■ CLINICAL INVESTIGATIONS

Lateral Position Decreases Collapsibility of the Passive Pharynx in Patients with Obstructive Sleep Apnea

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Background: Reduction of nocturnal obstructive events during lateral position in patients with obstructive sleep apnea was previously reported. However, little information is available regarding mechanisms of the improvement and the precise pharyngeal site influenced by the lateral position. The authors tested the hypothesis that structural properties of the passive pharynx change by changing the body position from supine to lateral.

Method: Total muscle paralysis was induced with general anesthesia in eight 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 positions allowed assessment of the influence of the position change on the mechanical properties of the pharynx.

Results: The static pressure–area curves of the lateral position were above those of the supine position, with increasing maximum cross-sectional area and decreasing the closing pressure at both retropalatal and retroglossal airways.

Conclusions: Lateral position structurally improves maintenance of the passive pharyngeal airway in patients with obstructive sleep apnea.

BODY position influences respiratory mechanics and breathing patterns. Beneficial effects of lateral position on maintenance of pharyngeal airway are far obvious to spouses who recognize that their husbands snore less while on their sides during sleep. In fact, obstructive respiratory events during sleep were reported to be fewer with the lateral position than the supine position in patients with obstructive sleep apnea (OSA).[1–5] Lateral position is recommended to be a preferable position for improving obstruction at the pharyngeal airway in these patients during sleep, suggesting usefulness of positional therapy even for pharyngeal obstruction during the perioperative period. However, little information is available regarding the mechanisms of the improvement and the precise pharyngeal site influenced by the lateral position.

The current concept of maintenance of pharyngeal airway suggests that interaction between intrinsic mechanical properties of the pharynx (anatomic mechanisms) and neural regulation of pharyngeal dilator muscle activities (neural mechanisms) determines the size of the pharynx.[6] Therefore, the improvement of the pharyngeal maintenance by the lateral position could be either structural alteration or increase in the pharyngeal dilator muscle activities. In this context, Boudewyns *et al.*[7] clearly demonstrated reduction of upper airway collapsibility during suppression of the upper airway muscle activities, indicating involvement of the anatomic mechanism. However, we still lack knowledge on structural changes within each pharyngeal segment by the lateral position. As reported previously, we developed a method for evaluation of anatomic properties of each pharyngeal segment independently of the neural mechanisms.[8–10] The neural mechanisms are completely eliminated by producing total muscle paralysis with general anesthesia. During such circumstances, the anatomic properties of the atonic pharynx can be assessed by measuring cross-sectional area at various airway pressures (P_{AW}) during conditions of no respiratory airflow. The static mechanics of the passive pharyngeal segment is graphically best expressed by a pressure–area relation plot, which exhibits the maximum area, the pressure at which the area is zero (closing pressure [P'_{close}]), and the passive pharyngeal compliance. Structural changes by the lateral position are demonstrated as changes of the static pressure–area relation. Accordingly, the purpose of this study was to assess effectiveness of the lateral position in improving structural properties of each pharyngeal segment while eliminating neuromuscular factors in patients with OSA.

Materials and Methods

Subjects and Overnight Oximetry

We studied eight male patients with OSA who were interested in undergoing uvulopalatopharyngoplasty as a treatment for their OSA and were scheduled to have endoscopic assessment of their pharyngeal mechanics to determine whether they were favorable candidates for this procedure. All had histories of excessive daytime sleepiness, habitual snoring, and witnessed repetitive apnea. Sleep disordered breathing (SDB) was evaluated by a pulse oximeter (Pulsox-5; Minolta, Tokyo, Japan) at

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♦ This article is accompanied by an Editorial View. Please see Drummond GB: Controlling the airway: Skill and science. ANESTHESIOLOGY 2002; 97:771–3.

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home. All subjects were instructed to attach an oximetry finger probe before sleep and to remove the probe on awakening. Digital readings of arterial oxygen saturation (Sp_{O_2}) and pulse rate were stored every 5 s in a memory card. 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 percent of time spent at Sp_{O_2} less than 90%. Although the oximetry evaluation alone does not clarify the nature of SDB, we believe that all patients can be safely diagnosed as having OSA based on the oximetry results and the clinical symptoms.[11]

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.

