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Original article

The effect of occlusal splints on the mechanical stress on teeth as measured by intraoral sensors

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Abstract

Purpose: Whether it is possible to prevent mechanical stress on teeth via an occlusal splint remains to be clarified. This study aimed to assess the same by simultaneously recording the occlusal pressure and strain on the teeth in humans.
Methods: Eleven participants (five women and six men; mean age 25.7 years) were enrolled in this study. Hard and soft oral appliances were fabricated for the maxillary arch of each participant. The strain on the four target teeth (right maxillary and mandibular first premolars, and first molars) and occlusal pressure were concurrently measured, while the participants performed maximum voluntary teeth clenching under each condition (hard, soft, or no occlusal splint).
Results: Compared to the absence of an occlusal splint, hard occlusal splints generated less strain on molar teeth but more strain on premolar teeth, while soft occlusal splints did not lower the strain on all target teeth significantly.
Conclusion: Considering the limitations of this study, hard occlusal splints should be used for the protection of molar teeth but for premolar teeth caution is required and depends on the case. On the other hand, soft occlusal splints may not have any benefit for the protection of either type of teeth for patients exhibiting excessive occlusal pressure.

Keywords; occlusal force, occlusal splint, tooth strain

Introduction

Vertical root fracture is the primary cause of tooth loss in patients with good oral hygiene [1]. Tooth surface loss and use of dental prostheses are typically observed in conjunction with common oral diseases including dental caries and periodontal disease [2,3]. Studies have previously demonstrated that these diseases have been associated with excessive mechanical strain on teeth due to abnormal occlusal pressure, e.g. parafunctional activity such as sleep bruxism, teeth clenching, tooth grinding, and even sporting activity [4-6], although the self-protective reflex, which includes periodontal mechanoreceptors, along with the jaw-closing muscles and their muscle spindles, are responsible for inducing negative feedback on the activity of the muscles [7-9].

In the 20 years since the question was raised whether it is possible for an occlusal splint to prevent mechanical stress on teeth [10], the preventive effect has not been clearly assessed. This could be due to the lack of a direct assessment of the relationship between occlusal pressure and the resulting mechanical strain on teeth, which can be attributed to the absence of viable technology for concurrent measurement of occlusal pressure at the intercuspal position and strain on teeth. Precise analysis that concomitantly incorporates time resolution and plots the distribution of forces within the occlusion is not possible when employing standard occlusal indicator methods. Detailed occlusal force and timing analysis can only be provided by performing computer-assisted analysis with intraoral sensors, which can record the changes in the relative occlusal force levels and real-time tooth contact sequence data using high definition sensors.

Furthermore, both hard and soft occlusal splints are often used to ameliorate the mechanical strain exerted on teeth [11,12]. However, there has only been a small number of studies that have provided definitive evidence on whether either type of occlusal splint can effectively reduce mechanical strain on teeth considering the aforementioned reasons. Despite the fact that some research has been conducted to elucidate the effect of occlusal splints on closing the jaw while using the pertinent muscles [13,14], it does not necessarily measure mechanical stress and prevents the possibility of ensuring a direct comparison. If the efficacy of occlusal splints for reducing disruptive strain on teeth is unequivocally established, treatment can be standardized, and it would be possible to improve prognoses considering the absence of the deleterious effects associated with these loads on their oral structure.

This study aimed to evaluate the relationship between occlusal pressure and mechanical strain on teeth to confirm if occlusal pressure could be considered as one of the factors that introduces mechanical tooth strain and to assess whether the use of occlusal splints decreases mechanical strain on teeth. Simultaneous recordings of occlusal pressure and the strain on the tooth were used to verify if occlusal splints were effective for reducing the mechanical strain on teeth.

