ELSEVIER

Journal of Dentistry 28 (2000) 475–480

Journal of Dentistry

www.elsevier.com/locate/jdent

Splints and stress transmission to teeth: an in vitro experiment

M. Halachmi[a,*], A. Gavish[a], E. Gazit[a], E. Winocur[a], T. Brosh[b]

[a]Department of Occlusion and Behavioral Sciences, The Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel
[b]Exact Measurements Laboratory, The Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel

Received 12 October 1999; accepted 10 March 2000

Abstract

Objective. To determine the influence of hard and soft splints with two thicknesses on the stress transmission to the tooth supporting the splint and the opposite tooth.

Methods. Continuous vertical forces up to 500 N were applied to two opposite first molar phantom teeth using a universal loading machine. Deformation was detected by strain gauges attached to the cervical area of the buccal and lingual aspects of the lower tooth. Strain, as a function of force, was collected and the slope, defined as the compliance (in μS/N) of the system, was calculated.

Results. The highest compliance was found with hard splints. When splints were constructed on the upper molar, the highest compressive compliance was registered on the buccal side (2.8 μS/N) and tension compliance on the lingual side (−0.35 μS/N). When constructed on the lower tooth, the opposite was found. Soft splints resulted in compression on both the buccal and lingual sides when adjusted to the upper or lower tooth. A higher compliance was found on the buccal side (1.26 μS/N), while on the lingual side, the values varied (0.48–0.78 μS/N).

Conclusions. Soft splints are more efficient in protecting teeth against the damage of bending forces although there is an increase of compression forces. The tooth opposing a hard splint is exposed to a higher risk of bending forces.

Keywords: Bruxism; Hard occlusal splints; Soft occlusal splints; Stress transmission; Strain gauge

1. Introduction

One of the most problematic parafunctional behaviors is bruxism, which is defined as clenching or grinding of the teeth during sleep, or during daytime when the individual is not chewing or swallowing [1]. Fractures of dental restorations and tooth structures can be the result of bruxism [2]. This can be very frustrating for the patient, as well as for the dentist, to see their work compromised within a few months. Often a dentist deliberates whether to propose complex and expensive rehabilitation, especially implants, to a heavy bruxer patient.

In the past 25 years, epidemiological studies have underscored the high incidence of bruxism. In a study conducted on groups of adults and children, it was concluded that the phenomenon was widespread enough to warrant including it as a public health problem [3].

During nocturnal bruxism activity, bite forces are much greater than those exerted during mastication [4]. The mean maximal bite force registrations among Europeans and Americans is in the range of 600–750 N [5], while masticatory forces are much lower (about 60–100 N) [6]. During clenching, forces of about 1000–1500 N, or higher, have been reported [7]. In some individuals, the forces generated and the duration of bruxing episodes can produce considerable loads within the masticatory system [8].

The most common damage to the dental unit is the wearing out of tooth surfaces (facets) [9], idiopathic cervical erosions [10], cusp or restoration fractures (fillings, crowns or porcelain bridges), and tooth mobility. Under excessive pressure, as part of the self-protective features of the dentition, the periodontal and/or pulpal receptors induce negative feedback on the activity of the jaw elevators [11]. Apparently, there is greater strain transmission to restorations on osseointegrated implants that have no proprioceptive receptors [12].

Direction of force resulting from a given occlusal load is important. Forces transmitted in an axial direction are best withstood. Horizontal forces are not tolerated as well as vertical forces [13] and can cause bending of the tooth, thus creating compressive and tensile stresses. Both dentin and enamel have high compressive strength, but their ability to withstand tension is limited [14]. The tensile force, which is highest at the tooth fulcrum (cervical area), could cause disruption of the chemical bonds between hydroxyapatite

* Corresponding author. Tel.: +972-3-6409112; fax: +972-3-6409250.

