Anesthesiology 2009; 110:885–90

Three-dimensional Morphological Analyses of Positional Dependence in Patients with Obstructive Sleep Apnea Syndrome

Hanako Saigusa, M.D., Ph.D., Masaaki Suzuki, M.D., Ph.D.,† Naoki Higurashi, D.D.S.,‡ Kazuoki Kodera, M.D., Ph.D.§*

Background: **It is generally considered that patients with obstructive sleep apnea syndrome (OSAS) at increased perioperative risk should be placed in nonsupine positions throughout the recovery process; however, not all patients with OSAS show positional dependence. The authors hypothesized that morphological differences exist in three-dimensional (3D) soft tissue and craniofacial structures of the pharyngeal airway between positional and nonpositional OSAS.**

Methods: **The subjects of the study were body mass index–matched, age–matched, and apnea hypopnea index–matched positional (n = 10) and nonpositional (n = 10) Japanese OSAS patients and body mass index–matched Japanese control subjects (n = 10). Pharyngeal magnetic resonance imaging and cephalometric radiography were performed during wakefulness.**

Results: **The patients with positional OSAS had a smaller volume of the pharyngeal lateral wall soft tissues, larger maxilla-nasion-mandible angle, and smaller lower facial height than the nonpositional OSAS and the control subjects. The patients with positional OSAS showed a significantly steeper sella-nasion-mandible angle and smaller craniofacial volume than the control subjects. There were no significant differences in tongue volume and 3D pharyngeal anatomical balance between positional and nonpositional OSAS. Multivariate stepwise regression for positional dependence showed that the dominant determinant was the volume of the lateral pharyngeal wall, followed by lower facial height and maxilla-nasion-mandible angle.**

Conclusions: **Patients with positional OSAS have wider airways in the lateral parts, lower facial height, and more backward position of the lower jaw, which may explain differences in the maintenance of pharyngeal airway patency in the lateral sleep position.**

IN patients with obstructive sleep apnea syndrome (OSAS), obstructive respiratory events during sleep are generally fewer when they lie on their side than when they lie on their back. This positional dependence in OSAS is defined as a condition in patients in whom the apnea hypopnea index (AHI) during lateral sleep is one-half or less than that during sleep in the supine position.[1] In accordance with the practice guidelines for the perioperative management of OSAS patients established by the American Society of Anesthesiologists, patients with an increased perioperative risk of respiratory compromise from OSAS should be placed in nonsupine positions throughout the recovery process.[2] A multivariate stepwise logistic regression study showed that the dominant determinant that significantly predicted positional dependence in OSAS was AHI, followed by body mass index and age.[3] Positional dependence tends to be associated with mild and moderate rather than with severe OSAS; however, not all cases of mild and moderate OSAS show positional dependence, and not all cases of severe OSAS show nonpositional dependence.

Structurally, the pharyngeal airway is surrounded by soft tissues such as the tongue and lateral pharyngeal wall, which are enclosed by bony structures such as the mandible and the vertebrae. It is considered that the pharyngeal airway size during sleep and anesthesia is determined by the anatomical balance between the soft tissue volume inside the bony structures and the bony structure size.[4,5] Characteristic anatomic factors may contribute to positional dependence in patients with OSAS; thus, we hypothesized that morphological differences exist in the three-dimensional (3D) soft tissue and craniofacial structures of the pharyngeal airway between positional and nonpositional OSAS.

Materials and Methods

Patients and Diagnosis

We newly determined whether Japanese male subjects had OSAS by clinical symptoms and attended overnight polysomnography in a sleep laboratory according to our previously reported method.[6] Overnight polysomnography was also recorded in control subjects in different positions. In all, 180 subjects were diagnosed with OSAS at diagnostic polysomnography. OSAS patients were recruited from the Sleep Outpatient Clinic of our university hospital; nonsnorers for the control group were recruited from the Ear, Nose, and Throat Outpatient Clinic of our university hospital. Body position during overnight polysomnography was measured using a position sensor, with a mercury switch attached to the anterior chest wall on the median line. We excluded subjects who had less than 90 min of sleep in the supine position, less than 90 min of sleep in the lateral position, and less than 15 min of rapid eye movement period in the lateral position during overnight polysomnography. The criteria for the diagnosis of positional OSAS in this study were an AHI during lateral sleep that was one-half

* Research and Clinical Associate, † Assistant Professor, § Professor, Department of Otolaryngology, Teikyo University School of Medicine. ‡ Director, Cosmos Dental Office, Narita, Japan.