Materials and Methods

Eleven fully dentate participants (five women and six men; mean age, 25.7 ± 0.8 years) volunteered to participate in this study. The inclusion criteria were the presence of a Class I incisor relationship and pristine periodontal health, i.e., neither bleeding on probing, modifying factors such as systemic disease, nor predisposing factors contributing to the accumulation of dental plaque such as abnormal tooth anatomy, position, and restoration [15]. The exclusion criteria were as follows: 1) fillings or crowns in the right first premolars or first molars, 2) presence of an anterior open occlusal relationship, 3) presence of a stomatognathic system dysfunction, or 4) presence of mobile teeth (Miller Classification II or III, i.e. >1 mm horizontal and/or vertical mobility). A temporomandibular-disorder screening questionnaire ruled out the possibility of any temporomandibular disorder or associated symptoms prior to participation [16]. The participants in this study were young university staff and students who were recruited by posting flyers in the university, and those who met the aforementioned criteria were enrolled in this study. The Osaka University Institutional Ethics Committee granted ethical approval for this study (H24 E-36), and written informed consent was obtained from all participants.

Well-fitting hard and soft U-shaped oral appliances were fabricated for the maxillary arch of each participant. The fabrication procedure has been described previously [17]— dental impressions (Aroma Fine Plus, GC Corporation, Tokyo, Japan) were used to acquire working models that were made of dental stone (New Plastone, GC Corporation). Hard splints were fabricated with a lost wax technique using a chemical polymerizing acrylic resin (Palapress Vario, Heraeus Kulzer, Hanau, Germany) with a Knoop hardness of 18.5 HK, and flexural strength of 1,090 kgf/cm^2. Soft splints were fabricated using a pressure-forming machine (Erkopress, Erkodent, Pfalzgrafenweiler, Germany) and 3-mm thick ethylene-vinyl-acetate copolymer sheets (Erkoflex, Erkodent) with a Shore A hardness value of 76. Occlusal table in the posterior region for both splint variations was

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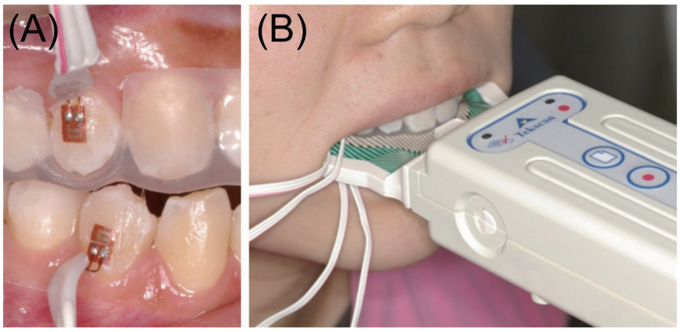

Fig. 1 Representative experimental set-up while using the soft type occlusal splint. (A) Strain gauges were attached to the target teeth, 1 mm from the buccal-gingival margin. (B) The strain on the tooth surface and the occlusal pressure are concurrently measured, while the participants clenched their teeth.

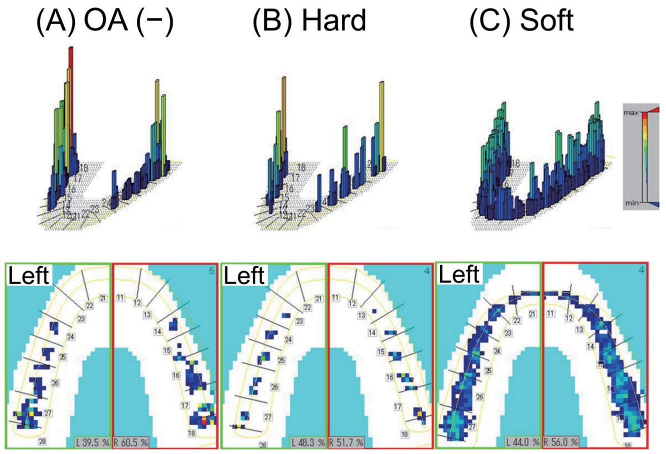

Fig. 2 A representative example of the force distribution during maximum voluntary teeth clenching. OA (−), no occlusal splint; Hard, hard occlusal splint; Soft, soft occlusal splint

