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<*Original Article*>

Effect of Prosthetic Mandibular Advancement in Patients with Obstructive Sleep Apnea

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ABSTRACT

Although prosthetic mandibular advancement (PMA) has been used as a therapy in treating obstructive sleep apnea (OSA), many aspects of the mechanisms of PMA remain unclear. In the present study, we analyze the change in tongue shape after PMA to explore mechanisms.

Subjects and Methods: Forty-two males who underwent PMA and experienced improvement in their OSA were selected as subjects. Cephalogram recordings of the length, height, and surface area of their tongues were analyzed before and after PMA.

Results: The following changes were observed with respect to change in tongue shape as a result of PMA; (1) significant decrease in the surface area of the tongue; (2) significant lengthening and flattening of the tongue; and (3) significant reduction in the oral cavity proper with particular reduction in the pharyngeal portion of the tongue.

Conclusion: The tongue was reduced and flattened as a result of PMA. Reduction in the oral cavity proper and pharynx occurred, with the latter being greater. We believe that these changes in tongue shape may have contributed to the improvement of OSA.

INTRODUCTION

Sleep-disordered breathing is classified into three types of breathing-inhibitive conditions: obstructive, central, and mixed. Obstructive is the type most often observed in clinical settings [1,2]. In dental/oral surgery, dental therapies for obstructive sleep apnea (OSA) are conducted on patients referred from other medical fields, such as those which focus on the ear, nose, and throat. OSA is treated with prosthetic mandibular advancement (PMA) by application of a dental prosthesis, the aim of which is to maintain the forward orientation of the mandible itself, moving the hyoid bone (H) and tongue structure forward. This expands the upper res-

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piratory tract and is considered to be useful as a therapy for OSA [3,4].

The efficacy of PMA has been evaluated based on the use of cephalometric analysis, indexing the H, mandible, and upper respiratory tract [5]. Our analysis showed the mandible, epiglottic vallecula, and hyoid bone had moved forward, and that the anteroposterior diameter between the lingual radix and posterior pharyngeal wall, i.e., the respiratory tract area, had widened. There, it was clear that PMA was useful for treating OSA [6,7]. On the other hand, although there are data showing ways in which tongue shape affects OSA [8], no detailed study of the changes in tongue shape resulting from PMA is known; further, it is unclear what these changes are and how they improve OSA.

Consequently, the aims of this study were (1) to determine tongue shape based on cephalograms taken before and after PMA, and (2) consequently, to evaluate the changes in tongue shape that accompany PMA.

SUBJECTS and METHODS

1) Subjects

Out of the 643 patients diagnosed with OSA and referred for PMA fitting to the oral surgical outpatient clinic affiliated with Osaka Medical College, 42 males showed no apparent abnormal occlusions, very few tooth defects, and improvement of their OSA after continuing the PMA (Figure 1) treatment.

The 42 subjects were aged from 39 to 78 years, and their mean age was 48.5 ± 13.2 years. AHI was 46.2 ± 16.5 times/h (21.3−88.7) before and 13.5 ± 6.2 times/h (2.6−18.3) after fitting of the PMA device; therefore, the improvement rate was 54.4 ± 3.5 %, BMI was 24.2 ± 1.2 kg/m^2, and when we applied the National Institute of Health [9] standard, which indicates that a BMI of 25 or above indicates mild obesity, we confirmed that no trend for obesity existed (Table 1). We confirmed that the OSA diagnoses were the results of polysomnographic apnea hypopnea index tests (AHI) recording more than five events per hour of sleep accompanying clinical symptoms of excessive daytime drowsiness, in accordance with the 1999 American Association of Sleep Medicine guidelines [10]. OSA was evaluated as improved when an AHI improvement rate of 50% or higher was observed during polysomnography (PSG) as well as when clinical symptoms such as excessive drowsiness during the day and frequent nocturnal awakening improved.

Figure 1 Prosthetic mandibular advancement for treatment of obstructive sleep apnea.

