

Reference range for periodontal mechanosensitive thresholds in molars stimulated from the buccal and occlusal directions in healthy subjects with natural dentition

Ryuhei Kanda¹, Norio Mukai², Junko Tanaka² and Masahiro Tanaka²

¹Graduate School of Dentistry (Department of Fixed Prosthodontics and Occlusion), and ²Department of Fixed Prosthodontics and Occlusion, Osaka Dental University, 8-1 Kuzuhahanazono-cho, Hirakata-shi, Osaka 573-1121, Japan

The purpose of this study was to determine reference ranges for the periodontal mechanosensitive thresholds in molars stimulated from the buccal and occlusal directions in healthy subjects with natural dentition. In addition, we compared the periodontal mechanosensitive threshold (PMT) of molars in middle-aged healthy subjects with natural dentition to the reference range for the PMT stimulated from both directions. We selected 50 healthy adults with no history of orthodontic treatment, no abnormalities in the occlusal contacts, and no occlusal discomfort as the subjects for setting the reference range for the PMT. For the middle-aged healthy group, we selected 12 subjects who were 40 years of age or older, had natural dentition with no abnormalities in stomatognathic function, and normal occlusion. The Semmes-Weinstein (SW) monofilament (Touch Test[®]; North Coast Medical, Morgan Hill, CA, USA) and the modified SW monofilament were used for measurement of the PMT. We set a reference range of the PMT from each stimulated direction. We found that all subjects were within this range. (J Osaka Dent Univ 2020 ; 54 : 61-72)

Key words : Occlusal discomfort syndrome ; Periodontal mechanosensitive threshold ; Reference range

INTRODUCTION

A challenging case that is encountered in the field of dentistry is occlusal discomfort syndrome (ODS). It is challenging because often there are poor objective findings from the patients, it has various etiologies, there is a deficiency in established testing methods for each etiology, and there is an absence of a treatment policy.¹ Various terms have been used for ODS in Japan and worldwide and include “abnormal malaise”,² “phantom bite syndrome”,³ and “occlusal dysesthesia”.⁴ Kuboki *et al.* reported a diagnostic tree for ODS centered on occlusion, and proposed the term “abnormal occlusion symptoms”.⁵ Therefore, the term for discomfort at the time of occlusion has not been unified and the definition has not been made clear. The Japan Prosthodontic Society published a position paper in 2013¹ in which ODS was classified and defined

both broadly and narrowly. ODS broadly includes cases with an obvious occlusal incompatibility in a comprehensive syndrome of a pathological condition that involves occlusal imbalances as well as those for which there is no apparent occlusal problem (so-called suddenness). ODS is defined in a narrow sense, and occurs regardless of the state of the occlusion. The definition of “occlusal dysesthesia” proposed by Clark *et al.* is “discomfort during intercuspation that continues six months or longer despite the absence of dental pulp disease, periodontal disease, disorders in the masticatory muscles or the temporomandibular joint, or any clinical evidence of abnormal occlusion”.⁴

ODS has a diverse etiology, with organic, perceptive, and psychological elements all being proposed to play a role.⁵ Difficulties are encountered in reaching a differential diagnosis. Therefore, abnormalities related to perceptive and psychological ele-

ments cannot be detected by conventional organic tests alone. ODS is often evaluated by inspection of occlusal contacts for symptoms related to imbalances using occlusal indicating paper and silicone. However, when the occlusal inspection,⁶ including an assessment of the stability of the intercuspal position, does not detect objective abnormalities, and when there are no other organic abnormalities in the stomatognathic region, the etiology of ODS often cannot be established. Therefore, ODS cannot be evaluated accurately without perceptual testing in combination with various organic tests. Organic and perceptive elements may be evaluated using perceptive tests, and the involvement of psychological elements may be clarified.

Tooth sensation is one of the perceptual elements closely related to ODS. Some ODS patients exhibit periodontal sensations that are hypersensitive or delayed.⁵ Tooth sensations, the periodontal mechanosensitive threshold of normal natural teeth, were previously examined by Manly *et al.*⁷ Based on the findings we obtained using SW monofilaments, we set a reference range for the periodontal mechanosensitive threshold (PMT), which demonstrated that the PMT is an objective index for tooth sensations.⁸ This reference range was applied to ODS patients, and the findings obtained showed that some of them had a PMT that deviated upward from the reference range, namely, those with abnormal sensations.⁹ However, Mukai *et al.*⁹ reported that none of the ODS patients examined had reduced thresholds. Periodontal mechanoreceptors have a low response threshold, and periodontal sensations are very sensitive. Therefore, even if the threshold value decreases, it may still be included in the reference range.

