Dental Traumatology 2006; doi: 10.1111/j.1600-9657.2006.00361.x

DENTAL TRAUMATOLOGY

Does hard insertion and space improve shock absorption ability of mouthguard?

Tomotaka Takeda, Keiichi Ishigami, Jun Handa, Kaoru Naitoh, Katsuhide Kurokawa, Mami Shibusawa, Kazunori Nakajima, Shintaro Kawamura

Department of Sports Dentistry, Tokyo Dental College, Chiba, Japan

Takeda T, Ishigami K, Handa J, Naitoh K, Kurokawa K, Shibusawa M, Nakajima K, Kawamura S. Does hard insertion and space improve shock absorption ability of mouthguard? © Blackwell Munksgaard, 2006.

Abstract – Mouthguards are expected to reduce sports-related orofacial injuries. Numerous studies have been conduced to improve the shock absorption ability of mouthguards using air cells, sorbothane, metal wire, or hard material insertion. Most of these were shown to be effective; however, the result of each study has not been applied to clinical use. The aim of this study was to develop mouthguards that have sufficient prevention ability and ease of clinical application with focus on a hard insertion and space. Ethylene vinyl acetate (EVA) mouthguard blank used was Drufosoft and the acrylic resin was Biolon (Dreve-Dentamid GMBH, Unna, Germany). Three types of mouthguard samples tested were constructed by means of a Dreve Drufomat (Type SO, Dreve-Dentamid) air pressure machine: the first was a conventional laminated type of EVA mouthguard material; the second was a three layer type with acrylic resin inner layer (hard-insertion); the third was the same as the second but with space that does not come into contact with tooth surfaces (hard + space). As a control, without any mouthguard condition (NOMG) was measured. A pendulum type impact testing machine with interchangeable impact object (steel ball and baseball) and dental study model (D17FE-NC.7PS, Nissin, Tokyo, Japan) with the strain gages (KFG-1-120-D171-11N30C2: Kyowa, Tokyo, Japan) applied to teeth and the accelerometer to the dentition (AS-A YG-2768 100G, Kyowa) were used to measure transmitted forces. Statistical analysis (ANOVA, $P < 0.01$) showed significant differences among four conditions of NOMG and three different mouthguards in both objects and sensor. About acceleration: in a steel ball which was a harder impact object, shock absorption ability of about 40% was shown with conventional EVA and hard-insertion and about 50% with hard + space. In a baseball that was softer compared with steel ball, a decrease rate is smaller, reduction (EVA = ~4%, hard-insertion = ~12%, hard + space = ~25%) was admitted in the similar order. A significant difference was found with all the combinations except for between EVA and hard-insertion with steel ball (Tukey test). About distortion: both buccal and lingual, distortions had become small in order of EVA, hard-insertion, and hard + space, too. The decrease rate is larger than acceleration, EVA = ~47%, hard-insertion = 80% or more, and hard + space = ~98%, in steel ball. EVA = ~30%, hard-insertion = ~75%, and hard + space = ~98% in baseball. And a significant difference was found with all the combinations (Tukey test).

Key words: mouthguard; hard insertion and space; shock absorption; injury

Tomotaka Takeda, Department of Sports Dentistry, Tokyo Dental College, 1-2-2, Masago, Mihama-ku, Chiba-chi, Chiba-ken, 261-8502, Japan
Tel.: 81 43 270 3609
Fax: 81 43 270 3609
e-mail: takedat@attglobal.net

Accepted 23 February, 2005

Especially, hard + space has decreased the distortion of teeth up to several percentages. Acceleration of the maxilla and distortions of the tooth became significantly smaller when wearing any type of mouthguard, in both impact objects. But the effect of mouthguard was clearer in the distortion of the tooth and with steel ball. Considering the differences of mouthguards, the hard-insertion and the hard + space had significantly greater buffer capacity than conventional EVA. Furthermore, hard + space shows quite high shock absorption ability in the tooth distortion. Namely, hard + space has decreased the distortion of teeth up to several percentages in both impact objects.

