Effects of Jaw, Head and Body Positions on Upper Airway Dimensions and Maximum Forced Inspiratory Airflow

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ABSTRACT

The purpose of this study was to evaluate jaw, head and body position-related changes in upper airway dimensions and maximum forced inspiratory airflow. Fifteen male normal subjects were selected and underwent magnetic resonance imaging in the following five different jaw, head and body positions: (1) supine with no jaw protrusion; (2) supine with jaw protrusion; (3) lateral decubitus with jaw protrusion; (4) supine, head rotation with jaw protrusion; (5) pronation, head rotation with jaw protrusion. The dimensional changes of the upper airway were measured according to the magnetic resonance images. To assess the changes in ventilation, the maximum forced inspiratory airflow was tested using a spirometer. This was accomplished with the subjects placed in the positions previously described. Data of airway dimensions and inspiratory velocity were reported using descriptive statistics. The results showed that upper airway dimensions and maximum forced inspiratory airflow changed by the changes of jaw, head and body positions. Jaw protrusion and head rotation could enlarge the upper airway dimensions and provided more maximum forced inspiratory airflow. These positions may prove beneficial for alleviating the symptoms of patients with obstructive sleep apnea syndrome.

Key words: Body position/Upper airway dimensions/Magnetic resonance imaging/
Forced inspiratory airflow/Obstructive sleep apnea syndrome
INTRODUCTION

Obstructive sleep apnea syndrome (OSAS) is a serious public health disorder that affects at least 4% of middle-aged men and 2% of middle-aged women. The disorder typically presents with excessive daytime sleepiness, impaired quality of life, and is often associated with an increased risk of automobile accidents and cardiovascular disease\(^1\)\(^2\). Treatments options of OSAS have included nasal continuous positive airway pressure (CPAP), oral appliance therapy (OA), upper airway surgery, excess weight reduction, drug therapy and so on. Body position shifting has been considered a conservative treatment for OSAS, especially for patients exhibiting minor upper airway obstruction\(^3\). It has been proved that body position can influence airway dimensions and modality, or improve airway ventilation\(^4\)\(^5\).

Dimensional and modal changes of the upper airway, especially the pharynx, provide a fundamental understanding of the pathophysiology associated with obstructive sleep apnea and as a result, provide insight into the treatment of the disorder. Upper airway imaging techniques are used to test these airway dimensional changes and have provided insight into the biomechanical basis of obstructive sleep apnea\(^6\)\(^7\). Several methods have been used in the analysis of upper airway structures in OSAS patients. Such examples include lateral cephalometric radiographs, endoscopic examination, fluoroscopy, conventional and electron beam computed tomography, and acoustic reflection\(^8\)\(^9\). These methods have limitations due to radiation exposure, and additionally only offer a two-dimensional evaluation. Magnetic resonance imaging (MRI) is widely accepted as the most ideal method for the three-dimensional evaluation of structures. Additionally, it provides no radiation exposure along with excellent soft tissue resolution\(^10\). MRI can provide transverse and sagittal images, as well as volumetric measurements of the area of airway dimensions. Therefore, it is frequently utilized by clinicians to provide extensive and precise examination of the pharyngeal anatomy in patients with OSAS\(^11\)\(^12\). It is believed that improvements in understanding the pharyngeal anatomy and physiology will aid in gaining insight into the pathogenesis of OSAS, ultimately leading to the development of more successful treatment strategies for OSAS.

