Nasal Ventilation Is More Effective than Combined Oral–Nasal Ventilation during Induction of General Anesthesia in Adult Subjects

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Background: The authors hypothesized that nasal mask ventilation may be more effective than combined oral–nasal mask ventilation during induction of general anesthesia. They tested this hypothesis by comparing the volume of carbon dioxide removed per breath with nasal *versus* combined oral–nasal mask ventilation in nonparalyzed, apneic, adult subjects during induction of general anesthesia.

Methods: Fifteen adult subjects receiving general anesthesia were ventilated first with a combined oral–nasal mask and then with only a nasal mask. The patient's head was maintained in a neutral position, without head extension or lower jaw thrust. Respiratory parameters were recorded simultaneously from both the nasal and oral masks regardless of ventilation approach.

Results: The volume of carbon dioxide removed per breath during nasal mask ventilation (median, 5.0 ml; interquartile range, 3.4–8.8 ml) was significantly larger than that during combined oral–nasal mask ventilation (median, 0.0 ml; interquartile range, 0.0–0.4 ml; $P = 0.001$); even the peak inspiratory airway pressure during nasal ventilation (16.7 ± 2.7 cm H_2O) was lower than that during combined oral–nasal ventilation (24.5 ± 4.7 cm H_2O; $P = 0.002$). The expiratory tidal volume during nasal ventilation (259.8 ± 134.2 ml) was also larger than that during combined oral–nasal ventilation (98.9 ± 103.4 ml; $P = 0.003$).

Conclusions: Nasal mask ventilation was more effective than combined oral–nasal mask ventilation in apneic, nonparalyzed, adult subjects during induction of general anesthesia. The authors suggest that nasal mask ventilation, rather than full face-mask ventilation, be considered during induction of anesthesia.

MASK ventilation is an essential component of airway management either as the primary technique during general anesthesia or only during the induction period. In each scenario, upper airway obstruction (UAO) is frequently encountered.[1] To overcome UAO, an oral or nasal airway device is frequently inserted. However, even when these devices are used, difficult mask ventilation (DMV) still occurs in 1.4–7.8% of patients.[2–4] Occasionally, although the patient can be ventilated with a full facemask, very high airway pressure is required. Such high pressure may lead to gastric insufflation through the partially obstructed upper airway and may precipitate vomiting and subsequent aspiration.[5] Therefore, the ability to successfully ventilate patients with low airway pressure using a bag–mask system is essential for the practice of anesthesia.

The exact pathogenesis of DMV is not fully understood, but UAO plays an essential role, because risk factors related to DMV include older age, obesity, a history of snoring, and a history of sleep apnea.[2–4] It has been recognized that mechanisms of UAO during sleep and anesthesia share similarities.[6] The reduction in upper airway muscle tone and the effect of gravity on the tongue and soft palate in the supine position are key factors causing upper airway collapse during both sleep and general anesthesia.[6,7] Nasal continuous positive airway pressure (CPAP) is used to successfully treat obstructive sleep apnea,[8] and studies using magnetic resonance imaging have shown that nasal CPAP decreases anesthesia-induced upper airway narrowing in both adults and infants.[9,10] Therefore, we hypothesized that nasal mask ventilation might provide a more effective ventilation than combined oral–nasal mask ventilation during induction of general anesthesia. We tested this hypothesis by comparing the volume of carbon dioxide removed per breath with nasal *versus* combined oral–nasal mask ventilation in nonparalyzed, apneic, adult subjects during induction of general anesthesia.

Materials and Methods

The study was approved by the Massachusetts General Hospital Human Research Committee, Boston, Massachusetts, and written informed consent was obtained from all study subjects.

