

Effects of Muscle Relaxants on Mask Ventilation in Anesthetized Persons with Normal Upper Airway Anatomy

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ABSTRACT

Background: Recent studies suggest advantages of muscle relaxants for facemask ventilation. However, direct effects of muscle relaxants on mask ventilation remain unclear because these studies did not control mechanical factors influencing ventilation. We tested a hypothesis that muscle relaxants, either rocuronium or succinylcholine, improve mask ventilation.

Methods: In anesthetized adult persons with normal upper airway anatomy, tidal volumes during facemask ventilation were measured while maintaining the neutral head and mandible positions and the airway pressures of a ventilator before and during muscle paralysis induced by either rocuronium ($n = 14$) or succinylcholine ($n = 17$). Tidal volumes of oral and nasal airway routes were separately measured with a custom-made oronasal portioning full facemask. Behavior of the oral airway was observed by an endoscope in six additional subjects receiving succinylcholine.

Results: Total, oral, and nasal tidal volumes did not significantly change at complete muscle paralysis with rocuronium. In contrast, succinylcholine significantly increased total tidal volumes at 60 s after its administration (mean \pm SD; 4.2 ± 2.1 vs. 5.4 ± 2.6 ml/kg, $P = 0.02$) because of increases of ventilation through both airway routes. Abrupt tidal volume increase occurred more through oral airway route than nasal route. Dila-

What We Already Know about This Topic

- Muscle relaxants have been reported to improve facemask ventilation, but previous studies have not controlled for changes in head and mandible position and have not measured the contribution of oral and nasal ventilation

What This Article Tells Us That Is New

- In 31 subjects with normal upper airway anatomy and head and mandible position held fixed during pressure-controlled ventilation, facemask ventilation was not worsened by rocuronium, but was improved by succinylcholine, especially at the time of fasciculations
- The increase in airflow after succinylcholine was primarily because of an increase in oral ventilation

tion of the space at the isthmus of the fauces was endoscopically observed during pharyngeal fasciculation in all six subjects.

Conclusions: Rocuronium did not deteriorate facemask ventilation, and it was improved after succinylcholine administration in association with airway dilation during pharyngeal fasciculation. This effect continued to a lesser degree after resolution of the fasciculation.

ADEQUATE facemask ventilation (FMV) is the most fundamental and important skill for safe airway management during anesthesia induction as well as successful resuscitation.¹ Optimal head, mandible, and body positions improve the upper airway patency and FMV.^{2,3,4} Nevertheless, difficult or impos-

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◆ This article is accompanied by an Editorial View. Please see: Richardson MG, Litman RS: Ventilation before paralysis: Crossing the rubicon, slowly. ANESTHESIOLOGY 2012; 117: 456-8.

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sible FMV accompanied with difficult tracheal intubation during anesthesia induction occurs in 0.4% of adult anesthesia cases, possibly leading to life-threatening complications.⁵

Because of possible development of such airway catastrophes, muscle relaxants have long been recommended to be administered after confirming adequate FMV without scientific validation of this principal.^{6,7} On the contrary, no tidal volume changes during FMV⁸ or improvement of FMV difficulty⁹ after administration of rocuronium were reported. Furthermore, succinylcholine improved FMV even in patients with grade III and IV FMV difficulty.^{10,11,12} Regrettably, factors influencing airway patency, such as head and mandible positions and airway pressure during FMV, were not controlled in these studies, and it is difficult to elucidate actual contribution of muscle relaxants to the FMV improvement. In contrast to progressive muscle paralysis following rocuronium administration, all striate muscles contract during the process of succinylcholine-induced muscle paralysis, and upper airway patency and thoracic compliance possibly dynamically change. Therefore, succinylcholine may differently influence FMV from rocuronium because of the different pharmacological actions on the muscles.

Both oral and nasal airway routes are usually used during FMV. Safar previously demonstrated that oral airway ventilation was more effective than nasal airway ventilation, whereas recent studies suggest advantage of nasal mask ventilation over combined oronasal mask ventilation.^{13,14} Because of the controversial results, it would be interesting to know relative contribution of each airway route to possible change of FMV efficacy during muscle paralysis.

Accordingly, we hypothesized that muscle relaxants improve FMV in anesthetized subjects. The primary hypothesis was tested by comparing tidal volume during pressure-controlled ventilation while maintaining the same head and mandible positions, and ventilator settings before and after administration of either rocuronium or succinylcholine. Airflow through oral and nasal airway routes was separately measured using an oronasal partitioning full facemask for determining relative contribution of each airway route to the tidal volume changes.

