J Med Dent Sci 2006; 53: 119－126

Original Article

Comparison of Tongue Volume/Oral Cavity Volume Ratio between Obstructive Sleep Apnea Syndrome Patients and Normal Adults Using Magnetic Resonance Imaging

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Obstructive sleep apnea syndrome (OSAS) is a group of disorders in which breathing stops intermittently and repeatedly for 10 seconds or more during sleep. The causal site of the disorders is thought to be in the upper airway above the glottis. In order to understand the three-dimensional features of the oral and peripharyngeal structures involved in the disorders, we calculated the tongue volume/oral cavity volume ratio (TV/OCV ratio) in the oral cavity using magnetic resonance imaging (MRI) for both OSAS patients and normal controls. The study subjects comprised 20 male patients with OSAS (apnea—hypopnea index [AHI]≧5.0, with a diagnosis of OSAS) and 20 normal male adults (AHI<5.0, with no history of OSAS) as the controls. We performed MRI to acquire T1- and T2-weighted images. We estimated tongue volumes on the basis of the cross-sectional area of each image, then using the tongue volume data, we calculated TV/OCV ratios. In the normal control group, mean (±SD) body mass index (BMI) was 21.68±1.73 and the mean TV/OCV ratio was 86.98±3.16%, whereas these values were 25.0±15.94 and 90.56±2.15%, respectively, in the OSAS patient group. The TV/OCV ratio of the OSAS patient group was significantly higher than that of the normal control group (*p*<0.01).

Key words: Obstructive Sleep Apnea, Tongue Volume (TV), Oral Cavity Volume (OCV), Tongue Volume/Oral Cavity Volume Ratio, Magnetic Resonance Imaging (MRI)

Introduction

Obstructive sleep apnea syndrome (OSAS) is a group of disorders in which breathing stops intermittently and repeatedly for 10 or more seconds during sleep. OSAS is expected to be associated with increased likelihood of hypertension, cardiovascular disease, stroke, daytime sleepiness, motor vehicle accidents, and diminished quality of life.

It is considered that the causal site of the disorders is in the upper airway above the glottis[1]. The upper airway is conceptually divided into three main areas: the nasal cavity; the area including the adenoids, soft palate and palatine tonsils; and the posterior part of the tongue. As described below, the cause of OSAS is dif-

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Received January 26; Accepted March 17, 2006

ferent depending upon the areas of the upper airway that are affected.

OSAS with its origin in the nasal cavity can be caused by nasal obstruction due to allergic rhinitis, hypertrophic rhinitis, chronic sinusitis, or a deviated septum. In adults, nasal obstruction during sleep alters ventilation patterns and can cause dyspnea, which leads to sleep disturbances. However, most cases of OSAS due to nasal obstruction are milder in severity than those due to other factors[1].

OSAS with its origin in the area including the adenoids, soft palate and palatine tonsils is caused by narrowing of the pharynx cavity due to hypertrophy of the adenoids or palatine tonsils, or soft palate deformities. When the muscles of the pharynx are relaxed during sleep, the airway further narrows to cause apnea. The majority of OSAS cases in infants and children are due to hypertrophy of the adenoids or palatine tonsils or both. Even in adults, degree 2－3 palatine tonsil hypertrophy often causes OSAS. Also, in cases where the soft palate hangs in loose folds toward the posterior part of the tongue[2], or where the palatine uvula is abnormally long[3,4] or large[3], OSAS is likely to occur.

OSAS with its origin in the posterior part of the tongue occurs when the tongue muscles relax during sleep and the tongue falls backward to obstruct the airway. Although patients with micrognathia are likely to experience airway obstruction by the tongue, it is a very common phenomenon, which can be seen in many OSAS patients.

Actually, it is seldom that only one of the areas described here is involved in OSAS independently of the other areas: the majority of cases involve a combination of areas[5]. Isono *et al.* reported that about 40% of cases of OSAS have their origins in both the tongue and the soft palate[1], the typical pattern of which is such that the lower part of the soft palate, including the palatine uvula, is tightly surrounded by the posterior part of the tongue, posterior wall of the pharynx, and the lateral walls, thus obstructing the airway[5].

