Effects of head and body positions on 2- and 3-dimensional configuration of the oropharynx with jaw protruded: a magnetic resonance imaging study

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Objective. The aim of this study was to evaluate the effect of altering changing head and body positions on the 2- and 3-dimensional (3D) configuration of the oropharynx with jaw protrusion.

Study design. Twelve healthy individuals (8 male, 4 female) with no history of sleep disturbances were invited to participate. For each subject, an acrylic splint was made with the mandible in protruded position. Subjects were imaged using magnetic resonance imaging in 4 different jaw, head, and body positions: 1) supine without protrusion; 2) supine with jaw protrusion; 3) supine with head rotation and jaw protrusion; and 4) laterally recumbent position with jaw protrusion. The 2- and 3D images of the upper airway in different positions were reconstructed by using a free DICOM reconstruction software. The dimension changes (anteroposterior and lateral dimensions, cross-sectional area, and volume) of the oropharynx (divided into retropalatal region and retroglossal region) were calculated and analyzed. Statistical analyses were performed using the Bartlett test and 1-way analysis of variance with α = .05.

Results. Compared with nonprotruded position, dimensions of the oropharynx for both retropalatal region and retroglossal regions were found to be greater than with jaw protrusion. Head and body positions had little effect on configuration of the oropharynx with jaw protrusion in either 2- or 3D. The only change noted was a greater anteroposterior dimension of retropalatal region with head rotation and lateral supine position compared with the supine position.

Conclusions. Head and body positions have little effect on 2- and 3D airway dimensions on supine patients with jaw protrusion. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111:778-784)

The mechanisms responsible for upper airway obstruction in patients with obstructive sleep apnea syndrome (OSAS) are highly complicated and, as yet, not fully understood. Dimensional and modal changes of the upper airway, especially the oropharynx, provide a fundamental understanding of the pathophysiology associated with obstructive sleep apnea and as a result, provide insight into the treatment of the disorder. Narrowing of the oropharynx is an important risk factor for the development of OSAS, because airway obstructive at these sites are consistently seen in this region. Some have demonstrated that the oropharynx, especially the retropalatal area (velopharynx), is the narrowest site in the supine position and the most responsive section to change regarding an alteration in body position during wakefulness. Studies of this region are therefore crucial to further understanding the role of the anatomy of the oropharynx anatomy in the pathogenesis of OSAS.

The treatment of OSAS is usually titrated to the severity of the disease and includes nasal continuous positive airway pressure (CPAP), mandibular appliance therapy, corrective jaw and/or upper airway surgery, and drug therapy. Positional therapy involving assisted repositioning of the torso during sleep has been considered as a conservative treatment for OSAS, especially for patients exhibiting minor upper airway obstruction, because body position can influence airway dimensions and concomitant treatment effects. Among the different sleep positions, lateral decubitus has been proved to be suitable treatment for OSAS by changing the airway dimensions. Cartwright et al. found that in patients who snore and who exhibit hypopnea and OSA, symptoms were more common when lying supine than when in a laterally recumbent position. This phenomenon may be explained by the influence of gravitational pull, which is responsible for posterior displacement of the tongue. Besides lateral...
decubitus, head and neck rotation may increase the upper airway caliber in normal subjects.\textsuperscript{7}

The use of oral appliances has become a promising therapeutic option in mild-to-moderate OSAS, compared with CPAP, to increase the airway caliber and maintain ventilative patency.\textsuperscript{10} Oral appliances directed toward mandibular advancement significantly increase the cross-sectional area of the velopharynx in OSAS patients.\textsuperscript{11,12} Oral appliances have been recommended with simultaneous with positional therapy, however the combined effects of these treatments have not been investigated.

The objective of the present study was to investigate the effect of head and body positions on the oropharynx caliber in normal subjects when their jaw was protruded by using magnetic resonance imaging (MRI). We investigated 3 positions: supine, supine-head rotation and lateral decubitus, and recumbent. If head rotation and lateral decubitus can induce larger airway dimensions compared with supine position, it suggests that ventilation may be further improved by positional therapy when using mandibular advancement oral appliances. Therefore, the present study was undertaken to test the hypothesis that when jaw is protruded, changes of head and body positions can induce changes of 2- and 3-dimensional (3D) configuration of the oropharynx. We further divided the oropharynx into retropalatal (RP) region and retroglossal (RG) region to evaluate the dimension changes.