Materials and Methods

Subjects

The investigation was approved by the institutional Ethics Committee (Graduate School of Medicine, Chiba University, Chiba, Japan). Informed consent was obtained from all subjects after the aim and potential risks of the study were fully explained to each.

Forty-two consecutive adult patients undergoing elective surgeries during general anesthesia participated in the tidal volume measurement study. We did not invite patients with severe comorbidities, allergies for muscle relaxants, upper airway structural abnormalities, difficult mask fit, full dentures, and suspected difficult mask ventilation. In particular, patients with more than two symptoms of the Chung STOP questionnaire for obstructive sleep apnea were uninvited.¹⁵

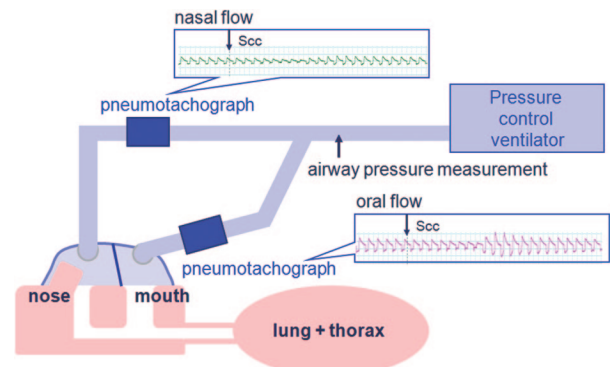


Fig. 1. The experimental setting. Scc = succinylcholine.

Participants were allocated either to receive rocuronium (rocuronium group) or succinylcholine (succinylcholine group) during anesthesia induction so that age, gender, and body mass index were matched between the groups. Complete randomization was not planned because of impossibility of blind administration of the muscle relaxants, and the primary purpose of this study is not to compare the muscle relaxants. In addition to the tidal volume measurement study, we performed endoscopic study in eight additional subjects to explore behavior of pharyngeal airway during the process of succinylcholine-induced muscle paralysis.

Preparation of the Subjects and Measurements of Ventilatory Changes during Muscle Paralysis

After oxygenation with oxygen for 3 min, anesthesia was induced and maintained by continuous infusion of propofol (target-controlled infusion: 3–4.5 $\mu\text{g}/\text{ml}$) following fentanyl administration. We administered 100 μg of fentanyl unless body weight did not exceed 80 kg, and 150 μg fentanyl for heavier subjects. Pulse oximetry, an electrocardiogram, neuromuscular function with acceleromyography (TOF-Watch; Organon Ireland Ltd., Dublin, Ireland) (rocuronium group), and the bispectral index (BIS[®] monitor, Aspect Medical Systems, Newton, MA) were continuously monitored, and blood pressure was noninvasively measured every 5 min. Subjects were initially hyperventilated with an anesthetic machine targeting the end-tidal carbon dioxide concentration less than 35 mmHg. After confirming cessation of spontaneous breathing, a custom-made partitioned facemask separating oral and nasal passages was tightly fitted with an elastic facemask band for eliminating air leakage through the facemask. Bite was kept open to 15 mm by a mouthpiece. Airflows of both oral and nasal passages were independently measured by Fleisch no. 2 pneumotachographs (4719; Hans Rudolph, Kansas City, MO) and differential pressure transducers (TP-603T; Nihon Koden, Tokyo, Japan) placed at each breathing branch and displayed on a computer screen together with their integrated signals, *i.e.*, expiratory tidal volumes (PowerLab; ADInstruments, Bella Vista, Australia) and airway pressure (23NB 005G; ICsensors, San Jose, CA) (Fig. 1). Airleak of the airway passages was checked by the

pneumotachographs and reduced less than 0.1 l/s while the subjects were ventilated using a bilevel positive-pressure ventilator (BiPAP; Respironics, Murrysville, PA). The anesthesiologist held the mask so that the airleak surrounding the mask was prevented. Respiratory frequency and duty ratio were fixed to be 16/min and 0.33. The initial levels of positive inspiratory (14 cm H₂O) and expiratory pressures (3 cm H₂O) were manipulated to achieve at least 2 ml/kg tidal volume in neutral head and mandible position. Peak inspiratory pressure was set at less than 18 cm H₂O to avoid possible gastric gas insufflation. Subjects were excluded from the study if the targeted tidal volume was unable to be achieved with the ventilator settings. After confirming stable ventilation, the respiratory variables were continuously measured, at least, until complete paralysis (no response to train-of-four stimulations) after rocuronium injection (0.6 mg/kg) or 60 s after succinylcholine injection (1 mg/kg) and stored for later analyses. Resolution of fasciculations following succinylcholine injection was visually confirmed. The measurements were performed while maintaining the neutral head and mandible position in supine posture and the ventilator settings.

