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Changes in Sensory Thresholds of the Pulp and Periodontal Ligaments after Standardized Tooth Clenching

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Abstract

Objective: It is not clear how the magnitude and duration of occlusal force affects pulpal and periodontal sensations. We investigated the effects of various tooth clenching loads, in which the product of the occlusal force and duration was kept constant, on pulpal and periodontal sensations.

Materials and methods: Ten men and 10 women associated with Tokyo Medical and Dental University (age ≥ 20 years) participated in this study. Changes in pulpal sensation and periodontal sensation at the left or right mandibular first premolar were compared before and after 3 experimental clenching tasks.

The total loading amount, determined as "occlusal force × duration", was kept constant across tasks. For pulpal sensation, the electrical stimulation threshold (EDT) was measured using an electric pulp tester that caused pulpal discomfort. For periodontal sensation, the interocclusal tactile threshold (ITT) was measured using the foil test.

Results: There was no significant difference with respect to the change rates of EDT and ITT relative to baseline between tasks. However, change rates varied across individuals. Both EDT and ITT could be divided into 3 types: increase type, decrease type ,and no-change type. For EDT, the smaller the bite force was, the more the proportion of the decrease type tended to increase. For ITT, the increase type was predominant in each task. However, there was no statistically significant difference between tasks in both EDT and ITT.

Conclusion: Although we observed no statistically significant differences, transient changes in pulpal as well as periodontal sensation were found. Even if the product of occlusal force and duration (total loading) remained constant, transient changes in pulpal and periodontal sensations might differ. In particular, the pulp may become hypersensitive, while periodontal sensation may become hyposensitive.

Keywords: Bruxism; Electrical detection threshold; Interocclusal tactile threshold; Ischemia; Tooth contacting habit

Introduction

Bruxism involves repetitive masticatory muscle activity, characterized by clenching or grinding of the teeth and/or by bracing or thrusting of the mandible, and can include sleep bruxism or awake bruxism [1]. When bruxism becomes a risk factor, it is considered to cause various stomatognathic dysfunctions. Bruxism can cause tooth wear, tooth fracture, abfraction, destruction of restorations, temporomandibular joint pain, and masticatory muscle pain [2-4].

Dentine hypersensitivity is defined as a "short, sharp pain arising from exposed dentine in response to stimuli, typically thermal, evaporative, tactile, osmotic, or chemical and which cannot be ascribed to any other form of dental defect or pathology" [5]. There are several theories about the mechanisms of dentinal sensation, such as the transducer theory, modulation theory, gate control theory, and vibration theory [6]. Currently, the hydrodynamic theory is the most widely accepted [7]. In many cases, dentine hypersensitivity is due to exposed dentine, which results from removal of enamel and/or denudation of the root surface [8]. On the other hand, even in the absence of exposed dentine, dentine hypersensitivity may occur. It has been reported that the threshold of pulpal pain sensation is decreased significantly, while the intensity of pain sensation upon electrical stimulation is increased significantly, after performing experimental clenching with maximum occlusion force [9].

In daily clinical practice, patients sometimes complain of having occlusional discomfort; this is mostly attributable to dental caries, periodontal disease, inappropriate prosthetic treatment, or temporomandibular disorders (TMD) [10]. However, some patients experience occlusal discomfort that cannot be explained by these factors; such discomfort is termed phantom bite syndrome (PBS) [11] or occlusal dysesthesia (OD) [12]. In 2012, the diagnostic criteria of OD was unified as follows [13]: "1) persistent complaint of uncomfortable bite sensation for more than 6 months, 2) symptoms do not correspond to any physical discrepancy affecting the pulp, periodontium, muscles, or the temporomandibular joints, 3) pain complaint may be concomitant, however, in low levels, 4) symptoms cause distress that makes the patient persistently search for dental treatments."

