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The Effects of Endotracheal Tube and i-gel® Supraglottic Airway Device on Respiratory Impedance: A Prospective Observational Study

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Abstract

Background: The forced oscillation technique (FOT) is a non-invasive means of measuring respiratory resistance and reactance. We tested our hypothesis that endotracheal intubation would cause more substantial preoperative increases in FOT parameters than a supraglottic airway device (SGD).

Methods: Forty patients requiring general anesthesia and mechanical ventilation for transurethral bladder tumor resection underwent spirometry the day before surgery. Forced oscillation was measured using a MostGraph-01 device the day before surgery and immediately after removal of the airway adjunct. Changes in respiratory resistance and reactance were compared between those intubated and those who used SGD.

Results: The trachea was intubated in 23 patients and SGD was used in the remaining 17 patients. Both airway adjuncts caused significant increases in preoperative respiratory resistance and reactance; however, the magnitude of the changes was significantly greater in the intubated patients.

Conclusions: The SGD appears to cause less pulmonary injury than tracheal intubation. Further study is needed to illuminate the influence of mechanical ventilation, and longer-term consequences and clinical significance of the changes we found in this study. Spontaneous ventilation through an SGD may be preferable in patients with severe respiratory disease.

Keywords: Forced Oscillation Technique, Respiratory Impedance, Endotracheal Intubation, Supraglottic Airway Device

1. Background

The forced oscillation technique (FOT) is a non-invasive method of measuring respiratory impedance, which is defined as the spectral relationship between pressure and airflow (1). Impedance is determined by two components: respiratory resistance (Rrs) and respiratory reactance (Xrs); the latter reflects the elastic and inertial properties of the lung. FOT measurement requires no special breathing maneuvers or interference with normal breathing (2). The clinical use of FOT has progressed as more FOT devices have become commercially available, such as the MostGraph-01® impulse oscillation system (Chest MI, Tokyo, Japan) (3). The evidence base for the clinical utility of FOT has expanded, especially for the evaluation and management of obstructive pulmonary diseases. Nonetheless, the changes in respiratory impedance that occur as a result of airway inflammation and pulmonary function are not fully understood. The Rrs measured at 5 Hz (R5) and 20 Hz (R20) are representative of low and high frequency resistances, respectively. The difference between R5 and R20 (R5 - R20) is referred to as the frequency dependence of Rrs. The reactance at 5 Hz (X5) reflects the combined effects of tissue elastance and inertia, although at this lower frequency, the effect of tissue elastance would be predominant. Therefore, X5 reflects the elastic recoil of the peripheral airways. The resonant frequency (Fres) is the frequency at which respiratory reactance equals 0 $cmH_2O/L/s$. The Fres marks the transition from capacitative dominance at low frequencies to inertial dominance at high frequencies. The area of low reactance (ALX) is the area created by three lines (those of frequency 5 Hz, Xrs = 0 $cmH_2O/L/s$, and the Xrs curve). The ALX is a useful index associated with respiratory compliance and therefore, reflects the patency of the small airways. The ALX is a single quantity that reflects changes in the degree of peripheral airway obstruction and closely correlates with R5 - R20 (4). We examined the changes in respiratory impedance after endotracheal intubation or the use of a supraglottic airway device (SGD) in mechanically ventilated patients. We hypothesized that endotracheal intubation would bring about more substantial preoperative increases in respiratory resistance and reactance than using SGD.

2. Methods

This prospective study was approved by the ethics committee of Osaka Medical College, Japan (approval reference

number 1252) and conducted in accordance with the declaration of Helsinki (1964). Written informed consent was obtained from all participants. The study was registered at the Japan medical association center for clinical trials on September 2nd, 2013 (reference JMA-IIA00136). The principal investigator was Junko Nakahira. We enrolled 40 patients with American Society of Anesthesiologists physical status classification 1 or 2 undergoing general anesthesia for transurethral resection of bladder tumor in a 5-month period in 2014. Potential participants underwent spirometry without bronchodilation. We excluded those with a history or symptoms of asthma, such as coughing or wheezing at rest, patients diagnosed with chronic obstructive pulmonary disease according to the global initiative for chronic obstructive lung disease guidelines (5), and patients who had taken oral steroids or had had respiratory tract infection or exacerbation within the previous 3 months.