flat. Occlusal contacts on the hard and soft splints were carefully adjusted with a carbide cutting bur (H251GSQ-060, Komet, Lemgo, Germany) to a thickness of approximately 1 mm at the molar regions followed by polishing with silicone polishers (AcryPoint, Shofu, Kyoto, Japan, for hard splints and Lisko-S Polishing Disc, Erkodent, for soft splints). Fit of the occlusal splints to the dental arch of the participants was confirmed by a dentist licensed by the Japan Prosthodontic Society, who also conducted all the procedures.

The strain on the tooth surface was measured using 3 × 1 mm strain gauge (KFG03-120-C1-11 L1M3R; Kyowa Dengyo Co., Tokyo, Japan). Using an instant adhesive (Aron Alpha; Daiichi Sankyo, Tokyo, Japan), strain gauges were attached to the four-target right maxillary and mandibular first premolars and first molars (one strain gauge per tooth), while being placed 1 mm away from the buccal-gingival margin (Fig. 1A).

The occlusal force and the occlusal contact area were simultaneously measured using a T-Scan III computerized occlusal analysis system (Tekscan Inc., South Boston, MA, USA) during the recording. Individual occlusal pressure was measured by dividing the individual occlusal force by individual occlusal contact area. Maximum voluntary clenching (MVC) was defined as the occlusal pressure obtained during maximum voluntary clenching in centric occlusion (Fig. 1B).

All strain gauges were connected to sensor interfaces (PCD300A; Kyowa Dengyo Co.) that were controlled by a personal computer (Dynabook; Toshiba, Tokyo, Japan). T-Scan III was connected to the computer via USB. Synchronizing signal from T-Scan III was transmitted to the computer via sensor interfaces (PCD320A; Kyowa Dengyo Co.), which facilitated the simultaneous measurement of outputs from the strain gauges and T-Scan III system. These sensors demonstrated a sampling frequency of 100 Hz during the process of measuring the parameters. The occlusal pressure-to-tooth strain relationship was evaluated by plotting occlusal pressure values and the corresponding tooth strain values to investigate if occlusal pressure was causatively associated with tooth strain. Tooth strain at any given percentage of MVC could be determined using this relationship.

Participants were positioned on a dental chair and were instructed to maintain MVC for approximately three seconds. The MVC of each participant was recorded under the following three conditions: 1) no occlusal splint (control); 2) with a hard occlusal splint; and 3) with a soft occlusal splint. For each of these three conditions, recordings were obtained five times; therefore, each participant performed 15 measurements in total. Three conditions were randomized, and each recording was separated from the next by a rest period of one minute. Participants were permitted to perform practice trials and were given feedback regarding their performance in the same prior to commencing the experiment. The T-Scan sensor sheet was replaced with a new sheet after each recording to control for deformation of the sensor.

To prevent increasing the possibility of a type I error, a one-way analysis of variance (ANOVA) test with repeated measurements was conducted to assess the overall difference between the mean values for the outcomes of the three conditions and four teeth; furthermore, pair-wise comparisons (followed by the Holm procedure) were made in cases where the ANOVA test indicated statistical significance. Therefore, a pair-wise test between the intervention groups was performed only when ANOVA demonstrated statistical significance. The least-squares method was used to obtain the regression coefficient of the occlusal pressure-to-tooth strain relationship at each target tooth for each condition. The statistical analyses were performed using R version 3.3.0 (R Foundation for Statistical Computing, Vienna, Austria) available as a free download from the URL (https://www.r-project.org/) at a 5% significance level.

Results

Occlusal force was primarily distribu.ted across the molar region in the absence of an occlusal splint (Fig. 2A); however, force distribution was more even across the tooth arch and was observed when both hard and soft occlusal splints were used (Fig. 2B, C).