Psychological factors are considered to underlie these symptoms [13,14]. However, it has also been suggested that the symptoms may be related to hypersensitivity of occlusal sensation. It was reported that the thickness discrimination threshold of patients who were diagnosed with OD tended to be lower in these patients than in healthy subjects, although without statistical significance [15]. Furthermore, it has been shown that the periodontal sensation of sleeping-bruxers is more sensitive than that of nonbruxers [16,17].

These results suggested that the non-functional occlusal force associated with bruxism may affect pulpal as well as periodontal sensation. However, it is not clear how the magnitude and duration of clenching affect these sensations. Our hypothesis was that a smaller occlusal force for a prolonged duration would cause pulpal and periodontal sensations to become more sensitive. Therefore, this study investigated the effect of the magnitude and duration of clenching, which simulated a non-functional occlusal force, on pulpal and periodontal sensations. To this end, we varied the magnitude and duration of force such that the total force loading (force × time) was kept constant.

Materials and Methods

Subjects and tested tooth

This study was approved by the ethics committee of the Faculty of Dentistry at Tokyo Medical and Dental University (approval no. D2016-092).

Twenty students or staff members from Tokyo Medical and Dental University (10 men, 10 women), aged ≥ 20 years, participated in the study. Based on the result of a power calculation using G-power (version 3.1.9.2, α=0.05, β=0.20, statistical power=80%) [18] and the number of healthy subjects in a previous study [17,19], the number of samples in this study was set to 20 people. The tested tooth was the mandibular first premolar on the left or the right side; occlusal contact with the antagonist tooth had to be present. Exclusion criteria were as follows: 1) the tested tooth had dental caries or a history of dental treatment (composite resin restoration, inlay restoration, or crown restoration). 2) The tested tooth was non-vital or had undergone root canal treatment. 3) Missing adjacent teeth or absence of contact with the adjacent surface. 4) Toothache or tooth mobility in the tested tooth or maxillary canines, first premolars, or second premolars on the ipsilateral side. 5) Moderate or severe periodontitis in the tested tooth or maxillary canines, first premolars, or second premolars on the ipsilateral side. 6) Currently undergoing orthodontic treatment. 7) Currently using a splint. 8) A score of 11 or higher for either subscale (anxiety and depression) of the Hospital Anxiety Depression Scale [20,21].

Measurement of occlusal force

The occlusal force was measured using a load cell (MCDW-50L, Toyo Sokki Co., Ltd., Kanagawa, Japan). In order to fix the load cell between the upper and lower occlusal surface, resin caps were made using the following procedures. Impressions of the maxillary and mandibular dentition ware obtained by alginate impression material (AROMA FINE PLUS, GC, Inc., Tokyo, Japan), which was then used for making gypsum models. Silicone bite registration material (Collect Plus Bite Superfast, Pentron Japan, Inc., Tokyo, Japan), was used for registering the interocclusal relations; this material with occlusal relationship recorded was placed between the maxillary and mandibular dentition gypsum models fix to an articulator. Thereafter, two resin caps were made with polymerized resin (UNIFAST III, GC, Inc.): the lower one fabricated for the tested tooth (i.e., the mandibular first premolar), and the upper one connecting for the maxillary canine, first premolar, as well as second premolar on the ipsilateral side. In addition, in the middle of labial-side, lower edge of the tested tooth's resin cap; we made a slit for measuring pulpal sensation. When measuring the occlusal force, these two resin caps were set up with the load cell placed between them (Figure 1). The signal from the load cell was transmitted to waveform software (TMM-Toolkit, Toyo Sokki Co., Ltd.) on a notebook computer (CF-B11RePCS, Panasonic, Kadoma, Japan) *via* a portable wireless indicator (TWI-701, Toyo Sokki Co., Ltd.).