**MATERIAL AND METHODS**

**Subjects**

Twelve healthy subjects (8 male and 4 female) with oxygen desaturation index (ODI) <5\textsuperscript{13} were recruited for this study. Individuals with temporomandibular joint dysfunction, a history of respiratory disease, or occlusal dysfunction and sleep disturbances were excluded from this study. The demographic characteristics of the subjects were as follows (mean ± SD): age 26.13 ± 3.21 years; body mass index 24.27 ± 3.05 kg/m\textsuperscript{2}, and ODI 2.89 ± 1.90. Informed consent was obtained from each subject, and all procedures of the study were approved by the Institutional Ethical Board of Kyushu Dental College.

To determine jaw position, an acrylic resin wafer (20 mm × 20 mm × 2 mm), was positioned on the mandibular incisors of each subject. The habitual closure position (0% jaw protrusion) and maximum protrusive position (100% jaw protrusion) were determined and marked on the wafer. The position of 75% jaw protrusion was then determined and marked. This position has been determined as the optimal protrusive position for OSAS patients with the least adverse effects.\textsuperscript{14} According to the marks on the wafer, 2 custom-made plastic oral devices were fabricated for each subject with the jaw protruded (75% jaw protrusion) and not protruded (0% jaw protrusion). There was a 2 mm opening between the maxillary and mandibular incisors with the devices in place as suggested by George.\textsuperscript{15}

**Imaging**

Each subject, wearing the 2 oral devices, underwent MRI during wakefulness in 4 different positions: supine without jaw protrusion (S0%), supine with jaw protrusion (S75%), supine-head rotation (−45\degree to the body) with jaw protrusion (SH75%), and lateral decubitus with jaw protrusion (LD75%). The imaging sequence for various jaw, head, and body positions was randomized. Each subject’s head was stabilized via a strap. In the head rotation and lateral decubitus positions, the head/body was turned to the left side. All subjects were instructed not to move or talk during the MRI scan. They were instructed to refrain from swallowing during scanning and maintain quiet nasal breathing. Imaging was performed using a 1.5-T full-body MR system (Visart; Toshiba, Tokyo, Japan) with a circular polarized neck coil. Three-dimensional fast spin-echo images were acquired for each subject. From the top of the hard palate to the bottom of the larynx, the continuous images of the upper airway were obtained in the axial direction in each position, with a section thickness of 1.5 mm, using the parameters of spin echo repetition time of 450 ms, effective exposure time of 12 ms, field of view of 200 × 200 mm, and matrix of 192 × 256 pixels. It took ~3 minutes for image acquisition in each position. Between each imaging session, we gave the subject a break to allow swallowing and to register the next position. Scanning was repeated if any movement was detected.

High-resolution images of MRI were observed and measured in all subjects for each position. The images data were exported into a personal computer (Windows XP), and 3D images of the upper airway in different positions were analyzed using a free Dicom 3D viewer (Intage Realia; KGT, Tokyo, Japan). Measurements made from MR images included anteroposterior (A-P) dimension (center of axial images of the oropharynx), lateral dimension (showed in Fig. 1), cross-sectional area, and volume of each slice from the top of the hard palate to the bottom of the larynx.

**Statistical analysis**

The upper airway has been subdivided into 3 anatomic regions: nasopharynx, oropharynx, and hypopharynx. The oropharynx is anatomically located as the area between the hard palate and the base of the epiglottis and it can be further divided into 2 parts: retropalatal region, defined from the level of the hard palate...
to the caudal margin of the soft palate, and retroglossal region, defined from the caudal margin of the soft palate to the base of the epiglottis (Fig. 1). Based on these anatomic landmarks, the images of retropalatal region and retroglossal region were selected. After selection of the desired images, the means of A-P dimension, lateral dimension, and cross-sectional area and the volumes of the 2 regions were calculated. After the Bartlett test, paired t test and an analysis of variance were used to analyze the statistical differences present in different positions. Statistical analysis was performed using Statistical Package for the Social Sciences (v. 11.5, IBM, Chicago, IL), and the a priori level of significance was set at \( P \leq .05 \).

**RESULTS**

An axial view at the level of the oropharynx for a representative subject in different head and body positions is shown in Fig. 2. Subjectively, head and body positions induced changes in the oropharynx caliber with jaw protrusion. On MRI images, the upper airway exhibited a symmetric shape in the supine position. The oropharynx assumes an elliptic configuration with the major axis oriented in the lateral dimension. However, when head and body position changed, the upper airway was remarkably distorted with an asymmetric shape. Three-dimensional reconstruction of the upper airway in a representative subject in different head and body positions is shown in Fig. 3.
The dimension values of the oropharynx in supine position with and without jaw protrusion are presented in Table I. The results of our study indicate that jaw protrusion increases the dimensions (A-P dimension, lateral dimension, cross-sectional area, and volume) of both retropalatal region and retroglossal region compared with nonprotruded positions \( (P < .01) \).