Endoscopic Observation of the Oral Airway Passage

In addition to the airflow measurements described above, behavior of the oral airway was continuously observed by an endoscope (FB10X; Pentax, Tokyo, Japan; 3-mm OD) inserted into the oral cavity through a self-sealing diaphragm of the elbow connector on the mask and the mouthpiece. A closed-circuit camera (ETV8; Nisco, Saitama, Japan) was connected to the endoscope, and the pharyngeal images were recorded on a videotape. We specifically focused on the airway patency at the isthmus of the fauces, the narrowest segment along the oral airway route, structurally bounded superiorly by the soft palate, laterally by the palatoglossal arches, and inferiorly by the tongue. Both the endoscopic image of pharyngeal airway and the computer screen displaying airflow tracings were displayed on a split-screen (MVS-44C; Ikegami Tsushinki, Tokyo, Japan) and recorded on a videotape for correlation of the pharyngeal airway behavior with the tidal volume changes.

Data Analyses

The baseline of the airflow signals was corrected by assuming the zero flow at the beginning of inspiration. Tidal volume of each airway passage was calculated by integration of the corrected expiratory airflow signal. Mean tidal volumes of five successive positive-pressure breaths immediately before administration of the muscle relaxants (control) were compared with those at confirmation of complete paralysis after rocuronium injection or 60 s after succinylcholine injection (paralysis) for testing our primary hypothesis.¹⁶ Mean tidal volumes of all breaths during the interval between the injection of the muscle relaxants and confirmation of complete paralysis after rocuronium injection or 60 s after succinylcholine injection (interval) were also calculated and compared with the control tidal volumes.

Statistical Analyses

Since there are no tidal volume data during mask ventilation available for the sample size calculation, we used the tidal volume data (3.8 ± 1.8 ml/kg) obtained from the initial 10 subjects. Appropriate sample size was determined to be 14 or more for detecting a 50% increase in tidal volume during muscle paralysis assuming $\alpha = 0.05$ (two tailed) and 80% power (SigmaStat 3.11; Systat Software Inc., Point Richmond, CA). All values are expressed by mean \pm SD. Paired Student *t* test was used to compare respiratory variables before and during muscle paralysis, and between airway routes. Unpaired Student *t* test was used for comparison of the background variables between the groups. *P* value < 0.05 (two tailed) was considered significant.

Results

In the tidal volume measurement study, measurements were performed without calibrations in four subjects (three in the rocuronium group, one in the succinylcholine group). Tidal volumes during control measurements were unstable in three subjects (one in the rocuronium group, two in the succinylcholine group). Head was not in the neutral head position in a subject receiving succinylcholine. Ventilation was inadequate

Table 1. Patients' Characteristics, Anesthetics Used for Anesthesia Induction and Ventilator Settings

Patients' Characteristics	Rocuronium Study	Succinylcholine Study	Endoscope Study
Number of subjects	14	17	6
Age (years)	48 \pm 14	54 \pm 10	55 \pm 10
Male/female	4/10	3/14	0/6
Body mass index (kg/m ²)	24 \pm 5	24 \pm 4	22 \pm 4
Fentanyl (μ g/kg)	1.8 \pm 0.4	1.8 \pm 0.3	2.0 \pm 0.3
Propofol (μ g/ml)	3.9 \pm 0.5	4.0 \pm 0.5	4.0 \pm 0.3
Succinylcholine (mg/kg)	—	1.0 \pm 0.1	1.0 \pm 0.1
Rocuronium (mg/kg)	0.7 \pm 0.2	—	—
Respiratory rate (/min)	16	16	16
Peak inspiratory pressure (cm H ₂ O)	15.3 \pm 0.2	14.2 \pm 1.2	16.0 \pm 0
Expiratory pressure (cm H ₂ O)	4.6 \pm 0.9	3.9 \pm 1.1	4.0 \pm 0

Values are mean \pm SD. No statistically significant differences were detected between the study groups.