0300-5712/00/$ - see front matter
PII: S0300-5712(00)00026-9

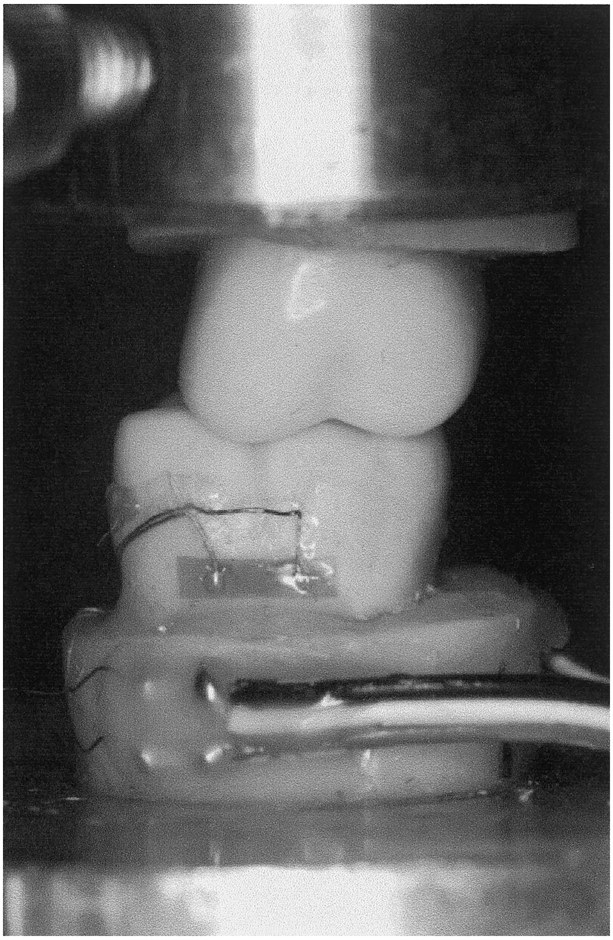

Fig. 1. Two phantom first molars mounted on two acrylic blocks in an intercuspal position. Strain gauges bonded to the buccal cervical area of the lower tooth and connected to a strain indicator.

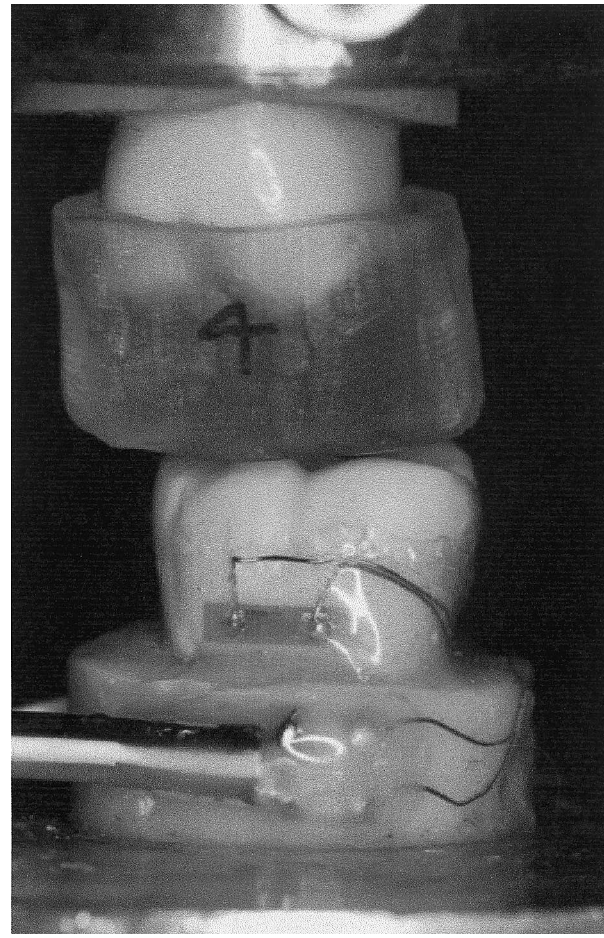

Fig. 2. Hard thick splint fitted to the upper or lower molar and adjusted to the opposite tooth according to the principles of ideal occlusion. Buccal view.

crystals, and could also be responsible for cervical erosion [15].

Occlusal splints have been advocated to reduce the harmful sequel to bruxism [16], especially when the goal is to protect large restorations. Splints may reduce the total amount of nocturnal activity in bruxers by decreasing the number of bruxing events per night. A splint may also reduce daytime postural muscle activity [6]. However, it is not actually known whether splints can absorb some of the stresses transmitted to the teeth. There is no universal agreement as to the effect of hard and soft splints on bruxism. It has been reported that hard stabilization splints significantly decrease muscle activity [17], while the vacuum-formed soft splints increase muscle activity [18,19].