Measurement of pulpal sensation

Pulpal sensation was measured by electric pulpal test [9,22,23], using an electric pulp tester (Digitest II, Morita Co., Ltd., Tokyo, Japan). During the test, subjects were instructed to keep their eyes closed. First, the probe tip of the electric pulp tester was placed on the tooth surface along the slit at the lower edge of the resin cap. Current was released after the probe touched the tooth surface; the current intensity was displayed on the digital screen of dental pulp tester. Subjects were asked to raise their hands when they felt discomfort, at which point the probe was moved away from the tooth surface. The value then displayed on the digital screen was set as the electrical detection threshold (EDT). This process was repeated 3 times, and the average value was recorded as a representative final EDT value.

Measurement of periodontal sensation

In order to measure the periodontal sensation, the foil test was used to measure the minimal thickness discrimination, as described by Baba, et al. [15]. In the foil test, articulating film (Arti-Fol BK25 and BK33, Bausch, Rochester, NY) with a thickness of 8 µm or 12 µm, trimmed to a size of 7 mm × 15 mm, were used. These articulating films were used individually or in combination, using an initial thickness of 8 mm, and thickened at 4-mm intervals, to produce test films that were held by the articulating paper holder.

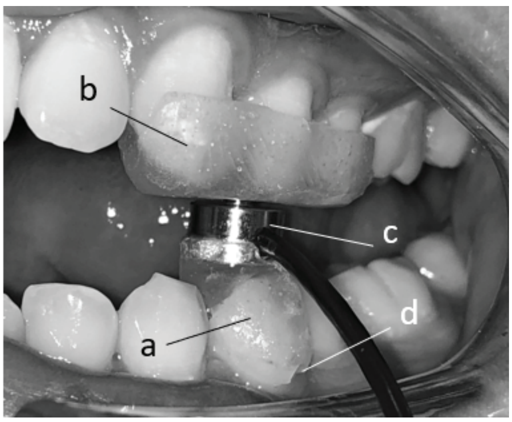

Figure 1: The load cell placed between upper and lower resin caps.
a: resin cap on tested tooth; b: resin cap on the opposing teeth; c: load cell; d: slit for placing probe tip of electric pulp tester to measure pulpal sensation.

During the test, subjects were instructed to close their eyes and to open their mouths about 1 cm. The first test film with a thickness of 20μm was placed between the tested tooth and its opposing teeth, and subjects were instructed to contact their teeth once and then rapidly open their mouth. The subject was then asked whether the test film was present after it had been removed. According to the answers from subjects, results were divided into 4 categories: 1) True positive (TP): the subject recognized the presence of the test film correctly; 2) false negative (FN): the subject mistook the absence of the test film for its presence; 3) false positive (FP): the subject mistook the presence of the test film for its absence; 4) true negative (TN): the subject recognized the absence of the test film correctly. If the result was TP, a thinner test film, decreased by 4 μm (i.e., 16 μm-thick: "one-step-thinner film") was used, while 4 μm-thicker test film (i.e., 24 μm: "one-step-thicker film") was used if the result was FN. This process was repeated step-wise, and the thickness of the thinnest test film that the subject could recognize correctly was recorded as the interocclusal tactile threshold (ITT).

The ITT was determined by the following 2 criteria: Criterion 1: when a test film resulted in TP 4 times, the ITT was taken as the median value of the thickness of this test film and its one-step-thinner film (Figure 2a).

Criterion 2: when a test film resulted in TP as well as FN 3 times respectively, the ITT was taken as the thickness of this test film (Figure 2b).

Bite force and experimental tasks

The resin caps were set on the tested tooth and on the maxillary canine, first premolar, and second premolar on the ipsilateral side, and the load cell was placed between them. Then, subjects were asked to clench for 3 seconds with their maximum occlusal force, for 4 times in total, with a 30-second interval. The data of the first clenching was discarded and the average value of the remaining 3 times was taken as 100% maximum bite force (MBF) for each tested tooth.

