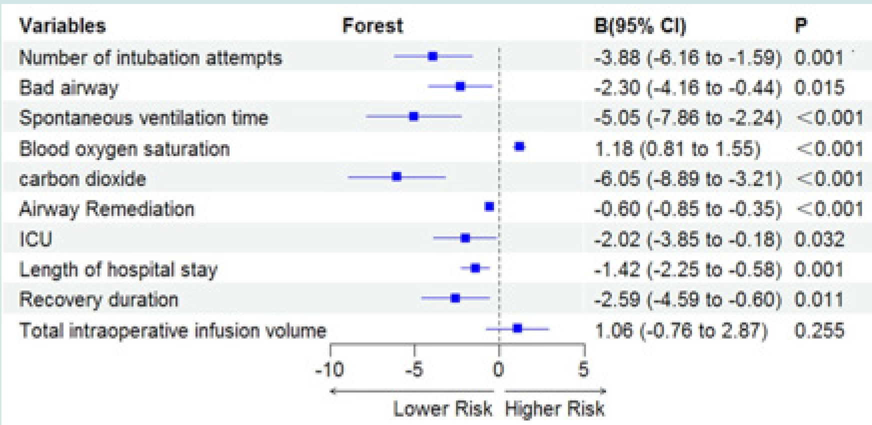
Results

Patient characteristics

There were no statistically significant differences in gender, age, weight, ASA grading, anesthesia duration, and surgical duration between the two groups of patients (Table 1).

Observation indicators of two groups of patients

The clinical data of the research subjects (Table 2). Normal data were analyzed using a two independent sample t-test, while non normal quantitative data were analyzed using a two independent sample rank sum test. Compared with the traditional self-breathing sevoflurane slow induction group, high oxygen flow can reduce the incidence of secondary and multiple intubation, adverse airway events, airway salvage rate, and postoperative ICU transfer. It can also reduce the spontaneous ventilation time before airway establishment, the length of hospital stay for children, and the duration of resuscitation; There was no statistically significant difference in intraoperative fluid replacement between the two groups, as the end tidal carbon dioxide was reduced and the minimum oxygen saturation was increased during spontaneous ventilation. (P<0.05) By using generalized estimation equations to calculate the effects of different airway treatment methods on various clinical indicators, we found that compared with the traditional self-breathing sevoflurane slow induction group, high oxygen flow can reduce the incidence of secondary and multiple intubation, adverse airway events, airway rescue rate, and postoperative ICU transfer. It can also reduce the spontaneous ventilation time before airway establishment, the length of hospital stay for children, and the duration of resuscitation; Reducing the end tidal carbon dioxide of spontaneous ventilation and increasing the minimum oxygen saturation, there was no statistically significant difference in intraoperative fluid replacement between the two groups (Figure 1) (P<0.05).



Note:

- The dependent variable is the slow induction group as the reference group;
- The independent variable intubation frequency is based on "once" as the reference value, while airway rescue, adverse airway, and ICU are all based on "none" as the reference value;
- To control the range of the horizontal axis, the B values of blood oxygen saturation and resuscitation duration in the graph are 1/10 of the actual values, and the B value of the total intraoperative infusion volume is 1/100 of the actual values.

Figure 1: Using generalized estimation equations to calculate the impact of different airway treatment methods on various observation indicators.

Table 1: Characteristics of the 27 Child patient.

Variable		Total (n=27)	HFNO group (n=27)	traditional group (n=15)	Statistical 1 value	P
Sex	Female	11 (40.74)	4 (33.33)	7 (46.67)	—	0.696
	Male	16 (59.26)	8 (66.67)	8 (53.33)		
Age		8.0 (7.0, 8.0)	7.5 (7.0, 8.0)	8.0 (7.0, 8.0)	Z=-0.409	0.683
Weight		25.4 ± 6.0	25.1 ± 5.9	25.6 ± 6.2	t=-0.223	0.825

ASA	Ⅲ	19 (70.37)	9 (75.00)	10 (66.77)	—	0.696
	Ⅳ	8 (29.63)	3 (25.00)	-33.33		
Anesthesia duration		205.0 (165.0, 340.0)	179.5 (158.2, 287.5)	220.0 (185.0, 360.0)	Z=-1.294	0.196
operation time		90.0 (60.0, 257.5)	62.5 (58.8, 223.8)	150.0 (63.0, 260.0)	Z=1.052	0.293

Note: The difference is significant (P<0.05).