Effects of occlusal splints on strain in the target teeth during MVC were assessed according to the relationship between the occlusal pressure and tooth strain. The representative waveforms of the relationship between individual occlusal pressure and the corresponding strain on the target teeth, under OA (−) condition, are shown in Fig. 3. The strain and the occlusal pressure begun to change at the same time and subsequently returned to the baseline at the same time (Fig. 3), indicating that the strain and the occlusal pressure were closely linked.

The representative relationships between occlusal pressure and tooth strain are presented in Fig. 4. The slope of the regression equation for the maxillary first premolar was steepest in the presence of a soft splint, which gradually increased under the hard splint and OA (−) conditions, in that order. The slope for the maxillary first molar was the steepest in the OA (−) condition, which then gradually increased in the presence of the soft- and hard-splints, in that order. The mandibular first premolar demonstrated tendencies similar to those of the maxillary first premolar, unlike the mandibular first molar, which demonstrated a more gradual slope in the hard-splint condition than the OA (−) and soft-splint conditions.

Analysis of the pooled data regarding the strain in the target teeth at MVC obtained from the 11 participants demonstrated the following results. Tooth strain for maxillary first premolars was significantly higher when using a hard or a soft occlusal splint than in the absence of an occlusal splint ($P < 0.05$) (Fig. 5A). Moreover, the strain was significantly higher when using a soft occlusal splint than when using a hard occlusal splint ($P < 0.05$) (Fig. 5A). Kolmogorov-Smirnov test revealed that tooth strain at maxillary first premolars under OA (−), Hard and Soft conditions showed normal distribution ($P = 0.40$, 0.99, 0.30, respectively) and Mauchly tests for sphericity showed homoscedasticity ($P = 0.17$). Tooth strain for the maxillary first molar was significantly lower when using a hard occlusal splint than when not using an occlusal splint ($P < 0.05$) while there was no significant difference in the tooth strain for the maxillary first molar between OA (−) and Soft ($P = 0.55$), and Hard and Soft ($P = 0.39$) (Fig.

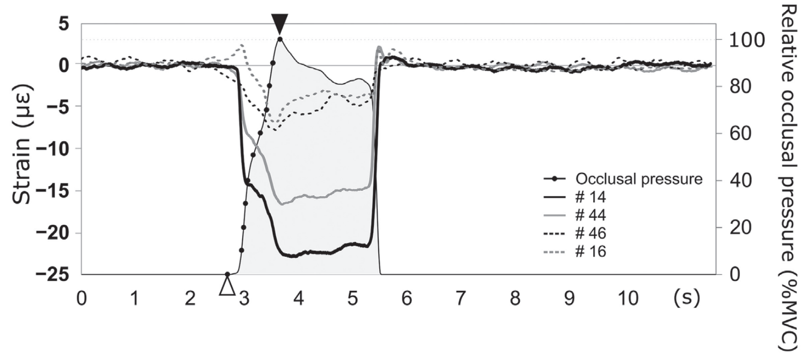

Fig. 3 Representative waveforms of changes in the tooth strain and occlusal pressure. The figure shows representative waveforms obtained from a participant in one recording when no oral appliances were used. The thick solid black line represents the mandibular first molar, the thick solid grey line represents the maxillary first molar, the dotted black line represents the mandibular first premolar, and the dotted grey line represents the maxillary first premolar. The thin solid black line with closed circles shows changes in occlusal pressure. One hundred percent MVC is defined as the maximum occlusal pressure due to voluntary teeth clenching. The period from the start of the teeth clenching (open arrowhead) to the 100% MVC (closed arrowhead) is categorized into 10 equal sections, with the dividing points representing relative occlusal pressure values. Time points corresponding to these 11 relative occlusal pressure values (11 closed circles) are used to analyze the amount of tooth strain. The #14, #16, #44, and #46 represent the maxillary right first premolar, maxillary right first molar, mandibular right first premolar, and mandibular right first molar, respectively. %MVC, percentage of maximum voluntary teeth clenching.