Patients

A total of 17 subjects older than 18 yr were recruited from the inpatient main operating rooms of the Massachusetts General Hospital. All recruited subjects required general anesthesia and had a preoperative physical status of I or II as defined by the American Society of Anesthesiologists. In addition, we ensured that all subjects, while awake, were able to breathe through both their nose and mouth without using accessory respira-

Fig. 1. Illustration of the oral mask, nasal mask, and application of both masks and their interface with the two noninvasive cardiac output monitors. One noninvasive cardiac output monitor was placed between the nasal mask and the breathing circuit (flowmeter 1), and the other was placed between the oral mask and the breathing circuit (flowmeter 2). *A* and *B* are the photos of the oral and nasal masks, respectively. *C* shows the application of the nasal and oral masks held by two separate straps.
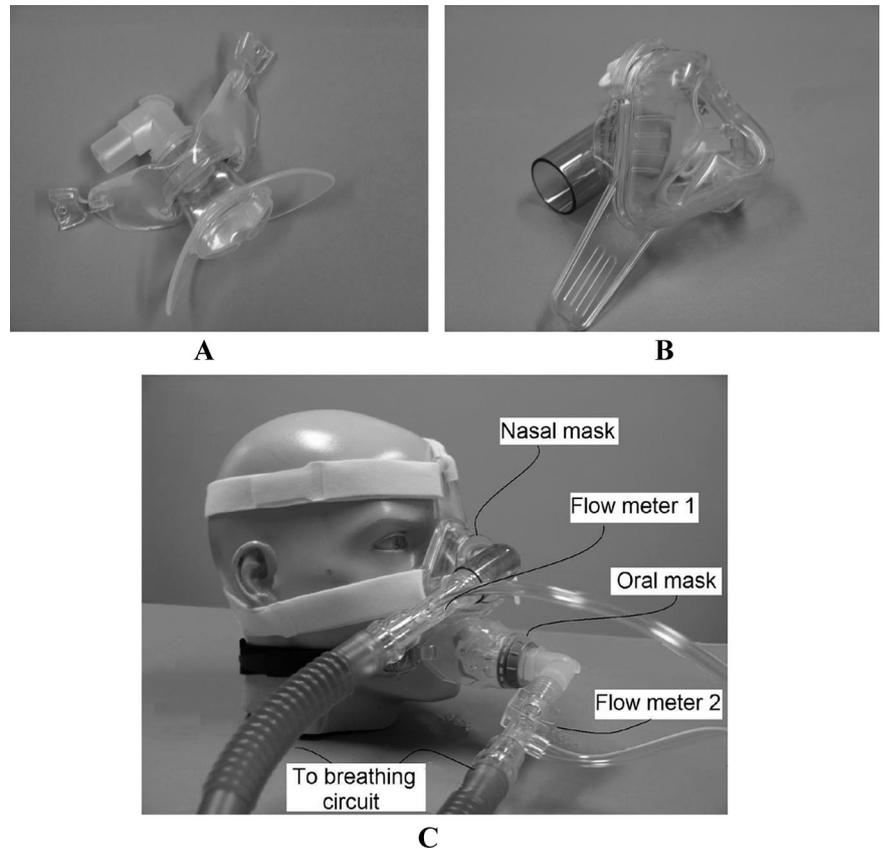
tory muscles. Exclusion criteria included major cardiovascular disease, respiratory disease, cerebral vascular disease, gastric–esophageal reflux, or a full stomach; known obstructive sleep apnea; body mass index greater than 35 kg/m^2; and the need for emergency surgery.

Study Design

After receiving preoperative medications, subjects were placed on the operating table, and electrocardiogram, noninvasive blood pressure, and cutaneous oxyhemoglobin saturation monitoring were applied. A Bispectral Index® monitor (model A-2000; Aspect Medical Systems, Natick, MA) was connected to monitor the depth of sedation. Separate oral (Oracle 452 Oral CPAP/BiPAP Mask; Fisher & Paykel Healthcare, Panmure, Aukland, New Zealand; fig. 1A) and nasal masks (Vinyl Nasal Disposable Mask; Respironics Corp., Murrysville, PA; fig. 1B) were placed as shown in figure 1C. The mouth was kept partially open by inserting the oral piece with self-contained bite block between the teeth. The distance between the upper and lower incisors was 1 cm. Various sizes of masks were tried on each patient to ensure the selection of the mask with the best fit. Both nasal and oral masks were secured by head straps. The seal on the masks was checked in the following ways: (1) visually inspecting and palpating to ensure that there was no air leak discernible to the subject or investigators; (2) if there were leaks after induction during posi-