In the present study, we noted the involvement of the tongue and soft palate to try to find the cause of OSAS. We determined the respective sizes of the tongue and oral cavity, and calculated the tongue volume/oral cavity volume ratio (TV/OCV ratio) on the basis of the shapes of the tongue and palate obtained by magnetic resonance imaging (MRI)[6], and compared them between OSAS patients and normal controls. Also, for Japanese patients with OSAS, it has been suggested that although soft tissue is enlarged in obese patients, abnormalities in hard tissue may be the main factor contributing to OSAS in non-obese patients[7]. It has also been suggested that for Japanese patients, morphologic characteristic such as a small jaw may contribute more to the etiology of OSAS than does obesity[8]. Thus, we investigated the relationship between tongue size and obesity, using the body mass index (BMI). Additionally, in patients with OSAS, we studied the relationship between the apnea—hypopnea index (AHI [number of apneic plus hypopneic events per hour][9]) and BMI or tongue volume or TV/OCV ratio.

Materials and Methods

The study subjects comprised 20 adult males in each of the normal control and OSAS patient groups. In both groups they had no anomalies in the oral cavity and almost no deficits of maxillomandibular teeth. In the control group, it was confirmed by interview and simple sleep monitoring (Pulsleep LS-100, Fukuda Denshi Co.) that the subjects had a BMI of 18.5－25.0, did not snore, and did not have apnea, tonsillar hypertrophy or adenoids. The OSAS patients selected were diagnosed as having sleep apnea syndrome (AHI ≧ 5.0) by polysomnography performed at the Sleep Disorders Center of the Neuropsychiatric Research Institute (Tokyo, Japan). In addition, they had not received nasal continuous positive airway pressure therapy. From all subjects, informed consent to participating in the study was obtained. The study was approved by the ethical review board of the Faculty of Dentistry, Tokyo Medical and Dental University.

BMI

On the basis of height and weight at the time of the polysomnography, their BMI (body weight [kg]/height $[m]^2$) was calculated and, as stated already, those with a BMI of 18.5－25.0 were selected as members of the control group.

MRI and Tracing

MRI (A 1.5-T superconducting system: Magnetom Vision; Siemens, Erlangen, Germany) was performed for all subjects. T1- and T2-weighted images were acquired. T1-weighted images were used with a TR of 560 ms, a TE of 14 ms, a flip angle of 90, matrix size of 154×256 or 179×256, FOV of 173×230 or 154×230, a NA of 2 and fat SAT of －. T2-weighted images were used with a TR of 3045ms, a TE of 90ms, a flip angle of

180, matrix size of 154×256 or 179×256, FOV of 173×230 or 154×230, a NA of 3 and fat SAT of +. Each slice was 3.0mm thick with gapless. T1-weighted images were used for tracing and T2-weighted images were used for comparison of palatine tonsils. The subjects were instructed not to move or swallow and to keep the upper and lower anterior teeth lightly touching during the MRI.

The MRI slices were 3.0 mm thick and gapless. Imaging was carried out in the axial direction from the hard palate to the lower end of the mandible (Figure 1). On the T1-weighted images obtained, the tongue and oral cavity of each subject was traced. Because the selection criteria for the control group included no history of tonsillectomy or adenoidectomy, the palatine tonsils were excluded from the tracing in the OSAS patient group. In the present study, the tongue was defined according to the anatomical definition which includes the anterior two thirds of the tongue, the posterior part, the palatopharyngeal muscle, the palatoglossus muscle, and the pharyngeal constrictor. The oral cavity was defined as including the oral cavity proper and the airway (Figure 2,3).

From the traced images, the areas of the oral cavity and tongue in each slice were measured by using area-measuring software (Scion Image Beta 4.0.2, Scion Corporation, MD, USA). The approximate volume was estimated by multiplying the area obtained by the slice thickness (3 mm).

Fig. 1. Target area for the MR imaging. The locations labeled ① and ② correspond to the cross-sections shown in Figures 2 and 3.

Fig. 2. Cross-section at location ① in Figure 1.