The purpose of this study was to test the effect of splints—made of hard acrylic and soft vacuum formed—on the strain developed at the tooth cervix. This effect was analyzed on the tooth bearing the splint and the opposite tooth, with reference to the material used and the thickness of the splint.

In several studies, the comparative mechanical properties of different materials have been examined for use as protective mouth devices, during sports activity [20,21,23]. To the best of our knowledge, this is the only in vitro study where tooth behavior using splints under simulation of occlusal forces, has been investigated.

2. Materials and methods

Two opposite phantom first molars were mounted onto two acrylic blocks in an intercuspal contact position and in an angulation similar to the natural dentition. Teeth were adjusted by occlusal equilibration to fit the occlusal contact according to the principles of ideal occlusion [13]. Two linear miniature strain gauges (EA-06- 031EC-350, Measurements Group, Raleigh, NC, USA) were bonded to the cervical area of the buccal and lingual aspects of the first lower molar and connected to a strain indicator (Vishay 2100, Measurements Group, Raleigh, NC, USA) (Fig. 1). Splints were constructed on either the upper (U) or the lower (L) molar tooth. Two hard (H) splints covered the occlusal surface of the molar in 6 mm (T) and 2 mm (t) thicknesses

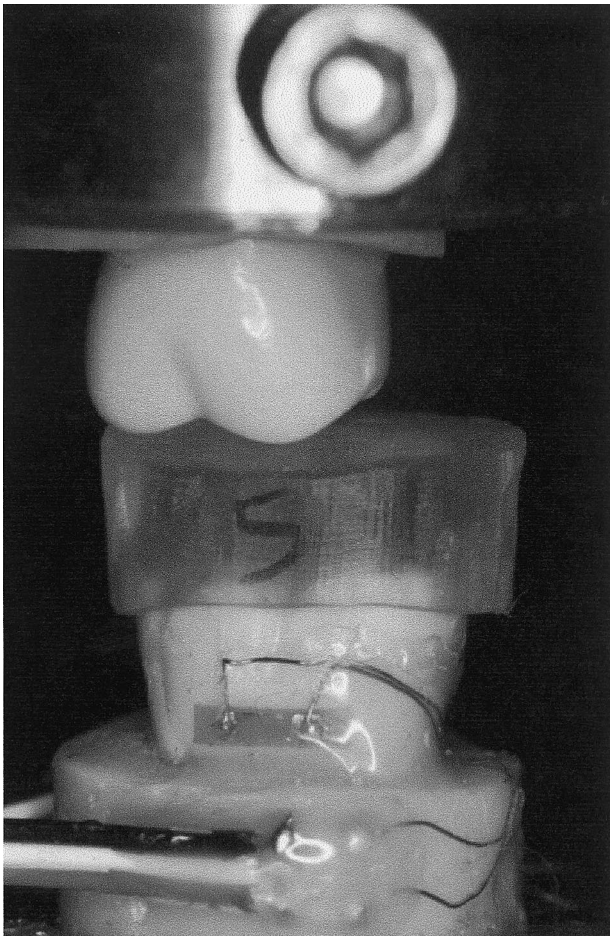

Fig. 3. Hard thick splint fitted to the upper or lower molar and adjusted to the opposite tooth according to the principles of ideal occlusion. Buccal view.

from self-curing dental acrylic (Orthocryl 2000-Dentaurum, Ispringen, Germany), and two soft (S) vacuum-formed splints, "150 Mouthgard" for the thick (T) and "040 soft EVA" for the thin (t) splint (DR Dental Resources, Delano, MN). For each combination of material, thickness and location, three initials were used for identification. Ten splints were prepared for HTL and HtL, and five splints for each of the following combinations: STL, STU, StL, StU, HTU and HtU, for a total of 50 splints. Each splint was adjusted according to the principles of ideal occlusion, i.e. where the supporting cusps (upper lingual or lower buccal) made contact with the flat occlusal surface of the splint on the opposite tooth (Figs. 2 and 3).

The teeth were mounted on a special jig connected to a loading machine (Instron 4502, High Wycombe Buckinghamshire, England). Compressive forces up to 500 N were applied using a 5 mm/min cross head speed. Since the teeth were mounted in an angulation similar to the natural dentition, compressive forces are translated at the tooth level as vertical and horizontal components that simulate the clinical condition. Strains, as a function of force, were automatically acquired upon loading by a Data Acquisition System (ViewDac, Kiethley/Assist, Taunton, MA, USA). Each trial consisted of three consecutive loading episodes. At the end of each loading cycle, the splint was removed and reseated. The mean slope, defined as the compliance in μS/N of the system, was calculated using the Data Acquisition System (ViewDac program).