tive pressure ventilation, the masks were readjusted until inspiratory airway pressure was close to the set maximal airway pressure. For each mask, a carbon dioxide/flow sensor (Adult Combined CO_2/Flow Sensor; Novametrix Medical Systems Inc., Wallingford, CT) was placed between the mask and the breathing circuit. The sensor was connected to a noninvasive cardiac output monitor (NICO; Noninvasive Cardiopulmonary Management System, model 7300; Respironics Corp., Murrysville, PA). The NICO monitor was calibrated before each study. The subject's head was placed in the neutral position on a pillow and elevated 10 cm from the operating room table, but no backward head tilt or jaw thrust was performed. One hundred percent oxygen was delivered throughout the study. The subject was encouraged to hyperventilate by taking deep breaths to facilitate preoxygenation before the induction of anesthesia.

Anesthesia was induced by an intravenous bolus injection of propofol (1–2 mg/kg) after an intravenous bolus injection of fentanyl (50–150 μg). Thirty seconds after the subjects' spontaneous breathing ceased, defined by measuring zero flow through both nasal and oral masks, they were ventilated with a volume-controlled operating room ventilator at a preset fresh gas flow of 10 l/min, tidal volume of 10 ml/kg, respiratory rate of 10 breaths/min, pressure limit of 25 cm H_2O, and inspiratory time of 2 s. Additional boluses of propofol were given to maintain the Bispectral Index reading between 40 and 60.

The subjects were first ventilated through both the nasal and oral masks simultaneously. If the subject could be adequately ventilated, as defined by perceivable chest movement and carbon dioxide measured during exhalation in at least one of the first three breaths, ventilation was continued for five to eight breaths. Then nasal mask ventilation only followed. If the subject could be ventilated nasally, ventilation continued for five to eight breaths. If the subject could not be ventilated adequately with combined oral–nasal mask for three breaths, nasal mask ventilation only was performed immediately. If ventilation was inadequate with a combined oral–nasal mask and also the nasal mask only, a jaw thrust was performed and/or an oral airway device was inserted, and the study was terminated.

Switching to the nasal mask was done by disconnecting the breathing circuit from the oral mask distal to the flow sensor, leaving the oral mask and sensors still connected and open to the atmosphere. Gas movement during inspiration and expiration was continuously and simultaneously monitored with the two sets of sensors. Upon completion of the study, the subject's airway was secured in the normal manner (*i.e.*, by placing a laryngeal mask airway or an endotracheal tube). Cutaneous oxyhemoglobin saturation of all subjects was always maintained above 95%.

All ventilation parameters, including respiratory rate, tidal volume, flow waveforms, flow rates during inspiration and expiration, peak inspiratory airway pressure (PIP), end-tidal carbon dioxide partial pressure, and exhaled carbon dioxide waveforms, were recorded with the NICO monitors. Vital signs were recorded with an automatic information recording system (Saturn Information System and Recorder version 4.1 software; Dräger Medical Inc., Telford, PA).

The primary endpoint of this study was the volume of carbon dioxide removed per breath ($\dot{V}_bCO_2$). Secondary endpoints were PIP, expiratory tidal volume, and $\dot{V}_bCO_2$/PIP.