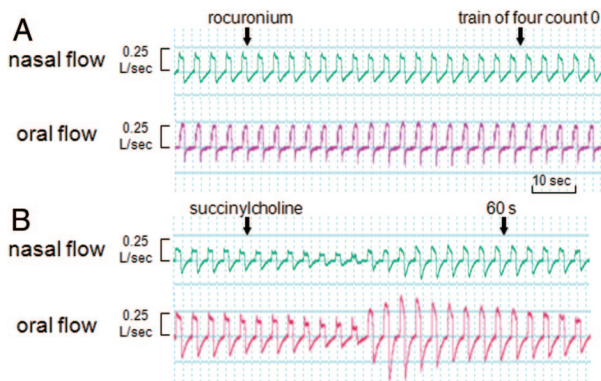


Fig. 2. Typical changes of oral and nasal airflows following intravenous injection of rocuronium (A) and succinylcholine (B). Note the abrupt increase of airflow, particularly through oral airway route during the process of succinylcholine-induced muscle paralysis.

quate without airway interventions in four subjects (rocuronium group). Therefore, the study was completed in 14 subjects of rocuronium group and 17 subjects of succinylcholine group (table 1). Background patients' anthropometric, anesthetic, and ventilator settings did not differ between the rocuronium and succinylcholine groups. In the endoscopic study, we successfully observed pharyngeal behavior in six of the eight participants, whereas ventilation was unstable in one subject and the endoscopic images was lost during fasciculation in another subject. Anthropometric variables did not differ between the succinylcholine subjects and endoscopic subjects (table 1).

Ventilatory Changes in Response to Rocuronium or Succinylcholine Administration

Typical changes of oral and nasal airflows following rocuronium or succinylcholine injection are illustrated in figure 2. Rocuronium injection did not change either oral or nasal airflows even at loss of train-of-four responses (fig. 2A). In contrast, after succinylcholine injection, airflows through both airway routes initially decreased, and then abruptly and significantly increased particularly through oral airway route

(fig. 2B). Thereafter, the airflows gradually decreased but remained increased even after complete paralysis.

Table 2 summarizes changes of tidal volumes during FMV before and after injection of the muscle relaxants while maintaining the neutral head and mandible positions in supine posture and the ventilator settings. Total, oral, and nasal tidal volumes before administration of the muscle relaxants did not differ between the groups. Both oral and nasal airway routes were used for achieving the total tidal volume whereas their contributions varied among the subjects. No statistically significant changes of the tidal volumes occurred after rocuronium injection. In contrast, the mean oral tidal volumes during the paralyzing process following succinylcholine administration significantly increased, whereas the total tidal volumes did not significantly increase because of tendency of reduction of the nasal tidal volumes. At 60 s after succinylcholine injection, the total tidal volume significantly increased by approximately 30% because of increase of both oral and nasal tidal volumes, whereas the tidal volume increased more in the oral route (64%) than nasal route (15%). The hypothesis of this study was supported for succinylcholine administration.

Changes of Ventilation and Airway Patency during Succinylcholine-induced Paralysis

Because of the dynamic tidal volume changes during process of the succinylcholine paralysis, we further measured onset of sudden change of airflow and time of minimal and maximal tidal volume in addition to the minimum and maximum tidal volumes in each airway route. Table 3 and figure 3 summarize changes of ventilatory parameters after succinylcholine injection. Onset of sudden changes (either increase or decrease) of airflow after succinylcholine injection was 23 s on average and did not differ between oral and nasal airway routes. The pattern of tidal volume changes was biphasic for both airway routes, as illustrated in figure 3. Although the airflow initially decreased at both airway routes, nasal tidal volumes decreased significantly more than oral tidal volume, as evidenced by significant differences of both tidal volume ratios and absolute tidal volumes between the airway routes.

Table 2. Effects of Muscle Relaxants on Ventilatory Volume

	Control	Interval (<i>P</i> Value)	Paralysis (<i>P</i> Value)
Rocuronium Study (n = 14): Tidal Volume			
Nasal route (ml/kg)	1.9 ± 1.8	2.1 ± 2.1 (0.30)	1.9 ± 2.1 (0.92)
Oral route (ml/kg)	1.8 ± 1.3	1.8 ± 1.5 (0.96)	1.7 ± 1.7 (0.69)
Total airway (ml/kg)	3.8 ± 1.7	3.9 ± 2.2 (0.65)	3.7 ± 2.5 (0.83)
Succinylcholine Study (n = 17): Tidal Volume			
Nasal route (ml/kg)	2.7 ± 2.6	2.3 ± 2.0 (0.14)	3.1 ± 2.7 (0.04)
Oral route (ml/kg)	1.4 ± 1.1	2.1 ± 1.5 (0.002)	2.3 ± 2.1 (0.04)
Total airway (ml/kg)	4.2 ± 2.1	4.3 ± 1.7 (0.39)	5.4 ± 2.6 (0.02)