Experimental clenching tasks were set so that the total loading amount (force × time) was the same: 10% MBF for 80 seconds, 20% MBF for 40 seconds, and 40% MBF for 20 seconds. While maintaining occlusal force, subjects were instructed to look at a computer screen showing the data output from the load cell, and to maintain the specified occlusal force as much as they possibly could. Clenching at each specified occlusal force was repeated 3 times, with a 10-second interval.

Measurement of pulpal as well as of periodontal sensations were performed before the MBF measurement (as baseline) and immediately after each experimental task. Pulpal and periodontal sensations were measured on different days. Subjects were allowed 15 minutes' rest after each experimental task. A block diagram of the measurement procedure is shown in figure 3.

Statistical analysis

The change rates of EDT and ITT were calculated according to the following formula, using the values obtained before (baseline) and after each task.

Change rate (%)=(after task/baseline) × 100

To compare the average value of the change rates between tasks, repeated-measures ANOVA (one-way ANOVA with correspondence) and post-hoc tests with Bonferroni correction were used. For changes of EDT and ITT from baseline, the proportion of subjects that showed increases or decreases exceeding the cutoff value were calculated for each cutoff value (10%, 20%), and their ratio was compared between each task using the chi-square test with Bonferroni correction. SPSS Ver. 23 (IBM, Japan) was used for statistical analysis and $p<0.05$ was regarded as indicating statistical significance.

Results

The change rate of EDT and ITT relative to baseline in all subjects is shown in figure 4. The average change rate (standard deviation) of EDT in each task was: 110.0% (78.9) at 10% MBF, 99.0% (41.2) at 20% MBF, and 156.1% (128.3) at 40% MBF. Repeated-measures ANOVA indicated a significant difference (P=0.047) among tasks; more specifically, a significant difference between 20% MBF and 40% MBF was observed (P=0.038) (the change rate at 40% MBF was increased significantly over that at 20%MBF). The average change rate (SD) of ITT in each task was: 212.0% (156.0) at 10% MBF, 226.4% (180.2) at 20% MBF, and 269.3% (194.3) at 40% MBF. Repeated-measures ANOVA revealed no significant differences among tasks (P=0.070); however, ITT tended to increase with every task from 10% to 40% MBF.

Changes in EDT and ITT for individual subjects are shown in figure 5. For EDT, the alteration in change rates varied across subjects. When comparing the change rate in each task to baseline on an individual basis, we found that 4 subjects showed increased values only, 6 subjects showed decreased values only, and 10 subjects showed a mixture of increased and decreased values. For the ITT,

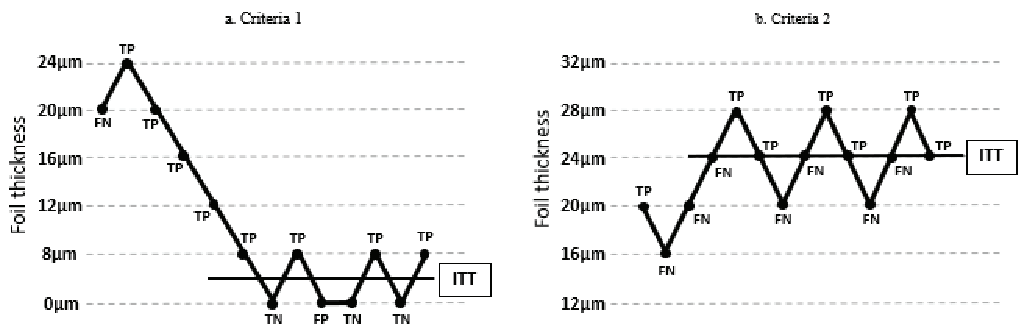

Figure 2: Criteria for determining interocclusal tactile threshold.
TP: true positive; TN: true negative; FP: false positive; FN: false negative; ITT: interocclusal tactile threshold