Maxillary front teeth often receive direct horizontal impacts. So it is assumed that more than 90% of sports-related teeth injuries had contained this area (1–6). Influences of these injuries reach not only a functional problem but also an aesthetic and a mental matter. While, a lot of other organizations damages can be recoverable by appropriate treatment and the natural healing power. But teeth fracture, dislocation and so on never recover naturally. Moreover, an endurance of teeth after treatment does not return thoroughly to intact teeth level. Treated teeth, which used a metal post-core or crown etc, became easy to receive a secondary injury, because of its' high elasticity modulus. Furthermore, after the slight injuries such as enamel clack, tooth concussion and so on, it is assumed that after effects such as pains and the necrosis of pulps were seen by about 25% (7).

However, it is assumed that mouthguards are effective to a reduction and a prevention of these injuries by many sports dentist. Hundreds of studies have been conduced to improve the shock absorption ability of mouthguards using air cells (8), a sorbothane (9), a metal wire (10), a sponge (11), or a hard material (12–14). Most of these study showed these materials or fabrication methods were effective. However, the results of each study have not been applied to clinical use. In addition, many sports-related orofacial injuries has still happened though the Mouthguard is used. So an aim of this study was to develop a mouthguard that has sufficient prevention ability and ease of clinical application with focus on a hard insertion and space.

Methods

Ethylene vinyl acetate (EVA) mouthguard blanks used were Drufosoft and acrylic resin sheets were Biolon (Dreve-Dentamid GMBH, Unna, Germany). Three types of mouthguard samples tested (Fig. 1) were constructed by means of a Dreve Drufomat (Type SO, Dreve-Dentamid) air pressure machine: a conventional laminated type of EVA mouthguard material (EVA 3 + 3; Fig. 1b), a three layer type with the acrylic resin inner layer (hard-insertion; Fig. 1c), a similar type as the second B but with a space that does not come into contact with the tooth surface (hard +space; Fig. 1d). The actual thickness of each mouthguards at the impact points was approximately 3.0 mm. And without any mouthguard was used as a control (NOMG; Fig. 1a). Three mouthguards were made for each three type and the impact tests described as below were carried out three times for each mouthguard.

A pendulum type impact testing machine (15–17) (with interchangeable impact object – steel ball and baseball (Table. 1.)) and a dental study model (D17FE-NC.7PS, Nissin, Tokyo, Japan) with strain gages (KFG-1-120-D171-11N30C2: Kyowa, Tokyo, Japan) applied to the teeth and the accelerometer fixed to maxilla (AS-A YG-2768 100G, Kyowa) were used to measure transmitted forces (Fig. 2.). Measured mechanical forces by means of the strain gauges and the accelerometer were amplified with a Strain Amplifier (DPM-712B, Kyowa) and then converted into an electric output voltage and stored as data with an Oscillographic Recorder (Kyowa RDM200A). The data was then analyzed with a personal computer (PC-SJ145V, Sharp Co., Ltd., Tokyo, Japan) and processed with Tooth Piece (Soft wear, Ami-system Co., Ltd., Tokyo, Japan) to distortion ($\mu\varepsilon$) and acceleration (g) respectively. Thus, means and standard deviation were calculated for each variable evaluated. Shock absorption ability (%) was calculated against the control as well. Statistical comparison was made using a one-way ANOVA test. And Tukey multiple comparison test was used for further comparisons ($P < 0.01$), using SPSS (SPSS Japan Inc., Tokyo, Japan).

Results

Waveform of the distortion

The distortion waveforms of four conditions at the buccal cervical with steel ball are showed in Fig. 3.