Preparation of the Subjects

Each subject was initially premedicated with 0.5 mg atropine. Studies were performed with the subjects in a supine position on an operating table, with the neck in a comfortable neutral position. A modified tight-fitting nasal mask was used. Care was taken to prevent from air leaks from the mask, particularly when the airway was pressurized above 20 cm H_2O. Use of a chin strap maintained contact of the upper and lower incisors and eliminated air leaks through the mouth. The air leaks through the mask and mouth were detected by inadequate increase in the P_{AW} and feeling them by hand. General anesthesia was induced by intravenous administration of thiopental sodium (4 mg/kg). Intravenous administration of muscle relaxant (0.2 mg/kg vecuronium) achieved complete paralysis throughout the experiment. Anesthesia was maintained by inhalation of sevoflurane (2–4%) while the subject was ventilated through the nasal mask with positive pressure using an anesthetic machine. Sp_{O_2}, electrocardiogram, and blood pressure were continuously monitored. A slim endoscope (FB10X; Pentax, Tokyo, Japan; 3-mm OD) was inserted through the modified nasal mask and the naris. The tip of the scope was placed at the upper airway to visualize the retropalatal airway space (airway space behind the soft palate) and the retroglossal airway space (airway space behind the base of the tongue). A closed-circuit camera (ETV8; Nisco, Saitama, Japan) was connected to the endoscope, and the pharyngeal images were recorded on a videotape. Reading of P_{AW}, measured by a water manometer, was simultaneously recorded on the videotape.

Experimental Procedures

To determine the pressure–area relation of the pharynx, the anesthetic machine was disconnected from the nasal mask. The latter was in turn connected to a pressure-control system capable of accurately manipulating P_{AW} from −20 to 20 cm H_2O in a stepwise fashion.

Cessation of mechanical ventilation resulted in apnea caused by complete muscle paralysis. P_{AW} was immediately increased up to 20 cm H_2O, dilating the airway. While the subject remained apneic for 2–3 min, P_{AW} was gradually reduced from 20 cm H_2O to a P'_{close} of the retropalatal airway in a stepwise fashion. The latter represented the pressure at which complete closure of the retropalatal airway occurred, as evident on the video screen. In this experimental setting, the retroglossal P_{AW} was not reduced below the retropalatal P_{AW}. Sp_{O_2} was maintained above 95% during the apneic tests. This procedure of experimentally induced apnea allowed construction of the 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 with a wire passed through the aspiration channel of the endoscope. Measurements were made for the retropalatal and retroglossal airways with patients in the supine and left lateral positions. Care was taken to maintain the neutral neck position throughout the procedure, particularly when the patient was in the lateral position while we did not measure the head angle. In the left lateral position, the down-side knee was bent to retain the legs on the table, improving stabilization of the position. The upside leg was bent to the lesser extent, and additional pillows supported the head so that the trunk and head were aligned. The elbows were flexed, and both arms were placed on the table in front of the patient's face.

Data Analysis

To convert the monitor image to an absolute value of cross-sectional area of the pharynx, 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 counted pixels included in the area (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, we tested the accuracy of our cross-sectional area measurements. For a constant distance, the measured areas were systematically deviated from actual areas. The largest known area tested (0.95 cm^2) was underestimated by 11% because of image deformation at outer image area, and the smallest known area tested (0.03 cm^2) was overestimated by 13% because of reduction of the image resolution.

The measured luminal cross-sectional area was plotted as a function of P_{AW}. We defined P'_{close} as the pressure corresponding to the zero area. At high values of P_{AW}, relatively constant cross-sectional areas were revealed; therefore, maximum area (A_{max}) was determined as the mean value of highest three P_{AW} (18, 19, and 20 cm H_2O). As

reported previously,[8-10] the pressure–area relation of each pharyngeal segment was fitted by the following exponential function:

$$A = A_{max}B \cdot exp(- K \cdot P_{AW}),$$

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 R^2 (SigmaPlot version 2.0; Jandel Scientific Software). A regressional estimate of 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:

$$P'_{close} = ln(B/A_{max}) K^{-1}.$$

The shape of the pressure–area relation was described by the value of 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 entire ranges of P_{AW}. By contrast, the K value represents a rate of changes in the slope of the curve. When the K value is high, small reduction of P_{AW} results in significant increase in compliance, leading to remarkable reduction in cross-sectional area. Accordingly, collapsibility of the pharynx increases with increasing K value. 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.