Received from the Department of Otolaryngology, Teikyo University School of Medicine, Tokyo, Japan. Submitted for publication July 14, 2008. Accepted for publication December 19, 2008. Supported by Research Grant No. 17591802 from the Ministry of Education, Culture, Sports, Science, and Technology, Tokyo, Japan (to Dr. Suzuki).

Address correspondence to Dr. Suzuki: Department of Otolaryngology, Teikyo University School of Medicine, 2-11-1 Kaga, Itabashi-ku, Tokyo 173-8605, Japan. suzukima@med.teikyo-u.ac.jp.

or less of that during sleep in the supine position (*i.e.*, the ratio of AHI in the lateral position to AHI in the supine position was 0.5 or less) and an AHI in the lateral position that was less than fifteen events per hour.[7] Patients in whom the ratio of AHI in the lateral position to AHI in the supine position was more than 0.8 were determined as having nonpositional OSAS. Patients with OSAS were excluded if the number of central sleep apnea events per hour was 5 or more, if they had been treated surgically for OSAS, or if there was evidence of enlarged tonsils or severe nasal obstruction. The criteria for the diagnosis of positional OSAS were defined prospectively. The numbers of body mass index–matched, age–matched, and AHI–matched positional and nonpositional OSAS patients were 25 and 16, respectively. The final study population consisted of ten randomly selected Japanese male patients with positional OSAS, ten with nonpositional OSAS, and ten control subjects.

The Institutional Review Board of our institute (Tokyo, Japan) approved the study after review by the Ethics Committee, and informed consent was obtained from all subjects.

3D MRI Reconstruction of Structures and Morphologic Analyses

Magnetic resonance imaging (MRI) scans were performed in the supine position during wakefulness on patients with OSAS and the control subjects (Signa Horizon LX1.5 Tesla CVi; GE Medical Systems, Milwaukee, MI). Technologists provided instructions on the intercuspal position, with the tongue touching the front teeth and tidal breathing through the nose. Intercuspal position is the position of the mandible when the cusps and sulci of the maxillary and mandibular teeth are in their greatest contact and the mandible is in its most closed position. The subject's head was secured on the scanner table with foam pads, and each subject was instructed not to move their head and encouraged to refrain from swallowing during scanning. Axial sections were positioned parallel to the raised baseline (the line connecting the sella turcica and the fourth cerebral ventricle); T1-weighted images were acquired using 3D spoiled gradient recalled pulse imaging (8.9/4.2/8.0 ms; scanning time, 6 min and 48 s; 220 × 220 mm; matrix, 256 × 192; slice thickness, 15 mm; 60 slices). In patients with OSAS, MRI was performed with continuous positive airway pressure before treatment.

The tongue, lateral pharyngeal wall, craniofacial volume, and mandible were reconstructed using 3D imaging software (V-works; Cybermed Inc., Seoul, Korea), in accordance with our previous study.[8] The tongue was carefully trimmed and outlined on each slice, from the tongue tip to the bottom of the tongue base (the level of the epiglottic vallecula), and the inside of the tongue was smeared on both the axial and sagittal planes. The image was then rotated 360 degrees, the smoothness on the surface was checked, and inaccurate parts were corrected. These procedures were repeated until smooth 3D structures of the tongue were obtained. We digitally calculated the integration of the soft tissue area bordered by the pharyngeal mucosa, posterior fascia of the middle pterygoid muscle, medial periosteum of the styloid process, anterior sheath of the internal carotid artery, and anterior fascia of the prevertebral muscle (hereafter referred to as the lateral pharyngeal wall), from the level of the upper surface of the hard palate to the level of the epiglottic vallecula. The craniofacial volume was measured by reconstructing the internal contents of the mandible and the lower part of the maxilla. We calculated the 3D pharyngeal anatomical balance by dividing the sum of the lateral pharyngeal wall and tongue volumes by the craniofacial volume. 3D reconstruction of the mandible was performed in the same way as for the tongue; the 3D structures of the mandible were then manipulated on the computer to determine the section showing the entire bottom of the corpus mandibulae.