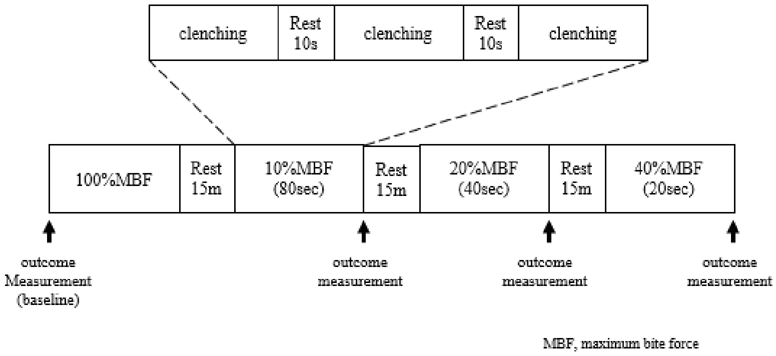

Figure 3: A block diagram of the measurement procedure.

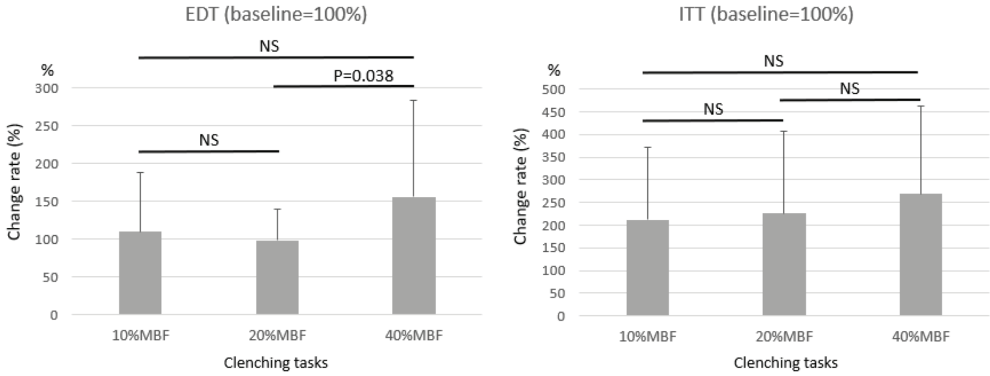

Figure 4: The comparison of change rates of EDT and ITT relative to baseline in all subjects between tasks.
EDT: electrical detection threshold; ITT: interocclusal tactile threshold; MBF: maximum bite force; NS: non significant

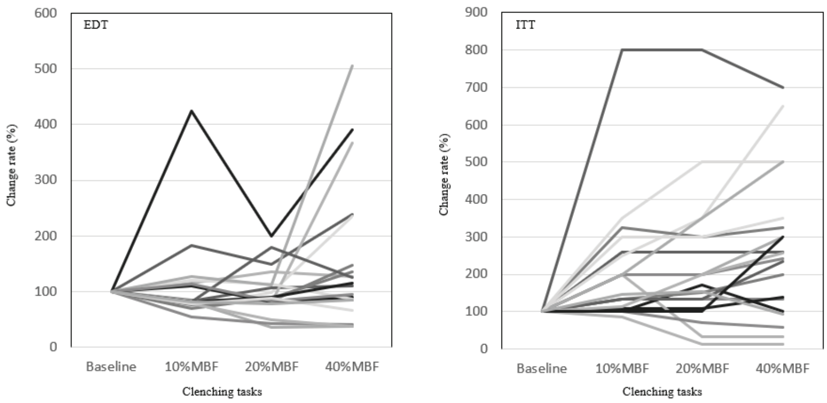

Figure 5: Change rates of EDT and ITT for individual subjects in each clenching task.
EDT: electrical detection threshold; ITT: interocclusal tactile threshold; MBF: maximum bite force

the alteration in change rates also varied across subjects: 16 subjects showed increased values only, or unchanged as well as increased values, 2 subjects showed decreased values only, or unchanged as well as decreased values, and 2 subjects showed a mixture of increased and decreased values.

