

Sniffing Position Improves Pharyngeal Airway Patency in Anesthetized Patients with Obstructive Sleep Apnea

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Background: Appropriate bag-and-mask ventilation with patent airway is mandatory during induction of general anesthesia. Although the sniffing neck position is a traditionally recommended head and neck position during this critical period, knowledge of the influences of this position on the pharyngeal airway patency is still inadequate.

Methods: Total muscle paralysis was induced with general anesthesia in 12 patients with obstructive sleep apnea, eliminating neuromuscular factors contributing to pharyngeal patency. The cross-sectional area of the pharynx was measured endoscopically at different static airway pressures. Comparison of static pressure–area plot between the neutral and sniffing neck positions allowed assessment of the influence of the neck position change on the mechanical properties of the pharynx.

Results: The static pressure–area curves of the sniffing position were above those of neutral neck position, with increasing maximum cross-sectional area and decreasing the closing pressure at both retropalatal and retroglossal airways. The beneficial effects of the sniffing position were greater in obstructive sleep apnea patients with higher closing pressure and smaller body mass index.

Conclusions: Sniffing position structurally improves maintenance of the passive pharyngeal airway in patients with obstructive sleep apnea and may be beneficial for both mask ventilation and tracheal intubation during anesthesia induction.

THE sniffing neck position, defined as neck flexion with upper cervical extension, is a traditionally recommended head and neck position for induction of general anesthesia unless contraindicated. Compared with the neutral neck position, the sniffing position significantly improves laryngeal view during direct laryngoscopy, particularly in obese persons.^{1,2} In addition to its advantages in direct laryngoscopy, the head and neck position should preferably accomplish patent airway during induction of general anesthesia, assuring appropriate bag-and-mask ventilation during the critical period. This is particularly important in obese patients with sleep-disordered breathing (SDB) who have narrow pharyngeal airways and rapid development of hypoxemia as a result

of reduced functional residual capacity without proper mask ventilation.^{3,4} Surprisingly, knowledge regarding influences of the sniffing neck position on pharyngeal airway patency in anesthetized and paralyzed persons is still inadequate.⁵ This prompted us to test a hypothesis that the sniffing position improves pharyngeal airway patency, by studying the influences of this neck position on pharyngeal airway patency in anesthetized and paralyzed patients with SDB, and furthermore, the possible impacts of obesity on mechanical influences.

Materials and Methods

Subjects and Overnight Oximetry

Twelve patients with SDB who were interested in undergoing pharyngeal assessment to determine their indications for uvulopalatopharyngoplasty^{3,6} participated in this study. All had histories of excessive daytime sleepiness, habitual snoring, and witnessed repetitive apnea. SDB was evaluated by a pulse oximeter (Pulsox-3i; Minolta, Tokyo, Japan). All subjects were instructed to attach an oximetry finger probe before sleep and to remove the probe upon awakening. Digital readings of arterial oxygen saturation and pulse rate were stored every 5 s in the oximeter. The stored data were displayed on a computer screen to check quality of the recordings. The computer calculated oxygen desaturation index, defined as the number of oxygen desaturation exceeding 4% from the baseline, and the percentage of time spent at oxygen saturation less than 90%. Table 1 lists all nocturnal oximetry data and anthropometric characteristics. Although the oximetry evaluation alone do not clarify the nature of SDB, we believe that all patients can be safely diagnosed as having obstructive sleep apnea (OSA) based on the oximetry results and the clinical symptoms.⁷ The diagnosis of OSA was later confirmed by a standard polysomnography in seven patients (range of apnea/hypopnea index, 19.8–70.1 h⁻¹).

Informed consent was obtained from all subjects after the aim and potential risks of the study were fully explained to each. The investigation was approved by the hospital ethics committee of our institution (Chiba University Hospital, Chiba, Japan).

Preparation of the Subjects

Each subject was initially premedicated with intramuscular injection of 0.5 mg atropine, and placed in the supine position on an operating table, where a modified tight-fitting nasal mask was attached. Care was taken to prevent air leaks from the mask, particularly when the

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Table 1. Anthropometric Characteristics and Results of Nocturnal Oximetry

	Median (Range)
Age, yr	49.5 (29.0–71.0)
Weight, kg	80.5 (56.9–100)
Height, m	1.70 (1.51–1.80)
BMI, kg/m ²	28.3 (22.1–35.6)
ODI, h ⁻¹	55.1 (15.4–78.6)
CT ₉₀ , %	28.5 (1.3–51.1)
Nadir SpO ₂ , %	83.7 (73.1–90.9)
Lowest SpO ₂ , %	60.0 (46.4–85.0)

Values are presented as median (10th–90th percentile).