Table 2: Clinical data of two groups of patients.

Variable		Total (n=27)	HFNO group (n=12)	Traditional group (n=15)	Statistical value	P
intubation attempts	1	14 (51.85)	11 (91.67)	3 (20.00)	—	0.001#
	2	6 (22.22)	1 (8.33)	5 (33.33)		
	3	7 (25.93)	0 (0.00)	7 (46.67)		
Adverse airway events	No	15 (55.56)	10 (83.33)	5 (33.33)	—	0.019#
	Yes	12 (44.44)	2 (16.67)	10 (66.67)		
duration of Spontaneous ventilation		21.2 ± 4.7	18.4 ± 3.2	23.5 ± 4.5	t=-3.265	0.003*
lowest SPO2		93.0 (85.0, 97.0)	97.0 (96.8, 97.0)	85.0 (82.5, 91.5)	Z=-4.437	<0.001*
Spontaneous ventilation end CO2		50.1 ± 5.0	46.8 ± 3.3	52.8 ± 4.6	t=-6.050	0.001*
Airway Remediation	No	18 (66.67)	12 (100.00)	6 (40.00)	—	0.004#
	Yes	9 (33.33)	0 (0.00)	9 (60.00)		
ICU	NO	16 (59.26)	10 (83.33)	6 (40.00)	—	0.047#
	Yes	11 (40.74)	2 (16.67)	9 (60.00)		
Hospitalization days		5.4 ± 1.4	4.6 ± 1.0	6.0 ± 1.3	t=-3.095	0.005*
Recovery duration		62.1 ± 22.4	52.4 ± 14.9	78.3 ± 24.5	t=-2.653	0.019*
Infusion volume		602.3 ± 235.4	659.2 ± 282.1	556.8 ± 188.1	t=1.124	0.272

Note: *The difference is significant (P<0.05); #Fisher exact probability.

The relationship between adverse airway occurrence and ICU transfer

Among the 12 children who experienced adverse airway events, 10 were transferred to the ICU after surgery, while among the 15 children who did not experience adverse airway events, only 1 was transferred to the ICU after surgery; There is a statistical difference between the two, and there is a positive correlation between the incidence of adverse airway events and the rate of postoperative ICU transfer. The more adverse airway events occur, the more postoperative ICU transfers (Table 3) (P<0.001).

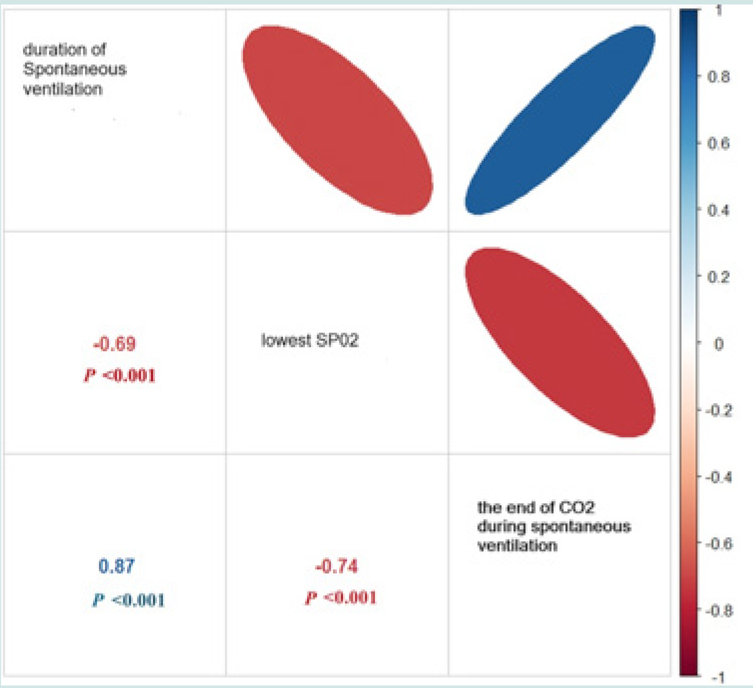
Table 3: The relationship between the incidence of adverse airway events and ICU transfer rate.