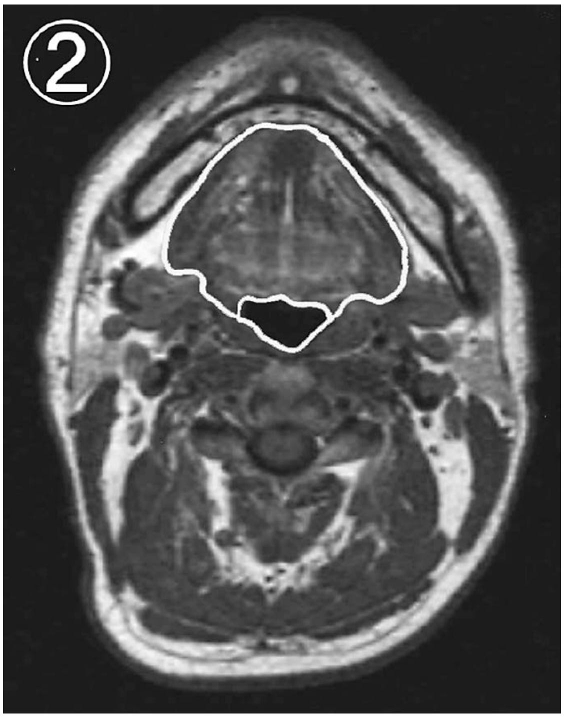

Fig. 3. Cross-section at location ② in Figure 1.

From the approximated values, the volumes of the oral cavity and tongue were calculated, from which the TV/OCV ratio was calculated.

Tests for statistical significance were performed with the Mann-Whitney U-test and the Student's t-test for two groups.

Results

BMI, tongue volume, oral cavity volume and TV/OCV ratio of the control and OSAS patient groups are shown in Table I.

The mean BMI (±SD) was 25.00±3.79 in the OSAS patient group and 21.68±1.73 in the control group. A BMI of 18.5−25.0 was stipulated in the selection criteria for the control group, and analysis by using the Mann-Whitney *U*-test showed that the BMI of the OSAS patient group was significantly higher than that of the control group ($p < 0.05$).

The control group tended to have larger tongue volume relative to the OSAS patient group, although the difference did not reach significance ($p < 0.05$) as assessed by the Student's *t*-test (Figure 4).

The mean (±SD) TV/OCV ratio was 90.56±2.15% in the OSAS patient group and 86.98±3.16% in the control group. The *t*-test indicated that there was a significant difference between the groups ($p < 0.01$) (Figure 5).

BMI was significantly correlated with tongue volume in the OSAS patient group (r=0.69), whereas a significant correlation was not observed in the control group (Figure 4). There was no significant relationship between the standardized TV/OCV ratio and BMI in either the OSAS patient group or the control group (Figure 5).

Table 1. BMI and cephalometric data for the control and OSAS patient groups.

〈Normal Adults〉

	Age (years)	BMI *1	TV (cm³)	OCV (cm³)	TV/OCV Ratio (%) *2
Mean	28.3	21.68	138.84	159.78	86.98
SD	4.29	1.73	16.92	20.24	3.16

〈OSAS Patients〉

	Age (years)	BMI *1	TV (cm³)	OCV (cm³)	TV/OCV Ratio (%) *2
Mean	47.2	25	131.26	144.9	90.56
SD	12.42	3.79	20	21.52	2.15

*1:p>0.05
*2:p<0.01

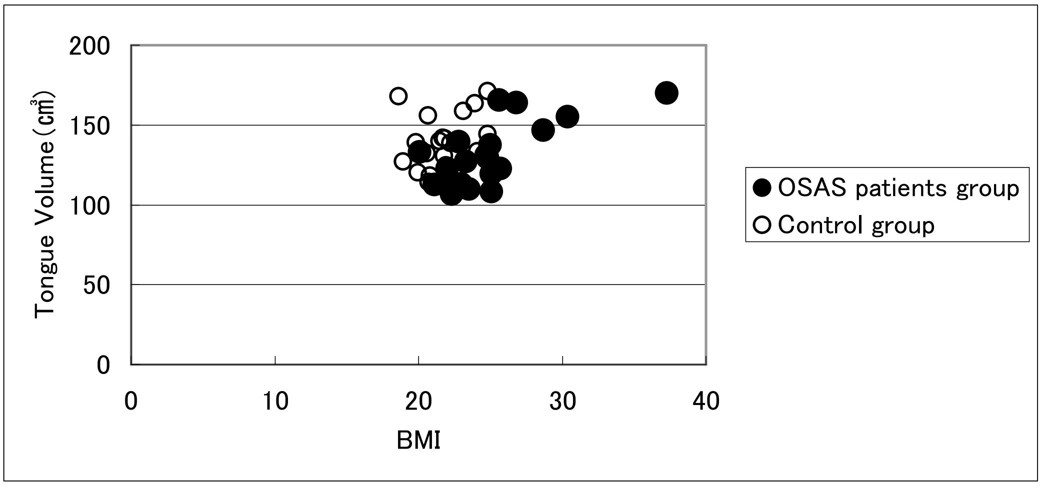

Fig. 4. Relationship between tongue volume and BMI in the control and OSAS patient groups.