Five mandibular measurements were analyzed from this section, in accordance with our previous methods (fig. 1)[8]: internal mandibular width was defined as the distance between the internal right gonion and the internal left gonion; mandibular bony thickness was defined as the mean of the distances between the right gonion and the internal right gonion and between the left gonion and the internal left gonion; mandibular divergence was defined as the angle between the spina mentalis–internal right gonion line and the spina mentalis–internal left gonion line; mandibular internal length was determined as the perpendicular distance from the spina mentalis to the line connecting the right and left gonions. The integration of the area within the internal

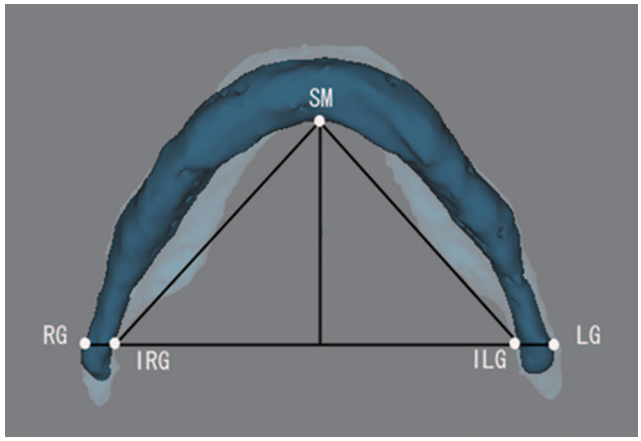

Fig. 1. ***Internal mandibular width*** **is the distance between IRG and ILG;** ***mandibular bony thickness*** **is the mean of the distances between RG and IRG and between LG and ILG;** ***mandibular divergence*** **is the angle between the SM–IRG line and SM–ILG line;** ***mandibular internal length*** **is the perpendicular distance from SM to the line connecting RG and LG;** ***mandibular area*** **is the integration of the area within the internal mandible. ILG = internal left gonion; IRG = internal right gonion; LG = left gonion; RG = right gonion; SM = spina mentalis.**

mandible, hereafter referred to as the mandibular area, was calculated digitally.

Lateral cephalometric radiographs of the intercuspal position (CX-90SP; Asahi Roentgen Co., Tokyo, Japan) were obtained in all subjects in the erect position. In accordance with our previous method,[9] we performed cephalometric analyses using the following parameters: S (sella), N (nasion), A (the deepest anterior point in the concavity of the anterior maxilla), B (the deepest anterior point in the concavity of the anterior mandible), H (hyoid bone), Me (menton), Go (gonion), Ba (basion), Pt (pterygoid point), GN (gnathion), PM (protuberance menti), Xi (center point of the body of the mandible), ANS (anterior nasal spine), facial axis angle (the angle between Ba–N and Pt–GN), the angle between S–N and N–A, the angle between S–N and N–B (SNB, sella–nasion–mandible angle), the angle between A–N and N–B (ANB, maxilla–nasion–mandible angle), the distance between the hyoid bone and the mandibular plane (Me–Go), lower facial height (LFH, the angle between ANS–Xi and Xi–pm), and total facial height (the angle between Ba–N and Xi–pm) (fig. 2).

Statistical Analyses

All descriptive statistical data are presented as the mean ± SD. Descriptive statistical data were calculated for each variable. Variables were evaluated by one-way analysis of variance (ANOVA) among the three groups (positional and nonpositional OSAS and control subjects). $P < 0.01$ was considered to indicate statistical significance. For multiple comparison (*post hoc* test), variables were evaluated by the Bonferroni test. $P < 0.05$ was considered to indicate statistical significance. Correlations between parameters were analyzed using the Spearman correlation coefficient test. Statistical comparisons were performed using the Statistical Package for Social Sciences (SPSS) for Windows, version 11.01 (SPSS Inc., Chicago, IL).