BMI = body mass index; CT₉₀ = percent of time spent with SpO₂ less than 90%; lowest SpO₂ = lowest SpO₂ value among the desaturation events; nadir SpO₂ = mean of the nadir SpO₂ values in all desaturation events; ODI = oxygen desaturation index defined as number of desaturations exceeding greater than 4%/h; SpO₂ = arterial oxygen saturation.

airway was pressurized above 20 cm H₂O. General anesthesia was induced and maintained by intravenous infusion of propofol, and intravenous injection of a muscle relaxant (vecuronium 0.2 mg/kg) producing complete paralysis throughout the experiment while the subject was ventilated with positive pressure through an anesthetic machine. Arterial oxygen saturation, electrocardiogram, and blood pressure were continuously monitored. The tip of a slim endoscope (FB10X; Pentax, Tokyo, Japan; 3 mm OD) was inserted through the modified nasal mask and the naris down to the upper airway to visualize the retropalatal followed by the retroglottal airway. A closed-circuit camera (ETV8; Nisco, Saitama, Japan) was connected to the endoscope, and the pharyngeal images were recorded on videotape. Reading of airway pressure (P_{aw}), measured by a water manometer, was simultaneously recorded on videotape.

Experimental Procedures

To determine the pressure–area relation of the pharynx, after disconnection from the anesthetic machine, the nasal mask was connected to a pressure-control system capable of accurately manipulating P_{aw} from –20 to 20 cm H₂O in a stepwise fashion. At cessation of mechanical ventilation of the subject under complete muscle paralysis, apnea resulted. P_{aw} was immediately increased up to 20 cm H₂O to dilate the airway, and then gradually reduced, within a 2- to 3-min span, from 20 cm H₂O to the closing pressure of the retropalatal airway in a stepwise fashion (apneic test). The latter represented the pressure at which complete closure of the retropalatal airway occurred, as evident on the video screen. The apneic test was terminated when arterial oxygen saturation decreased below 95%. This procedure of experimentally induced apnea allowed construction of a pressure–area relation of the visualized pharyngeal segment. The subject was manually ventilated for at least 1 min before and after the apneic test. Distance between the

tip of the endoscope and the narrowing site was measured by a wire passed through the aspiration channel of the endoscope. Measurements were made for the retropalatal and retroglottal airways both in the neutral neck position (no head elevation, with face straight up) and the sniffing neck position. The head was elevated by approximately 8 cm, with the face straight up, by placing cushions under the head in the sniffing neck position. The mouth was kept closed by a chinstrap.

Data Analysis

To convert the monitor image to an absolute value of the pharyngeal cross-sectional area, magnification of the imaging system was estimated at 1.0-mm-interval distances between the endoscopic tip and the object in range of 5–30 mm. At a defined value of P_{aw}, the image of the pharyngeal lumen was traced, and pixels included in the area were counted (SigmaScan version 2.0; Jandel Scientific Software, San Rafael, CA). The pixel number was converted to pharyngeal cross-sectional area according to the distance–magnification relation. Using known-diameter tubes, the accuracy of the cross-sectional area measurements were tested. For constant distance, the measured areas were systematically deviated from actual areas; the largest-known area tested (0.95 cm²) was underestimated by 11% because of image deformation of the outer image area, and the smallest-known area tested (0.03 cm²) was overestimated by 13% because of reduction of the image resolution.⁸

The measured luminal cross-sectional area was plotted as a function of P_{aw}. The closing pressure was defined as pressure corresponding to the zero area. Because relatively constant cross-sectional areas were revealed at high P_{aw} values, the maximum area (A_{max}) was determined as the mean of the highest three P_{aw} (18, 19, and 20 cm H₂O) values. The pressure–area relation of each pharyngeal segment was fitted by an exponential function, $A = A_{\max} - B \cdot \exp(-K \cdot P_{\text{aw}})$, where B and K are constants. A nonlinear least square technique was used for the curve fitting, and the quality of the fitting was provided by coefficient R² (SigmaPlot version 8.0; Jandel Scientific Software). A regressional estimate of closing pressure (P'_{close}), which corresponds to an intercept of the curve on the P_{aw} axis, was calculated from the following equation for each pharyngeal segment: $P'_{\text{close}} = \ln(B/A_{\max})K^{-1}$. The shape of the pressure–area relation was denoted as value K. When the pressure–area relation is curvilinear, compliance of the pharynx defined as a slope of the curve varies with changes in P_{aw}; therefore, a single value of compliance calculated for a given P_{aw} does not represent collapsibility of the pharynx for the entire P_{aw} ranges. In contrast, K represents the rate of changes in the slope of the curve; therefore, when K is high, a small reduction in P_{aw} results in a