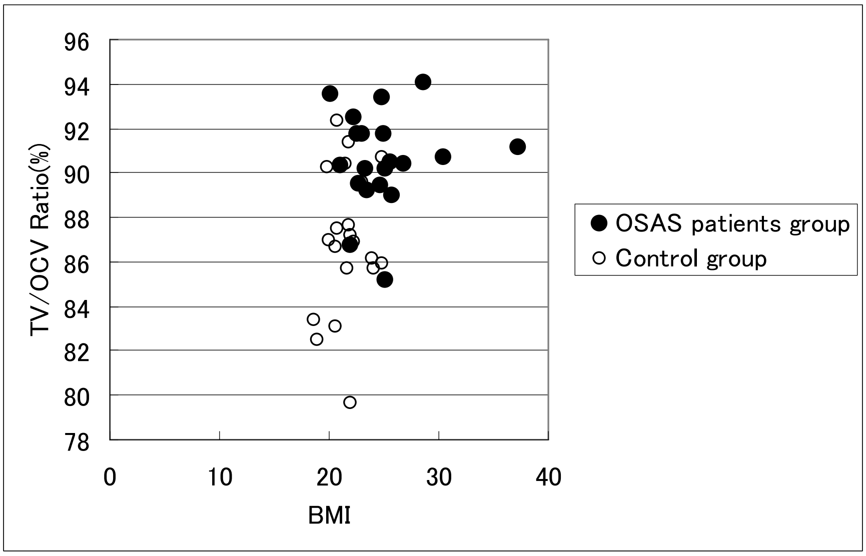

Fig. 5. Relationship between the TV/OCV ratio and BMI in the control and OSAS patient groups.

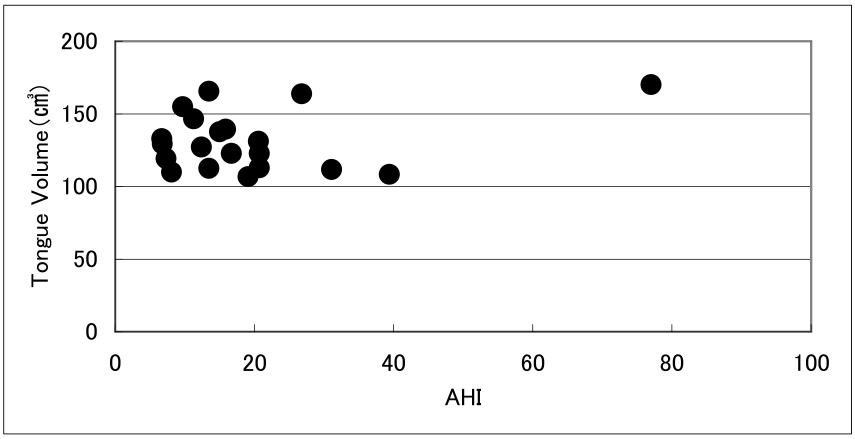

Fig. 6. Relationship between TV and the AHI in the OSAS patient group.

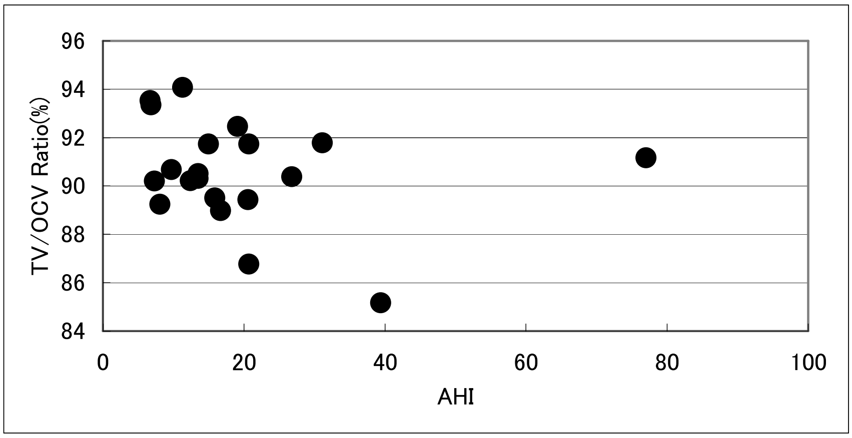

Fig. 7. Relationship between the TV/OCV ratio and the AHI in the OSAS patient group.