Two cutoff values of changes relative to baseline, i.e. 10% and 20%, were set in each task. Based on these 2 cutoff values, a situation showing increases or decreases greater than the cutoff value was named the "increase type" and "decrease type", respectively. When the increase or decrease was within the cutoff value, it was termed the "no-change type". The number of subjects in each type and their proportions were calculated. For EDT, there was no statistically significant difference between tasks (Figure 6). However, the smaller the occlusal force was, the more the proportion of the decrease type tended to increase. For

ITT, there was no statistically significant difference between tasks (Figure 6). However, the increase type was predominant for each task.

Discussion

Experimental clenching

In this study, we evaluated the effect of continuous clenching, which was regarded as a non-functional occlusal force, such as bruxism, at the mandibular first premolar on pulpal and periodontal sensations. The magnitude of clenching was set at 10%, 20%, and 40% of MBF, and the duration was 80 seconds, 40 seconds, and 20 seconds, respectively. Thus, the product of occlusal force and duration was constant, and the total loading applied on the test teeth during each task was equal.

A previous study on clenching force level, which used the entire dentition, reported that the endurance time (median value) for maintaining different magnitudes of clenching varied: for 40% MBF, it was 1.4 minutes; for 25% MBF, it was 2.1 minutes; and for 10% MBF, it was 33.3 minutes [19]. In this study, since the clenching with each occlusal force was performed 3 times in succession, the duration for 40% MBF as the largest bite force was set to 20 seconds. The duration for 20% MBF and 10% MBF was set on this basis, and the total loading remained constant.

Sensation of tooth pulp

The hydrodynamic theory is most widely accepted as an explanation of dentine hypersensitivity. When a load is applied to a tooth, movement of dentinal fluid will occur within the dentinal tubules [24], which may activate nociceptors and mechanical receptors in the pulp and cause pain [25,26].

Transient receptor potential ankyrin 1 (TRPA1) is one of the receptors in pulpal pain sensation. It has been reported that TRPA1 expression increases in the pulp and odontoblasts upon cold stimulation [27-30]. So, et al. [31] reported that tissue ischemia causes peripheral hypoxia, which leads to TRPA1 activation, according to animal experiments. In addition, reactive oxygen species produced by reperfusion after ischemia also causes TRPA1 activation. Furthermore, TRPA1 activation may induce peripheral sensory changes and hyperalgesia. Similarly, some studies have reported that pulpal blood flow decreased when applying a load to the tooth, and increased rapidly once the load was removed [32,33].

In this study, EDT tended to decrease after applying 10% MBF to the tested tooth. In addition, even compared to EDT obtained by applying 40% MBF, it seemed that the proportion of the "decrease type" of EDT in 10% MBF was larger. This decrease in EDT indicated that the pulp had become hypersensitive. The volume of dentinal fluid displacement in the dentinal tubule is said to increase with the increase of force applied to the tooth [24]. Therefore, it can be inferred that the dentinal fluid displacement caused by 40% MBF should be larger than that caused by 10% MBF, for the same tooth. However, in our study, the proportion of pulpal hypersensitivity tended to be higher at 10% MBF. According to a report published by So, et al. [31], a longer ischemia time would lead to a longer blood-flow recovery time upon reperfusion, and hypersensitivity was more likely to persist. Therefore, changes in the pulp sensory threshold in our study may be due to the prolonged pulpal blood-flow reduction time, caused by a longer clenching duration, which may have promoted activation of TRPA1.

It is generally believed that, if the changes in pulpal sensation are minimal, it would not cause severe clinical problems. However, when the pulp sensory threshold decreases, that is, when the dental pulp becomes hypersensitive, it is possible that dentine hypersensitivity may develop. In this study, 10% MBF was more likely to induce dentine hypersensitivity. Even though the magnitude of the occlusal force was small, it contributed to pulpal hypersensitivity, and our study also proved that such subjects do exist.