Table II shows the dimension of the oropharynx in different head and body positions with jaw protrusion. Although the shape change of the oropharynx was obvious when changing head and body positions, supine-head rotation position and lateral decubitus position induced larger A-P dimension \( (P \text{ values } .006 \text{ and } .017, \text{ respectively}) \) compared with supine position in the retropalatal region only.

**DISCUSSION**

Imaging and measurement techniques for evaluating the airway

Upper airway image techniques are used to visualize airway dimensional changes and have provided insight into the biomechanical basis of obstructive sleep apnea.\(^{17,18}\) Multiple imaging techniques have been used to evaluate the upper airway in patients with OSAS, including cephalometric radiography, computerized tomography (CT), and MRI. Dynamic techniques include fluoroscopy, somnofluoroscopy, cine CT, fast CT, MRI, and fluoroscopic MR. Many cephalometric studies have been performed to investigate the craniofacial architecture of patients with OSAS, in which measurements and abnormalities of the craniofacial structures are well documented. However, because cephalometric evaluation is usually applied to patients in upright position and can show craniofacial structures only in 2 dimensions, its value in evaluation of OSAS is low.\(^{19}\) Therefore, additional evaluation techniques are needed.
CT has been used to investigate the upper airway structures. CT is performed in the supine position and provides information about airway cross-sectional area and site of collapse, when performed in different phases of respiration.\(^2^0\) However, radiation exposure with CT is moderate.\(^2^1\) Recently, MRI has been widely accepted as the most ideal method for the 3D evaluation of structures.\(^1^1\) It provides no radiation exposure along with excellent soft tissue resolution.\(^2^2,^2^3\) MRI can provide transverse and sagittal images as well as volumetric measurements of the area of airway dimensions. Therefore, it is frequently used by clinicians to provide extensive and precise examination of the pharyngeal anatomy in patients with OSAS.\(^2^4\)

We used MRI to investigate the effect of head and body positions on the oropharynx caliber with jaw protrusion. Our results demonstrated that although jaw protrusion various head and body positions changed the shape of the oropharynx, there were few dimensional changes.

**Effect of jaw protrusion on the oropharynx dimensions**

Reversible mandibular advancement with oral appliances is used to increase the caliber of the upper airway in patients with OSAS. Clinically, oral appliances are fabricated to advance the mandible to ~75% of maximum protrusion.\(^1^5\) Therefore, 75% of maximum protrusion was used in the present study as the jaw forward position to investigate the changes of the oropharynx dimensions. According to our results, S75% position induced significantly larger dimensions of the oropharynx than S0% position in normal subjects. Gao et al.\(^2^5\) also proved with an MRI study that mandibular advancement could enlarge the upper airway cross-sectional area in nonapneic men. Soft palate and tongue are strongly affected by gravitational force, because they are massive soft tissues without rigid bone support. Therefore, these tissues are prone to easily position themselves against the posterior pharyngeal wall. Jaw protrusion can move forward not only the mandible but also the soft palate and/or tongue, which can subsequently enlarge the oropharynx area. Our study provided further evidence that using oral appliances can position the jaw in a more protrusive manner and therefore reduce upper airway obstruction.

**Effect of head and body positions on the oropharynx dimensions with jaw protruded**

Ohmae et al.\(^2^6\) and Karaho et al.\(^2^7\) examined morphologic changes in the pharynx during head rotation in normal subjects and found that morphologic changes in the upper airway are attributable to changes in the position of the hyoid bone and the larynx. The hyoid bone is suspended by supra- and infrahyoid muscles and surrounding soft tissue that could be deformed by head rotation. Similarly, Ono et al.\(^7\) also found that head rotation could increase the oropharynx caliber in normal subjects with jaw in a normal position. However, our results indicate that when the jaw is protruded, head rotation has no obvious effect on the oropharynx dimensions in normal subjects. Head rotation was found to induce only larger A-P dimension compared with supine position, and this dimension change occurred only in retropalatal region. Other dimensions of the oropharynx (lateral dimension, cross-sectional area, and volume) had no significant changes in both retropalatal region and retroglossal region induced by head rotation when jaw was protruded.

