Influence of tongue/mandible volume ratio on oropharyngeal airway in Japanese male patients with obstructive sleep apnea

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Objectives. The objective of this study was to investigate the influence on the upper airway of the size ratio of tongue and mandible (T/M ratio) with 3D reconstructed models from computed tomography (CT) data.

Study design. The subjects were 40 OSA male patients. The age of the patients ranged from 25 to 77 years, with an average age of 52.6 ± 12.5 years. The body mass index (BMI) of the patients ranged from 20.1 to 35.8 kg/m², with an average BMI of 25.4 ± 3.4 kg/m². All patients underwent a full-night polysomnography. The mean AHI for our subjects was 23.6 ± 18.3 events per hour. CT imaging examinations were carried out in each patient. The mandible and airway volume (between posterior nasal spine [PNS] and the tip of the epiglottis) were segmented based on Hounsfield units, automatically or semi-automatically, and their volume was calculated from the number of voxels. The tongue was carefully outlined, and the inside of the tongue was smears on each of the axial, frontal, and sagittal planes with a semi-automatic segmentation tool. The tongue/mandible (T/M) ratio was calculated from the volume of the mandible and the tongue. In addition, we investigated simple correlations between our anatomical variables and BMI, age, and AHI.

Results. In this study, the mean tongue and mandible volume were 79.00 ± 1.06 cm³ and 87.80 ± 1.21 cm³, respectively. As BMI increases, tongue volume increases (P = .004) and airway volume decreases (P = .021). However, no significant correlation was found between severity of OSA (AHI) and other variables. On the other hand, there was a negative correlation between airway volume and T/M ratio (P = .046).

Conclusion. As tongue volume increases with BMI, the posterior airway is affected, and thus is likely to be involved in the development of OSA; however, in this study there was no correlation between the severity of sleep apnea (AHI) and other variables in the study. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111:239-243)

The primary risk factors for obstructive sleep apnea (OSA) are either obesity or having an abnormal upper-airway anatomy. The craniofacial morphologies determined by cephalometric analyses are reported to be strongly associated with the development of OSA. In previous studies, the soft and hard tissue structures were analyzed with cephalometric images.1-4 The relationship between soft tissue variables and the Apnea Hypopnea Index (AHI) has also been investigated. In 1999, Sakakibara et al.1 carried out cephalometric analysis in 144 patients with OSA and 37 healthy controls. They reported that the nonobese patients with OSA showed enlarged tongue and inferior shift of the tongue volume, compared with their body mass index (BMI)-matched healthy controls. In 2003, Yu et al.4 reported that obese patients with OSA had a longer tongue than did simple snorers and nonobese patients with OSA, and the AHI showed a significant positive correlation with tongue length in the nonobese subgroup.

However, these early reports were limited to the analyses of data obtained from the sagittal view. Recent studies have demonstrated that 3-dimensional (3D) magnetic resonance (MR) imaging and cone-beam computed tomography (CBCT) techniques performed while the patient is awake are suitable for evaluation of upper airway volume in patients with OSA. In 2003,
Schwab et al.\textsuperscript{5} analyzed the upper airway soft tissue structures 3-dimensionally with an advanced analysis technique via MR imaging. They concluded that the volume of the tongue and lateral walls was shown to independently increase the risk of sleep apnea. On the other hand, Okubo et al.\textsuperscript{6} carried out a study similar to Schwab et al.\textsuperscript{5} and reported that the tongue volume was not significantly different between patients with OSA and controls, and the tongue volume did not correlate with BMI or AHI. In 2005, Ogawa et al.\textsuperscript{7} presented new techniques to quantitatively analyze the upper airway with CBCT images using commercial software (Amira 3.1; TGS, Berlin, Germany). In 2008, Osorio et al.\textsuperscript{8} described the potential of CBCT methods to help prepare for airway management. In 2009, Grauer et al.\textsuperscript{9} studied the relationship between airway volume and shape and facial morphology with CBCT.

The tongue is surrounded by the mandible and the airway. An enlarged tongue inside a small mandible might move posteriorly and produce a decreased airway. The relation between the airway and the size ratio of tongue and mandible (T/M ratio) has yet to be reported. In this study, the correlation of T/M volume ratio and airway volume was investigated with a 3D reconstructed model from CT data.