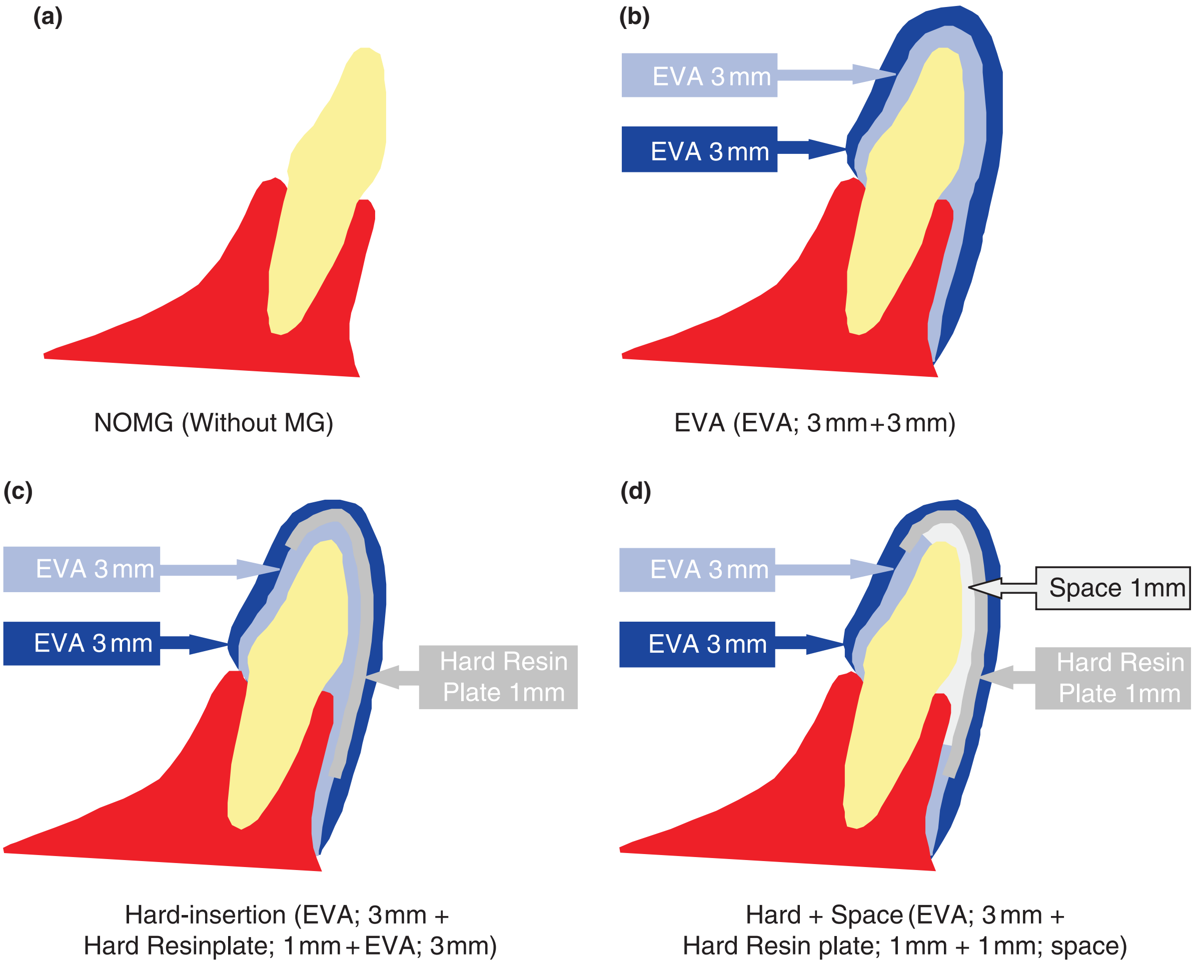


Fig. 1. Three types of mouthguards: (b)conventional laminated type of EVA mouthguard material (EVA 3 + 3), (c) three layer type with the acrylic resin inner layer (hard-insertion), (d) similar type as the second (b) but with a space that does not come into contact with the tooth surface (hard + space). And without any mouthguard was used as a control (NOMG) (a).