Statistical Analysis

All values are expressed by median (10–90 percentiles). Wilcoxon signed rank test was used for comparison of the supine and lateral positions. Spearman rank order test was performed for correlation analyses between P'_{close} difference between the positions and anthropometric and oximetry data. $P < 0.05$ was considered significant.

Results

Endoscopic measurements of static pressure–area relations of the retropalatal and retroglossal airways were successfully performed in both the supine and lateral positions in all patients. As listed in table 1, anthropometric characteristics and nocturnal oximetry data varied among the patients. Median values of these variables indicate that they were middle-aged, nonobese patients with moderate SDB.

Figure 1 shows representative pressure–area relations of the pharynx in one patient, clearly demonstrating that the pressure–area curves of both pharyngeal sites while in the lateral position are located above those while in

Table 1. Anthropometric Characteristics and Results of Nocturnal Oximetry

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Age (yr)	49.0 (27.5–60.8)
Weight (kg)	67.0 (57.3–82.1)
Height (m)	1.65 (1.55–1.75)
BMI (kg/m²)	24.3 (21.2–30.7)
ODI (h)	18.8 (11.7–58.3)
CT$_{90}$ (%)	5.5 (2.6–16.7)
Nadir Spo$_2$ (%)	89.1 (80.6–90.5)
Lowest Spo$_2$ (%)	73.0 (60.3–82.7)

Values are medians (10–90 percentiles).

BMI = body mass index; ODI = oxygen desaturation index, defined as number of desaturations exceeding greater than 4% per hour; CT$_{90}$ = percent of time spent with oxygen saturation measured by pulse oximetry (Spo$_2$) less than 90%; Nadir Spo$_2$ = mean of the nadir Spo$_2$ values in all desaturation events; Lowest Spo$_2$ = a lowest Spo$_2$ value among the desaturation events.

the supine position, with larger A_{max} and smaller P'_{close} while in the lateral position.

Table 2 summarizes changes in the static mechanic variables of the retropalatal and retroglossal airways of patients while in the supine and lateral positions. As indicated by relatively high R^2 values, the exponential function fitted reasonably well the measured pressure–area relations. Change from the supine to the lateral position significantly increased median A_{max} from 1.30 cm² to 2.39 cm² at the retropalatal airway and from 3.70 cm² to 5.83 cm² at the retroglossal airway. The position change significantly decreased median P'_{close} from 2.05 cm H_2O to −1.86 cm H_2O at the retropalatal airway and from 0.49 cm H_2O to −3.17 cm H_2O at the retroglossal airway. While K values representing stiffness of the pharyngeal airway wall tended to decrease while the patient was in the lateral position, the difference was not statistically significant between the positions.

Closing pressure of the retropalatal airway was higher than that of the retroglossal airway in six patients in the supine position, and seven patients had higher P'_{close} at the retropalatal airway than the retroglossal airway while in the lateral position. While the highest P'_{close} within
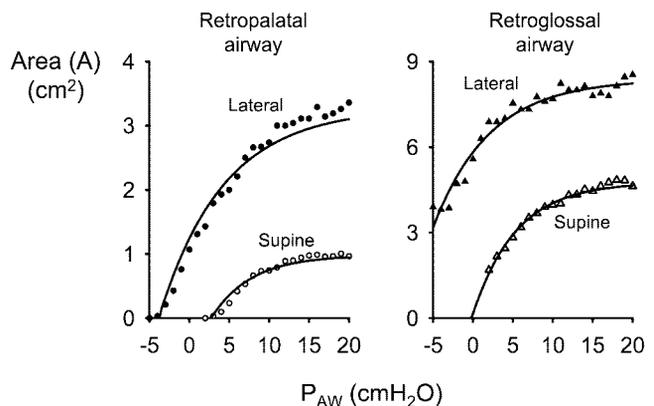
Fig. 1. Representative static pressure–area relations obtained from one subject, showing difference of the relations at the level of retropalatal and retroglossal airways between the supine and lateral positions. A = cross-sectional area; P$_{AW}$ = airway pressure.