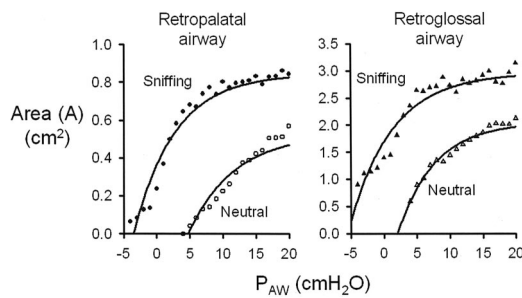


Fig. 1. Representative static pressure–area relations obtained from one subject, showing difference of the relations at the level of the retropalatal and retroglottal airways between the neutral and sniffing neck positions. A = cross-sectional area; P_{aw} = airway pressure.

significant increase in compliance leading to reduction in cross-sectional area. Consequently, collapsibility of the pharynx increases with increasing K. We suggest that both P'_{close} and K values represent collapsibility of the pharynx, whereby the former determines the position of the exponential curve, and the latter characterizes the shape of the curve. Reproducibility of the P'_{close} estimation for both pharyngeal segments was tested in 10 subjects randomly selected from our database. Differences between the first and the second measurements of P'_{close} ranged from +0.2 cm H₂O to –0.9 cm H₂O (mean \pm SD, -0.2 ± 0.3 cm H₂O) at the retropalatal segment and from +0.4 cm H₂O to –2.3 cm H₂O (mean \pm SD, -0.2 ± 0.8 cm H₂O) at the retroglottal segment.

Statistical Analysis

All values are expressed as median (10th–90th percentile). The Wilcoxon signed rank test was used for comparison between the neutral and sniffing neck positions. The Spearman rank order test was performed for correlation analyses between P'_{close} difference between the

positions ($\Delta P'_{close}$) and anthropometric and oximetry data. $P < 0.05$ was considered to be significant.

Results

Static pressure–area relations of the retropalatal and retroglottal airways were successfully obtained from both the neutral and the sniffing neck positions in all patients. As shown in table 1, the study included mild to severe SDB patients with a relatively wide range of age and body habitus.

Figure 1 shows representative pressure–area relations of the pharynx in one patient, demonstrating that the pressure–area curves of both pharyngeal segments in the sniffing position are located above those in the neutral neck position, revealing a larger A_{max} and a smaller P'_{close} in the sniffing position. No difference in curve shapes, denoted by K values, was evident between the positions.

Table 2 summarizes the changes in static mechanic variables of retropalatal and retroglottal airways in patients during the neutral and sniffing neck positions. The exponential function reasonably coincided with the measured pressure–area relations as indicated by relatively high R^2 values. Changes from the neutral to sniffing position significantly increased median A_{max} from 0.82 to 1.48 cm² at the retropalatal airway and from 2.67 to 3.68 cm² at the retroglottal airway. The K values did not differ significantly between the neck positions. The position change significantly decreased median P'_{close} from +2.68 cm H₂O to –1.78 cm H₂O at the retropalatal segment and from +0.80 cm H₂O to –3.72 cm H₂O at the retroglottal segment. Figure 2 illustrates individual changes of P'_{close} at both pharyngeal segments in response to neck position change from neutral to sniffing. Although the highest P'_{close} within the pharynx was above atmospheric pressure in 10 patients in the neutral

Table 2. Static Mechanics of the Retropalatal and Retroglottal Airways in Neutral and Sniffing Neck Positions

	Neutral	Sniffing
Retropalatal airway		
A_{max} , cm ²	0.82 (0.51 to 1.75)	1.48 (0.88 to 2.15)*
B	1.15 (0.55 to 2.76)	1.08 (0.54 to 1.93)
K	0.17 (0.13 to 0.26)	0.18 (0.12 to 0.24)
R^2	0.97 (0.92 to 0.98)	0.97 (0.94 to 0.98)
P'_{close} , cm H ₂ O	2.68 (–0.62 to +3.97)	–1.78 (–5.22 to +0.36)*
Retroglottal airway		
A_{max} , cm ²	2.67 (1.72 to 3.56)	3.68 (1.97 to 5.64)*
B	2.66 (1.27 to 5.85)	2.21 (0.88 to 3.05)
K	0.18 (0.13 to 0.27)	0.16 (0.10 to 0.21)
R^2	0.95 (0.90 to 0.98)	0.96 (0.87 to 0.98)
P'_{close} , cm H ₂ O	–0.80 (–3.08 to +3.28)	–3.72 (–8.43 to –1.73)*

Values are presented as median (10th–90th percentile).