Two-way analysis of variance (ANOVA) with data screening was used to determine the mean differences in compliance between thicknesses (thick and thin) and location (upper or lower) of the splints.

3. Results

Fig. 4 presents a characteristic diagram of strain versus force obtained from the HTU splint. All the diagrams presented a linear characteristic and therefore the slope (compliance) of each one could be obtained. The mean (±SD) of the buccal and lingual compliance of all the experiments are presented in Fig. 5. Positive values indicate the compression developed at the strain gauge area, while negative values represent tension.

Compressive strains were registered from the buccal and lingual aspects of the lower molar when there was no splint between the teeth. Compliance on the buccal and lingual aspects was 1.27 and 0.15 μS/N, respectively.

When the hard, thick and thin splints were constructed on the upper molar (HTU and HtU), the highest compressive compliance was registered on the buccal side (2.8 μS/N), and tension compliance on the lingual side. Values from the buccal side were about 5-fold higher than those from the lingual side. Furthermore, values on the buccal side were more than twice of those that were obtained without a splint, while the compliance on the lingual side was more than 3-fold higher and in the opposite direction (tension). When the hard splints were adjusted to the lower tooth, the opposite effect was found. Compression was registered on the lingual side and tension on the buccal side. Values on the lingual side were 6-fold higher than tension on the buccal side. Two-way ANOVA revealed a statistically significant main effect for the location ($p < 0.001$) of the hard splint and no effect for the thickness on the buccal and lingual compliance. No interaction was found between the thickness and the location.

Contrary to the hard splints, soft splints showed compression on both buccal and lingual sides, regardless of the location. Higher compliance (between 1.5- and 2.5-fold) was found on the buccal side compared to the lingual. Regarding the buccal compliance, the two-way ANOVA test revealed a statistically significant main effect for the thickness ($p = 0.023$) and no effect for the location of the splint. However, regarding the lingual compliance, the two-way ANOVA test revealed a statistically significant main effect for both the thickness ($p = 0.0001$) and the location ($p = 0.0001$). For both buccal and lingual compliance, no