Spirometry and FOT were performed the day before surgery. On the day of surgery, anesthesia was induced with intravenous propofol 2 mg/kg, rocuronium 0.8 mg/kg and an infusion of remifentanil at 0.5 μg/kg/min. The urologist determined the need for neuromuscular blockade during surgery according to the location of the tumor. Neuromuscular blockade was applied to patients with tumors located on the lateral bladder wall to avoid stimulation of the obturator nerve. The application of neuromuscular blockade was not needed for patients with tumors located at other sites. A cuffed endotracheal tube (Portex Soft Seal®, Smiths Medical, Kent, UK) of internal diameter 7.0 mm for women and 8.0 mm for men was placed in patients who needed a neuromuscular blocker; a supraglottic device (i-gel®, Intersurgical, Wokingham, UK) of size 3 for women or size 4 for men was inserted in the remainder. Anesthesia was maintained with inhaled sevoflurane 1.0% - 1.5% and intravenous remifentanil 0.25 - 0.5 μg/kg/min in a fraction of inspired oxygen (FiO_2) of 0.4. All patients in both groups were mechanically ventilated with volume controlled ventilation at 8 mL/kg predicted body weight without positive end-expiratory pressure. For postoperative analgesia, acetaminophen 1,000 mg was administered intravenously at the end of the surgery. Anesthetic agents were stopped immediately after the operation. After patients were breathing spontaneously, the FiO_2 was increased to 1.0, and sugammadex 1.5 mg/kg was administered intravenously to those who had received rocuronium. Extubation or removal of the supraglottic device occurred when the patients responded to their name, body temperature was > 35.5°C, peripheral oxygen saturation was > 97%, and their breathing became stable at a rate of 10 - 20/min. In those whose tracheas had been intubated, open suctioning with 14-Fr catheter at -20 kPa was performed through the endotracheal tube to remove sputum, but the catheter tip was not advanced into the bronchus. After the removal of the airway adjunct, oxygen was administered by facemask at a rate of 4 L/min for 4 hours. All participants were encouraged to walk on the first postoperative day.

Forced oscillation was measured according to standard techniques using a MostGraph-01 device (6, 7) the day before surgery and after removal of the airway adjunct. The measurements of postoperative respiratory impedance were taken after the patients were extubated while lying on the operation table and before they were sent back to their ward. Rrs and Xrs were recorded in patients in the sitting position under normal breathing conditions through a mouthpiece while they were wearing a nose clip. To minimize artifacts from vibrations, an investigator supported the patient's cheeks. For preoperative measurements, patients sat unsupported on a chair. Postoperative measurements were recorded on the operating table with the patients sitting at 45 - 50° with their legs straight, before they were sent back to the ward.

2.1. Sample Size Calculation

The sample size was determined based on our preliminary study of postoperative R5 on five patients in each group. In that study, mean postoperative R5 in those undergoing anesthesia with endotracheal intubation was 6.43 ($\pm$ standard deviation, SD 3.12 $cmH_2O/L/s$) compared to 4.16 $\pm$ 0.62 $cmH_2O/L/s$ in those undergoing anesthesia with an SGD. The sample size required to obtain 80% power at α error level of 5% was calculated to be 15 subjects per group. We enrolled 20 patients per group to account for possible difficulties with the FOT immediately after extubation that could lead to exclusion from the study.

2.2. Statistical Analysis

All results are presented as mean $\pm$ SD. For patients' preoperative demographic and clinical characteristics, the χ^2 test or Fisher's exact test was used to compare categorical data as appropriate. The distribution of continuous data was assessed using the Shapiro-Wilks normality test to determine whether parametric or non-parametric statistical techniques would be required for analysis. Guided by the normality test, Student's t-test with unequal variance (Welch's method) was used to compare preoperative parameters, and the Wilcoxon signed-rank test was used to compare preoperative and postoperative parameters. All statistical analyses except for analysis of covariance (ANCOVA) were performed using GraphPad Prism 5 software (GraphPad Software, La Jolla, CA); ANCOVA was performed using SPSS Statistics (version 22, IBM, Armonk, NY). Statistical significance was defined as $P < 0.05$.