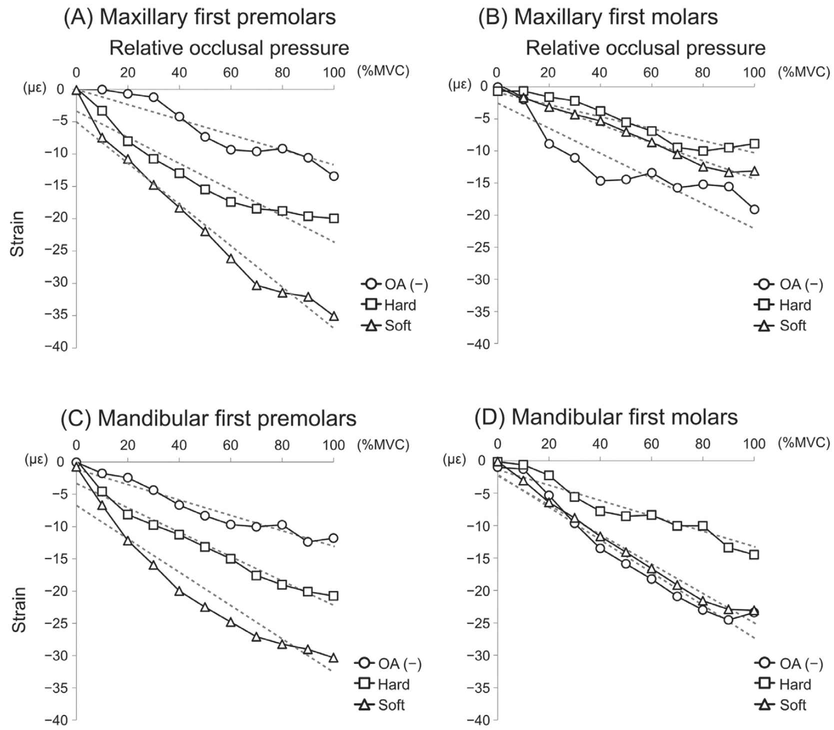

Fig. 4 Example of the relationship between the occlusal pressure and the tooth strain. The figure shows the mean values of 3 recordings of the tooth strain plotted against the 11 relative occlusal pressure values (see Fig. 3) under each condition for a representative participant. Regression equations for the relationship between the occlusal pressure and the tooth strain are calculated using the least-squares method. The results are depicted in the form of dotted lines. OA (−), no occlusal splint; Hard, hard occlusal splint; Soft, soft occlusal splint

5B). Kolmogorov-Smirnov test revealed that tooth strain at maxillary first molars under OA (−), Hard and Soft conditions showed normal distribution ($P = 0.30, 0.90, 0.51$, respectively) and Mauchly Tests for Sphericity showed homoscedasticity ($P = 0.59$). The mandibular first premolar exhibited tendencies similar to those of the maxillary first premolar (Fig. 5C). Kolmogorov-Smirnov test revealed that tooth strain at mandibular first premolars under OA (−), Hard and Soft conditions showed normal distribution ($P = 0.99, 0.76, 0.99$, respectively) and Mauchly Tests for Sphericity showed homoscedasticity ($P = 0.30$). Tooth strain for the mandibular first molar was significantly lower when using a hard occlusal splint than when not using an occlusal splint ($P < 0.05$) (Fig. 5D). Moreover, the strain was significantly lower when using a hard occlusal splint than when using a soft occlusal splint ($P < 0.05$), while there was no significant difference in the tooth strain for the mandibular first molar between OA (−) and Soft ($P = 0.23$) (Fig. 5D). Kolmogorov-Smirnov test revealed that tooth strain at mandibular first molars under OA (−), Hard and Soft conditions showed normal distribution ($P = 0.99, 0.99, 0.68$, respectively) and Mauchly Tests for Sphericity showed homoscedasticity ($P = 0.35$).