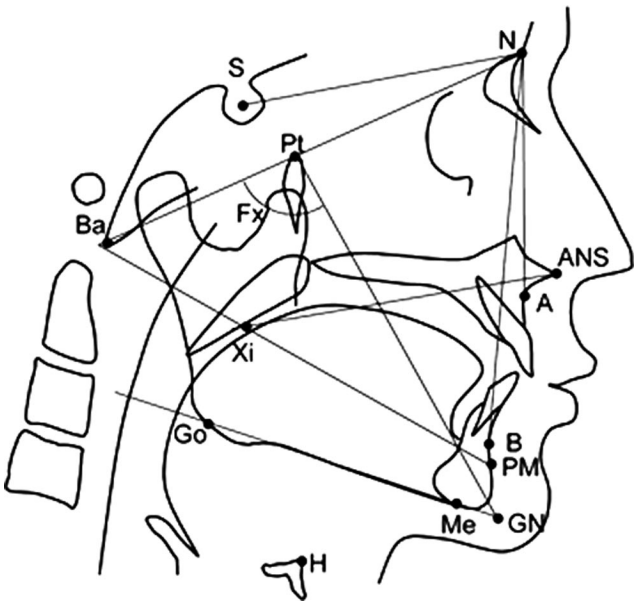

Fig. 2. Cephalometric analyses. A = the deepest anterior point in the concavity of the anterior maxilla; ANS = anterior nasal spine; B = the deepest anterior point in the concavity of the anterior mandible; Ba = basion; GN = gnathion; Go = gonion; H = hyoid bone; PM = protuberance menti; Pt = pterygoid point; S = sella; N = nasion; Me = menton; Xi = center point of the body of the mandible.

Results

The anthropometric and polysomnographic characteristics of the positional and nonpositional OSAS patients and control subjects are listed in table 1.

3D MRI Reconstruction Analyses

Comparisons of the soft tissue and craniofacial parameters using 3D MRI are shown in table 2. Figure 3 shows 3D MRI reconstructions. There were no significant differences among the three groups in terms of tongue volume. In contrast, there were significant differences in the volume of the lateral pharyngeal wall between the positional and nonpositional OSAS patients ($P = 0.01$), between the positional OSAS patients and control subjects ($P = 0.03$), and between the nonpositional OSAS patients and control subjects ($P < 0.01$). Patients with positional OSAS showed a significantly smaller craniofacial volume than the control subjects ($P = 0.045$). There

Table 1. Anthropometric and Polysomnographic Characteristics of Positional and Nonpositional Obstructive Sleep Apnea Syndrome Patients and of Control Subjects

Variable	Positional OSAS	Nonpositional OSAS	Controls
Age, yr	60.6 ± 9.4	52.6 ± 11.6	37.0 ± 7.3†‡
Body mass index, kg/m^2	27.4 ± 4.7	27.1 ± 3.0	26.7 ± 2.5
Total AHI, events/h	33.2 ± 7.3	46.6 ± 21.4	3.7 ± 0.9†‡
Lateral AHI, events/h	6.7 ± 4.9*	46.6 ± 19.6	1.7 ± 2.8‡
Supine AHI, events/h	59.3 ± 32.8	41.4 ± 19.7	6.0 ± 2.4†‡
Ratio of lateral/ supine AHI	0.13 ± 0.09*	1.19 ± 0.35	0.34 ± 0.6‡
CAI, events/h	0.29 ± 0.4	0.45 ± 0.3	0.35 ± 0.4
Total sleep time, min	377.1 ± 67.5	374.4 ± 66.2	424.9 ± 60.4
Lateral sleep time, min	146.7 ± 77.7	111.3 ± 57.4	105.5 ± 70.7
Lateral REM time, min	33.2 ± 33.4	28.9 ± 22.8	22.4 ± 21.1

* $P < 0.05$ between positional obstructive sleep apnea syndrome (OSAS) and nonpositional OSAS. † $P < 0.05$ between positional OSAS and controls. ‡ $P < 0.05$ between nonpositional OSAS and controls.

AHI = apnea hypopnea index; CAI = central apnea index; REM = rapid eye movement.

