

Sustained pharyngeal inflation on upper airway effects in infants—flexible bronchoscopy measurement

Wen-Jue Soong¹, Chia-Feng Yang², Chieh-Ho Chen³, Yu-Sheng Lee⁴, Chien-Heng Lin⁵, Pei-Chen Tsao⁶, and Nitin Dhochak⁷

¹Children's Hospital, Taichung China Medical University

²Taipei veterans general hospital

³China Medical University

⁴Taipei Veterans General Hospital

⁵China Medical University Hospital

⁶Veteran general hospital, Taipei, Taiwan (ROC)

⁷All India Institute of Medical Sciences

March 18, 2021

Abstract

OBJECTIVE: Sustained pharyngeal inflation (SPI) with pharyngeal oxygen and nose-close (PhO2-NC) can create positive peak inflation pressure (PIP) inside the pharyngolaryngeal space (PLS). This study measured and compared effects of four different SPI durations in the PLS. **METHOD:** In this prospective observational study, 20 consecutive infants aged less than 3 years, scheduled for elective flexible-bronchoscopy were enrolled. SPI was performed twice in four different durations (0, 1, 3 and 5 seconds) sequentially in each infant. PIP was measured for each SPI in the pharynx, and simultaneously took images at two locations of oropharynx and supra-larynx. Infants' demographic details and PIP levels, lumen expansion scores and images of PLS were measured and analyzed. **RESULTS:** Twenty infants with 40 measurements were collected. The mean (SD) age and weight were 11.6 (9.1) months and 6.8 (2.4) kg, respectively. The measured mean (SD) pharyngeal PIPs were 4.1 (3.3), 21.9 (7.0), 42.2 (12.3) and 65.5 (18.5) cm H₂O at SPI duration of 0, 1, 3 and 5 seconds, respectively; which showed significant positive association ($p < 0.001$). At assigned locations, the corresponding PLS images also show significant increase in lumen expansion scores and number of detected lesions with increase in SPI duration ($p < 0.001$). The mean (SD) study time was 5.7 (1.2) minutes. No study related complication was noted. **CONCLUSIONS:** SPI with PhO2-NC up to 5 seconds is a simple, safe and feasible clinical ventilation modality. It may provide enough PIP to expand the PLS and facilitate flexible-bronchoscopy performance in infants.

Title pages

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Wen-Jue Soong^{1,2,3}, Chia-Fang Yang^{2,3,4}, Yu-Sheng Lee^{2,3,4}, Pei-Jeng Tsao^{2,3,4}, Chien-Heng Lin¹, Chieh-Ho Chen¹, Nitin Dhochak⁵

¹*Division of Pediatric Pulmonology, Children's Hospital, China Medical University, Taichung, Taiwan*

²*Department of Pediatrics, Taipei Veterans General Hospital, Taipei, Taiwan*

³*Department of Pediatrics, Triservice General Hospital, National Defence Medical Center, Taipei, Taiwan;*

⁴*School of Medicine, National Yang-Ming University; Taipei, Taiwan*

⁵*Department of Pediatrics, All India Institute of Medical Sciences, New Delhi, India*

Key words :

Flexible bronchoscopy, noninvasive ventilation, pharyngeal pressure, Soong's ventilation, sustained inflation

Corresponding (reprint request) author:

Wen-Jue Soong, MD

Division of Pediatric Pulmonology, China Medical University Children's Hospital, Taichung, Taiwan.

No. 2, Yuh-Der Road, Taichung 40447, Taiwan.

Phone: +886-4-22052121 ext. 4648;

Fax.: +886-4-22032798;

Cell phone: +886-921067989;

E-mail: wjsoong3@gmail.com

Financial disclosure:

- This study was *granting supported* and *IRB proved* by both two organizations of: 1) Taipei-Veterans General Hospital (TVGH no.: V107C-179) and 2) China Medical University Children's Hospital (DMR-109-179).
- There is no support from any manufacture or company about this study.
- The first author, *Wen-Jue Soong*, wrote the first draft of the manuscript.
- Report to *Pediatric Pulmonology*: on behalf of all authors, the corresponding author states that there is no conflict of interest with any person or company.