Discussion

This study aimed to document the effects of hard and soft-type occlusal splints on tooth strain during maximum voluntary teeth clenching. First, occlusal force was primarily distributed across the molar area in the absence of a splint, whereas hard and soft splints elicited a more even force distribution across the tooth arch (Fig. 2). Second, there was a significant correlation between the occlusal pressure and tooth strain, under all occlusal splint conditions (Fig. 4). Finally, compared to the absence of an occlusal splint, hard occlusal splints reduced the strain in molar teeth but increased the strain in premolar teeth, while soft occlusal splints generated

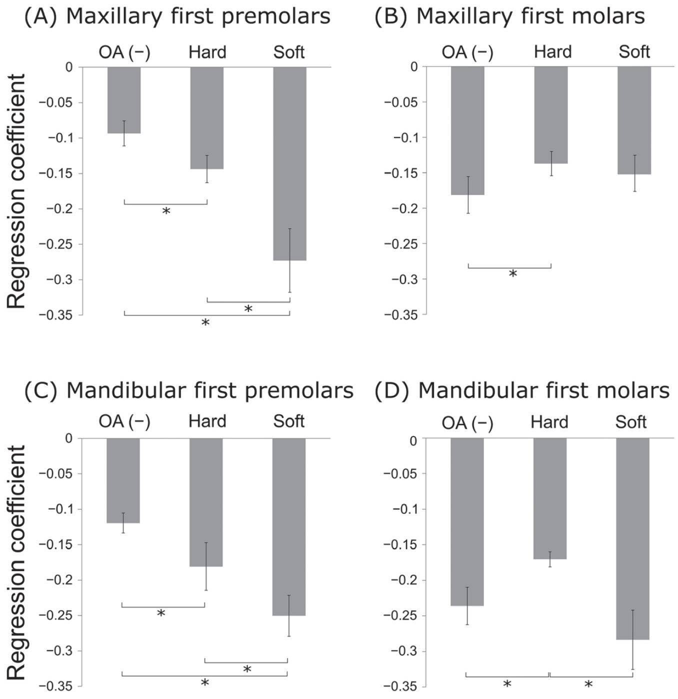

Fig. 5 Relationships between the occlusal pressure and the tooth strain for all the participants. This figure compares the slopes of the linear regression formulas for the relationships between the occlusal pressure and the tooth strain (see the dotted lines in Fig. 4). *$P < 0.05$, OA (−), no occlusal splint; Hard, hard occlusal splint; Soft, soft occlusal splint

a greater degree of strain in all target teeth (Fig. 5).

Force distribution during maximum voluntary teeth clenching revealed that occlusal force was primarily distributed across the molar area in the absence of a splint (Fig. 2A); however, this uneven distribution can be explained. A previous study simultaneously recorded maximum occlusal pressure exerted on teeth and the associated masseteric electromyographic activity, and reported that the occlusal pressure generated in the molar area was 3 to 4 times the pressure generated in the incisor area [18]. In addition, a lower masseteric activity-to-occlusal pressure ratio was observed with regard to the incisors than the molars, which was attributed to leverage. Less mobility in the molars than in the premolars [19,20] could also explain some of the differences in strain, considering the fact that the strain may be greater in cases of lower mobility.

The relationship between tooth strain and occlusal pressure suggested that the strain generated on the buccal tooth surface could be attributed to occlusal pressure, based on the following findings. Incremental occlusal pressure initially demonstrated an increase in the degree of strain noted in the target teeth (Fig. 3). Similarly, occlusal pressure and strain in the target teeth concurrently returned to the baseline (Fig. 3). The association between the occlusal pressure and tooth surface strain indicated that a nearly linear relationship existed between an increase in strain in each target tooth and the increasing occlusal pressure (Fig. 4).

