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Original Article

Comparison of oxygenation among different supplemental oxygen methods during flexible bronchoscopy in infants

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Abstract

Background: Supplemental oxygen (O_2) is mandatory during flexible bronchoscopy (FB) in infants, but there are limited studies that deal with the efficacy of different O_2 delivery methods. This study aims to compare the oxyhemoglobin saturation in infants during FB among three different O_2 delivery methods, as measured by pulse oximeter (SpO_2).

Methods: A prospective study enrolled infants with two criteria: (1) less than 2 years old; and (2) needing FB examination. All infants received intravenous sedation and topical anesthesia. They were randomly placed into the following three groups: (1) nasal cannula (NC; 0.5 L/kg/min); (2) nasal prongs with continuous positive airway pressure (NP-CPAP; 5−10 L/min, pressure 5 cmH_2O); and (3) nasopharyngeal catheter (NPC; 0.3−0.5 L/kg/min). SpO_2, heart rate, blood pressure and respiratory rate were measured and compared at different stages: (1) prior to the FB (baseline); the FB tip at (2) the nose tip; (3) the pharynx; (4) the carina and (5) 30 minutes after the FB.

Results: *A* total of 75 infants, with 25 infants per group, were enrolled during a 2-year period. There were no significant differences in basic characteristics and baseline SpO_2. After the designated O_2 was delivered, SpO_2 decreased significantly ($p < 0.05$) when the FB tip was advanced from the nostril to the pharynx, and further decreased ($p < 0.01$) when at the carina in all groups, especially in the NC group. After FB, SpO_2 returned to baseline levels in all three groups. The NC group had the lowest SpO_2 at the pharynx ($p < 0.01$) and carina ($p < 0.01$). The NP-CPAP and NPC groups had better SpO_2.

Conclusion: Supplemental O_2 via NPC is a simple and cost-effective method to maintain good SpO_2 during FB examination of infants.

Keywords: CPAP; desaturation; flexible bronchoscope; nasal prong; nasopharyngeal catheter; oxygen therapy

1. Introduction

Flexible bronchoscopy (FB) can provide direct visual examination of the infant airway, and has become a useful clinical diagnostic as well as therapeutic tool. However, the occurrence of hypoxia, which may cause cardiac arrhythmia and compromise systemic oxygenation, is common, and its most concerning adverse effects may occur during FB, especially in infants.[1−3] Hypoxia can occur by the combination of several mechanisms including underlying disease, oversedation, airway suction which may remove oxygen or decrease lung volumes, and increased ventilation-perfusion mismatching by concomitant airway block and spasm, bleeding, and instillation of fluids. Therefore, oxygen supplementation during FB as well as in the recovery stage after the procedure has routinely been recommended in infants to achieve an acceptable oxyhemoglobin saturation, especially those already with poor cardiopulmonary status.[4,5] There are various techniques for delivering supplemental oxygen during FB,[6−9] but limited studies addressing their safety, feasibility, and efficacy been reported.

Assessing oxyhemoglobin saturation by pulse oximetry (SpO_2) is regarded as a time-tested, reliable and convenient clinical tool.[10] Since it became widely available, monitoring SpO_2 during semi-invasive procedures has become a valuable

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routine in most institutions. The aim of this study was to compare the SpO_2 among three different techniques, which we had been clinically using for several years, for oxygen delivery during diagnostic FB procedures in infants.

2. Methods

This was a prospective 2-year study. FB procedures were performed by three qualified pediatric bronchoscopists. Each bronchoscopist had experience of executing more than 100 FB procedures.

2.1. Patients

Infants who were (1) less than 2 years old; and (2) undergoing selective FB examinations for suspected airway problems (persistent stridor, hoarseness, unexplained inspiratory retraction, or unresolved pneumonia, etc.) were enrolled. Infants who had (1) body weight less than 2.5 kg; (2) cyanotic heart disease; (3) significant cardiopulmonary compromise; or in whom (4) the FB could not be introduced via the nasal tract were excluded. Informed consent with all possible risks explained was obtained from all parents before the actual procedure, and this study was approved by the institutional review board of our hospital (TVGH 89-307).

2.2. Preparation and monitoring of SpO_2

Infants were prepared as usual and placed in the supine position. The nasal or oral gastric tube was removed to save the upper airway space and minimize esophageal insufflations. Four-channel waves (cardiac, respiratory, SpO_2, and non-invasive blood pressure) and a digit monitor (MP 30, Philips, Germany) were routinely applied before giving premedication, during, after the completion of FB, and until the patient returned to a stable cardiopulmonary condition. The SpO_2 was measured with a finger or toe probe, and continuous recording was obtained.