Authors list

Name	Highest academic degree	E-mail	Affiliation
Wen-Jue Soong	MD.	wjsoong3@gmail.com	Division of Pediatric Pulmonology Children's Hospital,, China Medical University Taichung, Taiwan. Department of Pediatrics, Taipei Veterans General Hospital, Taipei; Department of Pediatrics, Triservice General Hospital, National Defence Medical Ceter, Taipei, Taiwan; School of Medicine, National Yang-Ming University; Taipei, Taiwan
Chia-Feng Yang	PhD	Cfyang3@vghtpe.gov.tw	
Yu-Sheng Lee	PhD	leeys@vghtpe.gov.tw	
Pei-Chen Tsao	PHD	Phinphin.tw@yahoo.com.tw	

Name	Highest academic degree	E-mail	Affiliation
Chieh-Ho Chen	MD	pedlungcmu@gmail.com	1.Children's Hospital, China Medical University, Taichung, Taiwan
Chien-Heng Lin	MD	Lch227@ms39.hinet.net	5.Department of Pediatrics, All India Institute of Medical Sciences, New Delhi, India Current post: Research Officer
Nitin Dhochak	MD. DM.	nitind.aiims@gmail.com	

Abbreviated title: Sustained pharyngeal inflation effects in upper airway

Abstract

OBJECTIVE: Sustained pharyngeal inflation (SPI) with pharyngeal oxygen and nose-close (PhO₂-NC) can create positive peak inflation pressure (PIP) inside the pharyngolaryngeal space (PLS). This study measured and compared effects of four different SPI durations in the PLS.

METHOD: In this prospective observational study, 20 consecutive infants aged less than 3 years, scheduled for elective flexible-bronchoscopy were enrolled. SPI was performed twice in four different durations (0, 1, 3 and 5 seconds) sequentially in each infant. PIP was measured for each SPI in the pharynx, and simultaneously took images at two locations of oropharynx and supra-larynx. Infants' demographic details and PIP levels, lumen expansion scores and images of PLS were measured and analyzed.

RESULTS: Twenty infants with 40 measurements were collected. The mean (SD) age and weight were 11.6 (9.1) months and 6.8 (2.4) kg, respectively. The measured mean (SD) pharyngeal PIPs were 4.1 (3.3), 21.9 (7.0), 42.2 (12.3) and 65.5 (18.5) cm H₂O at SPI duration of 0, 1, 3 and 5 seconds, respectively; which showed significant positive association ($p < 0.001$). At assigned locations, the corresponding PLS images also show significant increase in lumen expansion scores and number of detected lesions with increase in SPI duration ($p < 0.001$). The mean (SD) study time was 5.7 (1.2) minutes. No study related complication was noted.

CONCLUSIONS: SPI with PhO₂-NC up to 5 seconds is a simple, safe and feasible clinical ventilation modality. It may provide enough PIP to expand the PLS and facilitate flexible-bronchoscopy performance in infants.

Introduction

Sustained pharyngeal inflation (SPI) is an assist positive pressure ventilation (PPV) maneuver with prolonged inspiration time while a positive and a peak inflation pressure (PIP) can be created inside the pharyngolaryngeal space (PLS). In children with a patent airway, the prolonged pressurized-air flow may actively move from the upper into the lower airways and providing the ample time and pressure gradient needed for expanding the airway lumens, alveoli and promoting gas exchange across the air-fluid interface. Traditionally, this sustained inflation is accomplished with a gas flow delivered via different devices of Ambu-facemask, bi-nasal prongs, laryngeal mask airway (LMA), or endotracheal tube (ETT).¹⁻⁸ The sustained inflation has gradually become a widespread clinical practice.

“Pharyngeal oxygen with optional nose-close and abdomen-compression (PhO₂-NC-AC)” is a novel model of noninvasive ventilation (NIV), without using any artificial device such as Ambu-bag, face or nasal mask,

LMA, ETT, or mechanical ventilator. It has already been demonstrated to provide adequate oxygenation and ventilation to assist interventional flexible bronchoscopy (FB) in pediatric patients, even in hypoxemic children on respiratory support.⁹⁻¹⁵ A prolonged duration of the action of NC indeed mimic an SPI. Theoretically, in a relatively close space like the PLS, with the setting of a continuous PhO_2 flow, the ventilation effect of the SPI may create as well as increase the PIP in the PLS. Closely measuring and monitoring the level of these PIPs are clinical imperative. To our knowledge, there is no study dealing with the SPI durations and associated changes of the PIP level and image in the upper airway of PLS in pediatrics.

In this study, we use the “ PhO_2 -NC” as a SPI technique to evaluate and compare the effect of different SPI durations on the associated changes of 1) the PIP levels generated, 2) the airway lumen images, and 3) the lesion detected which measured by FB in the PLS.