Sensation of periodontal ligament

Several sensory receptors are involved in inter dental thickness discrimination; these include periodontal mechanoreceptors and temporomandibular joint mechanoreceptors. However, it has been reported that discrimination below a thickness of 200 μm is mainly related to periodontal mechanoreceptors [34]. Since the thickest

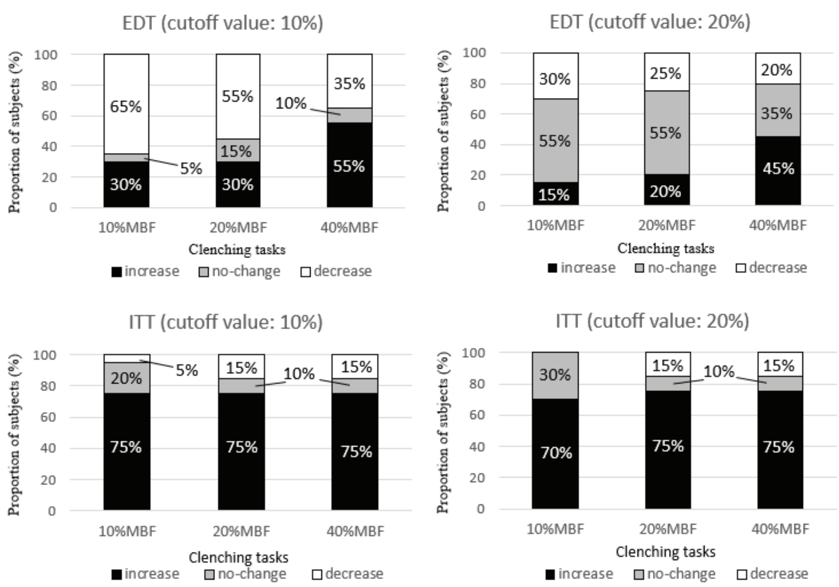

Figure 6: The proportion which was increased or decreased more than the cutoff value in EDT/ITT.
EDT, electrical detection threshold; ITT, interocclusal tactile threshold; MBF, maximum bite force

test film used in this study was 40 μm, this thickness discrimination measurement can be considered to be mostly due to periodontal ligament receptors.

In this study, the periodontal sensory threshold in each task was increased, that is, the proportion of periodontal hyposensitivity tended to be larger. When an external force, such as occlusal force, is applied to a tooth, the tooth is displaced. Such tooth displacement stimulates the periodontal mechanoreceptors and changes the periodontal sensory threshold.

Morimoto, et al. [35] reported that, when applying a 98-N transient occlusal loading to a tooth for 1 minute, the threshold of tooth tactile sensation would increase, that is, periodontal sensation would become hyposensitive due to tooth displacement permitted by the viscoelasticity of the periodontal ligaments. Tooth displacement caused by an external force does not recover immediately, but recovers gradually after the external force is removed. The greater the external force, the larger the tooth displacement, and the longer the displacement recovery time after removal of the external force. The duration of external force application is thus proportional to displacement recovery time [36].

It had been reported that the ITT for bruxers was significantly lower than that of nonbruxers, based on the foil test [16,17]. In addition, Baba, et al. [15] suggested that OD patients may have superior thickness discrimination ability as compared to healthy subjects. In our study, the periodontal sensory threshold tended to increase with continuous clenching. However, bruxism is a repetitive action during daily life. The decreased periodontal sensory threshold of a bruxer is the result of repetitive loading on periodontal ligaments, for a long period of time, which may explain why the results of the studies mentioned above are different from ours. In addition, in OD or PBS patients, not only the effect of peripheral periodontal sensitization, but also the central sensitization and psychological factors, should be taken into consideration [10-14].

Relationship with bruxism

The main disturbances caused by bruxism are said to be tooth wear, tooth fracture, abfraction, and destruction of restorations, temporomandibular joint pain and masticatory muscle pain. Our study suggests that bruxism may also affect pulpal sensation and periodontal sensation.