For individuals with mild to moderate OSAS, body position shifting and oral appliance therapy have been recommended simultaneously as suitable treatment options. In a previous study, Ono et al (2000)\(^3\), suggested the effects of head and body position on the upper airway dimensions in normal subjects, however, jaw position was not considered. It has been previously unknown whether or not head and body positions significantly affect the upper airway dimensions with appliance wear by the patient. In this study, our objective was to investigate the effect of head and body positions as they relate to the upper airway caliber, with the jaw in a protruded position. In our earlier study\(^13\), we evaluated the effect of jaw position on the middle portion (25–75%) of maximum forced inspiratory airflow (FIF\(_{25-75}\)) in normal subjects and patients with sleep apnea syndrome. We also
questioned whether the jaw position would exert any effect on the upper airway caliber. Therefore, the present study was undertaken to test the hypothesis that changes of jaw, head and body positions would induce changes of upper airway dimensions and FIF_{35-75} in normal subjects. Additionally, we hypothesized that the increase/decrease in upper airway dimensions would be consistent with the increase/decrease of FIF_{35-75}.

MATERIALS AND METHODS

I Subjects

To eliminate the potential effect of gender anatomical differences, only male subjects were recruited for this study. Individuals with temporomandibular joint dysfunction, a history of respiratory disease, or occlusal dysfunction were excluded from this study. As previously shown in a prior study[^10], the oxygen desaturation index (ODI) is a sensitive indicator in diagnosis of mild to moderate sleep apnea syndrome. It was suggested that an ODI<5 was considered to be a normal response. The ODI was measured for all subjects for one night with a Pulsox–300i machine (Konica Minolta, Japan). Fifteen subjects with an ODI<5 were selected. The demographic characteristics of the subjects were documented as follows: Age: 24.85±2.08y; Body Mass Index (BMI): 21.48±2.14 kg/m²; ODI: 2.46±1.83. Informed consent was obtained from each of the subjects, and all procedures of the study were approved by the institutional ethical board of Kyushu Dental College.

To determine jaw positions, a special jig, made from an acrylic resin block (20 mm × 20 mm × 12 mm), was fixated on the mandibular incisors of each of the subjects while maintaining an interincisal opening of 12 mm. The interincisal opening of 12 mm was established based on our earlier study[^5], which was proved to be a suitable opening for the FIF_{35-75} test, while avoiding any restriction of airflow. The habitual closure position (jaw 0% protruded), and maximum protrusive position (jaw 100% protruded) were marked on the jig. The 75% protrusive jaw position was then determined and marked on the jig. This position was chosen based on yielding the best treatment with the least adverse effects for OSAS patients[^10]. According to the marks on the jig, two set of occlusion-positioning blocks were made by modeling plastic impression compound in the mouth of the subject when the mandible was in the position of 0% protrusion and 75% protrusion respectively.

II MRI of the upper airway

Each subject underwent MRI of the upper airway during wakefulness in 5 different jaw, head and body positions: supine with jaw 0% protrusion (S0%); supine with jaw 75% protrusion (S75%); lateral decubitus with jaw 75% protrusion (L75%); supine, head rotation with jaw 75% protrusion (SH75%) and pronation, head rotation with jaw 75% protrusion (PH75%). Each subject’s head was stabilized via a strap and they were instructed to wear the bite-positioning blocks without motion or verbalization during the MRI scan. In the head rotation and lateral decubitus positions, the head/body was turned to the left side. Upper airway imaging was performed using a 1.5-T full-body MR system (VISART; Toshiba, Tokyo, Japan) with a circular polarized neck coil. The continuous
images of the upper airway were obtained with a slice thickness of 7 mm. The images were printed, and outlines of the upper airway were traced by the same operator manually. The outlines were then scanned into a personal computer and the cross-sectional area of each slice was calculated by an analysis software Scion Image (Scion Corporation, USA). The volume of each slice was estimated by multiplying the area by the thickness of the slice.

III FIF$_{35-75}$ measurement

The FIF$_{35-75}$ was tested by an electric spirometer (Spiro Sift SP-750, Fukuda Denshi, Japan). Each subject breathed into a standard mouthpiece while the nasal airway was occluded with a nose clip to ensure the absence of air leakage. The subject had the FIF$_{35-75}$ measured during wakefulness, wearing the bite–positioning blocks in the 5 different jaw, head and body positions mentioned above. All the positions were performed with the subject lying on a flat bed with the head supported by a pillow constructed of soft sponge material. Measurement of each position described earlier was done three times by random assignment, accomplished through the use of a randomization table.