Data Analysis

Waveforms recorded by the NICO monitors were reconstructed with Analysis Plus for Windows software (Novametrix Medical System Inc., Wallingford, CT). The exhaled tidal volume was calculated by determining the area under the gas flow–time waveform. The $\dot{V}_bCO_2$ was calculated as follows:

$$\dot{V}_bCO_2 = \sum \left(\text{airway carbon dioxide partial pressure} \right. \\ \left. \text{mmHg}/760 \text{ mmHg}\right) \text{expiratory outflow rate } (0.01 \text{ s})$$

at a data collection rate of 100/s. Exhaled tidal volume and $\dot{V}_bCO_2$ were calculated by summing the values from both the nasal and oral sensors. This method was verified with 5% carbon dioxide. The correlation between the volume of carbon dioxide delivered (V_{del}) and of that calculated (V_{Cal}) with this method was $V_{del} = 0.99 V_{Cal} -0.55$ ($r = 0.999$). The $\dot{V}_bCO_2$ was calculated at 25°C and 1 atmosphere pressure.

Statistical Analysis

Statistical analysis was performed with a commercially available statistical package (SPSS, version 12.0 for Windows; SPSS Inc., Chicago, IL). For all the respiratory parameters, the last five breaths were used for data analysis. Variables were first tested for a normal distribution with the Shapiro-Wilk test. Data are presented as mean ± SD for variables that were distributed normally. Variables that were not distributed normally are presented as medians with interquartile ranges. Differences between the combined oral–nasal and nasal mask ventilation were analyzed by the Wilcoxon signed rank test for continuous variables and the McNemar test for dichotomous variables. A *P* value less than 0.05 was considered significant.

Results

A total of 17 subjects were enrolled. Two subjects were excluded because of an inability to achieve an adequate mask seal. As a result, 15 subjects completed the study protocol. The demographic data of studied subjects are shown in table 1.

The PIP with nasal mask ventilation (16.7 ± 2.7 cm H_2O) was significantly lower than that with combined oral–nasal mask ventilation (24.5 ± 4.7 cm H_2O; *P* = 0.002) (fig. 2). The expired tidal volume with nasal mask ventilation had a median of 264.8 ml, with an interquartile range of 198.0–322.6 ml, whereas the combined oral–nasal mask ventilation had a median of 65.6 ml, with an interquartile range of 37.0–125.0 ml (*P* = 0.003). The $\dot{V}_bCO_2$ during nasal mask ventilation (median 5.0 ml, interquartile range 3.4–8.8 ml) was significantly larger than that during combined oral–nasal mask ventilation (median 0.0 ml, interquartile range 0.0–0.4 ml; *P* = 0.001). The $\dot{V}_bCO_2$/PIP during nasal mask ventilation also was larger (median, 0.26 ml/cm H_2O; interquartile range, 0.22–0.57 ml/cm H_2O) than that during combined oral–nasal mask ventilation (median, 0.0 ml/cm H_2O; interquartile range, 0.00–0.01 ml/cm H_2O;

Table 1. Demographic Data of Studied Subjects (n = 15)

Age, yr	47.1 ± 14.1
Sex, M/F	7/8
Height, cm	169.9 ± 7.3
Weight, kg	80.0 ± 16.6
Body mass index, kg/m^2	27.6 ± 4.3
Neck circumference, cm	40.5 ± 7.9

Data are mean ± SD.