Table 2. Static Mechanics of the Velopharynx and the Oropharynx in Supine and Lateral Positions

	Supine	Lateral
Retropalatal airway		
A_{max} (cm^2)	1.30 (0.58–3.37)	2.37 (1.25–4.27)*
B	1.97 (0.81–2.89)	2.04 (1.08–2.71)
K	0.18 (0.10–0.26)	0.14 (0.09–0.16)
r^2	0.98 (0.88–0.99)	0.97 (0.90–0.98)
P'_{close} (cm H_2O)	2.05 (−1.69–+2.74)	−1.86 (−4.79–+1.18)*
Retroglossal airway		
A_{max} (cm^2)	3.70 (1.67–4.83)	5.83 (2.69–8.35)*
B	3.46 (1.88–5.27)	2.54 (1.83–7.92)
K	0.17 (0.13–0.21)	0.14 (0.10–0.21)
r^2	0.96 (0.92–0.98)	0.96 (0.88–0.98)
P'_{close} (cm H_2O)	+0.49 (−2.97–+1.76)	−3.17 (−7.25–+0.11)*

Values are medians (10–90 percentiles). Quality of the fit is provided by coefficient r^2.

* $P < 0.05$ compared with supine.

$A = A_{max} - B * exp(-K * P_{aw})$, where A and P_{aw} denote cross-sectional area of the pharyngeal airway and airway pressure; A_{max} = maximum cross-sectional area; B and K = constants obtained by fitting the pressure–area relationship of each pharyngeal airway to an exponential function; P'_{close} = estimated closing pressure calculated by $ln(B/A_{max})K^{-1}$.

the pharynx was above atmospheric pressure in seven patients in the supine position, it remained above atmospheric pressure in two patients in the lateral position (fig. 2). The positional improvement of P'_{close} values did not differ between the retropalatal airway (2.9 [−0.3 to 6.2] cm H_2O) and the retroglossal airway (3.3 [1.0–7.0] cm H_2O). The degree of the positional improvement of P'_{close} values and absolute P'_{close} values while patients were in the lateral position at both segments was not statistically correlated with age, body mass index, and severity of nocturnal desaturation.

Discussion

We found that the position change from the supine to the lateral enlarged both retropalatal and retroglossal
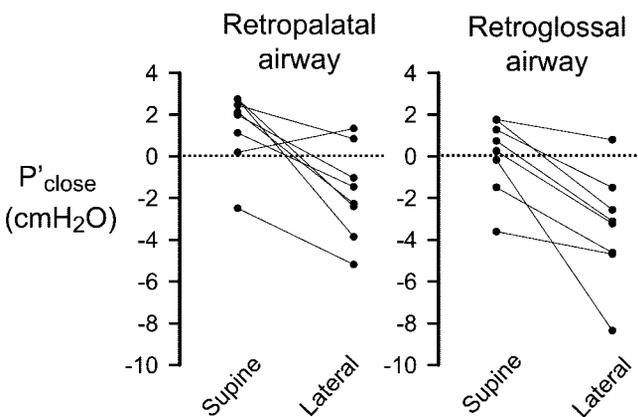
Fig. 2. Changes of closing pressures (P'_{close}) at the level of retropalatal and retroglossal airways in response to position change from supine to lateral. Each dot represents a different subject.

airways and decreased P'_{close} at both sites by approximately 3 cm H_2O on average in completely paralyzed and anesthetized patients with OSA. The results clearly demonstrate that anatomic properties of the passive pharynx improve while patients are in the lateral position.

Cartwright[1] first assessed the effects of the lateral position on breathing during sleep using polysomnogram. He found that the number of obstructive events during sleep was twice as high during the supine position than the lateral position in 24 patients with OSA, and five of them decreased it less than 5 h^{-1}. Although Cartwright did not differentiate non–rapid-eye-movement and rapid-eye-movement sleep, Pevernagie and Shepard[2] demonstrated that the positional effects were lost during rapid-eye-movement sleep,[2] possibly reflecting variable contribution of compensatory neural mechanisms to improvement of pharyngeal patency depending on sleep stages. Pevernagie *et al.*[12] further examined the positional effects on upper airway dimensions using computed tomography scan during wakefulness and demonstrated that mean cross-sectional area of the upper airway increased by changing the patient's position from the supine to the lateral even in the nonpositional OSA patient group. Unfortunately, this study was performed without controlling the neural mechanisms during wakefulness, when the upper airway muscles were reported to be actively contracting for compensation of anatomic abnormalities at the pharynx in these apneic patients.[13] Therefore, the observed increase in the area could be either further recruitment of the pharyngeal dilator muscles or structural improvement during the lateral position.