Table 2. Comparisons of Soft Tissue and Craniofacial Morphologies by Three-dimensional Magnetic Resonance Imaging Reconstruction between Patients with Positional and Nonpositional Obstructive Sleep Apnea Syndrome and Control Subjects

Variable	Positional OSAS	Nonpositional OSAS	Controls
Tongue volume, cm^3	121.3 ± 28.4	130.1 ± 8.8	121.7 ± 13.7
Volume of the lateral pharyngeal wall, cm^3	25.4 ± 2.2*	31.5 ± 5.6	19.9 ± 4.8†‡
Craniofacial volume, cm^3	176.3 ± 20.6	187.3 ± 20.5	208.5 ± 38.4†
3D pharyngeal anatomical balance	0.76 ± 0.1	0.79 ± 0.1	0.65 ± 0.1†‡
Mandibular internal width, mm	83.4 ± 4.0	85.6 ± 4.6	87.0 ± 5.1
Mandibular internal length, mm	52.3 ± 6.3	54.8 ± 4.0	54.1 ± 6.5
Mandibular bony thickness, mm	7.1 ± 0.2	8.1 ± 1.3	7.4 ± 1.4
Mandibular divergence, degrees	76.9 ± 2.7	76.7 ± 3.5	78.1 ± 4.2
Mandibular area, cm^2	30.9 ± 0.8	31.0 ± 4.2	36.6 ± 6.2†‡

* $P < 0.05$ between positional obstructive sleep apnea syndrome (OSAS) and nonpositional OSAS. † $P < 0.05$ between positional OSAS and controls. ‡ $P < 0.05$ between nonpositional OSAS and controls.

were significant differences in mandibular area and 3D pharyngeal anatomical balance between the positional OSAS patients and control subjects ($P = 0.04$ and $P = 0.047$, respectively) and between the nonpositional OSAS patients and control subjects ($P = 0.05$ and $P = 0.02$, respectively).

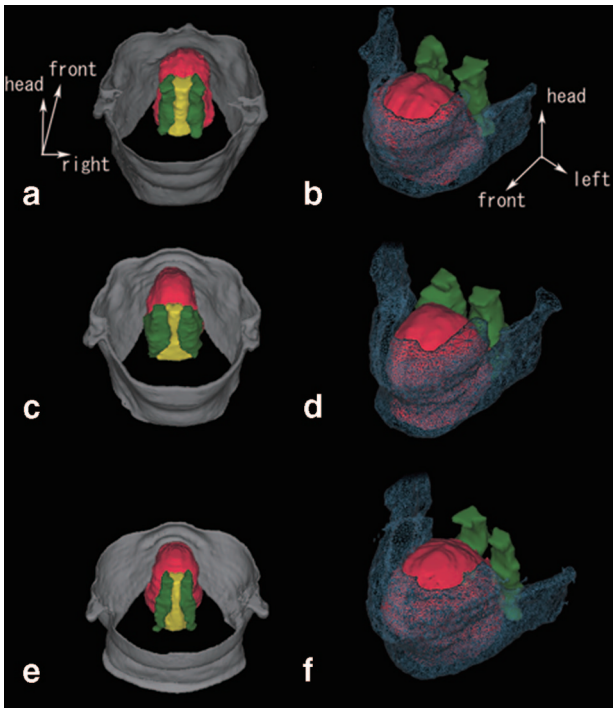

Fig. 3. Three-dimensional magnetic resonance imaging reconstructions of subjects with (*a, b*) positional obstructive sleep apnea syndrome (OSAS); (*c, d*) nonpositional OSAS; and (*e, f*) control subjects. (*a, c, e*) Lateral pharyngeal wall, tongue, and pharyngeal airway with outline of the face, posterosuperior view; (*b, d, f*) lateral pharyngeal wall, tongue, and craniofacial structures (mandible and lower part of maxilla), anterosuperior left oblique view. *Green* = lateral pharyngeal wall; *red* = tongue, red; *yellow* = upper airway space; *blue web* = craniofacial structures. Note that positional OSAS had relatively small volume of the lateral pharyngeal wall and the smallest craniofacial volume; nonpositional OSAS had relatively large craniofacial volume and the largest volume of the lateral pharyngeal wall; the control subjects had the largest craniofacial volume and the smallest volume of the lateral pharyngeal wall.

Two-dimensional (2D) Cephalometric Analyses

Comparisons of the craniofacial parameters using cephalometric parameters are shown in table 3. Patients with positional OSAS showed a significantly larger ANB angle than nonpositional OSAS patients ($P = 0.03$) and control subjects ($P = 0.02$). Patients with positional OSAS showed a smaller LFH than those with nonpositional OSAS ($P = 0.02$), and showed a significantly steeper SNB angle than the control subjects ($P = 0.01$). There were significant differences in facial axis between the positional OSAS patients and control subjects ($P = 0.01$), and between the nonpositional OSAS patients and control subjects ($P = 0.02$).