Changes in tooth surface strain differed according to the type of occlusal splint. Hard occlusal splints reduced the strain in the molars while increasing the same in the premolars, which could be attributed to the equal force distribution observed with the use of a hard splint, as shown in Fig. 2B. Hard occlusal splints are composed of materials that possess high hardness values and cover all of the maxillary teeth, resulting in equal mobility in the molar and premolar areas, which further explains the reason behind the fact that similar strain levels were observed in these areas under hard conditions. Conversely, soft occlusal splints generated a greater degree of strain in all the target teeth except the maxillary first molars (Fig. 5). In addition, soft occlusal splints did not lower the strain in the molar teeth, although soft occlusal splints exerted lower occlusal pressure on the molar area (Fig. 2C). This may have occurred because the soft-type appliances were more pliable, leading to a more lateral distribution of the forces on the target teeth, resulting in greater strain.

In relation to this, mouthguards, usually fabricated with ethylene-vinyl-acetate copolymer or polyolefin with a Shore A hardness value of 75-80, are thought to protect the maxillary incisors from traumatic injury during sports accidents [21] due to their shock absorption capability [22]. However, there is limited evidence of the capability of mouthguards in preventing the molar teeth from potential injury due to excessive force during sporting activities by limiting the tooth contact. The present study shows that a soft oral appliance does not lower the strain in all target teeth, suggesting that mouthguards may not have a significant benefit for the prevention of traumatic injury in molar teeth due to teeth clenching and a rapid movement of the mandible caused by a blow to the mandible. However, it should be noted that previous studies have revealed that not all sports players showed teeth clenching during sports [23,24].

This study has several limitations. Although it revealed that the in vivo use of a hard splint resulted in lower amount of tooth strain when compared with control conditions, development of cracks or vertical root fractures was not examined. The lack of abnormal forces could be due to the fact that the physical condition of all the participants was moderate, and parafunctional activity was not detected. To overcome this limitation, a linear regression analysis of the relationship between occlusal pressure and the corresponding strain on the target tooth was performed, and the parafunctional situation was assumed by extrapolating the lines. The extrapolated regression line for these appliances suggested that the strain generated by the soft-type occlusal splint could reach critical levels during parafunction, contrary to that generated by the hard-type occlusal splint, since soft-type appliances produced the greatest slope. While previous studies have investigated the biomechanical loads exerted on teeth during parafunction, most have been conducted in vitro [25-27]. However, oral tissues including teeth, gingivae, alveolar bone, and periodontal ligaments were difficult to simulate accurately, and this is a limitation that must be considered when interpreting the results of model analyses and computer simulations that do not directly measure mechanical strain on teeth in live humans. Compared with the measurement methods reported in previous studies, the current technique (simultaneous recording of tooth strain and occlusal pressure) facilitated the direct recording of loads in vivo. Furthermore, the T-Scan system which assesses the real-time changes in occlusal force and tooth contact area, along with simultaneous recordings with strain gauges also requires the following considerations. The system has been scrutinized in various studies that supported [28-31] and contradicted [32,33] its accuracy. Additionally, although the occlusal force is a vector with a magnitude and a direction, the direction of the force could not be assessed since the T-Scan system can only provide a magnitude of the relative value, despite the fact that tooth strain may be associated with the force direction. Furthermore, positioning the occlusal splint between the occluding teeth can significantly alter both the direction and the magnitude of the contact forces between the teeth [34]. Despite the abovementioned considerations, the system is still superior to computer simulation and model studies, which do not consider other anatomical structures including periodontal ligaments and natural mandibular flex. Additionally, there were several studies that had investigated the dynamic changes in occlusal force while eating a variety of foods using the similar system [35,36].

To conclude, hard occlusal splints reduced the strain in molar teeth but increased the strain in premolar teeth, while soft occlusal splints did not lower the strain in all target teeth significantly. Considering the limitations of this study, hard occlusal splints should be used for the protection of molar teeth but for premolar teeth caution is required and depends on the case. On the other hand, soft occlusal splint may not have any benefit for the protection of either type of teeth for patients exhibiting excessive occlusal pressure.

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Conflict of interest

The authors declare no conflict of interest, financial or otherwise, related to the publication of this manuscript.

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