Methods

In a one-year prospective study, 20 consequent infants who full-filled criteria including a) age less than 3 years, b) a clinical schedule for elective FB, and c) got parents signed-consent for this study, were enrolled. Two bronchoscopists (Soong and Chen) carried out the SPI studies. The Institutional Review Board of hospital and IRB approved this study (DMR-109-179, CMUH108-REC3-114). Patient confidentiality was maintained in accordance with Health Insurance Portability and Accountability Act guidelines.

The study child was laid supine on the endoscopy room table, with procedural sedation and continuous cardiopulmonary monitoring. A continuous oxygen flow (1.0 L/Kg/min, maximal 10.0 L/min) was delivered via a small nasopharyngeal catheter via (right) nostril as the “ PhO_2 ”. This NIV of PhO_2 -NC-AC supported the whole FB intervention. All the SPI studies were performed after completion of their original scheduled FB.

PIP measurement

Figure 1a shows the configuration of this study. A short (25 cm) working-length FB (OD 3.8mm, HYF-V, Olympus), with an inner channel (1.2 mm), inserted via one side (left) nostril. A small pressure transmitting catheter linked the working channel to a real-time pressure monitor (GB30, Galemed, Taiwan). Therefore, the real-time dynamic intra-pharyngeal pressures could be immediately revealed when the FB tip was freely located in the PLS. The PIP was measured at the end of SPI.

Modes of SPI

SPI (NC, inspiration) processed in four modes of different duration (0, 1, 3 and 5 seconds) consecutively, as depicted in Figure 1b. Each SPI maneuver was performed twice at same duration, then processed to the next mode. Each SPI was followed by an open-nose (deflation) period of 10 seconds for expiration and spontaneous breathing. PIP reading was measured and recorded levels for these maneuvers in the PLS.

Lumen imaging

With the FB visualization in the PLS, series of lumen images were taken along the course of dynamic changes with the inflation. In addition, associated anomaly or lesion if existed could also be detected along the different inflation courses of SPI. Simultaneously, took the lesion image at each plateau of PIP, at two assigned locations of oropharynx, and supra-larynx. All FB images and videos of SPI studies were stored.

For objective evaluation of the lumen changes, the four final captured lumen images of oropharynx and supra-larynx (including the lesions) each at different SPI mode were grouped and sent for evaluation. Their lumen expansion scores were judged independently on a five-point Likert scale (1 to 5: severe collapsed, collapsed, average, expanded, much expanded) within one week by five qualified pediatric pulmonologists who blinded to the sources of these image. The final scores were averaged and analyzed.

Data of patient demographics, PIP levels, expansion scores and images in the PLS were all collected for further analysis.

Statistics

Analyses for the PIP levels and airway lumen scores were performed using One-way ANOVA of the MedCalc statistical software (version 19.3.1, MedCalc Software Ltd, Acaciaaan 22, 8400 Ostend, Belgium). Analyses for the numbers of detected lesion were done using chi-square test and post hoc Bonferroni correction. Statistical differences were considered significant at $p < 0.05$.

Results

In these 20 studied infants (Table 1), the mean (SD) age was 11.6 (9.1) months and the mean (SD) body weight was 6.8 (2.4) kg. There were 40 sets of measured data. The mean (SD) operative time of this SPI study was 5.7 (1.2) minutes.

Table 2 presents the details of the intrapharyngeal PIP, lumen expansion scores, locations and number of detected lesions on these four SPI modes. In the collected 40 sets of measurements, the mean (SD) PIP in the pharynx were 4.1 (3.3), 21.9 (7.0), 42.2 (12.3) and 65.5 (18.5) cmH₂O at SPI duration of 0, 1, 3 and 5 seconds, respectively. As shows in the Figure 2, there is positive and significant ($p < 0.001$) linear increase in PIP levels with SPI duration from 0 through 5 seconds. In these changes of image sequences, there was progressive space expansion and significant greater lumen expansion scores ($p < 0.001$) in all locations of the PLS.

Those pressure-sensitive dynamical lesions, such as pharyngomalacia, laryngeal malacia, laryngeal cleft, glottic malacia, etc., which might be overlooked with a low PIP level of short duration SPI. But after adequate lumen expansion with a high PIP level, definite diagnosis could be achieved. Significantly higher number of lesions could be detected with higher PIP levels ($p = 0.004$). With the SPI of 5 seconds, the highest PIP, and lumen expansion score were achieved, and FB identified the most number of lesion ($p < 0.001$).