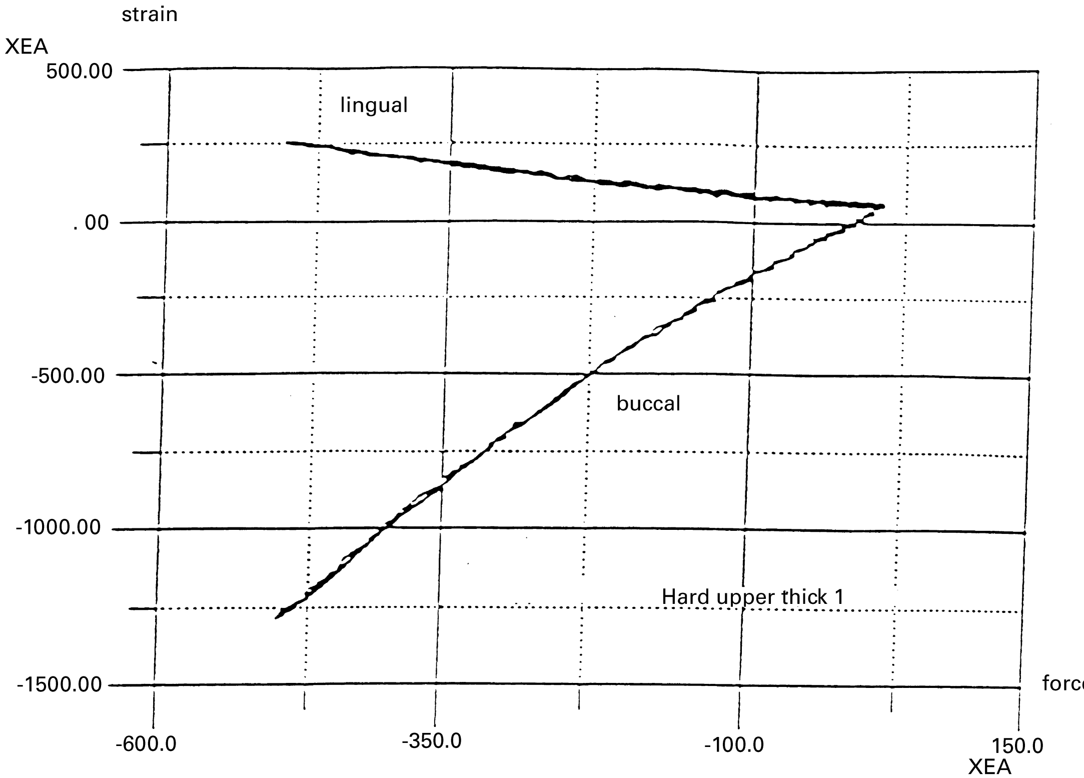

Fig. 4. Linear characteristic diagram of strain (y-axis) versus force (x-axis) obtained from the hard thick upper splint.

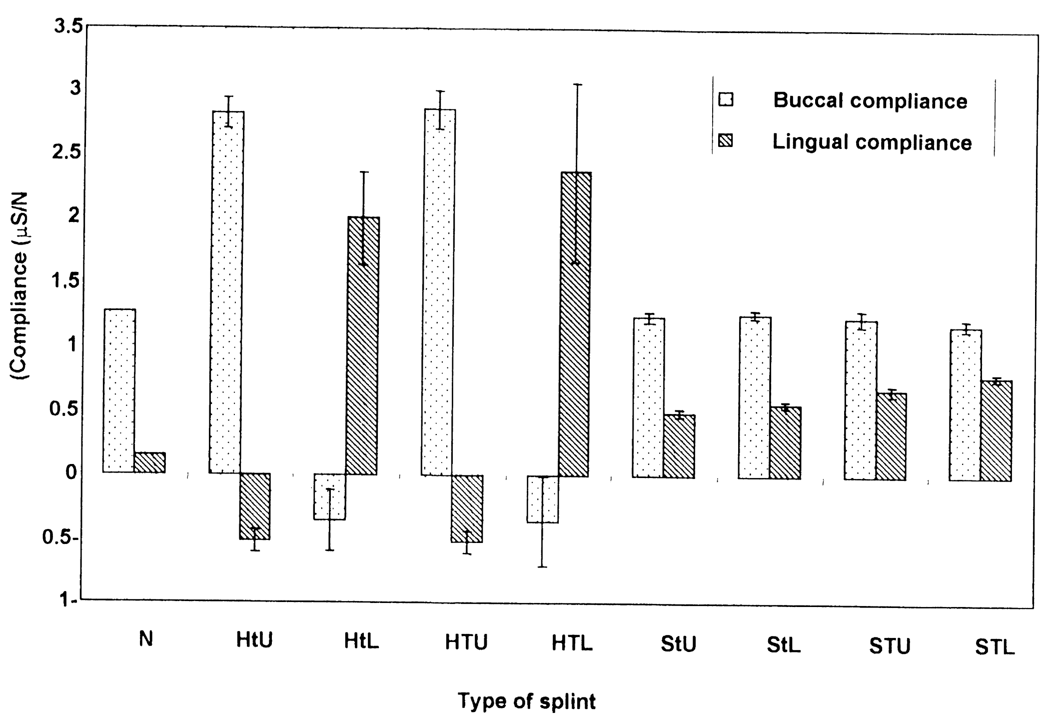

Fig. 5. Mean and SD of the buccal and lingual compliance for each type of splint: N, without splint; H, hard acrylic splint; S, soft vacuum proform splint; T, thick; t, thin; U, splint fitted on the upper molar; L, splint fitted on the lower molar.

interaction was found between the thickness and the location.

4. Discussion

This preliminary in vitro study, uses two opposite phantom head teeth to evaluate the differences in stress transmission to the tooth, as a function of the different kinds of customized splints. Phantom head teeth simulate the shape and size of natural teeth and present an advantage to using a matched pair of opposite first molars, as in this experiment. Although these teeth have very different stiffness properties when compared with natural teeth, they only serve as an anchor to the strain gauge and the splint in this model, and enable an analysis of the influence of various splints on stress transmission while all other parameters are steady. The same model could use natural teeth, but it should be remembered that biological homeostasis is impossible to retain in an in vitro model. In addition, phantom head teeth and natural extracted unmatched teeth cannot simulate the PDL as the biological shock absorber.