Fig. 2. Comparison of respiratory parameters during combined oral–nasal mask ventilation (CMV) and nasal mask ventilation (NMV). Each *symbol* represents an individual subject. Each *horizontal bar* represents the mean for peak inspiratory airway pressure (PIP) or the median for exhaled tidal volume (Vte), volume of carbon dioxide removed per breath ($\dot{V}_bCO_2$), and $\dot{V}_bCO_2$/PIP. All comparisons $P < 0.05$.
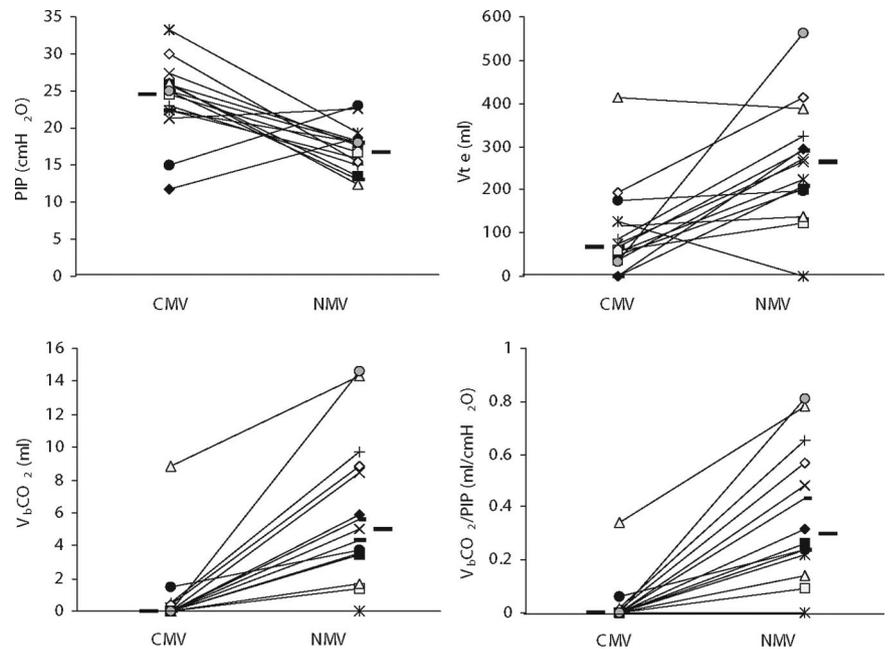
$P = 0.001$). After separating male from female subjects, the nasal ventilation still provided more effective ventilation than combined oral–nasal ventilation for both groups.

Discussion

The primary findings of this study are summarized as nasal mask ventilation: (1) removed more carbon dioxide, (2) required a lower PIP to effectively ventilate, and (3) generated higher tidal volume than combined oral–nasal mask ventilation.

Mask ventilation provides the anesthesia care provider with a rescue technique after unsuccessful attempts at intubation. Moreover, patients with DMV are more likely to have difficult intubations.[4] Therefore, management of DMV is an essential step in airway management during anesthesia and is critical in reducing the morbidity and mortality related to anesthesia. This study demonstrated that nasal mask ventilation produced more effective ventilation than combined oral–nasal mask even under suboptimized conditions attained without the benefit of lower jaw thrust and head extension. This finding indicates that nasal mask ventilation may reduce the incidence of difficult airways and decrease the probability of aspiration because the more patent airway requires lower pressures to ventilate.

It is well accepted that nasal CPAP works as a pneumatic splint to distend the collapsed upper airway in patients with sleep apnea.[8] The success of nasal mask positive-pressure ventilation during anesthesia is likely achieved in the same manner. In a supine human, several forces determine whether the soft palate and tongue will fall backward to obstruct the pharyngeal airway. First, gravity favors obstruction. It plays a dominant role in the mechanism of UAO and sleep apnea because sleep-dis-

ordered breathing is reduced in the microgravity of outer space.[11,12] Second, positive pressure in the oral pharynx during oral mask ventilation facilitates the tongue and soft palate falling posteriorly. Third, obstruction is opposed by positive pressure in the nasopharynx, as during nasal mask ventilation, that generates force below the tongue and soft palate pushing them upward. Therefore, whether the tongue and soft palate fall backward and obstruct the pharyngeal airway depends on the net effect of these three forces.

The velopharynx is the most common site of collapse during anesthesia in nonparalyzed patients.[7,9,13] With nasal mask ventilation, positive pressure is generated in the nasopharynx only, whereas pressure in the oral cavity remains at atmospheric pressure. The pressure gradient between these two cavities is able to overcome the effect of gravity on the soft palate and the tongue, forcing both forward, and opening the upper airway (fig. 3A). During full facemask ventilation, positive pressure is applied to both the nasopharyngeal and oral cavities and does not generate a pressure gradient between these cavities. Therefore, even though positive pressure is applied, gravity still forces the soft palate and tongue backward, obstructing the airway (fig. 3B). However, if the patient does not have a collapsed upper airway, both a nasal mask and a full facemask can generate adequate ventilation through the patent airway.