The corresponding levels of PIP, expansion scores, images of each SPI mode of pharyngeal and laryngeal lesion were illustrated in the Figure 3 and Figure 4, respectively. On the same row, all four images were taken at similar location of same infant but with different PIP levels generated by different SPI durations. In these changes of image sequences, there was a progressive and significant space expansion and greater lumen dimension scores in all locations of the PLS, especially with existing airway pathologic lesions such as pharyngomalacia, uvular cyst, vallecular cyst, etc. During FB assessment, these created lumen expansions also facilitated accurate and comprehensive evaluation of lesions which were not visible in the low PIP levels but became apparent with the high PIP levels of longer SPI duration.

All these SPI studies were successfully completed. There was no any study-related complication such as upper airway bleeding, subcutaneous emphysema, pneumothorax, desaturation ($< 90\%$) or bradycardia (< 100 beat/min).

Discussion

Our study demonstrated significant increase in PIP with the use of simple NIV of “PhO₂-NC” as an SPI technique. To the best of our knowledge, this is the first such study in the medical literature. Even with the frequent use of NIV worldwide, the types of device and the modes of delivery being used vary among countries and institutes. Clinically, this SPI is unique as it waives using other supplementary instruments, except a small oxygen catheter, and bronchoscopist himself can easily handle and control the whole procedure.

The PLS is a fibromuscular tube-like structure that is semicircular in cross section and relatively closed space. It serves as a continuation of the aerodigestive cavity, providing pathway from the nasal and oral cavities to the trachea, esophagus and the bilateral middle ears. PLS boundaries almost with soft tissues of the mouth and the nasal choanae anteriorly; the soft palate, velum, and portion of the skull base superiorly; the tonsils laterally; the inlets of larynx and esophagus inferiorly; and the pharyngeal constrictors posteriorly. Therefore, the PLS is a potential dynamic space which expands with increasing inside pressure.

FB examination via nasal track can offer real-time visualization and assessment of the whole PLS. FB is useful for detecting dynamic images that better demonstrate the presence, location, degree and extent of lesions. In this study, an optional action of SPI by PhO₂-NC could create enough and controllable

positive distending pressure which helps to open and expand the PLS, increase the cross-sectional area, and therefore allow accurate and precise inspection the anatomic structure with FB. Especially when there are pressure dynamic lesions which may lead to collapse or block airway path such as pharyngomalacia, adenoid hypertrophy, tonsil hypertrophy, vallecular cyst, laryngomalacia or glottis malacia laryngeal cleft, etc. as shown in the Figure 3 and Figure 4. While patients are sedated, these lesions may cause difficult breathing, hypoxia and desaturation. During FB interventions, these lesions may remain unrecognized when using traditional technique without appropriate or controllable pressure in the PLS. The PhO₂-NC itself can provide simultaneous and optional PPV. This is not only safe for the patient, but also assists for the therapeutic intervention of FB such as doing laser partial adenoidectomy and tonsillectomy, check bleeding, marsupialization of vallecular cyst,¹¹ epiglottoplasty,¹⁶ etc. Our team has already been using this SPI modality successfully in many pediatric endoscopy interventions of airway⁹⁻¹⁶ and esophagus.^{17,18}

Physiologically, this PhO₂-NC has combinational effects of “apnea oxygenation”¹⁹⁻²³ and PPV. In the setting of PhO₂, the continuous flow indeed fully fills the PLS with oxygen. For apnea oxygenation, randomized controlled trials have shown that it can extend the period of safe apnea, and reduce the unintended hypoxemia when used in patients after sedation or muscle paralysis, even with difficult airways. PhO₂ with addition of optional NC as SPI, both PIP and PPV can be created and sustained for a demand period. This allows appropriate and controllable levels of pressure and times to expand the collapsed PLS for FB detail inspection, as well as performing diagnostic and therapeutic interventions. Furthermore, it may also promote the pressurized oxygen flow into the lower airways and lungs.²⁰⁻²⁴