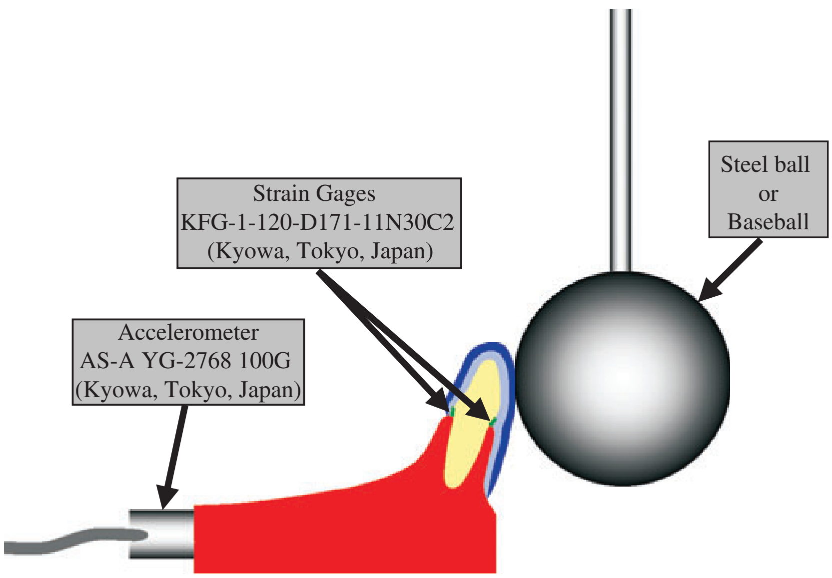


Fig. 2. Specially designed devices to measure the shock absorption ability of mouthguard and a dental study model.

The waveform consisted of two peaks. The first peak seems to be generated, when impact object was hit. And it seems that second peak originated in the impact caused after teeth moved in space where correspond to the periodontal ligament. And the first peak is analyzed as the impact power. The waveform of the NOMG was sharp and strong compared with wearing any types of mouthguards. Waveforms were become smooth by wearing mouthguards. The tendency was clear in the order of EVA, hard-Insertion, and hard + space. Hard + space showed almost flat waveform.

The acceleration and distortion each measuring point and object

Transmitted forces of acceleration and distortion of each measuring point are showed in Figs 4–9. And absorption ability (%) and results of Tukey test are also in each Figure.

Acceleration with the steel ball which was a harder impact object, shock absorption ability of about 40% was shown with EVA and hard-insertion, and about 50% with hard + space. With the baseball that was softer compared with steel ball, a decrease rate is smaller, but a reduction was admitted in the similar order (EVA = ~4%, hard-insertion = ~12%, hard + space = ~25%). Statistical analysis (ANOVA, $P < 0.01$) showed significant differences among four conditions of NOMG and three different mouthguards with both the steel ball and the baseball. And significant differences were found with all the combinations except for between EVA and hard-insertion with the steel ball (Tukey test, $P < 0.01$).

Distortion with the steel ball, both buccal and lingual distortion became small in order of EVA, hard-insertion, and hard + space, too. A decrease rate is larger than acceleration, EVA = ~47%, hard-insertion = 80% or more, and hard + space = ~98%, with the steel ball. EVA = ~30%, hard-insertion = ~75%, and hard + space = ~98% with the baseball. Thus, hard + space decreased the distortion of teeth up to several

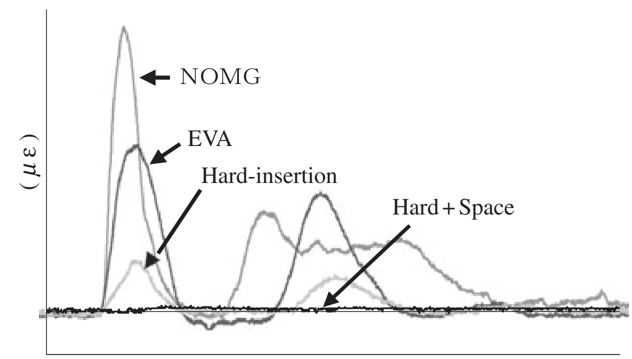


Fig. 3. Distortion wave forms of four conditions at buccal cervical with a steel ball. The waveform of the NOMG was sharp and strong compared with wearing any types of mouthguards. Waveforms were become smooth by wearing mouthguards. The tendency was clear in the order of EVA, hard-insertion, and hard + space. Hard + space showed almost flat waveform.

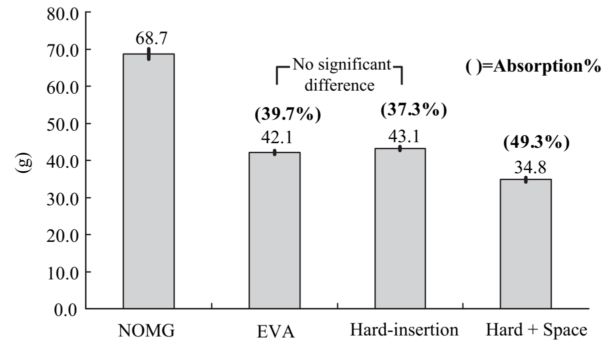


Fig. 4. Steel ball acceleration.