IV Statistical analysis

The upper airway has been subdivided into three anatomical regions: nasopharynx, oropharynx, and hypopharynx$^{17}$. The nasopharynx is defined as the region from the roof of the airway to the hard palate, the oropharynx is defined as the area between the hard palate and the top of the epiglottis, and the hypopharynx is anatomically located from the top of the epiglottis to the base of the epiglottis. Based on these anatomical landmarks, the images were selected. Following the selection of the desired images, the mean of each cross-sectional area, in addition to the volume of each of the three anatomical regions were calculated respectively. A statistical analysis was performed utilizing the results of the upper airway dimensions and FIF$_{35-75}$ of the different test groups. Statistical analysis was performed using SPSS 11.5 System for Windows. Following the Bartlett test, an analysis of variance was used to analyze the statistical differences present with upper airway caliber and FIF$_{35-75}$ in each of the different positions previously described. The statistical significance was established at the 5% and 1% level.

RESULTS

The representative MRI of the oropharynx region of the upper airway in each of the different jaw, head and body positions is shown in Fig 1. The mean of cross-sectional area and the volume of the three anatomical regions of the upper airway are listed in Table 1. The FIF$_{35-75}$values of the subjects in each position are listed in Table 2. The comparisons of airway cross-sectional area, volume, and FIF$_{35-75}$ in different positions are presented in Fig 2 and Fig 3 respectively.

The results of our study revealed that changes in jaw, head, and body positions induced changes in upper airway modality and caliber. According to MRI, the upper airway exhibited a symmetrical shape in the supine position. However, in the other positions, the upper airway was remarkably distorted with an asymmetrical shape. The change of
Fig 1 The representative MRI in the oropharynx region of the upper airway in different jaw, head and body positions.

Table 1 The cross-sectional area (cm²) and volume (cm³) of the upper airway in different jaw, head and body positions

<table>
<thead>
<tr>
<th>Positions</th>
<th>Nasopharynx</th>
<th>Oropharynx</th>
<th>Hypopharynx</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>area</td>
<td>volume</td>
<td>area</td>
</tr>
<tr>
<td>S0%</td>
<td>4.90 (0.76)</td>
<td>6.75 (1.04)</td>
<td>1.80 (0.45)</td>
</tr>
<tr>
<td>S75%</td>
<td>5.04 (0.92)</td>
<td>6.99 (1.33)</td>
<td>2.63 (0.76)</td>
</tr>
<tr>
<td>L75%</td>
<td>4.46 (0.72)</td>
<td>6.06 (1.00)</td>
<td>2.44 (0.54)</td>
</tr>
<tr>
<td>SH75%</td>
<td>4.89 (1.02)</td>
<td>6.94 (1.48)</td>
<td>2.83 (0.70)</td>
</tr>
<tr>
<td>PH75%</td>
<td>4.01 (0.84)</td>
<td>5.57 (1.21)</td>
<td>2.23 (0.64)</td>
</tr>
</tbody>
</table>

( ): SD

modality was accompanied by the change of dimensions. Cross-sectional area and volume of the upper airway was significantly affected by changing jaw, head, and body positions. There was a significant reduction (p < 0.01) of the dimensions in the jaw 0% protruded position, compared to the jaw 75% protruded position in the

Table 2 Forced Inspiratory Flow (L/S) of the subjects in different jaw, head and body positions

<table>
<thead>
<tr>
<th>Positions</th>
<th>FIF 25-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0%</td>
<td>4.07 (1.34)</td>
</tr>
<tr>
<td>S75%</td>
<td>4.45 (1.47)</td>
</tr>
<tr>
<td>L75%</td>
<td>4.94 (1.46)</td>
</tr>
<tr>
<td>SH75%</td>
<td>5.81 (1.47)</td>
</tr>
<tr>
<td>PH75%</td>
<td>4.31 (1.39)</td>
</tr>
</tbody>
</table>

( ): SD
oropharynx region. The largest upper airway dimensions (area and volume) were produced in the SH75% position, however, no significant differences were observed among the SH75% position, the S75% position and the L75% position.