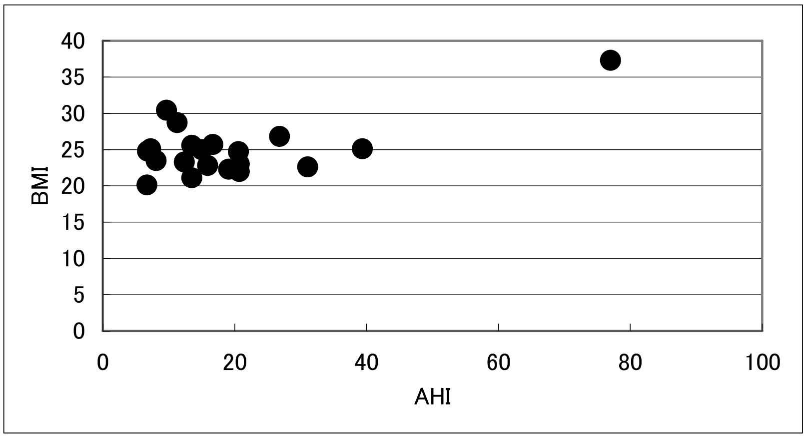

Fig. 8. Relationship between BMI and the AHI in the OSAS patient group.

In the OSAS patient group, although there was no significant relationship between tongue volume and AHI (Figure 6), or between the TV/OCV ratio and AHI (Figure 7), there was a significant correlation between BMI and AHI (r=0.63)(Figure 8).

Discussion

Generally, analysis of the oral and peripharyngeal structures involved in OSAS has been carried out using cephalometric radiography and computed tomography (CT). However, cephalography allows only two-dimensional analysis[7] and cannot provide a three-dimensional representation of the oral region. CT is used for three-dimensional analysis of structures and is useful for reconstructing the structure of hard tissue, but is not suitable for analyzing soft tissue. In addition a major drawback of CT is that it exposes patients to a relatively large dose of radiation. In the present study, we chose MRI as the imaging technique because it does not use radiation and is thus less harmful for patients, imaging can be performed with the patient in the supine position, and it makes it possible to measure both the cross-sectional area and volume of the upper airway and to reconstruct the three-dimensional structure of the soft tissue including the tongue, soft palate and lateral walls of the pharynx[6].According to Lowe *et al.*, there is no significant relationship between the two-dimensional cross-sectional area and the three-dimensional volume of the upper airway[10]. The results of the present study are different from those reported by Esaki *et al.*, who used cephalography in an investigation similar to ours and showed that patients with sleep apnea syndrome had a mean area of the upper airway larger than that of normal control subjects and that a large tongue and soft palate were associated with a narrowed airway[11]. Thus, two-dimensional analysis by cephalography may produce different results from those obtained by three-dimensional analysis using MRI[6], indicating the potential usefulness of MRI for determining the three-dimensional characteristics of the oral region. Furthermore, using both T1- and T2-weighed images allows easier identification of the palatine tonsils and better differentiation of the structure of the tongue and oral cavity, thus providing a clearer tracing.Patient status as shown by MRI, however, does not represent the airway obstruction as it occurs in day-to-day life, and the status may change depending on the positioning of the head[12]. Some improvements are needed in this respect to allow this method to be applied in clinical diagnosis. As shown in the study by Lauder *et al.*, the volumes of the tongue and oral cavity can be measured using MRI, but considering that the tongue itself is soft and moves freely in the oral cavity, it is necessary to develop more accurate methods for obtaining these data[13]. We used the TV/OCV ratio as the main index for comparing the oral configurations of patients with OSAS and controls. Because the TV/OCV ratio can be obtained based on the volumes of the tongue and oral cavity, irrespective of differences in physique and skeletal frame among patients, and because it represents the oral configuration only, it may be a useful indicator for exploring the pathogenesis of OSAS.