**MATERIAL AND METHODS**

**Subjects**

The subjects were 40 male patients who were diagnosed with OSA or, based on polysomnography, as a heavy snorer. The subjects were recruited from May 2006 to February 2009. The age of patients ranged from 25 to 77 years with an average age of 52.6 ± 12.5 years. The BMI of patients ranged from 20.1 to 35.8 kg/m\textsuperscript{2} with an average BMI of 25.4 ± 3.4 kg/m\textsuperscript{2}. All patients had a full-night polysomnography. The mean AHI for our subjects was 23.6 ± 18.3 events per hour.

**Device and software**

The spiral CT imaging of the airway was performed using a Radix Prima (Hitachi, Medical Co., Tokyo, Japan). The parameters used for the imaging were tube voltage = 120 kV; tube current = 75 mA; irradiation time = 1 second; scan = volume scan; slice thickness = 1 mm; table speed = 1 mm/s. From the resulting data, the tongue, mandible, and airway volume were extracted using image analysis software Amira 3.1 (Mercury Computer Systems/3D viz group, San Diego, CA) to reconstruct 3D images and to measure the volumes. Segmentation was performed semiautomatically based on Hounsfield units (details are provided in next section).
operator (Y.S.). The T/M ratio was calculated from the volume of the mandible and the tongue.

Statistical analysis

Statistical analysis was carried out with SPSS 12.0 J (SPSS Japan, Inc, Tokyo, Japan) with a significance level set at \( P < .05 \). All our variables passed the formal normality test of Kolmogorov-Smirnov (\( P > .05 \)) except BMI. Therefore, we used Pearson’s test to conduct simple correlations between our anatomical variables and age and AHI, and we used Spearman’s test to examine the correlations with BMI.

RESULTS

Table I presents descriptive statistics for our variables. Table II presents simple correlations between our variables. There was a significant negative correlation between BMI and airway volume (\( P = .021 \)). There was a significant positive correlation between BMI and tongue volume (\( P = .004 \)). There were no significant correlations between AHI and other variables. Airway volume did not significantly correlate with mandible volume or tongue volume. On the other hand, there was a negative correlation between airway volume and T/M ratio (\( P = .046 \)).

DISCUSSION

In this study with 40 male patients with OSA, the mean tongue volume was 79.00 ± 1.06 cm\(^3\). In 2006, Okubo et al.\(^6\) measured the volume of airway soft tissues from MR images in 51 Japanese males (31 patients with OSA and 20 healthy control subjects), and reported that the mean tongue volume was 78.1 ± 11.9 cm\(^3\) in patients with OSA, and 77.1 ± 11.6 cm\(^3\) in control subjects. Our results are very similar to theirs. Therefore, in Japanese males, the mean tongue volume can be considered to be about 77 to 79 cm\(^3\).

Welch et al.\(^10\) measured the volume of the upper airway and surrounding soft tissue structures from MR images. Each anatomical parameter was examined before and after weight loss. They reported that the upper airway volume increased after weight loss, and the increase of airway volume was mediated by reductions in the volume of the lateral pharyngeal wall and parapharyngeal fat pads. This result agrees with our data. We found a significant negative correlation between BMI and airway volume (\( P = .021 \)). However, in Welch et al.’s study,\(^10\) the volume of the tongue and

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**Table I.** Descriptive statistics for our variables

<table>
<thead>
<tr>
<th>Our variables</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airway volume (mm(^3))</td>
<td>4207</td>
<td>29,977</td>
<td>13,392</td>
<td>6101.3</td>
</tr>
<tr>
<td>Mandible volume (mm(^3))</td>
<td>62,453</td>
<td>112,682</td>
<td>87,806</td>
<td>12,079.6</td>
</tr>
<tr>
<td>Tongue volume (mm(^3))</td>
<td>60,594</td>
<td>115,806</td>
<td>78,990</td>
<td>10,607.8</td>
</tr>
<tr>
<td>Tongue/Mouth ratio (%)</td>
<td>65</td>
<td>131</td>
<td>91</td>
<td>16.4</td>
</tr>
</tbody>
</table>
soft palate were not reduced significantly with weight loss. In 2008, Brennick et al.11 investigated the effect of obesity on upper airway soft tissue structures in the New Zealand obese mouse and in the control lean mouse. They reported that in obese mice the airway caliber was significantly smaller with greater parapharyngeal fat pad volumes and a greater volume of other upper airway soft tissue structures (tongue, lateral pharyngeal walls, soft palate) than in the lean controls. They concluded that in addition to the increased volume of pharyngeal soft tissue structures, direct fat deposits within the tongue may contribute to airway compromise in the obese. Our results agree with their findings. We also found a significant positive correlation between BMI and tongue volume (P < .05).