* $P < 0.01$ vs. neutral neck position.

A_{max} = maximum cross-sectional area; B and K = constants obtained by fitting the pressure/area relation of each pharyngeal airway to an exponential function; P'_{close} = estimated closing pressure calculated by $\ln(B/A_{max})/K$. $A = A_{max} - B \cdot \exp(-K \cdot P_{aw})$, where A is cross-sectional area of the pharyngeal airway and P_{aw} is airway pressure. Quality of the fit is provided by coefficient R^2 .

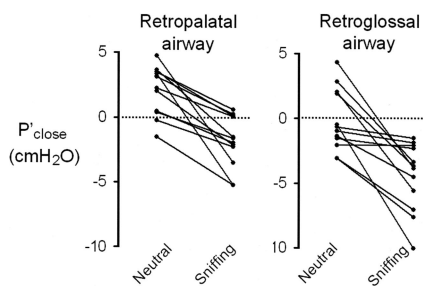


Fig. 2. Changes in closing pressure (P'_{close}) at the level of the retropalatal and retroglottal airways in response to neck position change from neutral to sniffing. Each dot represents a different subject.

neck position, it remained above atmospheric pressure in 4 patients in the sniffing position. The positional improvement of P'_{close} values ($\Delta P'_{close}$) did not differ between the retropalatal airway (3.13 cm H₂O) and the retroglottal airway (4.21 cm H₂O).

Results of the correlation analyses between $\Delta P'_{close}$ and both anthropometric and oximetry data are presented in table 3. Higher body mass index was associated with smaller $\Delta P'_{close}$ at the retroglottal airway, suggesting less beneficial effects of the sniffing position in obese OSA patients (fig. 3). Higher P_{close} was significantly associated with greater $\Delta P'_{close}$ at the retroglottal airway, suggesting beneficial effects of the sniffing position in

Table 3. Results of Correlation Analyses between P'_{close} (P'_{close} Difference between Neutral and Sniffing Neck Positions) and Anthropometric and Oximetry Data

	RP- $\Delta P'_{close}$	RG- $\Delta P'_{close}$
Age	-0.161	-0.158
BMI	-0.182	-0.657*
ODI	-0.399	0.375
P_{close}	0.543	0.594*

Values are presented as correlation coefficients (R) obtained by Spearman rank order tests.

* $P < 0.05$.

BMI = body mass index; ODI = oxygen desaturation index; P_{close} = observed highest closing pressure; P'_{close} = estimated closing pressure by fitting analysis of the pressure–area relation of each pharyngeal segment; RG = retroglottal segment; RP = retropalatal segment.

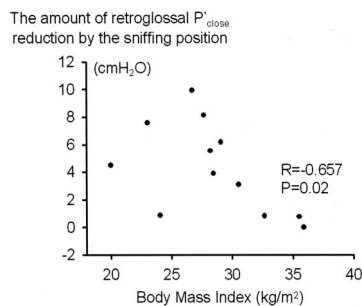


Fig. 3. Scatter plot demonstrating significant association between body mass index and the difference of retroglottal P'_{close} between neutral neck and sniffing positions. R = correlation coefficient obtained by Spearman rank order tests.

OSA patients with more collapsible pharynx. No statistically significant correlation with $\Delta P'_{close}$ was found in age and severity of SDB, and the lack of statistical significance possibly resulted from the small sample size.

Discussion

We found that neck position change from the neutral position to the sniffing position enlarged both retropalatal and retroglottal airways and decreased P'_{close} at both sites by approximately 3–4 cm H₂O in completely paralyzed and anesthetized patients with OSA. The beneficial effects of the sniffing position were greater in OSA patients with higher P_{close} and smaller body mass index.