Obesity is thought to be one of the factors contributing to OSAS. In the present study we found a higher mean BMI value in the OSAS patients compared with the controls, and a significant relationship between BMI and AHI in the OSAS patient group. It has been shown that, due to inherent maxillofacial morphology, Japanese patients may experience OSAS of similar severity to that experienced by European and American patients who have a BMI 2−3 kg/m^2 higher than their Japanese counterparts[14]. It has been reported that 30% of OSAS patients with an AHI of ≧ 20 have a BMI of 25 or less[15]. Furthermore, Peppard *et al.* reported that a 10% increase in body weight was associated with a 32% increase in AHI, and a 10% decrease in body weight reduced AHI by 26%[16]. By using CT, Vgontzas *et al.* found a significant linear correlation between AHI and abdominal visceral fat determined at the umbilical level[17]. These studies as well as the present study suggest that increases in BMI may contribute significantly to the development and severity of OSAS.

In the present study, we found that the tongue volume of the OSAS patients tended to be smaller than that of the controls but that the difference was not significant, allowing us to make no definite conclusion on the association between tongue volume and OSAS. In contrast to our results, however, Do *et al.* reported that patients with sleep-disordered breathing tended to have larger tongues relative to patients without sleep-disordered breathing[17]. A possible explanation for this discrepancy is differences between the studies in the characteristics of the subjects, such as age, BMI and AHI. In a cephalographic analysis, Mochizuki *et al.* showed that the tongues and soft palates of patients with OSAS were larger in size compared with those of controls[18]; the inconsistency with our results can be attributed to the differences between cephalography and MRI. Do *et al.* also reported that there was no relationship between tongue volume and AHI[17], which is consistent with our results. In our study, we found no significant relationship between tongue volume and BMI for the controls, but there was a significant relationship for the OSAS patients, which is consistent with the results of studies by Do *et al*[17]. and Esaki *et al*[10]. Consequently, there is a relationship between tongue volume and BMI in OSAS patients, in whom a higher BMI value is associated with a larger tongue volume, although the relationship may have a little effect on the severity of the disorder.

Comparison of the TV/OCV ratios revealed a significantly higher ratio in the OSAS patient group compared with the control group, suggesting that the TV/OCV ratio is likely to be involved in the development of OSAS and can be a useful diagnostic indicator of OSAS. However, no significant relationship was found between TV/OCV ratio and BMI either in the OSAS patient group or in the control group. Lowe *et al.* investigated the relationship between the tongue area/oral cavity area ratio and the degree of obesity in a two-dimensional analysis using CT and showed that subjects with a greater tendency for obesity had larger tongues and smaller cross-sectional airway areas[19]. A possible explanation for the discrepancy between the results of the present study and those of Lowe *et al.* is the method of measurement, because we used the volume of the oral cavity, whereas they only used the cross-sectional area of the airway for their analysis. There was no significant relationship between the TV/OCV ratio and AHI in our study. In contrast, Lowe *et al.* found that patients with more severe OSAS tended to have larger tongues and smaller airway volumes[18]. This difference in results may be attributable to differences in the study populations, for example the ethnic backgrounds of the study subjects[20,21]. Thus, we suggest that the TV/OCV ratio is likely to be involved in the development of OSAS but it is not sensitive to enough to indicate the severely of sleep apnea.

In conclusion, different factors may contribute to the development and severity of OSAS and, therefore, it is necessary to examine those that could influence the oral configuration. It is also important to analyze these factors not only two-dimensionally but three-dimensionally. Specifically, when comparing the tongue volume of OSAS patients and controls, the TV/OCV ratio should also be calculated and examined. In the present study we developed a method to determine the volumes of the tongue and oral cavity by three-dimensional analysis. To obtain more detailed data regarding the oral circumstances involved in OSAS, it is necessary to examine other factors, including the thickness and length of the soft palate, and the volume and diameter of the airway.

Acknowledgements

We would like to thank Professor Koji Araki from the Center for Education Research in Medicine and Dentistry, Assistant Professor Ikumi Shiozawa from the Department of Oral Health Care, and Assistant Professor Yoshiyuki Sasaki from the Faculty of Dentistry of the Center for Education and Research in Oral Health Care at Tokyo Medical and Dental University for their support in conducting this study.

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