Intravenous sedation with midazolam (0.2–0.5 mg/kg, maximum 5 mg), ketamine (0.5–2.0 mg/kg, maximum 15 mg), and atropine (0.02 mg/kg, maximum 0.2 mg), were recommended and carefully titrated to preserve spontaneous breathing, as possible. Topical anesthesia of 2% lidocaine was applied by (1) instillation into the bilateral nasal tract and pharynx with 0.2 mL/kg, maximal 1.0 mL, and (2) intratracheal injection, via either the larynx or the mid-anterior neck, into the tracheal lumen with 0.3 mL/kg, maximal 2.5 mL.

2.3. Three oxygen delivery methods

Supplemental oxygen was routinely given to infants undergoing FB. After the above preparation, infants were randomly applied the following three different oxygen delivery techniques during and 30 minutes after the FB procedure.

a) Nasal cannula (NC)

A traditional nasal cannula of 8-F size with double prongs was inserted into the infant's nostrils and then secured over the face. Pure oxygen was delivered with a flow of 0.5 L/kg/min (maximum 3.0 L/min).

b) Nasal prongs-continuous positive airway pressure (NP-CPAP)

NP-CPAP was applied via nasal double-prongs, 1.5 cm length (size 3 or 4, Hudson, Temecula, CA, USA). CPAP of 5 cmH_2O was applied by either simply immersing the distal expiratory tubing underwater to 5 cm vertical depth in a bottle (bubble-CPAP), or by mechanical ventilator (mechanical-CPAP). Pure oxygen with a constant flow of 5–10 L/min was delivered. In the bubble-CPAP setting, the flow was adjusted to create a constant bubbling from the end hole of the expiratory tubing under the water.

c) Nasopharyngeal catheter (NPC)

A suction catheter with size of 8-F serving as an NPC was inserted via one nostril (preferably right side). Insertion length was estimated from the nostril to the same-side ear lobe. Its outside tubing was secured on the face. The ideal tip location should be free in the oropharynx, without embedding the mucosa, which is routinely checked and confirmed by digital palpation (via mouth) and the following FB. Pure oxygen with a constant flow of 0.3–0.5 L/kg/min (maximum 3 L/min) was delivered.

All the oxygen flow was warmed and humidified. Flow rates and the NP-CPAP pressures used were according to conventional practice in infant patients. During FB procedures, any $SpO_2 < 85\%$, or bradycardia (<60 beats/min) that lasted more than 5 seconds was immediately managed by moving out the FB and supported with a manual, non-invasive positive pressure ventilation (NIPPV)[11] to recover the condition.

2.4. Flexible bronchoscopy and measurement of data

An FB with outer diameter of 3.5 mm without inner channel (ENF Type P4; Olympus) was used throughout the whole study. The FB was routinely inserted via the nasal route. In the NP-CPAP setting, one side of the prong might block the FB insertion, then it was moved out from this nare and the prong hole was sealed to keep the integrity of the CPAP circuit. Heart rate, respiratory rate and SpO2 were measured and collected at the following five different stages: (1) prior to the FB, before giving supplemental oxygen (baseline); after supplemental oxygen and with the FB tip positioned at (2) nose tip, prior to insertion; (3) the pharynx; (4) the carina; and (5) 30 minutes after the completion of the FB procedure. To stabilize and emphasize the FB effect and correctly measure the data, the FB was kept in place for 10 seconds when its tip was located at the levels of nose tip, pharynx and carina. Total

FB duration, from the insertion to the total removal of the FB from the nose, was also measured. Oxyhemoglobin desaturation was defined to be present when SpO2 < 85% continued for more than 5 seconds.

2.5. Statistical analysis

Data was expressed as mean ± standard deviation (SD). Statistical analysis included two-way ANOVA with repeated measurement in one factor (mixed model ANOVA). Comparison of data at baseline and each stage was evaluated by Student's *t* test. A $p < 0.05$ was considered significant.

3. Results

A total of 75 infants, 25 infants per group, were enrolled within a 2-year period. Their ages ranged from 2 days to 24 months, and body weights ranged from 2.5 to 13.5 kg (Table 1). There were no significant differences in their gender, age and body weight. Also, no significant differences were noted in the distributions of their main FB diagnosis (Table 2). All FB examinations were performed smoothly, without any significant complications such as pneumothorax or tracheobronchial bleeding. There was no measured SpO2 < 85%, or bradycardia (<80 beats/min) which lasted for more than 5 seconds. Average total duration of the FB examination was 4.6 ± 1.8 min, ranging from 2.4 to 7.3 min. The baseline heart rate and arterial blood pressures were all similar in these three groups.

3.1. Effect of FB on SpO2 with supplemental oxygen

All baseline measurements of SpO2 were greater than 90%, which indicated an original adequate lung oxygenation in room air breathing, in the presence of their underlying respiratory problems. After supplemental oxygen was delivered, before insertion of the FB (nose tip), a significant increase of SpO2 in all three groups was seen (Table 3).