The method employed by Mukai *et al.*⁹ may not have had the capacity to detect low-value perception abnormalities. By focusing on stimulus directions and sensitivity, Trulsson *et al.* reported a response that was characteristic of the stimulus direction for each tooth type.¹⁰ Manly *et al.* showed that sensitivity periodontal sensations when stimulated from the labial and buccal directions were 2- to 5-fold greater, respectively, than when stimulated

from the axial direction.⁷ Therefore, the PMT stimulated from the occlusal surface direction appears to be higher than that from the labial or buccal direction, and the reference range obtained may shift upward. By using the reference range of the PMT stimulated from the occlusal direction, perceptive abnormalities of low values may be detected. However, the total length of the measurement device may be greater than the distance between the occlusal surfaces of the upper and lower molars during stimulation from the occlusal surface using conventional SW monofilaments. Therefore, it may not be possible to insert the device for stimulation. In the present study, we needed to fabricate modified SW monofilaments to enable stimulation from the occlusal surface in the molar region. Because many ODS patients are middle-aged or elderly,¹ the sensory functions of their oral mucosa and tongue may have decreased. Teranaka *et al.* reported that the tactile threshold increased with aging at the central part of the dorsum of the tongue and the lateral side.¹¹ Therefore, to adapt each reference range to middle-aged and elderly individuals, the effects of the PMT on aging also needs to be examined.

In the present study we set a reference range for the PMT in molars stimulated from the occlusal direction as well as the buccal direction to detect sensory abnormalities in ODS patients. We also measured the PMT in middle-aged and elderly healthy dentition for application to middle-aged and elderly ODS patients, and investigated the effects of aging on PMT.

MATERIALS AND METHODS

Fabrication and calibration of the modified SW monofilaments

Fabrication of the modified SW monofilaments

SW monofilaments were used to produce modified SW monofilaments. Lengths from the bottom surface to the filament stump and from the bottom surface to the head tip were measured using an electronic caliper (Digital Caliper Capital 150 mm with Hold Function[®]; Shinwa Measurement, Niigata, Japan). Measurements were performed twice, and the average value was taken as the filament length for



Conventional monofilament



Modified monofilament

Fig. 1 A conventional Semmes-Weinstein (SW) monofilaments (Touch Test[®]; North Coast Medical, Morgan Hill, CA, USA), and a modified monofilament.

each number. Half the length of each number of filaments was measured with an electronic caliper, marked with an oil-based magic pen, the handle was fixed with a simple vise, and the filament was cut as perpendicular as possible to the long axis of the filament with sharp scissors. In addition, about 17 mm of the head part was cut using a diamond disk, and the stump was shaped like a dome using a Shofu Laboratory Carbide Burs HP dental carbide burs (Shofu, Kyoto, Japan), and polished using a Shofu Big Silicone Point HP (Shofu) (Fig. 1).

Load value setting for each filament

The load value of the modified SW monofilament was measured using an AUX-320 analytical balance (Shimadzu, Kyoto, Japan) in a monitor room with no vibrations or ventilation. The analytical balance was placed on a horizontal and stable platform. A 5-mm square of surgical tape was applied to the center of the top plate of the balance, and the stimulation site was marked with an oil-based magic pen. The filament of the modified SW monofilament was placed in contact perpendicular to the stimulation site of the upper plate, stimulated as slowly as possible, and pressed for approximately 1 sec after the filament bent. The maximum value



Fig. 2 Measurement of the load value with a modified SW monofilament.

displayed during that time was measured. An IXY Digital 10 (Canon, Tokyo, Japan) was used to record the measured values. The camera was fixed on a tripod and fixed-point photography was performed in the video mode at a frame rate of 15 fps. Two dentists (examiners A and B) familiar with this method performed measurements 10 times for each examiner for each filament number. The average value was used as the load for each filament number (Fig. 2).

Examination of the measurement reproducibility of the modified SW monofilaments

In-class correlation coefficients (ICC (1,10) and ICC (2,2)) were calculated to confirm intra- and inter-examiner reliabilities. SPSS Statistics Ver. 19 statistical analysis software (IBM Japan, Tokyo, Japan) was used for the analysis. The coefficient of variation was calculated for the load value in each filament. A Bland-Altman plot was created. The vertical axis was the difference between the load values measured by examiners A and B, and the horizontal axis was the average value of the load values of examiners A and B.

Comparison of the PMT from each stimulated direction and setting of the reference range

Subjects and test teeth

Fifty adults (25.7 ± 2.3 years of age) were selected

for this study who had no history of orthodontic treatment, no history of tooth extractions other than third molars or deciduous teeth, no temporomandibular disorders, no bruxism, and no subjective occlusal discomfort. The 16 test teeth for each subject were the first premolars to the second molars. This study was conducted with the approval of the Osaka Dental University Ethics Committee (Approval No.110894).