Variable		No adverse airway events (n=15)	adverse airway events (n=12)	P
ICU	No	14 (87.5)	2(12.5)	<0.001#
	Yes	1 (9.1)	10 (90.9)	

Note: The difference is significant (P<0.05); #Fisher exact probability.

Correlation analysis

Describing the relationship between spontaneous ventilation time and the lowest oxygen saturation during spontaneous ventilation, as well as the end tidal carbon dioxide during spontaneous ventilation, it was found that there was a correlation between the two (Figure 2) (P<0.001). In children with pre-existing upper respiratory obstruction, the longer the spontaneous ventilation time, the lower the minimum oxygen saturation and the higher the end tidal carbon dioxide during spontaneous ventilation.



Note: The difference is the significant ($p<0.05$).

Figure 2: The relationship between duration of spontaneous ventilation and the lowest oxygen saturation and the end of tidal carbon dioxide during spontaneous ventilation.

Discussion

Pediatric laryngeal papilloma is a multiple, rapidly growing, and easily recurrent benign tumor of the airway [1]. Children with recurrent laryngeal papilloma and severe upper respiratory obstruction have a very complex and unpredictable difficult airway, and appropriate contingency plans need to be developed [10]. The awake intubation protocol is not suitable for pediatric patients [4]. Blind tracheal intubation is very difficult on one hand, and on the other hand, it can cause additional airway damage in narrow airways [11]. Moreover, after using muscle relaxants, positive pressure ventilation may push phlegm and other secretions and blood deeper into the airway as the muscles relax [12]. Maintaining spontaneous breathing and inducing intubation with sevoflurane is equally dangerous [13]. Tracheotomy is not always effective and reliable. For children with difficult airways, anesthesiologists often interrupt intubation operations due to hypoxia, and repeated intubation operations can increase damage to the throat and respiratory tract bleeding. Extending the safe duration of intubation can reduce the occurrence of hypoxemia during anesthesia induction intubation in children with difficult airways and improve the success rate of one-time intubation [14].

Using high flow oxygen to maintain oxygenation and intravenous general anesthesia to provide anesthesia depth can facilitate surgical operations for otolaryngologists. In children with recurrent laryngeal papilloma, multiple and large tumors, partial resection of the tumor can be performed first to relieve upper respiratory obstruction, and then tracheal intubation can be performed to complete the surgery. To prevent airway fire during laser surgery, it is recommended to use oxygen concentrations below 30% [15]; At present, the most commonly used high flow oxygen therapy device is the Fisher & Paykel HEALTHCARE system, which is an adjustable FiO_2 system that includes a gas regulator that can adjust the inhaled oxygen concentration to 20% -100%. This provides the possibility of using high flow oxygen throughout the entire process of carbon dioxide laser resection of laryngeal papillomas using laryngoscopy, which requires more research to determine. The cases reviewed in this study suggest that for fire prevention reasons, high flow oxygen was discontinued before the start of carbon dioxide laser ablation of tumors, with a maximum usage time of 24 minutes and a minimum blood oxygen saturation of 96%. Among the 12 patients we observed, only one patient experienced hypoxia below 90%, with a duration of less than 30 seconds and a minimum SpO_2 of 88%. After the anesthesiologist used mandibular support, the condition gradually improved and the blood oxygen saturation increased to 98%, which did not affect the surgical operation of the otolaryngologist.

