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

Yuto Tanaka¹, Toru Yoshida², Yoshiaki Ono¹, and Yoshinobu Maeda²

¹Department of Special Care Dentistry, Osaka Dental University Hospital, Osaka, Japan
²Department of Prosthodontics, Gerodontology, and Oral Rehabilitation, Osaka University Graduate School of Dentistry, Suita, Japan

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, 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/cm². Soft splints were fabricated using a pressure-forming machine (Erkopress, Erkdent, Pfalzgrafenweiler, Germany) and 3-mm thick ethylene-vinyl-acetate copolymer sheets (Erkoflex, Erkdent) with a Shore A hardness value of 76. Occlusal table in the posterior region for both splint variations was
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 distributed 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 began 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.
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 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). Moreover, the strain was significantly lower when using a soft occlusal splint than when using a hard 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 ($P = 0.35$).
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 increased 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 polyethylene 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 contact force control 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.

Acknowledgments

The authors would like to express their gratitude to all the participants and volunteers who took part in this study. The authors would like to thank Dr. Kazuki Sako, Dr. Koorhide Arai and Dr. Tomohiko Okamura for reviewing the manuscript. This study was supported by JSPS KAKENHI (25670816 to YM and 19K19964 to YT).

Conflict of interest

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

References

1. Axelsson P, Nyström B, Lindhe J (2004) The long-term effect of a plaque control program on tooth mortality, caries and periodontal disease in adults. Results after 30 years of maintenance. J Clin Periodontal 31, 749-757.
2. Némecová CE, Artzi Z (1996) Erosion-abrasion lesions revisited. Compend Contin Educ Dent 17, 416-418, 420-423.
3. Cohen S, Berman LH, Blanco L, Bakland L, Kim JS (2006) A demographic analysis of vertical root fractures. J Endod 32, 1160-1163.
4. Fennis WM, Kuijs RH, Kreule CM, Rooters FJ, Creugers NH, Burgerstrijd RC (2002) A survey of cusp fractures in a population of general dental practices. Int J Prosthodont 15, 559-563.
5. Johansson A, Omar R, Carlsson GE (2011) Bruxism and prosthetic treatment: a critical review. J Prosthodont Res 55, 127-136.
6. Kato T, Yamaguchi J, Okura K, Abe S, Lavigne GJ (2013) Bite force and bite height: more sleep disorders associated with occlusal loads during sleep. J Prosthodont Res 57, 59-61.
7. Troulis M, Gnam HS (1998) Food-holding and -biting behavior in human subjects lacking periodontal receptors. J Dent Res 77, 574-582.
8. Tsukiboshi T, Sato H, Tanaka Y, Saito M, Toyoda H, Morimoto T et al. (2012) Illusion caused by vibration of muscle spindles reveals an involvement of muscle spindle inputs in regulating isometric contraction of masseter muscles. J Neurophysiol 108, 2524-2533.
9. Kumar A, Tanaka Y, Takahashi K, Grigoriadis A, Wiesinger B, Svensson P et al. (2019) Vibratory stimulus to the masseter muscle impairs the oral fine motor control during biting tasks. J Prosthodont Res 63, 354-360.
10. McCoy G (1999) Dental compression syndrome: a new look at an old disease. J Oral Implantol 25, 35-49.
11. Broth T, Zary R, Piló R, Gavish A (2012) Influence of periodontal ligament simulation and splints on strains developing at the cervical area of a tooth crown. Eur J Oral Sci 120, 466-471.
12. Hirai K, Ikawa T, Shigeta Y, Shigemoto S, Ogawa T (2017) Evaluation of sleep bruxism with a novel designed occlusal splint. J Prosthodont Res 61, 333-343.