Three anatomical regions of the upper airway presented different dimensional changes with alteration of jaw, head, and body positions. In the nasopharynx region, the smallest cross-sectional area and

![Graph showing changes in cross-sectional area and volume in three anatomical regions of the upper airway in different positions.](image)

**Fig 2** Changes in cross-sectional area and volume in three anatomical regions of the upper airway in different positions. *: $p < 0.05$, **: $p < 0.01$

![Graph showing comparisons of Forced Inspiratory Flow (L/S) in different positions.](image)

**Fig 3** The comparisons of Forced Inspiratory Flow (L/S) in different positions. *: $p < 0.05$, **: $p < 0.01$
volume were seen in the PH75% position. However, in the oropharynx region, the smallest cross-sectional area and volume were showed in the S0% position, which were significantly different from the SH75%, S75% and L75% positions \( (p<0.01) \). The decrease was also found in the hypopharynx region, however not as evident as the oropharynx region.

The data of FIF_{0.75} showed that there was no significant difference between the jaw 0% protrusive position and the jaw 75% protrusive position \( (p>0.05) \). The highest value of FIF_{0.75} was obtained in the SH75% position, which was significantly higher than that of the others \( (p<0.01) \) except the L75% position.

**DISCUSSION**

This study reviewed various sleep positions and estimated their effects on upper airway dimensions and ventilation. According to the results, it was observed that the dimensions of the upper airway changed when altering sleep positions. The changes of cross-sectional area were accompanied by changes in volume.

Jaw position showed obvious effects on the dimensional changes of the upper airway. The S75% position induced significantly larger cross-section area and volume of the upper airway than the S0% position, most notably observed in the oropharynx area. 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 manipulate the soft palate and/or tongue forward, 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, therefore, improving upper airway obstruction.

Furthermore, it was noted that dimensional changes of the upper airway were also observed when changing head and body positions. However, significant changes were found between the pronation position and the other positions. Pronation position showed poor values of airway dimensions. This sleeping position was found to be most related to sudden death in children with OSAS\(^6\). The SH75% position provided the largest cross-sectional area and volume of the upper airway in all positions, but there were no significant difference from the S75% position and the L75% position. However, Ono et al (2000)\(^9\) found that head rotation with no jaw protrusion could increase the upper airway caliber in normal subjects. This suggests that when the jaw position is protruded, the effect of the head rotation on the upper airway dimensions is not significant. The lateral decubitus position has been proved to be a better sleep position for OSAS patients in many studies\(^8,9\). However, in our study, upper airway caliber did not increase in the L75% position. Martin (1995)\(^10\) also demonstrated that in normal subjects, snorers, and obstructive sleep apnea patients, there were significant reductions in cross-sectional area in the lateral recumbent position compared to the supine position. Therefore, it is suggested that the lateral decubitus position improves the symptom of airway obstruction by other means instead of by enlarging airway dimensions. One of the limitations of our study is that the position of
head extension was not discussed because it made the subjects uncomfortable in the FIF test. This position was proved to be helpful to the breathing of moderate OSAS patients\textsuperscript{20}. It is interesting to note that the changes of upper airway dimensions were most significant in the oropharynx region. Additionally, there were significant decreases in airway sectional area and volume in the oropharynx region, as compared to the other two regions. This suggests that the oropharynx is the narrowest anatomic region of the upper airway, and is subject to change. The oropharynx, anatomically lacking rigid osseocartilaginous support, is particularly vulnerable to collapse. Thus, airway patency at this level is heavily dependent upon the activity of the pharyngeal dilator muscle\textsuperscript{32}. Tsuiki et al (2003)\textsuperscript{22} also demonstrated that the oropharynx, especially the retropalatal area (velopharynx), is the narrowest site in the supine position. Additionally, they showed that the velopharynx is most responsive to change with respect to an alteration in body position during wakefulness. Furthermore, it has been proven that airway obstructive sites in OSAS patients are consistently seen in this region\textsuperscript{20}. Therefore, it can be suggested that studies of this region are crucial to further understanding of this disease.