Occlusal contact test

Blue Silicone occlusal contact test material (GC, Tokyo, Japan) was used for the occlusal contact test. The test was performed at each subject's subjective weak and strong occlusal strengths in the intercuspal position. Weak occlusal strength was obtained by instructing the subjects to gently close the mouth and, after reaching the intercuspal position, to maintain occlusion with the bilateral molars at maximum strength. The material was kept in the mouth for approximately 2 minutes until it set. To achieve strong clenching, the subjects gently closed their mouth to reach the intercuspal position, and then maintained this state as firmly as possible with the bilateral molars for 30 seconds. Subjects were then instructed to weaken the occlusal force. Occlusal contact was maintained for approximately 90 seconds until the material set. The occlusal records obtained were analyzed with a Bite Eye BE-I tooth contact analyzer (GC, Tokyo, Japan). The thickness of blue silicone that was judged to have occlusal contact was set to 30 μm or less. The subjects who had one or more occlusal contact points in all of the bilateral molars, both weak and strong, and who showed no change in the position of the occlusal contact points with weak and strong occlusal forces, were used in subsequent experiments.

Measurement of the PMT

For the measurement conditions, the subjects were seated in a dental chair with their heads stabilized by a headrest, and measurements were performed with their eyes closed. For measurement of the PMT stimulated apically from the occlusal surface



Fig. 3 Measurement of the PMT stimulated from the occlusal direction.

(Fig. 3), a modified SW monofilament was used in each test tooth. The stimulation sites were the mesiodistal center and the buccolingual center of the occlusal surface of each test tooth. The direction of stimulation for the occlusal surface was the root axis. The filament of the modified SW monofilament was placed in perpendicular contact with the stimulation site, pressed until the hair was bent, and this load was then applied for approximately 1 sec. The stimulation rate was as slow as possible. The PMT was determined by the up-and-down method, a variation of the method of limits for psychophysical assessment.¹¹ The up-and-down method changes the stimulus intensity in a specific direction. In the ascending sequence, it changes from a very small to a large stimulus. When the subject continuously perceives the stimulus, the median value between the maximum point that was not perceived and the minimum point that was initially perceived is taken as the inflection point in the ascending series.

In the descending series, the stimulus intensity changes from a large to a small stimulus. When the subject continuously perceives the stimulus, the median value between the minimum point that was perceived and the maximum point that was initially



Fig. 4 Measurement of the PMT stimulated from the buccal direction.

perceived is taken as the inflection point in the descending series. The ascending and descending series were measured twice, and if the response was not stable, the measurement was repeated until it became stable. The measured values for two stable cycles were recorded. The median of each inflection point obtained in the ascending and descending series was set as the PMT.

For measurement of the PMT stimulated from the buccal to the lingual (Fig. 4), a conventional SW monofilament was used on each test tooth. Measurements were performed by applying a lip and cheek retractor. The stimulation site was 1/3 of the crown height at the center of the mesiodistal direction. The stimulated direction was from the buccal to the lingual. The stimulation site was marked with the oil-magic pen, and surgical tape that was cut into an approximately 3-mm square was affixed to the tooth surface of the stimulation site to prevent the filament from sliding. The PMT was assessed using the same method as that during stimulation from the occlusal direction.

Comparison of the PMT during stimulation apically from the occlusal surface with that of the PMT from the buccal to lingual direction

We compared the PMT stimulated from the occlusal surface in the direction of the root with that from the buccal to the lingual direction. Statistical analyses were performed using the Wilcoxon signed-rank test for each tooth type. SPSS ver. 19 (IBM Japan) was used as statistical analysis software, with the significance level set at 0.05.

Setting the reference range for each stimulated direction

The method of Iizuka and Kume¹³ was used to set the reference range. The data obtained on each target tooth (x) was considered as x , x^2 , x^3 , $x^{1/2}$, $x^{1/3}$ and $\log x$ for selection of the distribution type. The Smirnov-Grubbs rejection test was used for removal of outliers. It was performed on the samples obtained after various conversions, and values that had a significance level less than 0.05 were sequentially removed as unreliable. After removing outliers, the distribution with the largest maximum log likelihood was selected as the goodness of fit to the assumed distribution. When there was only one optimal distribution, it was selected, and when two or more optimal conversions were selected, a normality test was performed and the distribution type was selected. The average value ± 1.96 SD in the above distribution was calculated, and the inverse range of data was used as the reference range.