Pharyngeal airway size is determined by a precise interaction between neural regulation of pharyngeal dilator muscle activities (neural mechanisms) and structural properties of the pharyngeal airway (anatomical mechanisms).^{3,9} We recently presented a new conceptual model for the pharyngeal airway focusing on the anatomical mechanisms (fig. 4).^{10,11} Structurally, the pharyngeal airway is surrounded by soft tissue such as the tongue and soft palate, which is enclosed by bony structures such as the maxilla, mandible, and cervical vertebrae. Based on the finding that both obesity and craniofacial abnormalities, such as small mandible, contributed to increased pharyngeal collapsibility,¹⁰ we consider that the anatomical balance between the amount of soft tissue within the bony enclosure and the size of the bony enclosure determines the pharyngeal airway size. Neuromuscular mechanisms act as a fulcrum of the balance model and contraction of pharyngeal dilator muscles shift the fulcrum to the left, compensating the anatomical unbalance in the neutral neck position during wakefulness (fig. 4, top panel).¹² Total muscle paralysis during general anesthesia eliminates the neural compensatory mechanisms and shifts the fulcrum to the right, manifesting the anatomical unbalance and therefore narrowing the pharyngeal airway in the neutral neck position (fig. 4, middle panel). While eliminating the neural mechanisms, changes in pharyngeal airway size and collapsibility are attributable to changes in the anatomical balance.^{3,10} The bony enclosure size varies with head and mandible positioning changes even within one subject. Although the changes in arrangement of bony structures surrounding the pharyngeal airway were not evaluated in this study, an increase in the distance between mentum and cervical column should result from upper cervical extension with bite closure in the sniffing position, consequently leading to increase in the bony enclosure size, which was demonstrated in the magnetic resonance imaging study by Adnet *et al.*¹³ Accordingly, the sniffing position increases bony enclosure size and improves anatomical balance, resulting in the increase of pharyngeal airway size (fig. 4, bottom panel). Although

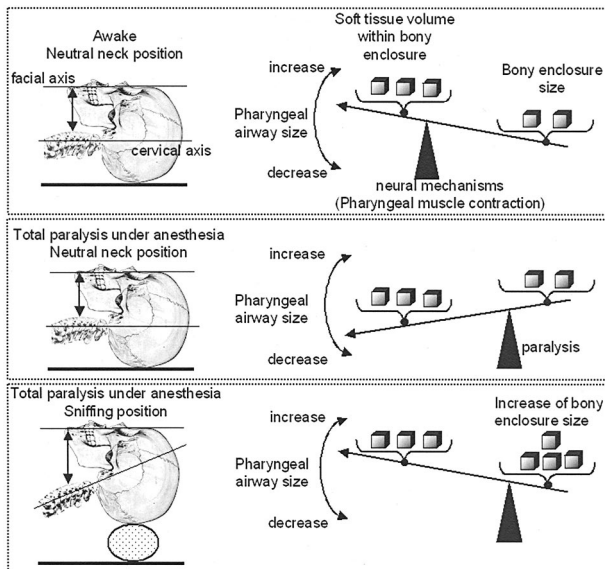


Fig. 4. Schematic balance model explains interaction between the anatomical and neuromuscular mechanisms determining pharyngeal airway patency in three different conditions. Configuration of head, neck, and mandible positions is illustrated for each condition. Note increase of the distance between the mentum and cervical column in the sniffing position, indicating increase in the bony enclosure size.

the results of this study coincide with the anatomical balance model, increase in the bony enclosure size may not be the only predominant mechanism for the improvement of pharyngeal airway collapsibility in the sniffing position.

It was found that the sniffing position influences airway collapsibility at both retropalatal and retroglottal segments. It is not surprising to find significant mechanical influences of the sniffing position on the retroglottal airway because tongue musculature originates from and is enclosed by the mandible. In contrast, soft tissue at the level of the retropalatal airway is not enclosed by the mandible, and there is no direct structural connection between the mandible and soft tissue, implying less or no influence of the sniffing position on the retropalatal airway patency. The sniffing position enables the mechanical load relief of the tongue soft tissue from the soft palate, which may be a possible explanation for the retropalatal airway patency improvement as demonstrated in our previous study, although speculative at present.¹⁴

Mechanical influences of the sniffing position differed slightly from those of simple neck extension, whereas both neck positions increased A_{max} and decreased P'_{close} to approximately the same extent.¹⁵ In our previous study, a significant reduction of the K value at the level of the retroglottal airway was demonstrated during simple neck extension.¹⁵ Increase in longitudinal force along the airway, presumably due to airway lengthening during simple neck extension,^{16,17} may be offset by lower cervical flexion in the sniffing position.