The lateral decubitus position has been proved to be a better sleep position recommended to OSAS patients in many studies.\(^4\) However, things were different in normal subjects. Using the acoustic reflection technique, Jan et al.\(^2^8\) found that there were no significant differences between upper airway cross-sectional areas in the supine and lateral recumbent positions in normal

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**Table II.** Dimension values [mean (SD)] of the oropharynx in different head and body positions when jaw was protruded

<table>
<thead>
<tr>
<th></th>
<th>S75%</th>
<th>SH75%</th>
<th>LD75%</th>
<th>P value (1-way ANOVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-P dimension (cm)</td>
<td>1.27 (0.30)</td>
<td>1.77 (0.43)</td>
<td>1.70 (0.41)</td>
<td>.006</td>
</tr>
<tr>
<td>Lateral dimension (cm)</td>
<td>2.28 (0.47)</td>
<td>2.31 (0.43)</td>
<td>2.13 (0.43)</td>
<td>.572</td>
</tr>
<tr>
<td>Sectional area (cm(^2))</td>
<td>2.01 (0.78)</td>
<td>2.12 (0.89)</td>
<td>1.97 (0.82)</td>
<td>.898</td>
</tr>
<tr>
<td>Volume (cm(^3))</td>
<td>3.19 (1.26)</td>
<td>3.32 (1.25)</td>
<td>3.22 (1.07)</td>
<td>.960</td>
</tr>
<tr>
<td>RG</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-P dimension (cm)</td>
<td>1.64 (.37)</td>
<td>1.77 (.35)</td>
<td>1.67 (.34)</td>
<td>.652</td>
</tr>
<tr>
<td>Lateral dimension (cm)</td>
<td>2.39 (0.64)</td>
<td>2.35 (0.55)</td>
<td>2.42 (0.50)</td>
<td>.947</td>
</tr>
<tr>
<td>Sectional area (cm(^2))</td>
<td>2.14 (0.78)</td>
<td>2.44 (0.91)</td>
<td>2.31 (0.81)</td>
<td>.681</td>
</tr>
<tr>
<td>Volume (cm(^3))</td>
<td>3.30 (1.14)</td>
<td>3.87 (1.43)</td>
<td>3.61 (1.34)</td>
<td>.568</td>
</tr>
</tbody>
</table>

SH75%, Supine-head rotation with jaw protruded; LD75%, lateral decubitus with jaw protruded; ANOVA, analysis of variance; other abbreviations as in Table I.
awake subjects. In our study, with jaw protrusion, the oropharynx caliber did not increase in the L75% position, except for the A-P dimension of retropalatal region. On one hand, the difference of anatomic factors between OSAS patients and normal subjects might explain the results of our study that lateral decubitus position had little effect on 2- and 3D configuration of the oropharynx. On the other hand, jaw forward position might reduce the effect of lateral decubitus on the oropharynx dimensions.

The interaction of body/head position and upper airway muscle function during wakefulness has been proved by many studies and may have profound implications for sleep-disordered breathing. Otsuka et al.29 concluded that in normal subjects, phasic activity of the genioglossus (GG) muscle decreased significantly when subjects rotated their heads and moved from the supine to the lateral recumbent position. Other studies have also shown that changes in head posture and body position induce changes in the electromyographic activity of the GG muscle in normal awake humans. Because the GG muscle is the main protractor of the tongue, its relaxation and contraction substantially affect the A-P dimension of the upper airway, especially the oropharynx. However, those studies were all done when the jaw was in a nonprotrusive position. The interaction of body/head position and upper airway muscle function when jaw is protruded is still unknown and should be studied in further research.

There were several limitations in the present study. First, the subjects were young, healthy, nonobese, nonapneic men and women, and the images were taken during wakefulness. Therefore, our findings should be interpreted with caution because they might differ from those in older obese OSAS patients during sleep. Second, the oropharynx has complex anatomic structures, and actions and may be altered by external influences. With the changing of head and body positions, besides the anatomic factor of the oropharynx, other factors may also play a role in changes of the oropharynx dimensions, such as craniofacial variables and neuromuscular variables.25,32 For the complex pathogenesis of OSAS, neuromuscular variables might be more important than anatomic variables. These effects were not measured and discussed in the present study.

CONCLUSIONS

Within the limitations of this study, we demonstrated that in normal subjects, jaw protrusion had significant effects on the oropharynx dimensions. It could induce obviously larger dimensions of the oropharynx in both retropalatal region and retroglossal region. We also found that with jaw protrusion, there were little changes in oropharynx dimensions accompanied by the changes of head and body positions. Head rotation and lateral decubitus could not induce larger oropharynx dimensions compared with supine position, except for the A-P dimension of retropalatal region. These results suggested that although head rotation and lateral decubitus could induce larger oropharynx dimensions with jaw in a normal position, according to a previous study,7 these effects turned not to be obvious with jaw in a protruded position. According to the results of our study, we can conclude that in normal subjects, head and body positions have little effect on 2- and 3D configuration of the oropharynx with jaw protrusion. Our results suggest that simultaneous use of oral appliances and positional therapy for OSAS may be not necessary, because airway caliber appears to be unaffected by changes in head and body position with jaw protrusion. However, further studies are recommended to investigate these effects on a population of snoring and OSAS patients.

REFERENCES


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