Measurement of the PMT in middle-aged healthy adults with natural dentation

Subjects and test teeth

We selected 12 middle-aged healthy adults over 40 years of age (7 men and 5 women with an average age of 51 ± 7 years) who had natural dentation, normal occlusion, no history of orthodontic treatment, no coronal repair with concatenated crowns, and no subjective or objective abnormalities in the maxillofacial region. The test teeth were the 16 teeth from the first premolars to the second molars.

Measurement of the PMT from each stimulated direction

This was as described above.

Comparison of PMT obtained from measurements of middle-aged adults with healthy dentition and the reference range

The PMT data obtained from the measurements of middle-aged adults with healthy dentition were compared by plotting them on the PMT reference range graph for each stimulation direction obtained for each tooth type.

RESULTS

Production of the modified SW monofilaments

Load value of the modified SW monofilaments

The modified SW monofilament load values were approximately 2- to 4-fold greater than the ideal values for conventional SW monofilaments (Table 1). Load values of monofilaments with numbers of 6.10 and greater could not be measured, because they exceeded the measurable range of the analytical balance used for calibration.

Table 1 Load value and ratio of load values of conventional and modified SW monofilaments

logF	Conventional type (g)	Improved type (g)	Conventional type/Improved type
1.65	0.008	0.026	3.277
2.36	0.02	0.084	4.177
2.44	0.04	0.134	3.348
2.83	0.07	0.255	3.637
3.22	0.16	0.492	3.073
3.61	0.4	1.279	3.197
3.84	0.6	1.959	3.266
4.08	1	3.105	3.105
4.17	1.4	4.023	2.873
4.31	2	6.274	3.137
4.56	4	11.46	2.864
4.74	6	15.32	2.552
4.93	8	22.36	2.795
5.07	10	26.86	2.686
5.18	15	43.01	2.867
5.46	26	59.85	2.302
5.88	60	136.5	2.274
6.10	100	—	—
6.45	180	—	—
6.65	300	—	—

ICC and the coefficient of variation

The ICC (1,10) for examiner A was 1.000, and for examiner B it was 1.000. The ICC (2,2) for examiners A and B was 1.000. All were almost perfect (over 0.8) by the criteria of Landis *et al.*¹⁴ (Table 2). The coefficient of variation was less than 0.1 for all values.

The Bland-Altman plot

As the number increased, the difference in the measured values and their average value increased, and the distribution of the point cloud was fan-shaped. The correlation coefficient r was 0.952, indicating a positive correlation (Fig. 5).

Occlusal contact images of healthy adults with natural dentation

The subjects had contact with the bilateral molars

Table 2 Criteria of Landis *et al.*¹⁴ for intraclass correlation coefficients (ICC)

ICC	Judgment
0.00-0.20	Slight
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Substantial
0.81-1.00	Almost perfect

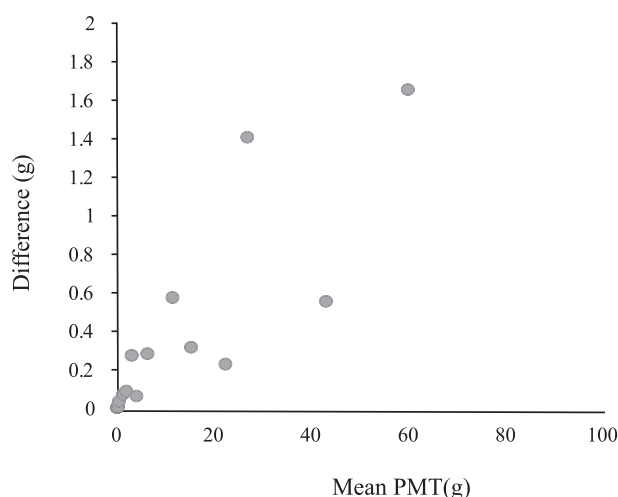


Fig. 5 Bland-Altman plot, where the vertical axis is the difference in the measured values between examiners A and B, and the horizontal axis is the mean of the measured values for examiners A and B.

during weak and strong clenching. No significant changes were observed in the position of the occlusal contacts during weak and strong clenching (Fig. 6).

PMT of healthy adults with natural dentation

Comparison of the PMT stimulated from the buccal and occlusal directions

The PMT in the maxilla and mandible from each of the stimulated directions are shown in Fig. 7. PMT was slightly greater in the more distal teeth in both jaws from each stimulation direction. In all tooth types, the PMT stimulated from the occlusal direction was significantly greater than that from the buccal direction.