The strain-gauge model is a very sensitive technique used to analyze tooth behavior under physiologic loads [23,24]. A higher compliance expresses greater deformation at the site of the strain gauge for the same applied force. When there is compression on one side of the tooth and tension on the other, it should be implied that bending occurs toward the side of the compression proportional to the compliance difference.

In the present system, the location of the point of force application (occlusal contacts) relative to the strain gauges, and the relative angulation of the two opposing teeth could influence the amount of strain registered by the strain gauges. When there is no splint, the occlusal relationship of the opposite tooth is established following the principles of ideal occlusion (four occlusal contacts on the lower tooth: two on the buccal cusps and two on the central fossa line) providing compressive strains developing at both sides. The closeness of the occlusal contacts to the strain gauge attached to the buccal aspect of the molar explains the greater deformation detected on that side, when compared to the lingual.

A hard splint has a flat occlusal surface that is adjusted to provide precise contact with the supporting opposite cusps (two occlusal contacts). When the hard splint fits over the upper tooth, bending of the lower tooth occurs toward the buccal side, since two contacts are established between the central portion of the occlusal surface of the splint and the buccal cusp tips of the lower tooth. In this case, displacement of the point of force application occurs toward the buccal side of the lower tooth. When the hard splint fits over the lower tooth, occlusal contacts occur between the lingual upper cusps and the central portion of the surface of the splint, causing a shift in force application toward the lingual side.

In the presence of the splint, the same amount of force has to be transferred to the lower tooth through two contact points instead of four, without a splint, causing higher contact stresses. It results in higher compressive forces being developed at the buccal or lingual aspects of the lower tooth.

This in vitro single tooth model study has some clinical application. In cases where a hard splint is located on the upper arch, our study model provides a relatively good simulation of the clinical behavior of the teeth that oppose the splint. The tooth reacts as an independent entity with minimal force transmission to the adjacent teeth. When the splint was located on the lower tooth (a simulation of a tooth-bearing splint), it acted independently in this in vitro study. However, in the clinic, a full coverage arch splint could have a significant impact on force distribution and could act in a different manner.

With soft splints, there are contact areas with the opposing tooth because of the resilient properties of the material. Therefore, there is a better distribution of the occlusal force, better energy absorption [20,22], and almost no change in compliance, which leads to a decreased bending effect on the teeth. The thick soft splints relative to thin ones decreased buccal compliance and increased the lingual causing the additional reduction of bending forces. Hypothetically, this finding is caused due to the better "spreading" capability of the material over the tooth surface.

From the results of this in vitro study, soft splints provided the best protective capacities against destructive bending forces, although the total compressive forces increased.

The use of splints in the treatment of bruxism ensures a reduction in the wearing out of the tooth and leads to a better force distribution in the dental arch supporting the splint. Moreover, the splint increases cognitive awareness and leads to a behavioral modification via the reduction in muscular activity.

The effect of soft splints on muscular activity have been investigated in TMD patients. Soft appliances have been shown to increase nocturnal masseteric EMG activity in 50% of cases, while 80% of cases had a significant reduction of nocturnal muscular activity with hard splints (17). In other studies, a higher therapeutic effect of hard splints when compared to soft ones for reducing TMD symptoms has been shown [18,19,25]. This effect may be based on behavioral modification. In daytime wearing out of soft splints, subjects are exposed to a considerable amount of conscious or unconscious nervous chewing [20,26]. Our model does not enable an estimation of these behaviors. We strongly believe that clinically controlled studies should focus on the stress transmission to the tooth bearing the splint and the one opposing the splint, to better understand the value of this widely used appliance, at the tooth level. In the light of the surprising results of this in vitro preliminary study, one should ask whether the use of splints is justified.

5. Conclusions

Two clinical implications can be drawn from this in vitro study:

1. Soft splints are more efficient in protecting teeth against the damage of bending forces, although there is an increase of compressive forces.
2. The tooth opposing a hard splint is exposed to a higher risk of bending forces.

Acknowledgements

The authors would like to express their gratitude to Mr Avi Meirowitz, CDT, for his contributions to the fabrication of the restorations presented in the article.

