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Original contribution

A pilot study of upper airway management using a remote-controlled artificial muscle device during propofol anesthesia☆

Shinji Kurata DDS, PhD (Assistant Professor)[a], Takurou Sanuki DDS, PhD (Associate Professor)[b], Ichiro Okayasu DDS, PhD (Assistant Professor)[b], Mari Kawai DDS, PhD (Assistant Professor)[a], Shunji Moromugi PhD (Associate Professor)[c], Takao Ayuse DDS, PhD (Professor)[a,b,*]

[a]*Department of Dental Anesthesiology, Nagasaki University Hospital, Nagasaki, Japan*
[b]*Department of Clinical Physiology, Nagasaki University Graduate School of Biomedical Science, Nagasaki, Japan*
[c]*Department of Electrical, Electronic, and Communication Engineering, Chuo University, Tokyo, Japan*

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Abstract

Study objective: To test the hypothesis that the jaw closure using a pneumatic actuator device affect airway collapsibility and resistance during propofol anesthesia.

Design: Prospective, randomized study.

Setting: University-affiliated hospital.

Patients: Six male subjects were included in the present study.

Intervention: We used pressure-flow relationships to evaluate critical closing pressure (P_{CRIT}) and upper airway resistance in different conditions of body and head position. Anesthesia was induced and maintained with a propofol infusion, targeting a constant blood concentration of 1.5 to 2.0 μg/mL to establish an adequate depth of anesthesia, with patients breathing spontaneously through a nasal mask. An air-inflatable pneumatic actuator was used to achieve jaw closure. Nasal mask pressure was intermittently reduced to evaluate upper airway collapsibility (passive P_{CRIT}) and upstream resistance under 4 different conditions: (1) neutral occlusion at 0-cm head elevation (baseline), (2) jaw closure at 0-cm head elevation, (3) neutral occlusion at 6-cm head elevation, and (4) jaw closure at 6-cm head elevation.

P_{CRIT} and upstream resistance under each condition were compared using 1-way analysis of variance. $P < .05$ was considered significant.

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* Corresponding author at: Department of Clinical Physiology, Nagasaki University Graduate School of Biomedical Science, 1-7-1 Sakamoto Nagasaki-shi, Nagasaki, 852-8588, Japan. Tel.: +81 95 819 7714; fax: +81 95 819 7715.
E-mail address: ayuse@nagasaki-u.ac.jp (T. Ayuse).

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Measurements: The pressure and inspiratory flow at the subjects' nose mask were recorded. Polysomonographic parameters (electroencephalograms, electrooculograms, submental electromyograms, and plethysmogram) were also recorded.
Main results: The combination of 6-cm head elevation with jaw closure using the pneumatic actuator decreased upper airway collapsibility ($P_{CRIT} \approx -3.0$ cm H_2O) compared to the baseline position ($P_{CRIT} \approx -1.2$ cm H_2O; $P = .0003$).
Conclusion: We demonstrated that jaw closure using an air-inflatable pneumatic actuator device can produce substantial decreases in upper airway collapsibility and maintain upper airway patency during propofol anesthesia.

1. Introduction

Maintenance of upper airway patency during anesthesia with spontaneous breathing is a critical issue because upper airway dilator muscle activity becomes significantly compromised with loss of consciousness [1-3]. During anesthesia, disturbances in upper airway neural control (ie, compensatory neuromuscular responses) may compromise pharyngeal patency [4,5]. Under these circumstances, mechanical upper airway properties predominate in governing overall collapsibility of the airway. Hence, improving the mechanical characteristics of the upper airway during anesthesia is of prime importance in the maintenance of airway patency.

Positional changes of the mandible, specifically avoiding opening of the mouth (jaw closure) [6-8], are known to play an important role in the maintenance of upper airway patency during anesthesia in adult and pediatric patients. We previously demonstrated that establishment of jaw closure with approximately 6-cm head elevation, achieved by lying on a table with a 6-cm-high pillow, might be necessary for maintaining upper airway patency in normal healthy subjects under propofol anesthesia, in spite of the concurrent occurrence of head flexion [8]. There are several clinical situations in which the attending medical staff cannot always remain by the side of the patient to maintain optimal jaw position to keep the upper airway open, for example, during anesthesia for gastrointestinal endoscopy and for diagnostic imaging, such as magnetic resonance imaging and computed tomography [7,9-12]. We recently showed that establishment of head elevation with jaw closure, achieved by a remote-controlled airbag device, can produce substantial decreases in upper airway collapsibility and maintain upper airway patency during propofol anesthesia (Ishizaka et al, in press). It has also been postulated that the commercially available jaw elevation device (JED Hypnoz Therapeutic Devices, Inc) may be useful for maintaining upper airway patency. However, such devices presume that the patient will be in the stable supine position during the procedure and examination. Nevertheless, postural changes are sometimes needed during procedures such as gastrointestinal endoscopy or fiberoptic intubation in patients with difficult airway management. Therefore, alternative positional devices for maintenance of the upper airway that can be applied and are controllable in any position are required. Artificial muscles (with a pneumatic actuator) have been used in supportive robotic devices, such as the artificial arm or robot hands. We opined that it might be possible to apply this device for supportive management of the upper airway. However, because air-inflatable pneumatic actuators have never been used in airway supportive devices, there are no data available evaluating achievement of jaw closure with such a device.

We hypothesized that use of an air-inflatable pneumatic actuator device, such as an artificial muscle, might effectively achieve the jaw closure required for maintaining upper airway patency during anesthesia. To address this hypothesis, we examined the effect of jaw closure using an air-inflatable pneumatic actuator device on upper airway collapsibility during propofol anesthesia.

2. Materials and methods

2.1. Subjects

Six healthy male volunteers were recruited, and a detailed clinical history was obtained from each of them. Subjects were excluded if they were overweight or obese (body mass index >25 kg/m^2); had a history of frequent or excessive snoring according to their bed partner (>3 times/week); had abnormal sleep patterns or reported excessive daytime sleepiness (Epworth Sleepiness Score >10); had a significant medical disease (eg, cardiopulmonary pathology) or other significant clinical history (eg, allergy to anesthesia); or reported tobacco, chronic alcohol, or drug abuse. Subjects were also excluded if they had anatomical deformations of the upper airway, such as retrognathia or maxillary hypoplasia (assessed by the lateral view and occlusal condition), and an abnormal range of overbite and overjet. The vertical occlusion condition was assessed by overbite, which indicates a degree of overlap between the upper and lower incisors of 3 mm. The horizontal occlusion condition was assessed by overjet, which indicates a horizontal distance between the upper and lower incisors of 3 mm. All subjects had to have a Mallampati score of I or II and a