Recently, influences of the lateral position on pharyngeal collapsibility have been evaluated during natural sleep.[7,14,15] Neill *et al.*[14] measured upper airway P'_{close} by occluding nasal airway in patients in both the supine and lateral positions, but they failed to find significant positional effects on the P'_{close}.[14] By applying Starling resistor concept, Penzel *et al.*[15] reported that critical P'_{close} of the upper airway decreased by approximately 3 cm H_2O in OSA patients in the lateral position compared with the supine position in all sleep stages. While the critical P'_{close} was obtained without suppressing pharyngeal dilator muscle contraction in the study by Penzel *et al.*, the amount of the critical P'_{close} reduction was similar to that of Boudewyns *et al.*,[7] who measured the critical P'_{close} of hypotonic upper airways in OSA patients during sleep. We confirmed the results of Boudewyns *et al.* by measuring the P'_{close} of the passive pharynx, and first demonstrated that both retropalatal and retroglossal airways responded to the position change. Probably reflecting the condition of the upper airway dilator muscle activities during the collapsibility assessments, the P'_{close} reported by Boudewyns *et al.* and us were significantly greater than those reported by Penzel

Supine   Lateral

Direction of gravity
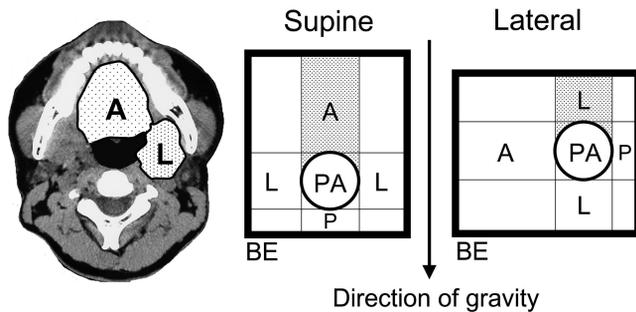
Fig. 3. Axial image of computed tomography scan at the level of the mandible (taken from a person unrelated to this study) and the schematic presentations of the axial structural arrangements while the patient is in the supine and lateral positions. BE = bony enclosure; PA = pharyngeal airway; A = mass of soft tissues locating anteriorly; L = mass of soft tissues locating laterally; P = mass of soft tissues locating posteriorly. Note that the amount of soft tissues acting on the mucosa of the pharyngeal airway shown by the shaded area is significantly less while patients are in the lateral than the supine position.

et al. in patients in the supine position. However, interestingly, all of these previous studies demonstrated reduction of P'$_{close}$ by approximately 3 cm H_2O in the lateral position regardless of the condition of the upper airway muscle activities, indicating that the neural mechanisms contribute little to the improvement of pharyngeal patency by the lateral position.

While the mechanisms of the structural improvement of pharyngeal collapsibility are not entirely clear at present, two possible mechanisms are considered. As illustrated in figure 3, the pharyngeal airway is structurally surrounded by the soft tissues such as the tongue and lateral soft tissue, which are enclosed by the bony structures such as the mandible and the spine. Based on the finding that both obesity and craniofacial abnormalities, such as small mandible, contributed to increased pharyngeal collapsibility in patients with OSA, we recently suggested that the balance between the amount of the soft tissues and the size of the bony enclosure determines the pressure within the soft tissue (P$_{tissue}$).[16] For a given P$_{AW}$, increase in the P$_{tissue}$ results in reduction of the transmural pressure (P$_{tm}$ = P$_{AW}$ − P$_{tissue}$) and therefore narrows pharyngeal airway. When we changed the body position from supine to lateral, the size of the bony enclosure was considered to be constant because we maintained the head and mandibular positions throughout the experiment. Therefore, the observed reduction of the P$_{tissue}$ with the patient in the lateral position can be mainly explained by changes in the amount of the soft tissues. As illustrated in figure 3, the soft tissues are not uniformly distributed within the bony enclosure, indicating that the P$_{tissue}$ may axially vary depending on the direction of gravity acting on the soft tissues, since gravity is considered to be one of significant determinants of the P$_{tissue}$.[17] This uneven distribution of the P$_{tissue}$ may be further altered by the position change from the supine to the lateral, assuming that the