2) Methods

The PMA prosthesis was manufactured as an all-in-one top and bottom fitting. The lower jaw position was determined by confirming the maximum possible forward range of the jaw, aiming to position the jaw at 80% of the forward distance while simultaneously producing a 3-mm overbite. When we examined anterior mandibular displacement, we used cephalometric radiography before and after PMA to measure the anteroposterior diameter of the lingual radix and posterior pharyngeal wall to confirm whether the respiratory tract area was sufficiently expanded. When no im-

Table 1 Age of OSA patients, BMI, and AHI improvement rate according to AHI before and after PMA.

Age	48.5 ± 13.2 years
BMI	24.2 ± 1.2 kg/m^2
AHI before PMA	46.2 ± 16.5 times/h (21.3−88.7)
AHI after PMA	13.5 ± 6.2 times/h (2.6−18.3)
AHI improvement rate	54.4 ± 3.5 %

provement was observed, we fitted the device after we made modifications and confirmed sufficient respiratory tract area expansion before subsequent patient use. PMA devices are made of hard resin, and because effects are achieved from the time of going to sleep until the time of waking, PMA devices are fitted when patients go to sleep and kept in place until they wake up.

An Asahi Roentgen AZ-3000CM (Asahi Roentgen Corporation, Kyoto, JPN) was used for cephalometric radiography before and after application of PMA. Subjects were instructed to rest their tongue, breathe lightly, and not to swallow during exposure in order to prevent movement of the soft tissues during x-radiography. In addition, each subject was instructed to touch the tip of their tongue to the base of their bottom front teeth in order to maintain a uniform tongue position each time.

To achieve distinct visualization of the soft tissues after exposure, grading and frequency processing was conducted using the CR imaging function of a Fuji-Film FCR-7000 (FujiFilm Corporation, Tokyo, JPN) (Figure 2).

The length, thickness, and area of the tongue were determined by scanning the cephalogram with an EPSON Scanner ES-2200 (SEIKO EPSON Corporation, Nagano, JPN) and analyzing the data with Image J-Win for Windows XP®. As described by Nakamura et al. [11], our cephalometric analysis established the X-axis connecting the sella (S) and nasion (N) points and the C-axis through the anterior parts of the 2nd and 4th vertebrae, and calculated the theta value of the X/C angle before and after application of PMA. In accordance with Nakamura's statement [11] that a difference of no more than 5° between the two angles means minimal interference on account of head placement, we ensured that the differences in theta before and after PMA were within the applicable range of 0−5° for all 42 subjects participating in the study (Figure 3).

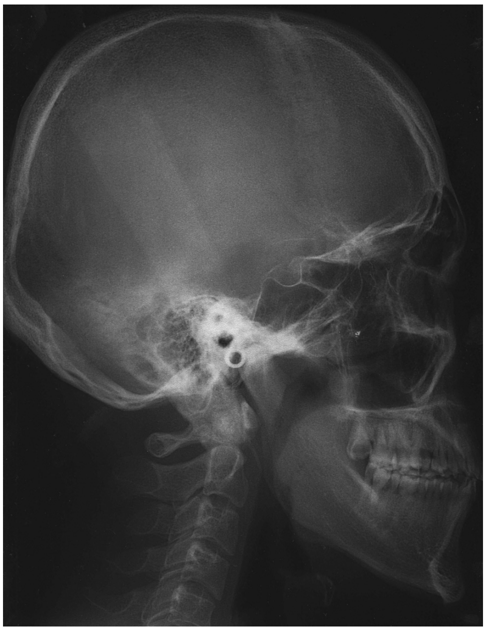

Figure 2 Cephalogram.