Control was mean tidal volumes of five successive breaths immediately before administration of the muscle relaxants; interval was mean tidal volumes of all breaths during the interval between the injection of the muscle relaxants and confirmation of complete paralysis after rocuronium injection or 60 s after succinylcholine injection; and paralysis was mean tidal volumes of five successive breaths at confirmation of complete paralysis after rocuronium injection or 60 s after succinylcholine injection. Values are mean ± SD. The values in the parentheses are the *P* values obtained by comparing to control conditions with paired Student *t* test.

Table 3. Changes of Ventilation during the Interval of Succinylcholine-induced Paralysis (n = 17)

Tidal Volume Times	Nasal Route	Oral Route	P Value
Onset of tidal volume change (sec)	23 ± 8.4	23 ± 8.1	0.98
Time to minimum tidal volume (sec)	29 ± 9	33 ± 12	0.30
Minimum tidal volume (ml/kg)	0.34 ± 0.42	1.0 ± 1.0	0.01
Tidal volume ratio: minimum/control	0.33 ± 0.39	0.74 ± 0.49	0.01
Time to maximum tidal volume (sec)	50 ± 12	35 ± 11	0.001
Maximum tidal volume (ml/kg)	4.0 ± 3.1	4.0 ± 2.7	0.97
Tidal volume ratio: maximum/control	2.0 ± 1.5	3.7 ± 2.6	0.02

Values are mean ± SD. *P* values were obtained by comparing variables between the airway routes with paired Student *t* test.

The maximum tidal volumes were achieved earlier in the oral airway route (35 s) than the nasal airway route (50 s). Although the achieved maximum tidal volumes after succinylcholine injection did not differ between the airway routes, ratios of the maximum tidal volumes to those of control condition were significantly greater in the oral route than the nasal route. These changes indicate preferential effects of succinylcholine-induced fasciculation on the oral airway passage.

Changes of Oral Airway Patency during Succinylcholine-induced Paralysis

Continuous endoscopic observation of the space at the isthmus of the fauces was successful in six subjects who

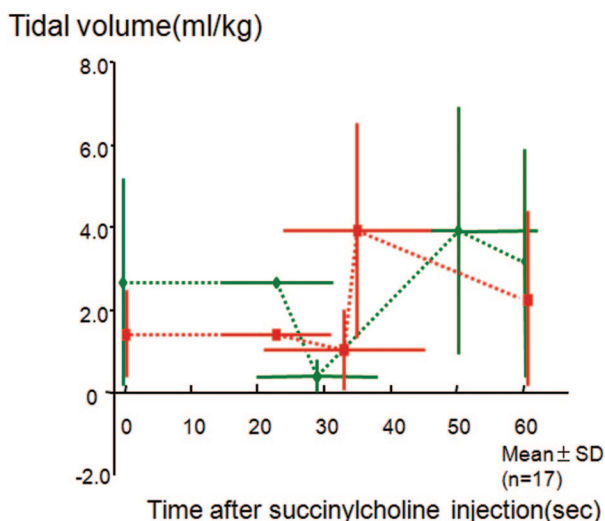


Fig. 3. Time course of mean changes of nasal and oral tidal volumes after succinylcholine injection. Dotted green and red lines represent tidal volume change of nasal and oral airway routes, respectively. Bars represent SD ranges. The graphs are produced by the data presented in tables 2 and 3.

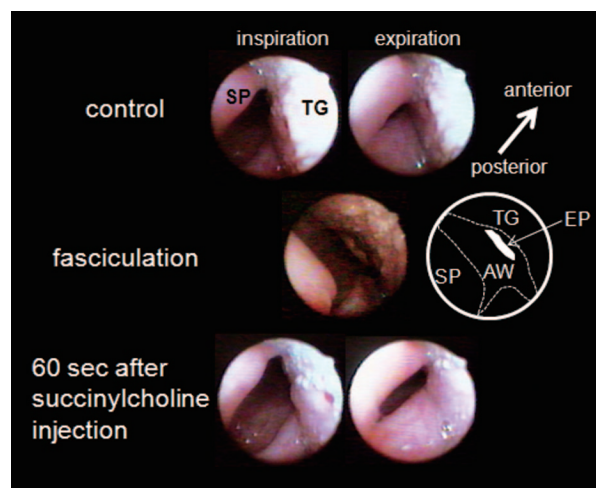


Fig. 4. Endoscopic observation of the space at the isthmus of the fauces during facemask ventilation in the process of muscle paralysis with intravenous administration of succinylcholine. The images were obtained by an endoscope inserted through the mouth. Note significant dilation of the airway space during succinylcholine-induced pharyngeal fasciculation. AW = airway space; EP = epiglottis; SP = soft palate; TG = tongue base.