Reference range of the PMT stimulated from the buccal to the lingual direction

The reference range of PMT for each subject stimulated from the buccal to the lingual direction with a conventional SW monofilament is shown in Fig. 8. In the maxilla, the first premolar was 1.12 to 3.77 g, the second premolar 1.34 to 5.63 g, the first molar 2.28 to 12.05 g, and the second molar 2.96 to 16.19 g. In the mandible, the first premolar was 1.04 to 4.13 g, the second premolar 1.36 to 5.73 g, the first molar 2.38 to 14.34 g, and the second molar 3.27 to 16.87 g.

Reference range of the PMT during stimulation apically from the occlusal surface

The reference range of PMT for each subject stimulated from the occlusal surface along the root

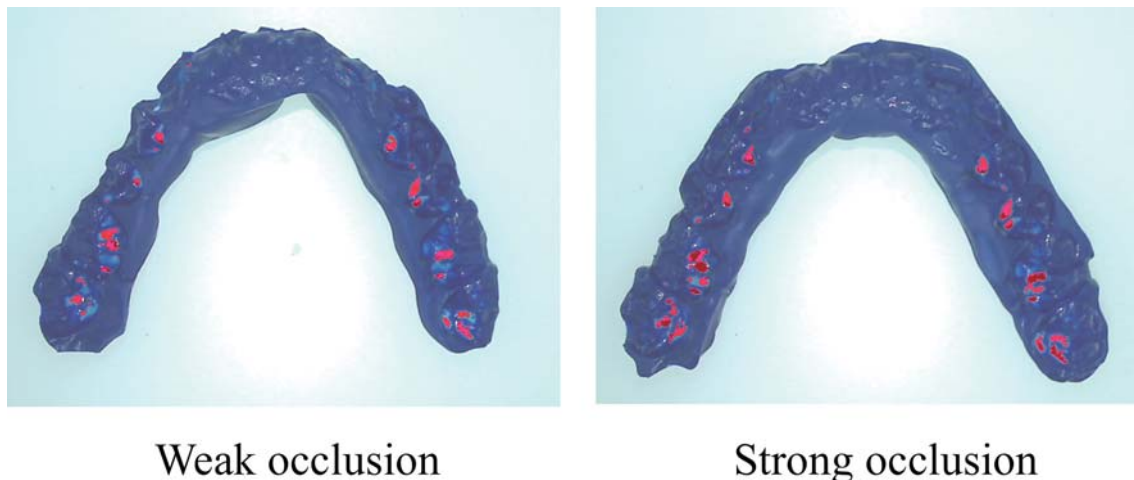


Fig. 6 Examples of an occlusal contact inspection during a weak occlusion, which has good balance, and during a strong occlusion, which has excellent balance.

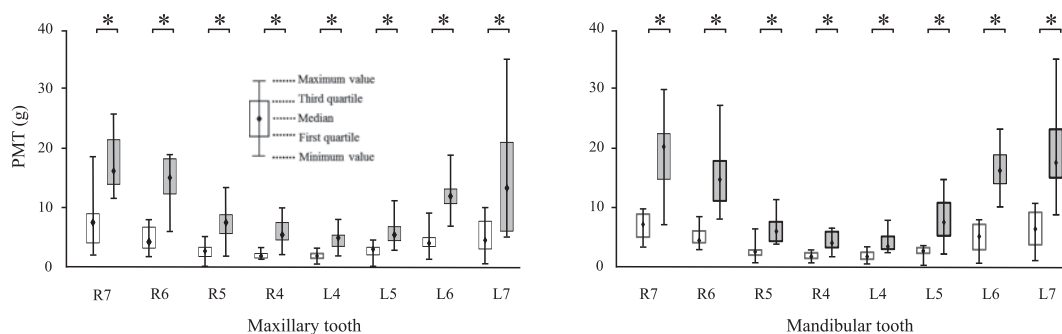


Fig. 7 Comparison of the PMT stimulated from the buccal and occlusal directions in the maxilla, and in the mandible. R7: Right second molar, etc., □ Lateral side of the tooth, ■ Occlusal surface, $n=50$, $*p<0.05$.

axis with the modified SW monofilament and the conventional SW monofilament is shown in Fig. 9. In the maxilla, the first premolar was 1.75 to 8.90 g, the second premolar 2.20 to 10.81 g, the first molar 5.72 to 22.60 g, and the second molar 5.30 to 29.9

g. In the mandible, the first premolar was 2.10 to 9.72 g, the second premolar 2.88 to 15.03 g, the first molar 6.67 to 26.90 g, and the second molar 7.62 to 31.83 g.