We measured the tongue using the cephalometric landmarks established by Low et al. [12]—namely, the tongue tip (TT), base of the epiglottis (Eb), H, and retrognathion (RGN). Based on these points, tongue length (TGL) was calculated as the distance between TT and Eb, and tongue height (TGH) was calculated as the greatest perpendicular distance from the TGL line to the back of the tongue. Tongue area was determined as the portion enclosed by the lines connecting TT, Eb, H, RGN, and circumference of the tongue's exterior. Our method, previously established by Mochizuki et al. [13], consisted of a dividing line passing through point B (supramentale) situated parallel to the X-axis. The tongue area in the greater oral cavity was measured above the line, and the pharyngeal tongue area was measured below the line. To determine which of the two areas showed a greater reduction, each of the area measurements after PMA was divided by the pre-PMA measurement in order to determine the reduction ratio (Figure 4).

This study was conducted with the authorization of the Osaka Medical College Ethics Committee (No. 1059). Names and personal information were numerically encrypted and an encoded comparison table was used in order to protect personal information. We explained the content of this study to all subjects and acquired their written consent.

3) Inspection Methods

During the comparison of the length, height, and area of the tongue, homoscedasticity was determined using the F test. Student's t test was then applied, yielding a significance level of $p<0.05$. The statistical analysis software used was SAS institute Japan JMP version 8.0 (SAS institute, NC, USA).

RESULTS

1) Changes in TGH and TGL before and after PMA

TGH started at 42.35 ± 4.22 mm (37.28−48.87) and changed to 39.56 ± 5.12 mm (33.11−46.10). TGL started at 90.2 ± 8.3 mm (75.2−97.6) and changed to 94.5 ± 7.9 mm (78.5−105.30). Compared with the condition without PMA, a significant increase in tongue length and a dramatic decrease in height was observed

Cephalometric Landmarks

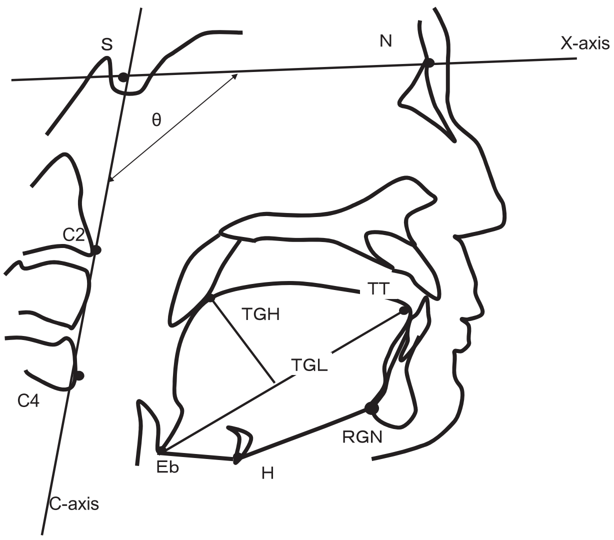

Figure 3 TT, tongue tip; Eb, base of epiglottis; H, hyoid bone; RGN, retrognathion; S, sella; N, nasion; C2, anterior superior tip of second cervical vertebra; C4, anterior superior tip of fourth cervical vertebra X-axis; the line that connects S and N,C-axis; the line that connects S and N; θ, angular distance from X-axis to C-axis; TGL, linear distance between Eb and TT; TGH, maximum height along perpendicular line Eb −TT.

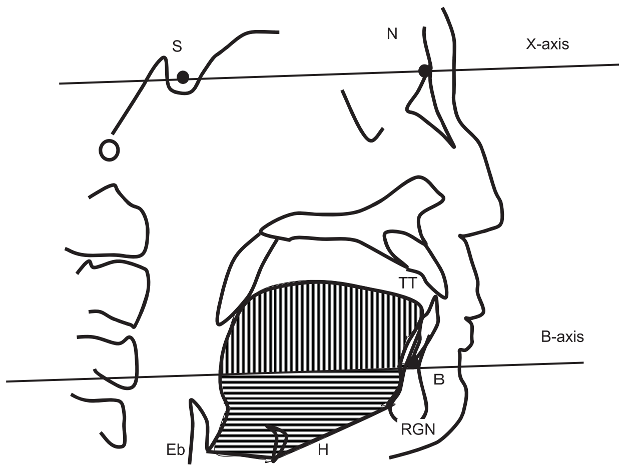

Figure 4 Cephalographic tongue area measurements. B: supramentale, B-axis: Through B, parallel with X-axis.
Tongue: area outlined by dorsal configuration of tongue surface and lines that connect TT, RGN, H, and Eb.
Above B-axis: Area of tongue located in greater oral cavity, Below B-axis: Area of tongue located in pharyngeal area.
Greater Oral Cavity Tongue Area
Pharyngeal Tongue Area

in the condition with PMA (Table 2).