References

[1] Rugh JD, Ohrbach R. Occlusal parafunction. In: Mohl ND, Zarb GA, Carlsson GE, Rugh JD, editors. A textbook of occlusion, Chicago: Quintessence, 1988.
[2] Ramfjord SP, Ash MM. Occlusion, Philadelphia: W.B. Saunders, 1971. p. 120 (see also p. 248).
[3] Reding GR, Rubright WC, Zimmerman SO. Incidence of bruxism. Journal of Dental Research 1966;45:1198–204.
[4] Ow RKK, Carlsson GE, Jemt T. Biting forces in patients with craniomandibular disorders. Journal of Craniomandibular Practice 1989;7:119–25.
[5] Hagberg C. Assessment of bite force—a review. Journal of Craniomandibular Disorders 1987;1:162–9.
[6] Boero RP. The physiology of splint therapy: a literature review. Angle Orthodontics 1989;59:165–80.
[7] Okeson JP. Management of temporomandibular disorders and occlusion, St. Louis: CV Mosby Year Book Inc, 1993. p. 162 (see also p. 489).
[8] Waltimo A, Kononen M. A novel bite force recorder and maximal isometric bite forces values for healthy young adults. Scandinavian Journal of Dental Research 1993;101:171–5.
[9] Xhonga FA. Bruxism and its effect on the teeth. Journal of Oral Rehabilitation 1977;4:65–76.
[10] Nemcovsky CE, Artzi Z. Erosion–abrasion lesions revisited. Compendium of Continuing Education in Dentistry 1996;17:416–23.
[11] Kikuchi M, Korioth TWP, Hannam AG. The association among occlusal contacts, clenching effort and bite force distribution in man. Journal of Dental Research 1997;76:1316–25.
[12] Jacobs R, van Steenberghe D. Role of periodontal ligament receptors in the tactile function of teeth: a review. Journal of Periodontal Research 1994;29:153–67.
[13] Kraus BM, Jordan RE, Abrams L. The self-protective features of the dentition. Dental anatomy and occlusion. Baltimore: Williams & Wilkins, 1969.
[14] Lee WC, Eakle WS. Possible role of tensile stress in the etiology of cervical erosive lesions of teeth. Journal of Prosthetic Dentistry 1984;52:374–80.
[15] Heymann HO, Sturdevant JR, Baynes S, et al. Examining tooth flexure effects on cervical restorations: a two-year clinical study. Journal of the American Dental Association 1991;122:41–47.
[16] Clark GT. Interocclusal appliance therapy. In: Mohl ND, Zarb GA, Carlsson GE, Rugh JD, editors. A textbook of occlusion, Chicago: Quintessence, 1988.
[17] Okeson JP. The effect of hard and soft splints on nocturnal bruxism. Journal of the American Dental Association 1987;114:788–91.
[18] Block SL, Apfel M, Laskin DM. The use of a resilient latex rubber bite appliance in the treatment of MPD syndrome. Journal of Dental Research 1978;57:92 (sp. issue, abstr 71).
[19] Nevarro E, Barghi N, Rey R. Clinical evaluation of maxillary hard and resilient occlusal splints. Journal of Dental Research 1985;64:313 (sp. issue, abstr 1246).
[20] Going RE, Loehman RE, Chan MS. Mouthguard materials: their physical and mechanical properties. Journal of the American Dental Association 1974;89:132–8.
[21] Bishop SM, Davies EH, von Fraunhofer JA. Materials for mouth protectors. Journal of Prosthetic Dentistry 1985;53:256–61.
[22] Oikarinen KS, Salonen MAM, Korhonen J. Comparison of the guarding capacities of mouth protectors. Endodontics and Dental Traumatology 1993;9:115–9.
[23] Reeh ES, Douglas WH, Messer HH. Stiffness of endodontically-treated teeth related to restoration techniques. Journal of Dental Research 1989;68:1540–4.
[24] Pilo R, Brosh T, Chweidan H. Cusp reinforcement by bonding of amalgam restorations. Journal of Dentistry 1998;26:467–72.
[25] Craig A, Pettengill CA, Growney MR, et al. A pilot study comparing the efficacy of hard and soft stabilizing appliances in treating patients with temporomandibular disorders. Journal of Prosthetic Dentistry 1998;79:165–8.
[26] Ramfjord SP, Ash MM. Occlusion, 3rd ed. Philadelphia: W.B. Saunders, 1983. p. 359–83.