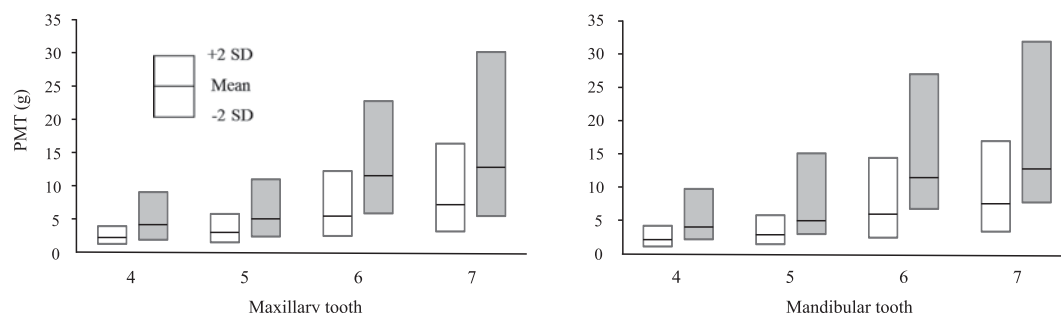


Fig. 8 Reference range of the PMT stimulated from buccal to the lingual directions in the maxilla, and in the mandible. □ Reference range from the lateral side of the tooth (n=100), ■ Reference range from the occlusal surface (n=100).

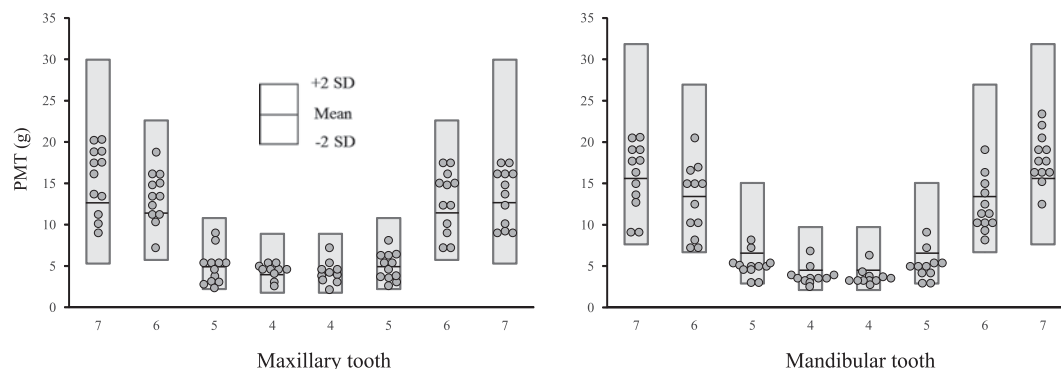


Fig. 9 Comparison with the reference range for the PMT stimulated from the occlusal direction in the maxilla, and in the mandible. ■ Reference range from the occlusal surface, ●PMT in middle-aged individuals with a healthy dentulous jaw, n=12.

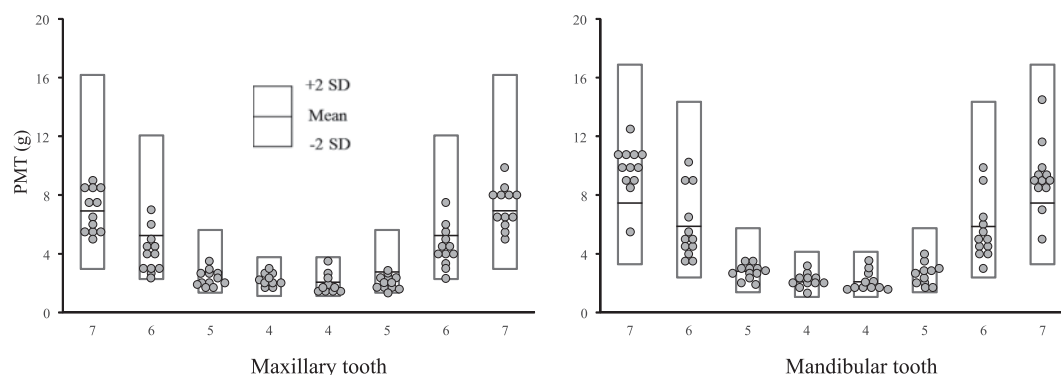


Fig. 10 Comparison with the reference range for the PMT stimulated from the buccal direction in the maxilla, and in the mandible. □ Reference range from the lateral side of the tooth, ●PMT in middle-aged individuals with a healthy dentulous jaw, n=12.

PMT of middle-aged healthy adults with natural dentation

The PMT from the occlusal and buccal directions were within the reference range for all subjects and tooth types (Fig. 10).