attachment forces between the soft tissues and the bony structures do not differ between the positions. The larger mass of the soft tissues, such as the tongue, anteriorly overrides on the pharyngeal airway, producing greater P$_{tissue}$ derived from the gravity onto the anterior pharyngeal airway wall while the patient is in the supine position, whereas the relatively smaller amount of the soft tissues locating laterally may produce smaller P$_{tissue}$ onto the lateral pharyngeal airway wall while the patient is in the lateral position. Alternatively, difference in lung volume in patients in the supine and lateral positions may explain the improvement of pharyngeal collapsibility during the lateral position, because the lung volume is reported to influence the pharyngeal patency.[18] Functional residual capacity was reported to increase during left lateral position compared with supine position in anesthetized and paralyzed human subjects.[19] Although speculative at present, caudal tracheal displacement resulted from the lung volume increase may decrease pharyngeal collapsibility, as Rowley *et al.* reported.[20] The caudal movement of the trachea also possibly leads to shift of the soft tissue volume out of the bony enclosure to submandibular space, resulting in reduction of the P$_{tissue}$. Accordingly, the possibly increased lung volume during the lateral position may partly account for the increase in the pharyngeal area and reduction of the P'$_{close}$.

Patients with OSA are reported to have higher rate of severe respiratory complications associated with upper airway obstruction during anesthesia and sedation or immediately after anesthesia.[21] While our results only apply to this particular group of patients, we believe that the positional treatment may be beneficial, when applicable, in any perioperative patients as far as the amount of the anterior tissue volume within the mandibular enclosure is greater than the lateral tissue volume as discussed above. Considering that one of common respiratory complications during the perioperative period is related to upper airway obstruction even in general population,[22] and that prevalence of the patients who have more than 5 obstructive events per hour with or without daytime sleepiness is 24% and 9% in middle-aged adult male and female populations, respectively,[23] we believe that our study provides clinically useful information applicable to anesthesia practice in the general population for development of safer perioperative management.

Our clinical goal is a resolution of pharyngeal obstruction, normalizing the breathing pattern. We previously reported that the P'$_{close}$ measured in paralyzed and anesthetized persons without SDB was −3.8 cm H_2O at the retropalatal airway and −5.5 cm H_2O at the retroglossal airway on average.[8] While we found significant improvement of the P'$_{close}$ at both pharyngeal sites in patients in the lateral position, the lateral P'$_{close}$ of each site appears to be still higher by approximately 2 cm H_2O than that of

normal persons, indicating that complete reestablishment of patent airway and normal breathing may not be accomplished by the lateral position. Probably because we did not differentiate SDB events in patients in the supine position from those in the lateral position, we failed to find a significant correlation between the severity of SDB and the lateral P'_{close} values. It would be reasonable to speculate that the two patients who had a lateral P'_{close} value greater than atmospheric pressure would not normalize their breathing during sleep, as Boudewyns *et al.* clearly demonstrated.[7] Furthermore, mandibular advancement, which is one significant component of the triple airway maneuvers usually performed during mask ventilation on induction of anesthesia, was reported to decrease the P'_{close} from 1.5 cm H_2O to -8.1 cm H_2O on average in anesthetized and paralyzed patients with OSA,[10] suggesting application of the triple airway maneuvers with the patient in the supine position is preferable to the lateral position on induction of anesthesia. We believe that lateral positioning would be useful in maintaining ventilation, particularly in spontaneously breathing persons who are lightly sedated for minor surgeries or examinations.

In conclusion, lateral position structurally improves maintenance of the passive pharyngeal airway in patients with obstructive sleep apnea and may be a useful treatment technique for less severe upper airway obstruction.

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