Many studies have confirmed the effectiveness of HFNO technology in airway surgery [16-18]. HFNO can provide additional flushing of dead spaces in the throat, reducing respiratory work and airway resistance; HFNO can generate sustained positive airway pressure (CPAP), providing patients with a ventilation effect of positive end expiratory pressure (with an average of 2.7 to 7.4 cm H2O), and providing a constant proportion of inhaled oxygen concentration (20% -100%) [12,19,20]. In Riva's study, six children with upper respiratory tract stenosis treated under general anesthesia with endoscopic therapy were reported, ranging in age from 2 months to 14 years. Among these children treated with HFNO, there were no complications such as laryngeal spasms or bloating, indicating that HFNO technology can be safely applied in pediatric airway surgery that preserves spontaneous breathing [21]. In Jeong's retrospective study, it was found that HFNO can provide a clear surgical field of view and ensure oxygenation in children undergoing respiratory surgery, making it an effective and feasible respiratory support regimen [22]. Millar reported that HFNO can be used for airway surgery in children of all ages, helping to reduce the number of interruptions in surgery due to hypoxia, providing sufficient surgical time for surgeons, and reducing the incidence of throat and other injuries caused by tracheal intubation due to hypoxemia [23].

In our observational studies, we also found that HFNO can reduce the incidence of secondary and intubation, adverse airway events, airway salvage rate, and postoperative ICU transfer (P<0.05). It can also reduce the spontaneous ventilation time before airway establishment, the length of hospital stay for children, and the duration of resuscitation; Reduce the end tidal carbon dioxide of spontaneous ventilation and increase the minimum oxygen saturation (P<0.05). Among the 12 children in the HFNO group, only 2 experienced airway adverse events. During spontaneous ventilation, the lowest blood oxygen saturation was 96%, and there were no episodes of respiratory arrest or complete airway obstruction. There was no airway rescue, and at the end of spontaneous ventilation, the PETCO2 in the HFNO group was significantly lower than that in the traditional sevoflurane induced group(P=0.001).

In previous studies, it has been confirmed that HFNO can improve oxygenation and respiratory mechanics by increasing end expiratory lung volume (i.e. functional residual volume) in postoperative patients and respiratory failure patients with pre-existing hypoxemia and hypercapnia [19,24-25]. These lower respiratory effects may be the reason why HFNO provides better oxygenation and does not significantly increase ETCO2. Some studies suggest that the positive airway pressure generated by HFNO can counteract the tendency of collapse, improve airway patency, and reduce airway resistance, which is beneficial for airway support in patients with spontaneous breathing during general anesthesia, especially those with laryngotracheal stenosis [19,21]. HFNO maintains oxygenation by preventing respiratory pauses and complete airway obstruction, while achieving sufficient anesthesia depth through intravenous general anesthesia to tolerate airway instruments and surgery [21]. Studies have also reported similar benefits of using HFNO in relieving upper respiratory obstruction in adult patients undergoing bronchoscopy, attributed to the nasopharyngeal pressure generated by high flow oxygen [26]. HFNO technology can prolong the suffocation oxygenation time of patients with airway difficulties, thereby improving the overall process of difficult intubation. Our observational study also confirmed this, that children with recurrent laryngeal papillomatosis complicated with upper respiratory obstruction who use HFNO for airway management have smooth and calm airway management throughout the entire process, and significantly reduce the occurrence of adverse airway events.

Limitations

However, due to the rarity of pediatric laryngeal papilloma as an airway disease, the small sample size is a limitation of this study and further research is needed. Like all unprotected airways, we also believe that HFNO technology is not suitable for high-risk aspiration patients; Secondly, another disadvantage of HFNO compared to closed respiratory systems such as endotracheal intubation is the difficulty in accurately measuring end tidal carbon dioxide levels [14].

Conclusions

The physiological benefits of HFNO on the upper and lower airways may increase the safety margin for spontaneous breathing induction and intraoperative maintenance, including in patients with pre-existing difficult airways and/or airway obstruction. It can be said that HFNO is an effective supplement to traditional inhalation anesthesia and slow induction, and is another way to solve difficult airways. It is worth further research to explore its application in managing difficult airways.

In summary, high flow nasal oxygen therapy can be successfully used for airway management in pediatric patients with recurrent laryngeal papillomatosis and severe upper respiratory obstruction before surgery to support laryngoscopy. This technique is safe and effective.

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