DISCUSSION

Fabrication of the modified SW monofilaments

To date, von Frey's hairs,⁷ spring esteometers,¹⁵ and strain gauges^{16, 17} have been used to measure periodontal sensation. We used SW monofilaments, a version of von Frey's hairs that are easy to use and have high measurement reproducibility, in consideration of the complexity of manufacturing and operating the devices. However, in preliminary studies using conventional SW monofilaments, the occlusal surface in the molar region was not stimulated in many subjects because the total length of the device was greater than the distance between the upper and lower molars. Therefore, we fabricated modified SW monofilaments that allowed for the occlusal surface of the molar region to be stimulated. Komiyama *et al.* cut the filament into half in order to use SW monofilaments to measure sensations in the oral cavity.¹⁸ Ogawa stimulated the mandibular molar region from the occlusal direction, and the device was downsized to achieve the desired stimulation intensity.¹⁹ In the present study, the modified SW monofilament was cut in half according to the method of Komiyama *et al.*¹⁸ Since this was done manually, the cut may not have always been perpendicular to the long axis of the modified SW monofilament. Therefore, in a preliminary study, we investigated the effects of different cut surfaces on load values.

Modified stimulation hairs were fabricated and adjusted in order for the filaments to be cut as perpendicular as possible. When the load value was measured, no significant differences were observed. The coefficient of variation was less than 0.1 for all numbers, and the relative variation due to the shape of the cut surface was judged to be small. Furthermore, two dentists who were familiar with and trained in this method measured load values using the modified SW monofilament, and the

ICC obtained were high for intra- and inter-rater reliabilities. This confirmed measurement. Measurements of the load value using the modified SW monofilament were highly reliable and judged useful for the present study.

Selection of subjects

The subjects in this study were healthy adults in their early 20s and 30s with natural dentition who were unlikely to have severe periodontal diseases, and had no history of orthodontic treatment, no subjective findings, such as bruxism or tooth contacting habit (TCH), no missing teeth, and no cuspal restorations. These inclusion criteria were selected based on the following studies; Mukai *et al.* reported that the PMT deviated from the normal range after orthodontic treatment,⁸ Oki *et al.* showed that the threshold of dental sensations fluctuated as a result of clenching or bruxism,^{16, 20} and Van Steenberghe *et al.* demonstrated that the threshold of dental sensations increased with severe periodontal disease.²¹ We selected the subjects using a questionnaire, oral examination by visual inspection, and examination of the dental wear. If more detailed screening is considered necessary in future studies, a periodontal tissue examination, X-ray examination, and polysomnography²² may also be performed. However, since the present study required measurements from a large number of subjects, only simple screening was performed in consideration of human, economic, and time considerations.

Occlusal contact test

In the present study, we assumed that occlusal contact was an organic element closely associated with ODS. We adopted a method in which occlusal strength was determined by the subject's evaluation as a screening test to exclude those with abnormal occlusal contacts. Occlusal contact is affected by occlusal strength. The method of defining clenching strength at the intercuspal position when maximum voluntary clenching (MVC) is 100% by visual feedback using an electromyogram is highly reproducible and considered optimal. However, in the pre-

sent study, the contact of one or more teeth in the molar region was confirmed at the time of weak and strong clenching. We also confirmed whether the occlusal contact position changed between strong and weak clenching. We used a method in which different occlusal strengths were determined subjectively by the subjects.

Measurement method

The trial order may affect sensations depending on whether the measurement series is first performed from the occlusal or buccal direction. Therefore, in the present study, the order of the trials was randomized and assigned to each subject. Subjects were instructed to close their eyes to prevent the misperception of visual sensations. Measurements were stopped when the subject became sleepy. With the up-and-down method, which is a psychophysical procedure used to select the threshold, there may be the expected error that a change will soon occur or should have already occurred.¹² Furthermore, the same judgment may be unduly repeated depending on a subject's familiarity.¹² Therefore, the measurement was repeated until a subject's response was stable, and trials were performed until two stable cycles were obtained.

Setting the reference range

The method of Iizuka and Kume¹³ was used to treat non-parametric data as parametric data. Conventionally, methods of plotting healthy subjects selected based on certain rules of probability and the methods of obtaining normal values as percentiles without assuming a distribution type were used. However, their low estimation accuracy was a problem.²⁴ Furthermore, if the distribution is cut off at both ends for the purpose of removing outliers, there is a risk of removing data by human manipulation that is not an outlier.²⁵ Since the method described above only considers a normal distribution, SD corrections may be required.²⁶ The method of Iizuka and Kume¹³ used in the present study is a procedure to determine the distribution type while excluding outliers that are incidentally mixed in with the healthy population data and to minimize the

possibility that the eventually determined reference range is affected by potentially abnormal values. In addition, since it is a parametric method, estimation accuracy is high and it is considered an objective method. We set the reference range using the method of Iizuka and Kume.¹³ Since no significant difference was observed between the opposite corresponding teeth in the preliminary study, the corresponding teeth were assumed to be the same tooth type.