Our results indicate less improvement of the retroglottal airway in obese patients with OSA. It is possible that increase in bony enclosure in the sniffing position may be less effective in compensating for the excessive amount of soft tissue in obese patients. The assumption that the sniffing position with the same cushioning produces identical head elevation and cervical displacements may be invalid because of the heavier head and thicker soft tissue of the back in the more obese patients with OSA. Regardless of the mechanism, in obese OSA patients, the use of a higher pillow with a straight-up face position for the maintenance of pharyngeal airway, at least during induction of general anesthesia, is recommended.

Surprisingly, this is the first study to examine the effects of the sniffing position on pharyngeal airway patency in adults during general anesthesia; only the effects of simple neck extension have been reported previously.^{15,18,19} Shorten *et al.*⁵ reported that sedated children positioned on the sniffing position pillow demonstrated significantly greater nasopharyngeal diameter than those with shoulder elevation, whereas the airway diameter did not significantly differ at the level of the oropharynx and hypopharynx. Although their study population and experimental conditions significantly differ from ours, the limited beneficial effect of the sniffing position partially disagrees with our study in which the sniffing position improved the whole pharyngeal airway patency. Lack of assessment in the neutral neck position as control or structurally stable pharyngeal airway of children without SDB may have elicited the nonsignificant improvement of airway size at levels of the oropharyngeal and hypopharyngeal airways in their study.⁸ Our finding that the sniffing position improves airway patency less in patients with less collapsible pharyngeal airways may support the latter speculation. Alternatively, because neural mechanisms were not eliminated in their study, active contraction of the pharyngeal dilator muscles could have successfully maintained patency of the pharyngeal segments without the use of the sniffing position pillow.²⁰

Among the five risk factors for difficult mask ventilation identified by Langeron *et al.*,⁴ history of snoring, obesity, and advanced age are common clinical features of patients with OSA. In addition, high incidences of fatal intubation difficulty and failure have also been reported in these patients.²¹ Accordingly, proper placement of the head and neck to achieve a patent airway for adequate mask ventilation and an unobstructed laryngeal view during direct laryngoscopy is vital, particularly in obese OSA patients. Because the suitability of the sniffing position for the former purpose was investigated by the authors, Adnet *et al.*^{1,13} examined the superiority of the position for the latter purpose. Both results indicate advantages of the sniffing position over the neutral neck position and equally favorable outcome with simple

neck extension. Notably, Adnet *et al.*¹ found that the sniffing position improved the laryngeal view during direct laryngoscopy in obese persons. This is a significant contrast to our finding that the sniffing position was less effective in obese OSA patients for pharyngeal airway patency. Nevertheless, it is recommended that all patients be placed in the sniffing position during induction of anesthesia because the primary goal during this period is to place an endotracheal tube successfully, and a more patent pharyngeal airway can be established by application of triple airway maneuvers with two hands in the sniffing position.²²

Despite the high incidence of postoperative upper airway obstruction,²³ to our knowledge, optimal head and neck positioning immediately after tracheal extubation has not been examined and documented in anesthesia textbooks or in the literature. Our results indicate that postoperative use of a pillow is potentially beneficial for maintaining patent pharyngeal airway. Although head elevation with a pillow seems to dose-dependently improve the pharyngeal patency,²⁴ the possibility of mouth opening or accidental neck flexion, both of which would attenuate the beneficial effects, may increase with pillow height increase. From this context, the clinically optimal height of a pillow would be less than what theory indicates. Accordingly, there is no reason to refrain from postoperative use of a pillow, although a high pillow is not recommended. A pillow specially designed for maintaining the sniffing position is preferable if available. It should be recognized that the sniffing position alone does not completely establish a patent airway and normalize breathing in patients with OSA, as is evident from our observation that four patients demonstrated closing pressure above atmospheric pressure even in the sniffing position. In addition, Kushida *et al.*²⁵ found no significant improvement of SDB in severe OSA patients with use of a pillow maintained at the sniffing position, whereas the improvement was evident in mild OSA patients. Application of nasal continuous positive airway pressure or nasal airway insertion is necessary to establish patent airway and normalize breathing during sleep immediately after surgery in patients with severe OSA.²⁶

We conclude that the sniffing position structurally improves maintenance of the passive pharyngeal airway at both retropalatal and retroglossal segments in patients with obstructive sleep apnea and may be beneficial for both mask ventilation and tracheal intubation during induction of anesthesia.

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