Even if the magnitude of the occlusal force is small, it may cause changes in pulpal sensation and periodontal sensation over a prolonged period. It is conceivable that the magnitude of occlusal force in awake-bruxism is smaller than that in sleep-bruxism. Low-level clenching can be sustained for a longer period of time than high-level clenching [19]. In addition, Bracci, et al. [37] reported that, in 4 kinds of behavior in awake-bruxism, the tooth contact habit was the most frequently reported condition, with an average frequency of 14.5%, followed by jaw-clenching, with an average frequency of 10%. In other words, the frequency of light teeth contact is higher.

Sato, et al. [38] showed that TMD patients tended to find it easy to maintain non-functional occlusal contact; this behavior was termed the tooth-contacting habit (TCH). The TCH is defined as a habitual behavior in which the upper and lower teeth are continuously brought together with minimal force in a non-functional manner (i.e., contact is made, rather than clenching). Habitual behaviors, such as the TCH, are considered nervous habits, that is, behaviors that are aggravated by tension or performed to reduce tension [39]. In the present study, the periodontal sensory threshold tended to increase transiently due to continuous clenching; however, this may indicate a hyposensitivity of occlusal sensation. Hyposensitivity of occlusal sensation may increase the frequency of confirming contact condition of upper and lower teeth or lengthen the time of occlusal contact, which may lead to a decreased periodontal sensory threshold in bruxers, or occlusal discomfort.

When occlusal force is applied to teeth by actions such as the TCH, it could cause ischemia and reperfusion in the pulp and periodontal ligaments. Based on an experiment involving compressive ligation of the hind limb in mice, So, et al. [31] reported that the scores for the paw-withdrawal response to von Frey filaments were decreased during hind limb ischemia (i.e., hypersensitivity); however, with the prolongation of ischemia time, the reperfusion recovery time tended to be prolonged, and the duration of the licking behavior evoked by ischemia/reperfusion also tended to be extended. In other words, prolonged ischemia duration may cause a delay in the improvement of sensory changes.

In this study, we demonstrated that the effects of continuous clenching on pulpal and periodontal sensations differed across subjects, and even within individuals; in some cases there was no effect, while pulpal sensation or/and periodontal sensation differed in other cases. This suggests that continuous clenching can also be considered as a cause of dentine hypersensitivity and occlusal discomfort. In particular, in the low pulp sensory threshold type or high periodontal sensation type, it is likely that persistent and repetitive bruxism, such as TCH, may arise, which will lead to dentine hypersensitivity or occlusal discomfort in future.

Limitation of study

We found no statistically significant differences in our study, although our sample size was determined by referring to previous studies. Therefore, when using the conditions employed in the present study, it may be necessary to use a larger sample size. In addition, with regard to the repeated clenching experiments, we performed each task 3 times in this study; it may be necessary to increase the number of repetitions. To measure periodontal sensation, we used the foil test to examine the thickness discriminative ability; however, it took a while for the subjects to discriminate the minimal thickness, which suggests the possibility that recovery after loading may have affected the results. Other measurement methods might also need to be considered.

Conclusion

In this study, effects of various levels of tooth clenching, the non-functional occlusal force associated with bruxism, on pulpal and periodontal sensations were investigated. We had assumed that a smaller occlusal force over a prolonged period would cause the pulpal and periodontal sensations to become more sensitive. Indeed, we found that the smaller the magnitude of clenching was, the more easily pulp sensory thresholds tended to decrease (i.e., pulpal sensation became hypersensitivity). However, periodontal sensory thresholds increased after all types of clenching tasks (i.e., periodontal sensation became hyposensitivity). In conclusion, even if the product of occlusal force and duration (total loading) remained constant, transient changes in pulpal and periodontal sensations might differ.

Competing Interests

The authors declare that they have no competing interests.

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