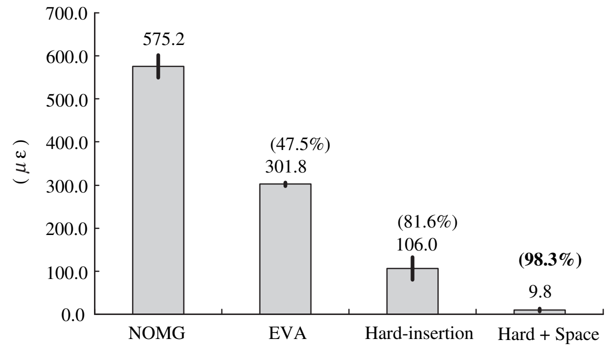


Fig. 5. Steel ball distortion (buccal cervical). Buccal distortion became small in order of EVA, hard-insertion, and hard + space. The decrease rate is, EVA = ~47%, hard-insertion = 80% or more, and hard + space = ~98%. Statistical analysis (ANOVA, $P < 0.01$) showed significant differences among four conditions of NOMG and three different mouthguards. And a significant difference was found with all the combinations (Tukey test).

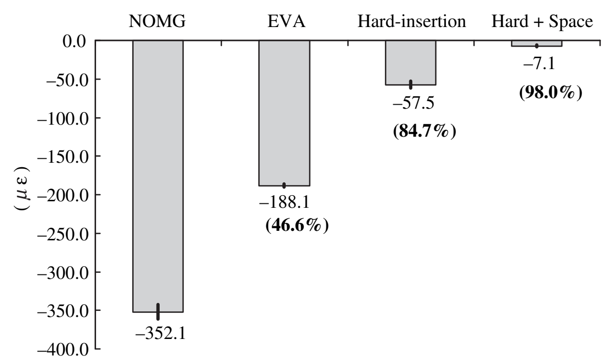


Fig. 6. Steel ball distortion (palatal cervical).

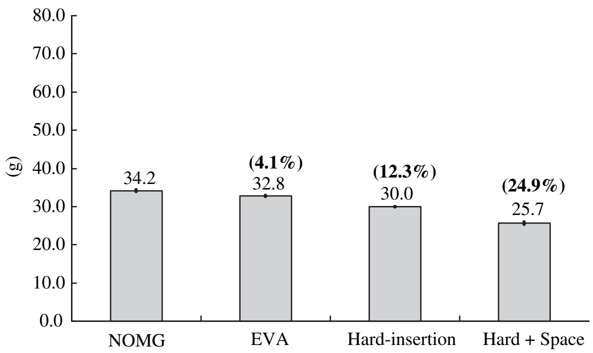


Fig. 7. Baseball acceleration.

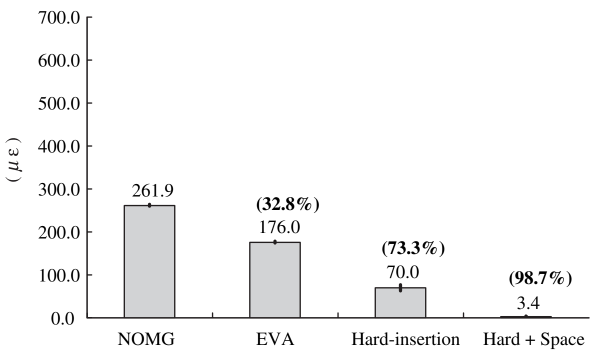


Fig. 8. Baseball: distortion (buccal cervical).