In 2006, Iida et al.12 compared the tongue volume/oral cavity volume (TV/OCV) ratio between 20 male patients with OSA and 20 normal male adults. They described that BMI was significantly correlated with tongue volume in the OSA patient group, which is consistent with our results. Iida et al.12 reported that patients with OSA had a larger TV/OCV ratio than controls, and AHI did not correlate with tongue volume or TV/OCV ratio. In addition they concluded that the TV/OCV ratio is likely to be involved in the development of OSA and can be used as a diagnostic tool, even if AHI was not correlated with TV/OCV. Although this study is similar to theirs, it differs in how we limited OCV to tongue volume and airway volume. Because of this distinction we were able to investigate the relation between airway volume and other variables, whereas the inclusion of the airway in OCV in Iida et al.’s study12 did not allow for this particular course of investigation. However, our study is limited to the airway, tongue, and mandible. In this study, the airway was negatively influenced by the T/M ratio (P = .046). Although the tongue volume increased with BMI, the mandible volume did not. Consequently, the mandible is less able to properly accommodate the increased tongue volume. As a result, the enlarged tongue moves posteriorly, decreasing the airway volume. As tongue volume increases with BMI, the airway volume decreases and thus is likely to be involved in the development of OSA, however it did not affect the severity of sleep apnea (AHI) in this sample.

Limitations of this study include the absence of controls, as it is difficult to get healthy subjects to consent to undertake a sleep study and a CT scan. The fact that metal artifacts might interfere with segmentation and volume computation is an inherent limitation of using CT. The metal artifacts were observed on axial, sagittal, and coronal images, and carefully removed manually by one operator (Y.S.). This is a standard procedure for dealing with artifacts. Also, the fact that the subjects are awake might influence their tongue position and possibly volume of the tongue. Our reasoning to examine tongue volume using CT taken on awake subjects is that we were exploring if CT can be used as a predictor or screening tool for OSA. CTs are taken for many reasons but they are almost universally performed on awake subjects. CTs on sleeping subjects are not the norm in a clinical setting. Millions of patients a year receive a CT scan for dental implants, trauma, tumors, and cancer and we would like to use that opportunity to screen for sleep apnea.

CONCLUSIONS

In this study, we investigated the influence of T/M ratio on airway volume using 3D reconstructed models from CT data. There was a significant positive correlation between BMI and tongue volume, and a significant negative correlation between BMI and airway volume. There was a negative correlation between airway volume and T/M ratio. As tongue volume increases with BMI, the T/M ratio is affected, and thus is likely to be involved in the development of OSA;

Table II. Pearson’s linear correlations and P value for Pearson’s test

<table>
<thead>
<tr>
<th>Our variables</th>
<th>BMI (kg/m²)</th>
<th>AHI (Events/h)</th>
<th>Airway volume (mm³)</th>
<th>Mandible volume (mm³)</th>
<th>Tongue volume (mm³)</th>
<th>T/M ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI (kg/m²)</td>
<td>0.197* (P = .222)</td>
<td>-0.363* (P = .021)†</td>
<td>0.060* (P = .712)</td>
<td>0.441* (P = .004)†</td>
<td>0.246* (P = .126)</td>
<td></td>
</tr>
<tr>
<td>AHI (events/h)</td>
<td>-0.063 (P = .698)</td>
<td></td>
<td>0.048 (P = .768)</td>
<td>0.243 (P = .131)</td>
<td>0.115 (P = .478)</td>
<td></td>
</tr>
<tr>
<td>Airway volume (mm³)</td>
<td>0.291 (P = .069)</td>
<td></td>
<td></td>
<td>-0.149 (P = .358)</td>
<td>-0.318 (P = .046)†</td>
<td></td>
</tr>
<tr>
<td>Mandible volume (mm³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.096 (P = .556)</td>
<td>-0.677 (P &lt; .0001)§</td>
</tr>
<tr>
<td>Tongue volume (mm³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.661 (P &lt; .0001)§</td>
</tr>
</tbody>
</table>

AHI, Apnea Hypopnea Index; BMI, body mass index; T/M, tongue/mouth.

*Spearman’s correlation coefficient and P value of Spearman’s test for nonparametric variables
†P < .05.
§P < .0001.
however, in this study, there was no correlation between the severity of sleep apnea (AHI) and T/M ratio.

REFERENCES

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