received succinylcholine. Because of difficulty in endoscopically capturing this whole area, we simply observed cross-sectional changes at the one-sided isthmus and did not measure its absolute cross-sectional area. As demonstrated in the video clip (see Supplemental Digital Content 1, <http://links.lww.com/ALN/A869>, which is a video-clip demonstrating changes of oral airway patency during succinylcholine-induced paralysis; the space at the isthmus of the fauces was observed by an endoscope inserted through the mouth) and figure 4, the narrowed space abruptly and significantly dilated during oscillatory movements of the soft palate and the tongue base (pharyngeal fasciculation). The dilated airway space gradually narrowed, but remained dilated more compared with the original luminal size before succinylcholine administration. Although extent and duration of the airway dilation immediately after the pharyngeal fasciculation varied among the subjects, the space at the isthmus of the fauces dilated in all six patients.

Discussion

We systematically examined influences of muscle relaxants on FMV in anesthetized subjects with normal upper airway anatomy while maintaining the neutral head and mandible position in supine posture and the ventilator settings. We found that rocuronium administration did not change FMV efficacy, and succinylcholine administration improved FMV by 30% in association with pharyngeal fasciculation, supporting the hypothesis that muscle relaxants improve FMV in anesthetized subjects. We also found that succinylcholine-induced FMV improvement was primarily because of oral airway dilation.

Mechanisms and Clinical Implications of Succinylcholine-induced FMV

The most interesting and novel finding in this study is the succinylcholine-induced FMV improvement. Obviously, this phenomenon is not because of muscle paralysis, because rocuronium did not improve FMV. In fact, we found that the FMV improvement was initiated by reopening of the airway during succinylcholine-induced pharyngeal muscle contraction. Pharmacological contraction of the muscle fibers, including both pharyngeal dilators and constrictors, during pharyngeal fasciculation is similar to a pharyngeal muscle burst at arousal from obstructive sleep apnea, which is considered to serve to both reopen and stiffen the pharyngeal airway for breathing.^{17,18} Pharyngeal airway behavior is known to be influenced by surface attractive forces between the opposed luminal surfaces, and the pressure required to open the airway is higher than the pressure the airway closes.¹⁹ The opening force produced by the pharyngeal fasciculation appears to be potent because it opened up the closed or narrowed pharyngeal airway. This may explain reversal of difficult or impossible mask ventilation after succinylcholine injection in the Amathieu study.¹⁰ Although we have no explanation for the transient reduction of the tidal volumes, particularly through the nasal airway route, this may be because of contraction of either pharyngeal constrictors increasing airway resistance or thoracic muscles decreasing thoracic compliance. The biphasic tidal volume change during the pharyngeal fasciculation could be alternatively explained by a Bowditch-Treppe effect on the pharyngeal muscle contraction, but no study has demonstrated occurrence of this phenomenon during succinylcholine-induced fasciculations.

Another interesting finding in this study is maintenance of improved positive-pressure ventilation even after disappearance of visible fasciculation. Maintenance of a patent pharyngeal airway in persons without obstructive sleep apnea requires 13% of maximum pharyngeal muscle activation, which would be much less during visible fasciculation.²⁰ We consider the succinylcholine-induced depolarization of the pharyngeal muscles diminishes but continues until total paralysis.²¹ Therefore, the residual muscle contraction, which is produced by both muscle fibers under succinylcholine-induced depolarization and intact muscle fibers, could be sufficient for preventing or delaying reocclusion of the dilated pharyngeal airway. Succinylcholine-induced improvement and maintenance of adequate FMV condition by the time tracheal intubation procedure starts have a significant clinical advantage for safe anesthesia induction. However, this advantage should be weighed against its potential adverse effects upon use of succinylcholine for anesthesia induction.^{22,23}