2.3. Consent

Written informed consent for publication of this research article was obtained from all participants in this study.

3. Results

Of the 40 participants, the trachea was intubated in 23 (ET group) and an SGD was used in the remaining 17 (SGD group). There was no significant between-group difference in demographic or preoperative clinical characteristics (Table 1). None of the patients required endotracheal suction during mechanical ventilation, and patient-ventilator asynchrony was not observed. Endotracheal suction was performed in all patients in the ET group just before extubation. None of the patients needed a bronchodilator or expectorant agent, and none had intra- or post-operative respiratory failure or airway complications. Three patients in whom an SGD was used ultimately required endotracheal intubation.

Table 1. Patients' Preoperative Demographic and Clinical Characteristics[a]

	ET (n = 23)	SGD (n = 17)	P Value
Female, %	0 (0.0)	3 (17.6)	0.069
Current smoker, %	6 (26.1)	2 (14.3)	0.438
Age, y	65 ± 13	60 ± 13	0.222
Height, cm	161.3 ± 21.7	165.3 ± 7.7	0.859
Weight, kg	68.1 ± 22.9	65.7 ± 16.1	0.621
Body surface area, m^2	1.7 ± 0.1	1.7 ± 0.2	0.707
VC, L	3.5 ± 0.7	3.6 ± 0.8	0.833
VC, % predicted	104.0 ± 16.7	108.8 ± 16.2	0.963
FVC, L	3.4 ± 0.7	3.4 ± 0.8	0.985
FVC, % predicted	101.7 ± 17.5	105.7 ± 14.3	0.724
FEV1.0, L	2.5 ± 0.6	2.7 ± 0.6	0.986
FEV1.0, % predicted	91.7 ± 16.3	97.5 ± 13.3	0.762
FEV1.0, %	74.9 ± 7.6	78.0 ± 5.7	0.817
FEV1.0/FVC × 100, %	76.2 ± 15.0	82.5 ± 12.3	0.691

Abbreviations: ET, endotracheal tube; FEV1.0, forced expiratory volume in the first second; FVC, forced vital capacity; SGD, supraglottic airway device; VC, vital capacity.
[a]Values are expressed as mean ± standard deviation or No. (%).

There were no significant differences in preoperative FOT parameters between the groups. Postoperatively, R5, R20, R5-R20, and ALX were significantly higher than baseline in the ET group (P = 0.002, 0.004, 0.015, and 0.035, respectively with Student's t-test with unequal variances, P = 0.002, 0.002, 0.025, and 0.019 with ANCOVA; Table 2). In each group, postoperative R5, R20, R5-R20, Fres, and ALX increased significantly, and X5 decreased significantly ($P < 0.005$ for all). Preoperative changes in all FOT parameters of respiratory resistance and reactance were significantly greater in the ET group than the SGD group.

4. Discussion

We found that endotracheal intubation had a greater influence on Rrs (R5, R20, and R5-R20) and ALX than using supraglottic airway device. Although the normal limits for Rrs have not been established, Kurosawa suggested that R5 >3 $cmH_2O/L/s$ is abnormally high (8). The abnormally increased Rrs, which we detected after airway management including mechanical ventilation and extubation, might reflect narrowing or obstruction of the trachea, bronchi or bronchioles. Generally, edema of the vocal folds does not occur when an SGD is used, and tracheal suctioning is not required. The SGD, therefore, would not be expected to adversely influence the anatomy or function of the trachea or bronchi. Other possible explanations for the significant postoperative deterioration in all FOT parameters are proximal and peripheral airway edema caused by excessive infusion of intravenous fluids or the lithotomy position, and sputum-, asthma- and/or ventilator-induced lung injury. The present study does not allow us to differentiate between these possible causes.

Respiratory reactance generally reflects parenchymal integrity, but may be difficult to interpret. Xrs reflects the elastic and inertial properties of the lung, while Fres and ALX are somewhat abstract parameters. The normal range for Fres is approximately 6 - 11 Hz, and is generally < 0.33 kPa/L (3.37 cmH_2O/L) for ALX (9). In this study, preoperative changes in all FOT parameters were influenced by anesthesia to a certain extent, independent of airway adjunct.