Correlation and Multivariate Analyses

Correlation analyses were performed to clarify the direct relationships between the soft tissue volume and craniofacial parameters. Lateral pharyngeal wall volume in nonpositional OSAS correlated with tongue volume ($r = 0.78$, $P = 0.01$) and LFH ($r = 0.71$, $P = 0.03$). In contrast, lateral pharyngeal wall volume in positional OSAS and control subjects did not correlate with tongue volume or LFH. Variables were included in a multivariate

Table 3. Comparisons of Cephalometric Parameters in Patients with Positional and Nonpositional Obstructive Sleep Apnea Syndrome and in Control Subjects

Variable	Positional OSAS	Nonpositional OSAS	Controls
Facial axis, degrees	82.2 ± 5.7	82.5 ± 4.9	88.3 ± 3.6†‡
SNA, degrees	80.8 ± 4.3	82.1 ± 4.0	83.7 ± 4.7
SNB, degrees	76.7 ± 3.9	79.3 ± 4.2	81.4 ± 3.2†
ANB, degrees	4.1 ± 2.6*	2.8 ± 2.3	2.4 ± 2.6†
MP-H, mm	22.4 ± 5.0	19.8 ± 5.9	17.2 ± 6.3
LFH, degrees	49.7 ± 4.9*	55.1 ± 4.3	47.1 ± 2.8‡
TFH, degrees	60.1 ± 6.7	64.8 ± 3.9	64.1 ± 4.3

* $P < 0.05$ between positional obstructive sleep apnea syndrome (OSAS) and nonpositional OSAS. † $P < 0.05$ between positional OSAS and controls. ‡ $P < 0.05$ between nonpositional OSAS and controls.

ANB = angle of the maxilla–nasion–mandible; LFH = lower facial height; MP-H = distance between the hyoid and the mandibular plane; SNA = angle of the sella–nasion–maxilla; SNB = angle of the sella–nasion–mandible; TFH = total facial height.

stepwise regression in an analysis of positional dependence (the ratio of AHI in the lateral position to AHI in the supine position). The regression model was significant (n = 20, adjusted $R^2 = 0.699$, F = 15.73, $P < 0.001$) with three determinants. The determinant that most significantly predicted positional dependence was the volume of the lateral pharyngeal wall (t = 4.30, β = 0.56, $P = 0.001$); the second determinant was LFH (t = 4.10, $\beta = 0.65$, $P = 0.001$), and the third determinant was ANB (t = 2.83, $\beta = 0.43$, $P = 0.012$). On the other hand, age and body mass index were not significant variables.

Discussion

The current study reveals novel findings that may contribute to our understanding of the pathogenesis of positional dependence in patients with OSAS. First, patients with positional OSAS had a smaller volume of the lateral pharyngeal wall soft tissues. Second, patients with positional OSAS showed a larger ANB angle and steeper SNB angle, indicating that the mandible is in a backward position relative to the maxilla in these patients; a smaller LFH, indicating a tendency for mid facial pattern rather than long facial pattern in these patients and a smaller craniofacial volume. Although the mechanism of pharyngeal collapse is often explained on the basis of the 2D pharyngeal cross-sectional area,[10] the details of the pathogenesis of positional dependence were clarified for the first time by 3D structural analyses of the current study.

