Published in final edited form as:

Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011 February ; 111(2): 239–243. doi:10.1016/j.tripleo.2010.10.013.

Influence of Tongue/Mandible Volume Ratio on Oropharyngeal Airway in Japanese Male Patients with Obstructive Sleep Apnea

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1. Introduction

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 2 3 4} The relationship between soft tissue variables and Apnea Hypoapnea Index (AHI) has also been investigated. In 1999, Sakakibara et al.¹ carried out cephalometric analysis in 144 OSA patients and 37 normal controls. They reported that the non-obese OSA patients showed enlarged tongue and inferior shift of the tongue volume, compared to their BMI-matched normal controls. In 2003, Yu et al.⁴ reported that obese OSA patients had a longer tongue than did simple snorers and non-obese OSA patients, and AHI showed a significant positive correlation with tongue length in the non-obese 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 techniques performed while the patient is awake are suitable for evaluation of upper airway volume in OSA patients. In 2003, Schwab et al.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 were shown to independently increase the risk of sleep apnea. On the other hand, Okubo et al.⁶ carried out a similar study than Schwab and reported that the tongue volume was not significantly different between OSA and controls, and the tongue volume did not correlate with BMI or AHI. In 2005, Ogawa et al.⁷ presented new techniques to

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IRB approval:

The patients gave written consent to participate in this study approved by the Ethics Committee at Tsurumi university dental hospital.

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quantitatively analyze the upper airway with Cone-Beam Computed Tomography (CBCT) images using commercial software. In 2008, Osorio et al.⁸ described the potential of CBCT methods to help prepare for airway management. In 2009, Grauer et al.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 Computed Tomography (CT) data.

2. Subjects and Methods

Subjects

The subjects were 40 male patients who were diagnosed as OSA or, based on PSG, 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 Body Mass Index (BMI) of patients ranged from 20.1 to 35.8 kg/m² with an average BMI of 25.4 ± 3.4 kg/m². 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 3-dimensional images and to measure the volumes. Segmentation was performed semi-automatically based on Hounsfield units (details are provided in next section).

Investigation Points

CT imaging examinations were carried out in each awake patient in supine position before making an occlusal appliance. CT was taken in the intercuspal position, and the patient was asked to place the tip of their tongue on the lingual surface of the upper incisors to standardize tongue positioning. The points of inquiry were the volume of the airway, the mandible and the tongue (Figure 1–2). First, we selected the airway volume of interest from the posterior nasal spine to the tip of epiglottis. Airway volume within this slab was calculated from the number of voxels that had a CT value range from a minimum value (CT value -2000 HU) to -100 HU (to exclude soft and hard tissues). The mandible volume was not restricted to the slab and was calculated from the number of voxels that had a CT value range from 200 HU (to exclude soft tissues) to a maximum value (CT value 4000 HU). Mandible and airway were segmented based on the Hounsfield units mentioned above with an automatic segmentation tool (thresholding). On the other hand, the automatic segmentation of tongue was difficult, because the tongue contacted with the suprahyoid muscles and the soft palate which have similar Hounsfield units than the tongue. Therefore, a semi-automatic segmentation tool (auto-tracing) was used for segmentation of the tongue. This tool can detect subtle changes in image intensity, so it can detect the border between tongue and surrounding muscles. The tongue and other muscles were manually separated with this tool. The inside of the tongue was smeared on each of the axial, frontal and sagittal planes with a semi-automatic segmentation tool (auto-trace) and the tongue volume was calculated. The metal artifacts were observed on axial, sagittal and coronal slabs, and

carefully removed manually by one operator (YS). The T/M ratio was calculated from the volume of the mandible and the tongue.

Statistical Analysis

Statistical analysis was carried out with SPSS 12.0J (SPSS Japan Inc. Tokyo, Japan) with a significance level set at $p < 0.05$. All our variables passed the formal normality test of Kolmogorov-Smirnov ($P > 0.05$) 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.

3. Results

Table 1. presents descriptive statistics for our variables. Table 2 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 ($p = .046$).

4. Discussion

In this study with 40 male OSA patients, the mean tongue volume was $79.0 \pm 1.06 \text{ cm}^3$. In 2006, Okubo et al.⁶ measured the volume of airway soft tissues from MR images in 51 Japanese males (31 OSA patients and 20 healthy control subjects), and reported that the mean tongue volume was $78.1 \pm 11.9 \text{ cm}^3$ in OSA patients, and $77.1 \pm 11.6 \text{ cm}^3$ in control subjects. Our results are very similar to theirs. Therefore, in Japanese males, the mean tongue volume can be considered to be about $77\text{--}79 \text{ cm}^3$.

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's study the volume of the tongue and 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 ($p = .004$).

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. reported that OSA patients 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. While

this study is similar to theirs, it differs in how we limited OCV to tongue volume and airway volume. Due to this distinction we were able to investigate the relation between airway volume and other variables, where as the inclusion of the airway in OCV in Iida's study 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 ($p=.046$). While 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 (YS). 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 are exploring if CT can be used as a predictor or screening tool for OSA. CT's are taken for many reasons but they are almost universally performed on waking subjects. CT's 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, cancer and we would like to use that opportunity to screen for sleep apnea.

5. Conclusion

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. 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, however in this study there was no correlation between the severity of sleep apnea (AHI) and T/M ratio

Acknowledgments

Dr. Enciso was partially supported by NIDCR grant #5 K25 DE016391. No conflicts of interest.

Dr. Ogawa was partially supported by "High-Tech Research Center" Project for Private Universities and grant # 18390501: matching fund subsidy from MEXT (Ministry of Education, Culture, Sports, Science and Technology). No conflicts of interest.

Dr. Shigeta was partially supported by MEXT grant # 20500430. No conflicts of interest.

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Fig. 1.
Investigation points

Fig. 2.
Axial, sagittal, coronal and multiple views of mandible (yellow color), tongue (purple color) and airway (blue color).

Table 1

Descriptive statistics for our variables

Our variables	Minimum	Maximum	Mean	Standard Deviation
Airway volume (mm ³)	4207	29977	13392	6101.3
Mandible volume (mm ³)	62453	112682	87806	12079.6
Tongue volume (mm ³)	60594	115806	78990	10607.8
T/M ratio (%)	65	131	91	16.4

Table 2

Pearson's linear correlations and p-value for Pearson's test.

<i>Our variables</i>	BMI (kg/m ²)	AHI (events/hour)	Airway volume (mm ³)	Mandible volume (mm ³)	Tongue volume (mm ³)	T/M ratio (%)
BMI (kg/m ²)		0.197 [‡] (p=.222)	-0.363 [‡] (p=.021) *	0.060 [‡] (p=.712)	0.441 [‡] (p=.004) *	0.246 [‡] (p=.126)
AHI (events/hour)			-0.063 (p=.698)	0.048 (p=.768)	0.243 (p=.131)	0.115 (p=.478)
Airway volume (mm ³)				0.291 (p=.069)	-0.149 (p=.358)	-0.318 (p=.046) *
Mandible volume (mm ³)					0.096 (p=.556)	-0.677 (p<.0001) ****
Tongue volume (mm ³)						0.661 (p<.0001) ****

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

[‡] Spearman's correlation coefficient and p-value of Spearman's test for non-parametric variables

* p<.05,

** p<.001,

*** p<.0001