It has been reported that preoperative FOT measurements and spirometry parameters improve in children with cystic fibrosis undergoing general anesthesia breathing spontaneously through an SGD for insertion of a peripheral central venous catheter (10). Given these findings, we believe that spontaneous breathing likely explains these improvements. We use remifentanil routinely, so spontaneous breathing tends not to occur in the SGD group. It seems likely that spontaneous breathing through an SGD is the best anesthetic strategy for patients with severe respiratory disease, although further research is needed.

Our study had several limitations. First, it was not randomized; patients were allocated to each group on the basis of surgical need for neuromuscular blockade. Second, perioperative fluid balance might have influenced the outcomes, but it was not possible to make an accurate as-

Table 2. Preoperative Outcomes in the Endotracheal Intubation and Supraglottic Airway Device Groups[a,b,c]

	ET (n = 23)	SGD (n = 17)	P Value	95% CI
Duration of anesthesia, min	90 ± 19	81 ± 22	0.757	-43.32 to 33.60
Duration of surgery, min	46 ± 15	38 ± 17	0.822	-35.10 to 29.16
Infusion fluid volume, mL	600 ± 109	524 ± 125	0.052	-153.70 to 0.73
Preoperative R5, $cmH_2O/L/s$	2.30 ± 0.8	2.34 ± 0.61	0.863	-0.50 to 0.42
Postoperative R5, $cmH_2O/L/s$	5.64 ± 2.48	3.68 ± 1.20	0.002	0.74 to 3.17
Change in R5, $cmH_2O/L/s$	3.33 ± 2.37	1.34 ± 0.87	< 0.001	0.90 to 3.09
Result of ANCOVA in R5			0.002	
Preoperative R20, $cmH_2O/L/s$	1.73 ± 0.50	1.83 ± 0.39	0.465	-0.39 to 0.18
Postoperative R20, $cmH_2O/L/s$	4.17 ± 1.91	2.76 ± 0.88	0.004	0.49 to 2.33
Change in R20, $cmH_2O/L/s$	2.45 ± 1.78	0.93 ± 0.68	< 0.001	0.69 to 2.35
Result of ANCOVA in R20			0.002	
Preoperative R5-R20, $cmH_2O/L/s$	0.57±0.40	0.51 ± 0.38	0.604	-0.19 to 0.31
Postoperative R5-R20, $cmH_2O/L/s$	1.46±0.81	0.92 ± 0.52	0.015	0.11 to 0.97
Change in R5-R20, $cmH_2O/L/s$	0.89 ± 0.82	0.41 ± 0.39	0.020	0.08 to 0.86
Result of ANCOVA in R5-R20			0.025	
Preoperative X5, $cmH_2O/L/s$	-0.48 ± 0.38	-0.54 ± 0.46	0.625	-0.21 to 0.35
Postoperative X5, $cmH_2O/L/s$	-2.22 ± 1.55	-1.47 ± 1.01	0.071	-1.58 to 0.07
Change in X5, $cmH_2O/L/s$	-1.74 ± 1.49	-0.92 ± 0.90	0.037	-1.59 to -0.05
Result of ANCOVA in X5			0.053	
Preoperative Fres, Hz	8.83 ± 2.93	8.69 ± 3.43	0.894	-1.97 to 2.24
Postoperative Fres, Hz	14.3 ± 4.89	11.8 ± 3.93	0.089	-0.39 to 5.26
Change in Fres, Hz	5.44 ± 4.28	3.15 ± 2.56	0.042	0.09 to 4.50
Result of ANCOVA in Fres			0.056	
Preoperative ALX, cmH_2O/L	2.22 ± 2.10	2.61 ± 2.86	0.630	-2.08 to 1.28
Postoperative ALX cmH_2O/L	15.48 ± 11.97	8.59 ± 7.82	0.035	0.52 to 13.23
Change in ALX, cmH_2O/L	13.24 ± 11.39	5.97 ± 6.67	0.016	1.44 to 13.10
Result of ANCOVA in ALX			0.019	