The modality of FB with this SPI offers several clinical advantages. First, transnasal approach of FB provides a good assessment for dynamic movements of airway lumens, as in small infants. Second, the ventilation interface of this SPI is in the PLS, near the larynx, which much reduces the respiratory dead-space. Third, this SPI is an easy PPV technique that can be performed with only a continuous gas (oxygen or air) flow and a soft catheter with distal tip sitting in the pharynx that minimizes impediment to airway access during FB procedures. FB operator can provide PPV himself while simultaneously execute FB interventions. Fourth, SPI can gradually and appropriately open and expand a collapsed PLS, as demonstrated in this study, which facilitates the passage of FB for thorough measurement of the PLS. This allows clear visualization of contents, structures and lesions that helps to yield more accurate diagnosis and subsequent effective management. All of these can be achieved without interference by artificial airway devices of facemask, nasal prong, LMA or ETT. Fifth, it is technically simple and readily available, therefore, can be used in resource-limited scenarios. Sixth, it causes less distortion in PLS structure, less invasive, better-tolerated and cost-effective compared to the traditional techniques of PPV. In this study, the trend of long SPI presents more effective than short SPI to more expansion of airway space for better and detailed measurement which not easily be achieved in lower inflation levels. Furthermore, these positive and dynamic pressures of SPI may also transmit and facilitate tracheobronchial lumen expansion and lung ventilation. For patients with risk of compromised airway and oxygen desaturation, SPI may provide ventilation and reduce hypoxia, therefore, facilitate patient safety and FB procedures.

We observed that significant number of observations achieved very high PIP at SPI duration of 5 seconds. We did not observe any adverse effects of high PIP as it was used only transiently for our study. But safety of such high pressure cannot be confirmed due to small sample size of our cohort. We recommend SPI duration of 1-3 seconds for routine ventilation during FB and procedures, and 5 seconds inflation should be reserved for special situations where lesions are not adequately visible at lower inflation duration.

Some limitations may exist in this study. There might be variation of the tightness of the nose (mouth)-closure between, or even, in the same operators. This indeed may affect the level of measured PIP. A more prolonged duration of SPI, up to 15 seconds or more has been reported,^{3,8} but we restricted duration of SPI to 5 seconds as longer duration may create risky high PIP. In clinical practice, the real effort of SPI may be individualized which can be controlled by the operators.

Nonetheless, the findings of the present study are important and suggest the need for further investigations. The opening pressure of a collapse PLS or occult lesions can be measured and which helps to determine

appropriate pressure of NIV support. The similar SPI effects may also be noted in the lower airway lumens, ventilation, and lung recruitment.

Conclusion:

We propose that the application of SPI by PhO₂-NC with different durations is a simple, safe and viable modality. This prolonged, up to five seconds, SPI could provide enough PIP to expand the PLS, benefit FB performance and comprehensive inspection in infants. This technique could unmask otherwise difficult recognized lesions. Further larger controlled trials are needed before widespread clinical application.

Acknowledgements

None.

Conflict of Interests

All authors declare that there is no conflict of interests regarding the publication of this paper.

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Figure legends

Figure 1. Flexible endoscopy with nasopharyngeal oxygen support: a) nose-open with narrow pharyngeal space; b) SPI (nose-close) expands the pharyngeal space for clear inspection of the structures.

Figure 2. The trend of measured intra-pharyngeal peak pressure with different durations of sustained pharyngeal inflation.

Figure 3. Changes of intra-pharyngeal space (IPS) peak inflation pressure (PIP), lumen dimension score and images# of pharyngeal lesions in four durations of sustained pharyngeal inflation (SPI).