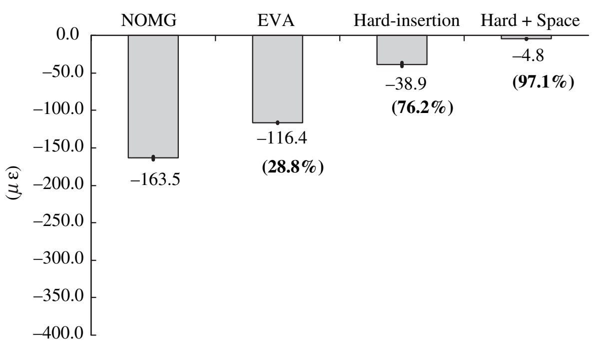


Fig. 9. Baseball distortion (palatal cervical).

percentages. Statistical analysis (ANOVA, $P < 0.01$) showed significant differences among four conditions of NOMG and three different mouthguards, in both measuring point and objects. And a significant difference was found with all the combinations (Tukey test).

Discussion

Many researches to improve the impact absorption ability of the mouthguard by using some intermediate layers or by improving the mouthguard material itself have been conduced. Among them, only one paper reported negative results (14). All other researches insisted on having improved the impact absorption abilities of the mouthguard by their methods.

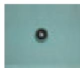
Modified mouthguard material with an inclusion of air cells in a 4 mm thick EVA reduced transmitted forces by 32% when compared with traditional EVA mouthguards of the same thickness (18). An intermediate layer of sorbothane (a visco-elastic polyurethane that has been used in sports and orthopedic applications because of its shock-absorbing properties) reduced a peak force significantly than a comparable thickness EVA mouthguard (9). A half-round arch wire strengthener extending between the first molars embedded in a double layer EVA mouthguard was the most efficient (10). Bilaminated mouthguard with a piece of sponge as an intermediater showed the highest shock absorption (49%) (11). Hard layers of EVA insert reduced energy absorption when compared with a control sheet of the EVA without the hard insert (13). A specially designed two layers custom-formed protector consisted of a rigid outer layer of polycarbonate and an inner layer of EVA with approximately 1 mm wide space has been retained between protector and anterior teeth absorbed the much of impact energy (12).

However, these were not the methods, which was able to applied to clinical easily. Moreover, because half-round arch wire and hard material outer layer are used, they are not necessarily safe. So these methods are not being used now.

Consequently, this present study was planned and conduced to develop a mouthguard that has sufficient prevention ability and ease of clinical application with focus on a hard insertion and space. By means of a pendulum type impact testing machine with interchangeable impact object (15–17) and dental study model with the strain gages applied to teeth and the accelerometers to the dentition.

As the result, distortions of the tooth and acceleration of the maxilla became significantly smaller when wearing any type of mouthguard, in both steel ball and baseball impact objects. But the effect of mouthguard was clearer in the distortion of the tooth. Considering the differences of

Table 1. Impact equipment

		Weight (g)	Hardness
	Steelball	172.5	–
	Baseball	147.3	82.5

Durometer hardness

mouthguards, hard-insertion and hard + space had significantly greater buffer capacity than conventional EVA. Furthermore, hard + space shows quite high shock absorption ability in the tooth distortion. Namely, hard + space has decreased the distortion of teeth up to several percentages in both impact objects.

Only the buffer ability of a material thickness contributes a prevention level for horizontal direct impact force in a lot of conventional mouthguard. If the mouthguard have the impact absorption ability of 80–90% (15,16,18) which are the highest values of previous studies. It is difficult to protect all sports related teeth and orofacial bone injuries.

However, in this present study, the impacted energy was distributed backward and decreased an amount of the destructive energy to teeth by using hard inner layer. In addition to this effect, the mouthguard material can bend in applied space between mouthguard and teeth, and energy should be absorbed greatly while mouthguard transforming. Therefore, it is considered that the distortion was hardly transmitted to the tooth in this impact power level. And if the impact power is so strong and mouthguard cannot bear it, for this situation, hard inserted materials will break down and absorb the much energy at the moment. So the injury might be preventable or reduced with this type of hard + space mouthguard.

This distinct improvement by hard + space is achieved with small design change and easy to clinical use. So we should recommend and produce this type of mouthguard in consideration of the type of sports (ice hockey, cricket, women's lacrosse, etc.), level and condition of player's mouth condition (with fractured and repaired tooth, tooth with veneer metal crown, porcelain facing crown, implant prosthetics, fixed partial denture, etc.). In addition, we should conduce well-formed prospective studies on the field that evaluate whether this type of mouthguard is sufficient to reduce incidence or severity of oro-facial sport-related injuries.