13. Okeson JP (1987) The effects of hard and soft occlusal splints on nocturnal bruxism. J Am Dent Assoc 114, 788-791.
14. al-Quran FA, Lyons MF (1999) The immediate effect of hard and soft splints on the EMG activity of the masseter and temporalis muscles. J Oral Rehabil 26, 559-563.
15. Lang NP, Bartold PM (2018) Periodontal Health. J Clin Periodontal 45, 58-66.
16. González YM, Schiffman E, Gudmond SD, Seago B, Truelove EL, Slade G et al. (2011) Development of a brief and effective temporomandibular disorder pain screening questionnaire: reliability and validity. J Am Dent Assoc 142, 1183-1191.
17. Suganuma T, Itoh H, Ono Y, Baba K (2013) Effect of stabilization splint on occlusal force distribution during voluntary submaximal tooth clenching: a preliminary sleep simulation study. Cranio 31, 100-108.
18. Medina R, Tsuchida Y, Salarz A, Muramatsu M, Kohno S, Medina R et al. (1998) Influence of the Location of the bite point on the electrical efficiency of human jaw elevator muscles. J Jpn Soc Stomatognath Funct 4, 161-172.
19. O’Leary TJ, Stanley DB, Drake RB (1972) Tooth mobility in cuspid-protected and group-function occlusions. J Prosthodont Dent 27, 21-25.
20. Siebert G (1981) Recent results concerning physiological tooth movement and anterior guidance. J Oral Rehabil 8, 479-493.
21. Tanaka Y, Maeda Y, Yang TC, Ando T, Tsuchi Y, Miyawaga H (2015) Prevention of oro-facial injury via the use of mouthguards among young male rugby players. Int J Sports Med 36, 254-261.
22. Tanaka Y, Miyawaga H, Maeda Y, Abe M, Miwa S (2015) A method for detecting the deterioration in the shock absorption capability of mouthguards. Int J Sports Med 36, 684-687.
23. Himejima A, Shirao K, Tsurumi A, Tanaka M, Morita S (2013) Occlusal contact and muscle activity during jaw. In J Sports Dent 6, 43-56.
24. Fukushima T, Tsurumi A, Tanaka M (2016) Stomatognathic function during continuous physical activity in Nippon Kempo. J Jpn Sports Dent 9, 58-71.
25. Deines DN, Eick JD, Cobb CM, Bowles CQ, Johnson CM (1993) Photoelastic stress analysis of natural teeth and three osseointegrated implant designs. Int J Periodontics Restorative Dent 13, 540-549.
26. Poggetti R, Fambri L, Zappini G, Bianchetti M (2002) Finite element analysis of a glass fibre reinforced composite endodontic post. Biomaterials 23, 2667-2682.
27. Hayashi M, Takahashi Y, Imazato S, Ebisu S (2006) Fracture resistance of pulpless teeth restored with post-cores and crowns. Dent Mater 22, 636-643.
28. Garrido García V, García Cartagena A, González Sequeiros O (1997) Evaluation of occlusal contacts in maximum intercuspation using the T-Scan system. J Oral Rehabil 24, 899-903.
29. Kerstein RB, Lowe M, Harty M, Radje J (2006) A force reproduction analysis of two recording sensors of a computerized occlusal analysis system. Cranio 24, 15-24.
30. Koos B, Godt A, Schille C, Göz G (2010) Precision of an instrumentation-based method of analyzing occlusion and its resulting distribution of forces in the dental arch. J Orofac Orthop 71, 403-410.
31. Liu CW, Chang YM, Shen YP, Hong HH (2015) Using the T-Scan III system to analyze occlusal function in mandibular reconstruction patients: a pilot study. Bismal J 38, 52-57.
32. Threecromption GS, Rasmussen J, Caloss R (2009) Calibration of T-Scan sensors for recording bite forces in denture patients. J Oral Rehabil 36, 636-643.
33. Cernea M, Ferreira R, Zorar C, Navarro P, Sandovol P (2015) Validity and reliability of the T-Scan(®) III for measuring force under laboratory conditions. J Oral Rehabil 42, 544-551.
34. Helsos RB, Katona TR, Eckert GJ (2012) Do occlusal contact detection products alter the occlusion? J Oral Rehabil 39, 357-363.
35. Dan H, Watanabe H, Kohyama K (2003) Effect of sample thickness on the bite force for apples. J Text Stud 34, 287-302.
36. Kohyama K, Kazumata Y, Shimada H, Kazumata K, Hayakawa F (2013) Texture of sliced apples. J Text Stud 34, 287-302.