Distribution of the Soft Tissue of the Lateral Pharyngeal Wall

The pharyngeal cross-sectional area, which is the luminal size of the collapsible tube, is determined by the mechanical properties of the tube and the pressure difference (transmural pressure) between the inside of the tube (P_{lumen}) and the outside (P_{tissue}).[5] For a given mechanical property of the tube and P_{lumen}, lumen closure is determined by P_{tissue}, which is higher in OSAS patients than in control subjects, resulting in a greater decrease in transmural pressure and subsequent narrowing of the pharyngeal airway. The current study revealed significant differences in the volume of the lateral pharyngeal wall soft tissues among the three groups. The different distributions of soft tissues surrounding the pharyngeal airway indicate that P_{tissue} may vary axially depending on the direction of gravity relative to patient position.[11] In the lateral position, the positional OSAS patients had a smaller volume of soft tissues blocking the pharyngeal airway; thus, a smaller gravitational force acted on the pharyngeal lumen to pull it downward, producing lower pressure on the pharyngeal space in the positional OSAS patients than in the nonpositional OSAS patients. Investigators at the University of Pennsylvania (Philadelphia, Pennsylvania) showed that lateral pharyngeal wall thickening is singularly associated with upper airway narrowing during sleep and that patients with OSAS have abnormally thick lateral pharyngeal walls that encroach on the pharyngeal airway.[12,13] All the muscles of the pharynx work back and forth to move the tongue and soft palate; however, there are no muscles that pull the pharynx outward or inward for the lateral pharyngeal wall and tonsils.[14] Our current study of body mass index–matched patients revealed that fat distribution in the lateral pharyngeal wall is also an important factor for positional dependence in patients with OSAS.

Craniofacial Structures

Craniofacial morphologies are reported to be associated with the development of OSAS in Japanese men.[15–17] Our previous study showed that the craniofacial features of patients with OSAS are particularly associated with each obstructive site.[18] The backward position of the mandible relative to the maxilla (larger ANB angle and steeper SNB angle), smaller LFH, and smaller craniofacial volume shown in the patients with positional OSAS in the current study are closely associated with obstruction at the retroglossal level during sleep.[18] Collapse at the retroglossal level might have an effect on the occurrence of position dependence in patients with OSAS.

3D Pharyngeal Anatomical Balances

3D pharyngeal anatomical balance was calculated by dividing the sum of the lateral pharyngeal wall and tongue volumes by the craniofacial volume. As the 3D pharyngeal anatomical balance increases, the pharyngeal airway space decreases. In the current study, control subjects had large craniofacial volume and small pharyngeal soft tissue volume compared with OSAS patients, resulting in significantly lower 3D pharyngeal anatomical balance than that of OSAS patients. Thus, patency of the pharyngeal airway was maintained during sleep in the control subjects. In contrast, 3D pharyngeal anatomical balance failed to prevent pharyngeal collapse during sleep both in patients with positional and nonpositional OSAS. Positional OSAS had relatively small total pharyngeal soft tissue volume and the smallest craniofacial volume, whereas nonpositional OSAS had relatively large craniofacial volume and the largest total pharyngeal soft tissue volume. Therefore, there were no significant differences in 3D pharyngeal airway anatomical balance between the positional and nonpositional OSAS patients; this may explain the nonsignificant differences in AHI between the two groups. Correlation analyses in this study also support the hypothesis that pharyngeal soft tissue volume plays a more important role in nonpositional OSAS than in positional OSAS. The results of this study were in agreement with the 2D cephalometric analyses of anatomical balance of the upper airway

in OSAS patients and control subjects reported by Tsuiki *et al.*[5]

Limitations of the Study

There were several limitations of this study. First, although there was no significant difference in age between the positional and nonpositional OSAS patients, the ages of OSAS and control subjects were significantly different. A significant increase in the size of the fat pads with increasing age is reported in people of European descent,[19] meaning that there might be the effect of age in the control subjects of this study. Second, the patients were awake during MRI examination. The effect of decreased pharyngeal muscle tone may be important when determining the size of airway space; however, the effect on soft tissue volumes and craniofacial structures is probably minimal.

Conclusions

Patients with positional OSAS had smaller volume of the lateral pharyngeal wall soft tissues, backward position of the mandible relative to the maxilla (larger ANB and steeper SNB angles), and smaller LFH. Mechanisms certainly exist to prevent pharyngeal collapse and maintain the patency of the pharyngeal airway when patients with positional OSAS are in the lateral position.

The authors thank John E. Remmers, M.D., Professor, Department of Medicine, University of Calgary, Calgary, Alberta, Canada, for critical comments on the manuscript.