2) Change in the profile area of the tongue before and after PMA

The profile area of the tongue started at 3669.8 ± 407.3 mm² (3161.9−4705.7) before PMA and reduced to 3138.2 ± 301.87 mm² (2284.9−3960.9) after PMA (Table 3).

3) Changes in areas of the oral cavity proper and pharyngeal sections of the tongue

The tongue was divided into upper and lower portions, the upper portion comprising the area of the tongue located in the oral cavity proper and the lower portion comprising the area of the tongue closer to the pharynx. The former was 1615.1 ± 347.14 mm² (814.06−2221.61) before PMA and was reduced to

Table 2 Post - PMA TGH, TGL.

TGH	Before PMA	42.35±4.22mm(37.28−48.87)	*
	After PMA	39.56±5.12mm(33.11−46.10)	
TGL	Before PMA	90.2±8.3mm(75.2−97.6)	*
	After PMA	94.5±7.9mm(78.5−105.30)	

Mean ± SD. *p<0.05.

Table 3 Post - PMA Tongue Area.

Entire Tongue Area	Before PMA	3669.8±407.3mm²(3161.9−4705.7)	*
	After PMA	3138.2±301.87mm²(2284.9−3960.9)	
Oral Cavity Proper Tongue Area	Before PMA	1615.1±347.14mm²(814.06−2221.61)	*
	After PMA	1497.0±323.83mm²(784.66−2003.60)	
	Reduction Rate	81.97%	
Pharyngeal Tongue Area	Before PMA	2043.0±369.9mm²(1264.2−3061.0)	*
	After PMA	1614.13±372.29mm²(1086.0−2655.8)	
	Reduction Rate	78.06%	

Reduction Ratio : Post - PMA Area / Pre - PMA Area. Mean ± SD. *p<0.05.

1497.0 ± 323.83 mm^2 (784.66−2003.60) after PMA. The pharyngeal tongue area was 2043.0 ± 369.9 mm^2 (1264.2−3061.0) before PMA and was significantly reduced to 1614.3 ± 372.29 mm^2 (1086.0−2655.8) after PMA. Subsequently, the oral cavity proper tongue area was 81.97% of the value before PMA and pharyngeal tongue area was 78.06% of the value before PMA.

DISCUSSION

There are various methods of treatment for OSA, both surgical and conservative. Conservative methods of treatment include nasal CPAP and intraoral devices. Since treatment methods using PMA for OSA were approved for insurance coverage in Japan from April 2004, they have gradually become more widely known. When the conservative treatment methods of nasal CPAP and PMA are compared, they have both advantages and disadvantages and appear to be methods that can be put to continuous clinical use by patients. Compared with nasal CPAP, advantages of the PMA device are its easy portability, simplicity of intraoral placement, and relatively low invasiveness. On the other hand, the disadvantage of PMA compared with nasal CPAP is the fairly high number of contraindications. Because of the burden placed on teeth and the temporomandibular joint (TMJ) while fitting of the PMA device, it cannot be used for cases with few remaining teeth, severe periodontitis, severe tooth decay, or TMJ arthrosis. Maintenance is also required each time tooth morphology changes because of dental treatment, and patients using the device in the long term may exhibit TMJ arthrosis or occlusal discomfort, which appear to be side effects.

However, PMA can be used in the long term even when these side effects occur if it is regularly maintained. Regular maintenance and not fitting the PMA device for a fixed amount of time can lead to improvement in symptoms.