FIF is used as the arbitrary index of upper airway patency\textsuperscript{16}. It was originally hypothesized that the change of airway caliber would be similar to that of FIF\textsubscript{25-75} with alteration of jaw, head and body positions. However, the results of this study revealed that the two changes were not consistent. It was observed that jaw positions strongly affected the dimensions of the upper airway in normal subjects, however it did not significantly affect the FIF\textsubscript{25-75}. This was consistent with the results of our prior study\textsuperscript{13} which showed that normal subjects could not obtain more inspiratory airflow by a protrusive jaw position as observed in OSAS patients. The maximal FIF\textsubscript{25-75} value was also found in the SH75% position and it was significant higher than the results of other positions, which was different from the result of the changes of upper airway dimensions. These results mean that FIF\textsubscript{25-75} is not necessarily affected by airway dimension. It should be noted that other factors such as craniofacial shape might also play an important role in the FIF\textsubscript{25-75} test, which was showed in our prior study\textsuperscript{13}.

CONCLUSION

Within the limitations of this study, we demonstrated that in normal subjects, changes of upper airway dimensions and maximum forced inspiratory airflow occurred when there were changes in jaw, head and body positions. It was observed that jaw position had a significant effect on upper airway dimensions, but not on maximum forced inspiratory airflow. Jaw protrusion could enlarge the dimensions of the upper airway while head rotation could improve the maximum forced inspiratory airflow. These results suggest that the positions of jaw protrusion and head rotation show respective advantages for increasing airway dimensions or ventilation. Therefore, these positions may be recommended to OSAS patients for improving airway obstruction. However, further research is needed on snoring and OSAS patients to advance our knowledge in providing treatment modalities to improve
quality of life.

REFERENCES

顎位、頭位、体位の変化が上気道形態および最大中間吸気速度に及ぼす影響

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抄録
本研究の目的は、顎位、頭位および体位の変化が上気道形態および最大中間吸気速度にどの様な影響を及ぼすかについて検討することである。いびきや睡眠障害を認めない健康成人15名を被験者とし、習慣性閉口位（下頸0％前方位）と下頸前方位（下頸100％前方位）における2種のポルトブロックを作製した。被験者に各ポルトブロックを装着させ、5種の顎位、頭位、体位（下頸0%前方位－頭位前倒回転－仰臥位、下頸75%前方位－頭位前倒回転－仰臥位、下頸75%前方位－頭位側方回転－仰臥位、下頸75%前方位－頭位側方回転－伸展位）における上気道MRIを撮影し、上気道断面積と体積を計測するとともに、電子スパイロメータを用いて、上記5種の顎位、頭位、体位における最大中間吸気速度を計測した。得られたデータを分析し、顎位、頭位、体位の変化による上気道形態および最大中間吸気速度の関連性について検討したところ、下頸75%前方位－頭位前倒回転－仰臥位において上気道の断面積、体積および最大中間吸気速度が有意に増加した。以上のことから、睡眠時の呼吸をスムーズに保つ姿勢としては、下頸75%前方位－頭位前倒回転－伸展位が最適であることがわかった。この結果は、睡眠時無呼吸症候群患者の睡眠姿勢の参考となり、患者の症状を軽減する方法として有効であることが示唆された。

キーワード：体位/上気道形態/MRI/最大吸気速度/睡眠時無呼吸症候群