After introduction of the FB, SpO2 values displayed wide variation. In all three groups, SpO2 decreased when the FB tip was advanced to the pharynx, especially in the NC groups ($p < 0.05$). It dropped further ($p < 0.01$) when the FB reached the carina level. The NC group had the greatest reduction of SpO2 (by 4%) compared with the NP-CPAP group (by 3%), ($p < 0.05$) and the NPC group (by 2%) ($p < 0.01$). No difference ($p > 0.05$) between the NP-CPAP and the NPC groups was seen. Thirty minutes after completion of FB, still with the supplemental oxygen, the SpO2 measurements gradually recovered and rose beyond their original baseline level. The NPC group had the highest level of SpO2 at all three different airway locations among the three groups, but the difference was not significant when compared with the NP-CPAP group ($p > 0.05$). The heart rate, respiratory rate and blood pressure had no significant differences.

Table 1
Clinical characteristics of study infants (N = 75).

Groups	Nasal cannula	Nasal prongs-CPAP	Nasopharyngeal catheter	*p*
Case number	25	25	25	
Male/female	12/13	13/12	14/11	NS
Age (months)				
Range	0.2 − 23	0.1 − 24	0.1 − 23	NS
Mean	9.2 ± 11.2	8.7 ± 12.5	8.9 ± 12.2	
Body weight (kg)				
Range	2.5 − 12.5	2.6 − 12.3	2.6 − 13.5	NS
Mean	8.6 ± 4.1	8.8 ± 4.3	9.0 ± 3.2	

Values are mean ± SD.

Table 2
Distributions of infant number and main bronchoscopy diagnosis in three study groups ($n = 75$).

Bronchoscopy diagnosis	Nasal cannula ($n = 25$)	Nasal prongs-CPAP ($n = 25$)	Nasopharyngeal catheter ($n = 25$)	*p*
Normal airway lumen	9	11	10	NS
Laryngomalacia, mild	6	5	6	NS
Bronchiole swollen/ infection	6	4	4	NS
Compromised pharynx	4	5	5	NS

4. Discussion

The practice of FB is subject to great variation both within and among institutions. A mail survey of FB practices in USA found that 88.9% of respondents routinely used supplemental oxygen and 84.2% routinely used oximetry.[4] The British Thoracic Society recommends that all patients undergoing FB should have pulse oximetry measured and supplemental oxygen should be given "to maintain the arterial oxyhemoglobin saturation at or above 90%"[12] to reduce the risk of tissue hypoxia and cardiac arrhythmias.[13] However, there was little mentioned in the literature about what method(s) of providing supplemental oxygen could feasibly and efficiently achieve the ≥ 90% arterial oxyhemoglobin saturation, especially in the infant age group.

In this study, a striking finding was the step-down and significant desaturation when the FB was advanced from the

Table 3
Changes and comparisons of arterial oxyhemoglobin saturation in three supplemental oxygen groups during infant flexible bronchoscopy (FB) with the tip at different airway locations.

FB tip locations	Nasal cannula ($n = 25$)	Nasal prongs CPAP, ($n = 25$)	Nasopharyngeal catheter, ($n = 25$)	*p*
Baseline, room air (before FB)	94 ± 3	94 ± 3	94 ± 3	NS
Supplemental O2				
Nose tip	96 ± 2	97 ± 2	97 ± 2	NS
Pharynx	90 ± 2*	95 ± 2*	95 ± 2*	<0.05
Carina	86 ± 4*	92 ± 3*	93 ± 2*	<0.01
After FB	95 ± 3	96 ± 2	96 ± 2	NS

Data are presented as mean ± SD. * = significant ($p < 0.01$) dropped compared to the previous data.

nose tip to the pharynx, and then to the carina. This desaturation occurred in all three groups and more significantly in the NC group. This may be caused by several factors, including topical anesthesia, sedation, partial airway obstruction, abnormal distribution of ventilation and reflex response to the FB.[14] Correspondingly, the most likely explanation for our measurements in the pharynx and carina is diminished pharyngeal, glottis and tracheal lumen by the presence of the FB itself and by the sedation effect. Infants, who typically have a small airway diameter, would be at greater risk for this obstruction-induced desaturation than older children and adults. In addition, patients' underlying problems, airway secretions or hypoxic illness would aggravate desaturation during the FB procedure. In our infants, all the desaturation disappeared 30 minutes after the FB procedure; this most likely resulted from a gradual recovery from sedation, and absence of the FB.