In this study, the subject's head was purposely maintained in a neutral position without head extension or forward lower jaw thrust. By assuming this position, upper airway obstruction was more likely produced. Safar *et al.*[1] found the most common sites of obstructions in neutral head position were obstruction of the oropharynx by the tongue being pushed against the
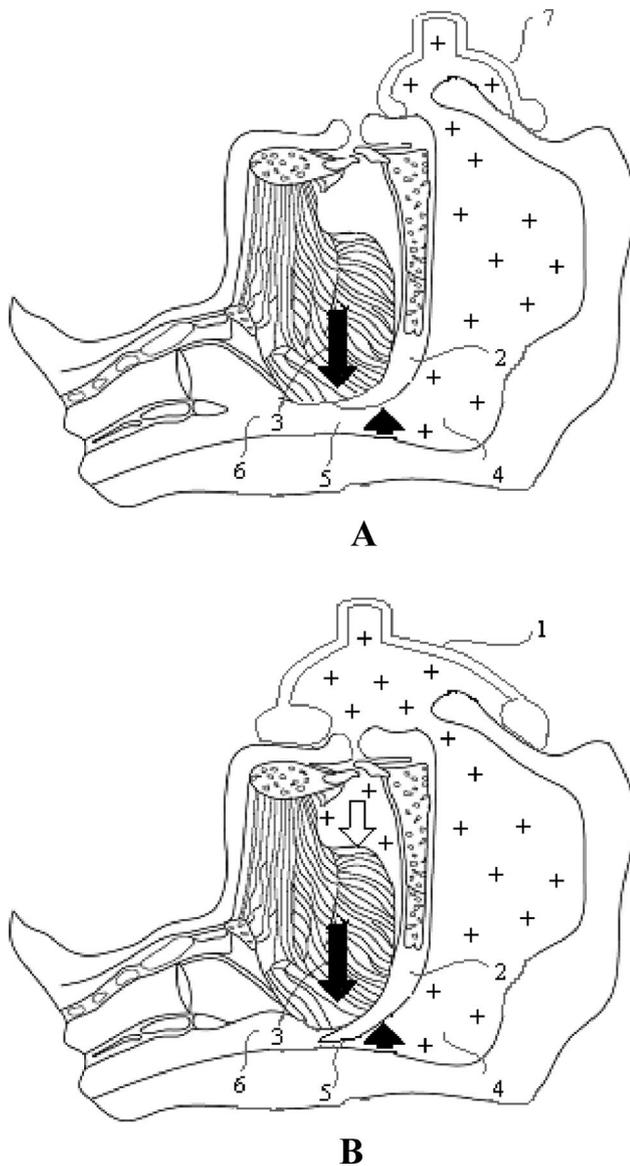
Fig. 3. Mechanism for providing a patent airway during nasal mask ventilation. (*A*) During nasal mask ventilation, positive pressure is generated only in the nasopharynx; the pressure gradient between the nasopharyngeal and oropharyngeal cavities is able to overcome the effect of gravity on the soft palate and the tongue, pushing forward and opening the upper airway. (*B*) Full facemask applies positive pressure in both the nasopharyngeal and oral cavities and does not generate a pressure gradient between the two cavities. As a result, gravity forces the soft palate and tongue backward, causing airway obstruction. 1 = Facemask; 2 = soft palate; 3 = tongue; 4 = nasopharynx; 5 = velopharynx; 6 = oropharynx; 7 = nasal mask. *Up arrowhead* represents pressure in nasopharyngeal cavity; *down filled arrow* represents gravity; *down unfilled arrow* represents pressure in oropharyngeal cavity.