Optimal Airway Routes for FMV

We found that both oral and nasal airway routes contributed to FMV before and during muscle paralysis. Recently, Liang *et al.* demonstrated that nasal ventilation was more effective

than combined oral-nasal ventilation in nonparalyzed anesthetized subjects with a neutral head and neck position without airway maneuvers.¹⁴ Because both Liang's and our studies did not perform airway maneuvers, the results should be carefully interpreted. This study, however, provides new insight into optimal airway routes for FMV. Ventilation increased more through the oral route than the nasal route after succinylcholine, suggesting advantage of use of both airway routes and disadvantage of using nasal airway route alone when receiving succinylcholine. We previously demonstrated that mandible advancement is less effective for improving nasal airway patency in obese than nonobese subjects.²⁴ These are in agreement with the Amathieu study finding that FMV improved after succinylcholine injection in morbidly obese patients with oral airways.¹⁰

In most cases, anesthesiologists use one hand alone for holding a mask. The hand often closes the bite and oral airway route. Even with the anesthesia full facemask, the mask ventilation is performed predominantly or exclusively through the nasal airway route without an oral airway in place or active bite opening with the two hands. Our results suggest use of both airway routes for maximizing ventilation in patients receiving muscle relaxants under general anesthesia, preferably with using an oral airway and/or two hands specifically in obese patients and patients with severe obstructive sleep apnea.^{25,26}

Limitations of the Study

Our study has several methodological limitations for mechanical and clinical understanding of the results. Although muscle relaxants could affect both thoracic compliance and airway resistance, these factors were not directly assessed in our study. Fortunately, differential effects between rocuronium and succinylcholine and between the nasal and oral airway routes observed in this study indicate that contribution of succinylcholine to the succinylcholine-induced FMV improvement is predominantly because of reduction of the upper airway resistance, because both succinylcholine and rocuronium are expected to equally influence the thoracic compliance.

To explore pharyngeal airway behavior during the process of succinylcholine-induced muscle paralysis, we endoscopically observed the pharyngeal isthmus, but did not measure cross-sectional area because of technical limitation. Quantitative and concomitant assessments of both nasal and oral airway behavior are necessary to elucidate the detailed mechanisms of the succinylcholine-induced FMV improvement. Furthermore, we did not perform airway maneuvers, such as mandible advancement and neck extension, in order to assess pure effects of muscle relaxants on FMV. Although the airway maneuvers are particularly important in patients with difficult FMV, our study did not include these patients and mimic difficult airway scenario, limiting clinical implications of the results of this study. Future studies should test safety

and efficacy of muscle relaxants in known or unexpectedly difficult FMV situations.

We considered that muscle paralysis would be achieved by 60 s after succinylcholine administration based on results of the previous reports (50 ± 17 s for maximum paralysis),²⁷ and did not assess neuromuscular function in patients receiving succinylcholine. Although we begin tracheal intubation procedure approximately 60 s after succinylcholine injection in clinical practice, this is a significant methodological limitation possibly contributing part of the succinylcholine-induced FMV improvement. Clearly, the positive effect of succinylcholine decreased with time and would have disappeared after achieving maximum paralysis, but we did not assess how long its effect lasted in this study.

In conclusion, both rocuronium and succinylcholine did not deteriorate FMV in anesthetized subjects with normal upper airway anatomy without airway interventions. Rather, succinylcholine administration improved FMV in association with airway dilation during pharyngeal fasciculation, and this effect continued to a lesser degree after resolution of the fasciculations. Results suggest advantage of succinylcholine administration during anesthesia induction and use of both airway routes for achieving adequate FMV.