Comparison of the PMT stimulated from buccal and occlusal directions

According to Manly *et al.*,⁷ the PMT stimulated from the incisal and occlusal directions was approximately 1 g in the anterior teeth and 8-10 g in the molars. The PMT stimulated from the buccal was 2- to 5-fold more sensitive than that from the occlusal direction. However, the reference range of the PMT in healthy subjects in this study was larger than that reported by Manly *et al.*⁷ Yamauchi *et al.*²⁷ also reported higher values than those of Manly *et al.*⁷ and Loewenstein.¹⁵ Ogawa *et al.*¹⁹ found no significant difference in the mandibular molar region due to differences in the direction of stimulation, except for the second molar, which is inconsistent with the present results. The present study showed that the PMT stimulated from the occlusal direction was significantly greater for all tooth types, which was consistent with the findings of Manly *et al.*⁷ Furthermore, Trulsson *et al.* reported that periodontal ligament response specificity depended on the stimulation site and direction for each tooth type.¹⁰ Therefore, the results of our study may differ from those of the above reports or differ depending on the stimulation direction.

Furthermore, the amount of tooth displacement may vary depending on the stimulation direction due to anatomical characteristics. Thus, when a tooth is stimulated from the buccal, it is displaced by rotational movement around the apical third, and the periodontal ligament fibers are easily stretched. On the other hand, when the target tooth is stimulated from the occlusal surface, the periodontal ligament fibers are difficult to stretch due to increased

resistance to displacement of the teeth in the apical direction by oblique fibers that account for most of the periodontal ligament fibers. The PMT from the occlusal surface may have a higher threshold than during stimulation from the buccal due to these differences. However, few studies have examined differences in threshold values that depend on the stimulation direction after securing a sufficient number of subjects. Therefore, further data accumulation and analyses are warranted.

PMT in middle-aged healthy adults with natural dentition

In a multicenter survey, the average age of ODS patients was 52.9 ± 15.3 years, with middle-aged and elderly individuals accounting for a large proportion.¹ Therefore, based on age-related changes, it currently remains unclear whether the reference range obtained in the present study for healthy subjects with natural dentition in their 20s and 30s is applicable to ODS patients. Previous studies have reported that the sensory function of the oral mucosa and tongue decreases with age.^{11, 28} However, aging did not affect the PMT. According to Maeda *et al.*,²⁹ because the periodontal ligament is always exposed to occlusal force, active tissue remodeling occurs. The periodontal ligament innervation has potentially high neuroplasticity. Periodontal mechanoreceptors are often present towards the apex.³⁰ They are considered less susceptible to histological changes, including alveolar bone resorption, with age. Based on these findings, the sensory function of the periodontal ligament may change little. In other words, the effects of age-related changes on the PMT are negligible, and, thus, the reference range obtained in the present study may be applied to middle-aged and elderly individuals.

In the present study, we measured and examined the PMT during stimulation from the buccal direction in patients with ODS after orthodontic treatment and in ODS patients who visited our university hospital. The results obtained confirmed that the PMT is an objective index of dental sensations⁸ and perceptive abnormalities in ODS patients.⁹ However, since periodontal sensations are very

sensitive, the reference range of the PMT measured from the buccal may include a perceptual abnormality in which the PMT deviates to a low value. The present results also show that sensory abnormalities that deviate from low and high values may be detected by applying the reference range of the PMT from the occlusal direction set in the present study together with the PMT stimulated from the buccal direction sets in previous studies on ODS patients. Furthermore, ODS involving psychological elements may be diagnosed by excluding the possibility of organic and perceptual abnormalities.

The pathology of ODS has not yet been elucidated in detail and an objective test method has not yet been established. In current clinical settings, unnecessary and irreversible treatments, such as occlusal adjustments that rely on a patient's senses, may be performed despite poor objectivity. Therefore, patient symptoms may worsen, leading to a broken relationship of trust and the creation of new iatrogenic diseases. The establishment of an examination and diagnostic method for ODS will contribute to the development of an appropriate treatment strategy, and further research will clarify its etiology.

In the molar region, the PMT stimulated apically from the occlusal surface was significantly greater than that from the buccal to lingual in all types of teeth. We determined the reference range of the PMT for stimulation from the buccal to lingual direction, and apically from the occlusal surface in the molar region. Furthermore, in this study we found that the PMT in middle-aged healthy individuals with natural dentition was within the reference range for all subjects and tooth types for all directions of stimulation.

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