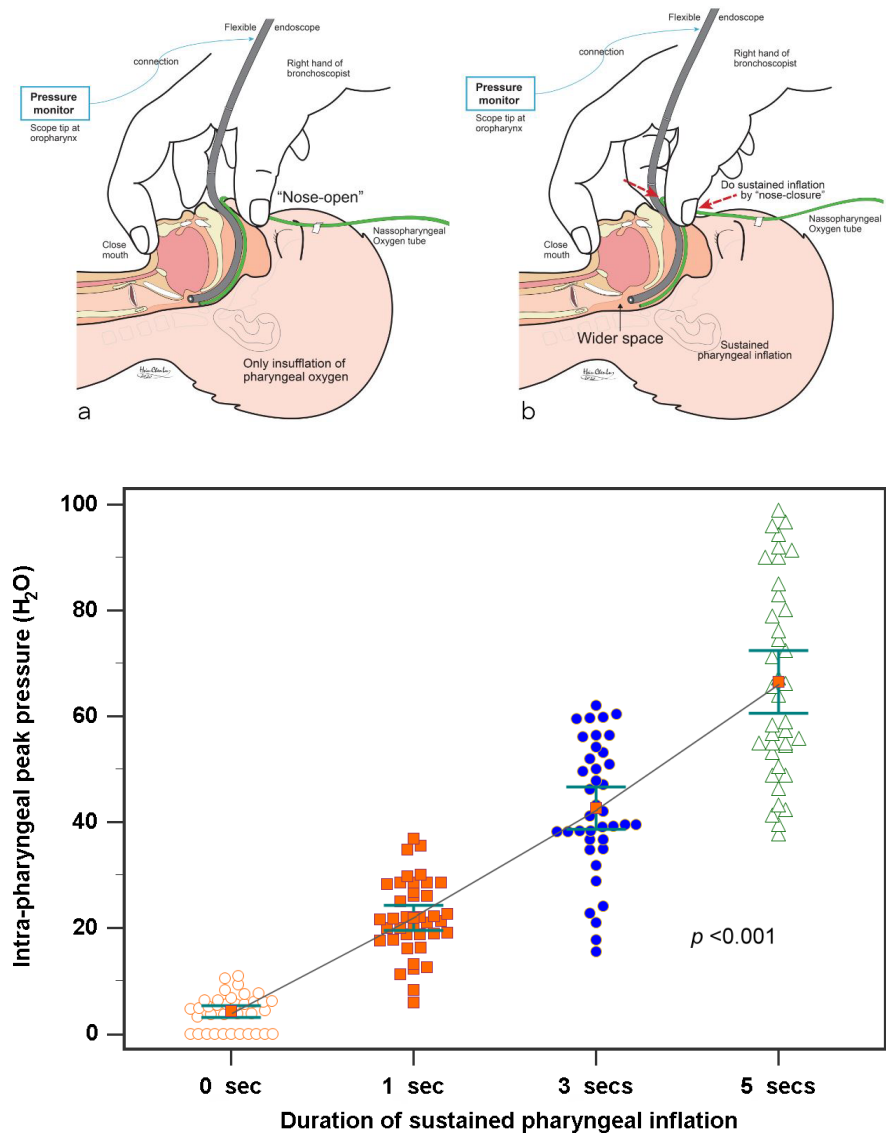
Figure 4. Changes of intra-pharyngeal space (IPS) peak inflation pressure (PIP), lumen dimension score and images# of laryngeal lesions in four durations of sustained pharyngeal inflation (SPI).



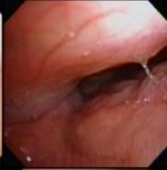
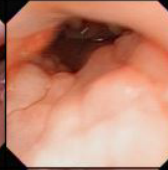

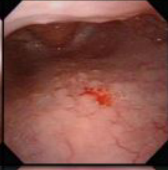
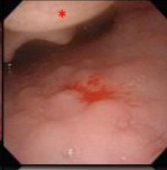




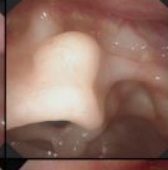




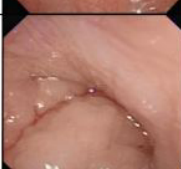



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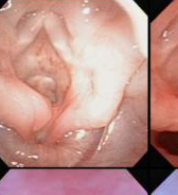








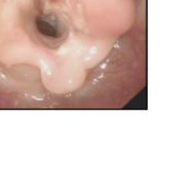
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Oxygen flow rate	Pharyngeal oxygen (1.0 L/kg/minute, maximal 10 L/min)			
SPI duration (sec.)	0	1.0	3.0	5.0
IPS PIP (cmH ₂ O)	4.1 (3.3)*	21.9 (7.0)*	42.2 (12.3)*	65.5 (18.5)*
Lumen expansion score	1.1 (0.2)*	2.5 (0.3)*	3.5 (0.5)*	4.5 (0.2)*
Pharyngo-malacia				
Uvula cyst*				
Epiglottis cyst (anterior aspect)				
Vallecular cyst				
Supraglottic collapse				

#, images of each row take at same location of same infant. *, p< 0.001.

Oxygen flow rate	Pharyngeal oxygen (1.0 L/kg/minute, maximal 10 L/min)			
SPI duration (sec.)	0	1.0	3.0	5.0
IPS PIP (cmH ₂ O)	4.1 (3.3)*	21.9 (7.0)*	42.2 (12.3)*	65.5 (18.5)*
Lumen expansion score	1.1 (0.2)*	2.5 (0.3)*	3.5 (0.5)*	4.5 (0.2)*
Laryngomalacia				
Laryngeal cleft				
Vocal cord palsy and thickness				
Glottis malacia				

#, images of each row take at same location of same infant. *, $p < 0.001$.