posterior pharyngeal wall, and obstruction of the nasopharynx by the soft palate. It also has been demonstrated that patients with high risk of DMV often have an enlarged or posteriorly displaced tongue that impinges on the hypopharyngeal space, causing UAO.[14–16] Therefore, the pathogenesis of UAO in this situation and during real DMV should be similar. Safar *et al.*[1] observed

that 36% of unconscious, nonparalyzed patients had complete UAO and 54% had partial UAO when the head was in the neutral position. In addition, we observed a gross outward movement of the cheeks during inspiration with combined oral–nasal mask ventilation, whereas this was rarely observed with nasal mask ventilation. We believe this represents oropharyngeal and nasopharyngeal obstruction during oral–nasal ventilation with the head in the neutral position. Therefore, we used the volume of carbon dioxide removed per breath instead of tidal volume as the primary endpoint because it reflects alveolar ventilation. Nasal mask ventilation may also decrease the gas leak in heavily bearded patients, which is an independent risk factor of DMV.[4] By decreasing contact with the bearded area, the potential for leakage is reduced.

Anesthesiologists frequently face the dilemma of achieving a tight facemask seal while maintaining adequate lower jaw thrust. Because the joint between the upper and lower jaw is unstable after muscle relaxation is achieved, the pressure added to the facemask in trying to ensure a good seal often displaces the mandible posteriorly, causing upper airway obstruction. Moreover, some anesthesiologists' hands may not be large enough to perform an adequate jaw thrust while adding pressure to the facemask to ensure a tight seal. However, an anesthesiologist's hand is usually large enough to manage a nasal mask. High pressure applied to the nasal mask will not displace the lower jaw posteriorly because no unstable joint is pressured. In addition, the edentulous patient has less friction between the upper and lower jaw to maintain the joint stable, contributing to air leakage around the facemask.[2] With nasal mask ventilation, the only contact of the mask is with the maxillary plane, thus preventing excessive gas leak.

In this study, the mouth was kept open during nasal mask ventilation. This was because the design of the oral mask maintained a 1-cm space between the incisors. Despite the potential for gas leak from the mouth, nasal ventilation consistently generated larger tidal volumes than the combined oral–nasal mask ventilation (fig. 2B). We expect that the efficiency of nasal mask ventilation would be improved if the oral leak were eliminated. One could simply hold a patient's mouth closed to prevent gas leak during nasal mask ventilation. Such a leak should be prevented easily because the soft palate functions as a one-way valve when nasal CPAP is in use.[17]

Because head position significantly influenced airway patency,[1] we used a combined oral–nasal mask in this study (fig. 1) instead of a full facemask to avoid manipulation of head position during switching of masks. Switching to nasal mask ventilation was performed by simply disconnecting the breathing circuit from the oral mask distal to the NICO sensor. This avoided a change in the patient's airway patency when switching to nasal ventilation from combined oral–nasal mask ventilation.

There are a number of limitations of this study. First, it was performed in patients without head extension and jaw thrust. Rather, it was performed in a neutral position with the head elevated approximately 10 cm. An oral piece instead of an artificial oral airway device was used to open the patient's mouth. This intentionally created DMV may not be identical to that encountered in clinical practice after head extension and insertion of an artificial airway. The result from this study situation may not be readily applicable to the clinical practice. However, as stated above, the mechanism of UAO under these two circumstances should be similar. Further studies comparing the efficiency of nasal mask ventilation and combined oral–nasal mask ventilation are needed in patients with a high risk of UAO when head extension and jaw thrust are included. Second, the influence of the order of treatments cannot be neglected, because this was not a randomized study. However, ventilation was initiated approximately 2 min after an intravenous bolus of propofol. During this time, the upper airway anatomy should be constant, because sedation level as detected by the Bispectral Index monitor was stable.

Conclusion

Nasal mask ventilation has been demonstrated to be more effective than a combination of oral and nasal mask ventilation in apneic, nonparalyzed, adult subjects during induction of general anesthesia. This suggests that nasal mask ventilation, rather than full facemask ventilation, should be considered during anesthesia.

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