Traditionally, administering oxygen to non-intubated and dominant nasal breathing infants is via the nasal route, such as the three methods in our study. Among them, the NC is the most commonly and clinically used. Its advantages include simplicity, low cost, comfort and that it is easily secured in the nostrils.[15,16] However, when compared to the other two groups, its measured SpO_2 was the lowest, and the amount of decrement was greatest when the FB was advanced to the distal airways of the pharynx and the carina. That might contribute to two factors: (1) a low inspiratory oxygen concentration; and (2) low airway pressure due to the compromise effects of sedation and FB.

NP-CPAP, which uses short nasal prongs to deliver positive pressure and oxygen, is a less invasive respiratory support. It has been widely used in infants with various pulmonary disorders. We have successfully used this device in infants with distal airway disease.[17] An appropriate CPAP pressure can stent open both the upper airways of the pharynx and the larynx as well as the lower airways of the trachea and the distal bronchioles.[18,19] The subsequently reduced airway resistance and increased transpulmonary pressure can ultimately improve both ventilation and oxygenation. In the present study, there was reported to be significantly higher SpO_2 in the NP-CPAP group than the NC group. NP-CPAP could maintain SpO_2 at no less than 85% for 5 seconds during the whole FB procedure. However, among these three methods, its performance requires the highest oxygen flow, special and bulky equipment, and the nasal approach of the FB may confront the prong inside. Therefore, it is relatively inconvenient and expensive for clinical use.

NPC oxygen supplementation can deliver pure oxygen and generate positive end expiratory pressure (PEEP) in the pharynx. In patients with spontaneous breathing, the highly concentrated oxygen and positive pressure will be delivered into the tracheobronchial lumen and alveoli. Both effects may contribute to the high measured SpO_2. NPC insertion for the management of upper airway obstruction during sleep has been reported in children,[20,21] and in adult lung transplant patients.[22] There was a study in infants that demonstrated significant increases in PEEP when receiving oxygen through an 8-F NPC. Mean levels of PEEP achieved were 1.6 ± 1.4 cmH_2O, 2.8 ± 2.7 cmH_2O, and 4.0 ± 2.9 cmH_2O at flow rates of 0.5 L/min, 1.0 L/min, and 2.0 L/min, respectively.[23] Mechanisms of PEEP on oxygenation may be related to an increase in functional residual capacity, alveolar recruitment, reduced work of breathing, and better distribution of ventilation to perfusion.[24,25]

Airway obstruction has been shown to be the main cause of desaturation during FB, and in our study this could be successfully managed by supplemental oxygen via either NP-CPAP or NPC. In these three methods, the oxygen flow rates and the 5-cmH_2O pressure in NP-CPAP were all conventional settings in the clinical care of infant patients. Among them, the NPC method of 0.3–0.5 L/min had the most economical oxygen flow demand for running a FB, especially in developing countries or areas where medical oxygen is expensive or in limited supply. Therefore, the NPC method offers benefits of clinical convenience, less oxygen flow, being less invasive, providing good oxygenation and cost-effectiveness (Table 4). For its application in infants, a flow meter which can delicately deliver flow rate in the range from 0.5 to 3.0 L/min may be needed. In infants with difficult nasal approach, a well-secured oropharyngeal catheter can be substituted.

There may be some adverse effects when using NPC oxygen, including drying mucosa, kinking, lumen blocking with mucus[16] and esophageal migration. Therefore, even in its short-term use, we advise that its oxygen flow should be appropriately warmed and humidified. Effective cleaning of the pharyngeal secretion and routine checking of the tip location are always recommended.

Some limitations of our study need to be recognized. The measurement of SpO_2 rather than arterial blood PO2 and PCO2, was used because of the rapid response time (2–3 seconds), non-invasiveness, continuity and self-calibration. These factors all make the pulse oximeter an efficient and accurate monitoring device. However, monitoring oxygenation is not a substitute for monitoring ventilation;[26,27] this axiom is even more important as the depth of sedation increases. While supplemental oxygen will mask the desaturation, it can also delay the recognition of significant hypoventilation, in some cases even beyond the ability to rescue the patient. Oxygen supplementation may lead to an increase in the arterial PCO2 level; therefore, in patients who have severe CO2 retention, oxygen supplementation should be given with caution.

In conclusion, a decline of SpO_2 is frequently noted during FB examination in infants. The risk of desaturation is

Table 4
Summary and comparison of three oxygen supplemental techniques* in clinical application for flexible bronchoscopy in infants.

	Nasal cannula	Nasal prongs CPAP	Nasopharyngeal catheter
Convenience	+	no	+
Less oxygen flow	+	no	+
Less invasive	++	+	+
Oxygen saturation	+	++	++
Cost-effectiveness	no	+	++

* = in conventional setting; + = yes.

increased when the FB is located in the central airway of the pharynx and the carina, and can be successfully managed by using supplemental oxygen. NPC technique is a simple and cost-effective among these three studied techniques.

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