The mechanism of action of PMA in the treatment of OSA is maintenance of the mandible in a protruded position, which causes the hyoid bone and soft tissue of the tongue to move forward. This appears to widen the upper respiratory tract, thus proving useful for OSA treatment.

It has been reported that OSA patients tend to have relatively large tongues [14] and lower jaws that are smaller than their upper jaws [15]. Additionally, according to an analysis based on models used in these studies on jaw morphology, narrowing of the greater oral cavity appears to be a characteristic of OSA patients [16].

These studies suggest that either the tongues of OSA patients are actually large or their tongues are not particularly large but rather their lower jaws are small, making their tongues relatively large in proportion. Consequently, it is believed that either the tongue occupies a large part of the oral cavity proper or the resting space for the tongue within the oral cavity proper is too small, causing the tongue to retreat backwards into occlusion with the pharynx.

From these considerations, it was speculated that the tongue's shape had a significant influence on the OSA patient's condition, and it was considered that examination of changes in tongue shape after PMA were important in evaluating PMA itself.

Until now, PMA has been evaluated on the basis of cephalometric analysis, indexing the H, lower jaw, and epiglottis [5,6,7]. However, it is impossible to obtain detailed information from cephalometric analysis involving indexing the tongue. The aim of this research was to elucidate the changes that occur in tongue shape after PMA and how these changes affect OSA.

Regarding the changes in tongue shape, cephalometric analysis is a useful method for viewing the changes in soft tissues in OSA patients. As followed by Partinen et al. [17], we also performed cephalometric analyses in the present study.

The result of this study showed that TGL significantly increased after PMA, while TGH significantly decreased. This is a result of the PMA guiding the tongue forward, and the tongue also appeared to become flatter. We also found that the lateral profile area of the tongue after PMA was smaller than that before PMA.

These results show that the tongue became flatter and decreased in size, and that these changes contributed to airway enlargement and the improvement of OSA.

In addition, when considering OSA therapy, it is important to determine which of the generally recognized OSA occlusion zones (nasal, soft palate, or pharynx) experience occlusion in a given instance [18]. Hudgel [19] reported that many cases of occlusion occured on the soft palate or the root of the tongue. There are reports of cephalometric analyses showing that PMA has improved occlusions occurring in the root of the tongue [20]. However, there has been no reports focusing on whether or not PMA has improved occlusions on the soft palate.

Thus, in the present study, we investigated the morphological change in the tongue after PMA, particularly in the occlusion areas by setting the greater oral cavity as the soft palate and the pharynx as the tongue root, and subsequently analyzing the changes in tongue shape in each area. We divided the tongue into two sections according to Mochizuki et al. [13]. The upper portion represented the oral cavity proper and the lower portion represented the pharyngeal area. The results showed significant reduction in both areas. Not only did we find reduction in the pharynx, but there was evidence that PMA was also effective in treating occlusions in the oral cavity proper.

Our findings suggest that it is important to consider soft palate and frontal-view tongue area measurements as well as additional soft tissue measurements in future studies.

In addition, having confirmed the factors associated with PMA that cause changes in tongue shape, we consider that our findings should be useful not only for the improvement of the respiratory aspects of OSA and the swelling and edema resulting from invasive surgery or intraoral pathology, but also for other ailments of the mouth. Future research initiatives should address these issues.

CONCLUSIONS

Using cephalometric analysis, we analyzed the tongue shapes of 42 males diagnosed with OSA and fitted with a PMA device. The conclusions were as follows:

1. Changing the position of the lower jaw by PMA affects tongue height and length.
2. Examination of the differences in the profile area of the tongue before and after PMA showed that:
   a. Tongues of OSA patients after undergoing PMA exhibited significant decreases in height and significant increases in length.
   b. The profile area of the tongue exhibited a significant decrease after PMA.
   c. Tongue area showed reduction in both the oral cavity proper and the pharynx, with a greater reduction occurring in the pharynx.

We believe that the morphological change in the tongue after PMA contributes to the improvement of OSA.

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