Abbreviations: ALX, area of low respiratory reactance; ANCOVA, analysis of covariance; CI, confidence interval; ET, endotracheal tube; Fres, resonance frequency; R5, respiratory resistance at 5 Hz; R20, respiratory resistance at 20 Hz; SGD, supraglottic airway device; X5, respiratory reactance at 5 Hz.
[a] Values are expressed as mean ± standard deviation or No. (%).
[b] Change represents postoperative value minus preoperative value.
[c] P values were determined from the analysis of covariance comparing pre- and post-operative values between the groups.

sessment of fluid input due to the use of bladder irrigation fluid during transurethral resection. Finally, our findings may have been influenced by differences in the proportions of smokers between the groups, or differences in other unmeasured variables, such as the requirement for intraoperative tracheal suctioning, postoperative pain, and difficulty in holding the mouthpiece or discomfort caused by a urethral catheter.

4.1. Conclusions

We found that endotracheal intubation and SGD insertion both influenced respiratory resistance and reactance, but endotracheal intubation had a greater influence on all FOT parameters. The extent to which these changes might influence clinical outcomes for patients requires further study.

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None

Footnotes

Authors' Contribution: Shoko Nakano collected the data and wrote the manuscript. Junko Nakahira helped write the manuscript and edit the tables. Yosuke Kuzukawa helped write the manuscript. Toshiyuki Sawai assisted with the literature review. Toshiaki Minami revised and approved the manuscript. All authors read and approved the final manuscript.

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References

1. Oostveen E, MacLeod D, Lorino H, Farre R, Hantos Z, Desager K, et al. The forced oscillation technique in clinical practice: methodology, recommendations and future developments. *Eur Respir J.* 2003;**22**(6):1026–41. [PubMed: 14680096].
2. Shirai T, Mori K, Mikamo M, Shishido Y, Akita T, Morita S, et al. Respiratory mechanics and peripheral airway inflammation and dysfunction in asthma. *Clin Exp Allergy.* 2013;**43**(5):521–6. doi: 10.1111/cea.12083. [PubMed: 23600542].
3. Hellinckx J, Cauberghs M, De Boeck K, Demedts M. Evaluation of impulse oscillation system: comparison with forced oscillation technique and body plethysmography. *Eur Respir J.* 2001;**18**(3):564–70. [PubMed: 11589356].
4. Nakano S, Nakahira J, Sawai T, Kuzukawa Y, Ishio J, Minami T. Perioperative evaluation of respiratory impedance using the forced oscillation technique: a prospective observational study. *BMC Anesthesiol.* 2016;**16**(1):32. doi: 10.1186/s12871-016-0197-y. [PubMed: 27389091].
5. Global Initiative for Chronic Obstructive Lung Disease. . Global Strategy for the Diagnosis, Management, and Prevention of Chronic Obstructive Pulmonary Disease-2016. ; 2016.
6. Kuzukawa Y, Nakahira J, Sawai T, Minami T. A Perioperative Evaluation of Respiratory Mechanics Using the Forced Oscillation Technique. *Anesth Analg.* 2015;**121**(5):1202–6. doi: 10.1213/ANE.0000000000000720. [PubMed: 25839180].
7. Ohishi J, Kurosawa H, Ogawa H, Irokawa T, Hida W, Kohzuki M. Application of impulse oscillometry for within-breath analysis in patients with chronic obstructive pulmonary disease: pilot study. *BMJ Open.* 2011;**1**(2):e000184. doi: 10.1136/bmjopen-2011-000184. [PubMed: 22021880].
8. Kurosawa H. MostGraph, development and application. ; 2010. pp. 2940–7.
9. Bickel S, Popler J, Lesnick B, Eid N. Impulse oscillometry: interpretation and practical applications. *Chest.* 2014;**146**(3):841–7. doi: 10.1378/chest.13-1875. [PubMed: 25180727].
10. Pandit C, Valentin R, De Lima J, Robinson P, Fitzgerald D, van Asperen P, et al. Effect of general anesthesia on pulmonary function and clinical status on children with cystic fibrosis. *Paediatr Anaesth.* 2014;**24**(2):164–9. doi: 10.1111/pan.12256. [PubMed: 24004189].