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References

- Ramachandran SK, Kheterpal S: Difficult mask ventilation: Does it matter? *Anaesthesia* 2011; 66 Suppl 2:40–4
- Isono S: Optimal combination of head, mandible and body positions for pharyngeal airway maintenance during perioperative period: lesson from pharyngeal closing pressures. *Semin Anesth* 2007; 26:83–93
- Isono S, Tanaka A, Sho Y, Konno A, Nishino T: Advancement of the mandible improves velopharyngeal airway patency. *J Appl Physiol* 1995; 79:2132–8
- Isono S, Tanaka A, Tagaito Y, Ishikawa T, Nishino T: Influences of head positions and bite opening on collapsibility of the passive pharynx. *J Appl Physiol* 2004; 97:339–46
- Kheterpal S, Han R, Tremper KK, Shanks A, Tait AR, O'Reilly M, Ludwig TA: Incidence and predictors of difficult and impossible mask ventilation. *ANESTHESIOLOGY* 2006; 105:885–91
- Calder I, Yentis SM: Could 'safe practice' be compromising safe practice? Should anaesthetists have to demonstrate that face mask ventilation is possible before giving a neuromuscular blocker? *Anaesthesia* 2008; 63:113–5
- Pandit JJ: Checking the ability to mask ventilate before administering long-acting neuromuscular blocking drugs. *Anaesthesia* 2011; 66:520–2
- Goodwin MW, Pandit JJ, Hames K, Popat M, Yentis SM: The effect of neuromuscular blockade on the efficiency of mask ventilation of the lungs. *Anaesthesia* 2003; 58:60–3
- Warters RD, Szabo TA, Spinale FG, DeSantis SM, Reves JG: The effect of neuromuscular blockade on mask ventilation. *Anaesthesia* 2011; 66:163–7
- Amathieu R, Combes X, Abdi W, Housseini LE, Rezzoug A, Dinca A, Slavov V, Bloc S, Dhonneur G: An algorithm for difficult airway management, modified for modern optical devices (Airtraq laryngoscope; LMA CTrach™): A 2-year prospective validation in patients for elective abdominal, gynecologic, and thyroid surgery. *ANESTHESIOLOGY* 2011; 114:25–33
- Shetty N, Rao S, Vijayakumar V: Questioning succinylcholine usage in grade IV (difficult) mask ventilation. *ANESTHESIOLOGY* 2011; 115:444–7
- Han R, Tremper KK, Kheterpal S, O'Reilly M: Grading scale for mask ventilation. *ANESTHESIOLOGY* 2004; 101:267
- Safar P: Ventilatory efficacy of mouth-to-mouth artificial respiration; airway obstruction during manual and mouth-to-mouth artificial respiration. *J Am Med Assoc* 1958; 167:335–41
- Liang Y, Kimball WR, Kacmarek RM, Zapol WM, Jiang Y: Nasal ventilation is more effective than combined oral-nasal ventilation during induction of general anesthesia in adult subjects. *ANESTHESIOLOGY* 2008; 108:998–1003
- Chung F, Yegneswaran B, Liao P, Chung SA, Vairavanathan S, Islam S, Khajehdehi A, Shapiro CM: STOP questionnaire: A tool to screen patients for obstructive sleep apnea. *ANESTHESIOLOGY* 2008; 108:812–21
- Magorian T, Flannery KB, Miller RD: Comparison of rocuronium, succinylcholine, and vecuronium for rapid-sequence induction of anesthesia in adult patients. *ANESTHESIOLOGY* 1993; 79:913–8
- Kuna ST, Smickley JS: Superior pharyngeal constrictor activation in obstructive sleep apnea. *Am J Respir Crit Care Med* 1997; 156:874–80
- Kuna ST: Respiratory-related activation and mechanical effects of the pharyngeal constrictor muscles. *Respir Physiol* 2000; 119:155–61
- Wilson SL, Thach BT, Brouillette RT, Abu-Osba YK: Upper airway patency in the human infant: Influence of airway pressure and posture. *J Appl Physiol* 1980; 48:500–4
- Mezzanotte WS, Tangel DJ, White DP: Waking genioglossal electromyogram in sleep apnea patients *versus* normal controls (a neuromuscular compensatory mechanism). *J Clin Invest* 1992; 89:1571–9
- Connelly NR, Silverman DG, Brull SJ: Temporal correlation of succinylcholine-induced fasciculations to loss of twitch response at different stimulating frequencies. *J Clin Anesth* 1992; 4:190–3
- Turan A, Mendoza ML, Gupta S, You J, Gottlieb A, Chu W, Saager L, Sessler DI: Consequences of succinylcholine administration to patients using statins. *ANESTHESIOLOGY* 2011; 115:28–35
- Lee C: Succinylcholine should be avoided in patients on statin therapy. *ANESTHESIOLOGY* 2011; 115:6–7
- Isono S, Tanaka A, Tagaito Y, Sho Y, Nishino T: Pharyngeal patency in response to advancement of the mandible in obese anesthetized persons. *ANESTHESIOLOGY* 1997; 87:1055–62
- Isono S: Obstructive sleep apnea of obese adults: Pathophysiology and perioperative airway management. *ANESTHESIOLOGY* 2009; 110:908–21
- Joffe AM, Hetzel S, Liew EC: A two-handed jaw-thrust technique is superior to the one-handed "EC-clamp" technique for mask ventilation in the apneic unconscious person. *ANESTHESIOLOGY* 2010; 113:873–9
- Magorian T, Flannery KB, Miller RD: Comparison of rocuronium, succinylcholine, and vecuronium for rapid-sequence induction of anesthesia in adult patients. *ANESTHESIOLOGY* 1993; 79:913–8