Conclusion

Within the limit of this laboratory study, the acceleration of the maxilla and the distortions of the tooth became significantly smaller (ANOVA) when wearing any type of mouthguard, in both steel ball and baseball. But the effect of mouthguard was clearer in the distortion of the tooth and with steel ball. Considering the differences of mouthguards, the hard-insertion and the hard + space had significantly greater buffer capacity than conventional EVA (Tukey tests). Furthermore, hard (acrylic inner layer) + space (between the tooth surface and mouthguard material) showed quite high shock absorption ability in the tooth distortion. Namely, hard + space has decreased the distortion of teeth up to several percentages in both impact objects.

Acknowledgement – The authors are indebted to Mr Koji Otsu, Tokyo, Japan, for his assistance in the measuring methods.

References

1. Chapman P. The prevalence of orofacial injuries and use of mouthguards in Rugby Union. Aust Dent J 1985;30:364–7.
2. Marrow RM, Kuebker WA. Sports dentistry: a new role. Dent Sch Q Univ of Texas 1986;2:11–13.
3. Lombardi S, Sheller B, Williams BJ. Diagnosis and treatment of dental trauma in a children's hospital. Pediatr Dent 1998;20:112–20.
4. Kvittem B, Hardie NA, Roettger M, Conry J. Incidence of orofacial injuries in high school sports. J Public Health Dent 1998;58:288–93.
5. Garon MW, Merkle A, Wright JT. Mouth protectors and oral trauma: a study of adolescent football players. J Am Dent Assoc 1986;112:663–5.
6. Josefsson E, Karlander EL. Traumatic injuries to permanent teeth among Swedish school children living in a rural area. Swed Dent J 1994;18:87–94.
7. Komatu E, Kuriu Y, Sasano T, Hanzawa K, Marumo M, Sanjo D. A clinical, statistical study of traumatized teeth Jpn. J Oral Diag/Oral Med, 1988;1:136–40. (Article in Japanese).
8. Westerman B, Stringfellow PM, Eccleston JA. An improved mouthguard material. Aust Dent J 1997;42:189–91.
9. Bulsara YR, Matthew IR. Forces transmitted through a laminated mouthguard material with a sorbothane insert. Endod Dent Traumatol 1998;14:45–7.
10. Watermeyer GJJ, Thomas CJ, Jooste CH. The protective potential of mouthguards. J Dent Assoc S Afr 1985;40:173–7.
11. de Wet FA, Heyns M, Pretorius J. Shock absorption potential of different mouth guard materials. J Prosthet Dent 1999;82:301–6.
12. de Wijn JR, Vrijhoef MM, Versteegh PA, Stassen HP, Linn EW. A mechanical investigation to the functioning of mouthguards. Biomechanics: Principles and Applications. Nijmegen, the Netherlands: Selected Proceeding of the 3rd general Meeting of the European Society of Biomechanics, 1982 January;21–3.
13. Westerman B, Stringfellow PM, Eccleston JA. The effect on energy absorption of hard inserts in laminated EVA mouthguards. Aust Dent J 2000;45:21–3.
14. Bemelmanns P, Pfeiffer P. Shock absorption capacities of mouthguards in different types and thicknesses. Int J Sports Med 2001;22:149–53.
15. Takeda T, Ishigami K, Shintaro K, Nakajima K, Shimada A, Regner CW. The influence of impact object characteristics on impact force and force absorption by mouthguard material. Dent Traumatol 2004;20:12–20.
16. Takeda T, Ishigami K, Jun H, Nakajima K, Shimada A, Ogawa T. The influence of the sensor type on measured impact absorption of mouthguard material. Dent Traumatol 2004;20:29–35.
17. Takeda T, Ishigami K, Ogawa T, Nakajima K, Shibusawa M, Shimada A et al. Are all mouthguards the same and safe to use? The influence of occlusal supporting mouthguards in decreasing bone distortion and fractures. Dent Traumatol 2004;20:150–6.
18. Craig RG, Godwin WC. Properties of athletic mouth protectors and materials. J Oral Rehabil 2002;29:146–50.