References

1. Cartwright RD: Effect of sleep position on sleep apnea severity. Sleep 1984; 7:110–4

2. Gross JB, Bachenberg KL, Benumof JL, Caplan RA, Connis RT, Coté CJ, Nickinovich DG, Prachand V, Ward DS, Weaver EM, Ydens L, Yu S: Practice guidelines for the perioperative management of patients with obstructive sleep apnea. ANESTHESIOLOGY 2006; 104:1081–93

3. Oksenberg A, Silverberg DS, Arons E, Radwan H: Positional *versus* nonpositional obstructive sleep apnea patients: Anthropomorphic, nocturnal polysomnographic, and multiple sleep latency test data. Chest 1997; 112:629–39

4. Watanabe T, Isono S, Tanaka A, Tanzawa H, Nishino T: Contribution of body habitus and craniofacial characteristics to segmental closing pressures of the passive pharynx in patients with sleep-disordered breathing. Am J Respir Crit Care Med 2002; 165:260–5

5. Tsuiki S, Isono S, Ishikawa T, Yamashiro Y, Tatsumi K, Nishino T: Anatomical balance of the upper airway and obstructive sleep apnea. ANESTHESIOLOGY 2008; 108:1009–15

6. Suzuki M, Saigusa H, Furukawa T: Comparison of sleep parameters at titration and subsequent compliance between CPAP-pretreated and non-CPAP-pretreated patients with obstructive sleep apnea. Sleep Med 2007; 8:773–8

7. Jokic R, Klimaszewski A, Crossley M, Sridhar G, Fitzpatrick MF: Positional treatment *versus* continuous positive airway pressure in patients with positional obstructive sleep apnea syndrome. Chest 1999; 115:771–81

8. Okubo M, Suzuki M, Horiuchi A, Okabe S, Ikeda K, Higano S, Mitani H, Hida W, Kobayashi T, Sugawara J: Morphologic analyses of mandible and upper airway soft tissue by MRI of patients with obstructive sleep apnea hypopnea syndrome. Sleep 2006; 29:909–15

9. Higurashi N, Kikuchi M, Miyazaki S, Itasaka Y: Comparison of Ricketts analysis and Downs-Northwestern analysis for the evaluation of obstructive sleep apnea cephalograms. Psychiatry Clin Neurosci 2001; 55:259–60

10. Pevernagie DA, Stanson AW, Sheedy PF 2nd, Daniels BK, Shepard JW Jr: Effects of body position on the upper airway of patients with obstructive sleep apnea. Am J Respir Crit Care Med 1995; 152:179–85

11. Isono S, Tanaka A, Nishino T: Lateral position decreases collapsibility of the passive pharynx in patients with obstructive sleep apnea. ANESTHESIOLOGY 2002; 97:780–5

12. Schellenberg JB, Maislin G, Schwab RJ: Physical findings and the risk for obstructive sleep apnea: The importance of oropharyngeal structures. Am J Respir Crit Care Med 2000; 162:740–8

13. Schwab RJ, Pasirstein M, Pierson R, Mackley A, Hachadoorian R, Arens R, Maislin G, Pack AI: Identification of upper airway anatomic risk factors for obstructive sleep apnea with volumetric magnetic resonance imaging. Am J Respir Crit Care Med 2003; 168:522–30

14. Leiter JC: Upper airway shape. Is it important in the pathogenesis of obstructive sleep apnea? Am J Respir Crit Care Med 1996; 153:894–8

15. Esaki K: Morphological analysis by lateral cephalography of sleep apnea syndrome in 53 patients. Kurume Med J 1995; 42:231–40

16. Sakakibara H, Tong M, Matsushita K, Hirata M, Konishi Y, Suetsugu S: Cephalometric abnormalities in non-obese and obese patients with obstructive sleep apnea. Eur Respir J 1999; 13:403–10

17. Ito D, Akashiba T, Yamamoto H, Kosaka N, Horie T: Craniofacial abnormalities in Japanese patients with severe obstructive sleep apnea syndrome. Respirology 2001; 6:157–61

18. Baik UB, Suzuki M, Ikeda K, Sugawara J, Mitani H: Relationship between cephalometric characteristics and obstructive sites in obstructive sleep apnea syndrome. Angle Orthod 2002; 72:124–34

19. Malhotora A, Huanq Y, Fogel R, Lazic S, Pillar G, Jakab M, Kikins R, White DP: Aging influence on pharyngeal anatomy and physiology: The predisposition to pharyngeal collapse. Am J Med 2006; 119:9–14