Dental Traumatology

Dental Traumatology 2013; **29**: 218–225; doi: 10.1111/j.1600-9657.2012.01159.x

Shock absorption ability of laminate mouth guards in two different malocclusions using fiber Bragg grating (FBG) sensor

Ashish Bhalla[1], Navneet Grewal[2], Umesh Tiwari[3], Vandana Mishra[3], Nahar Singh Mehla[3], Suryanarain Raviprakash[4], Pawan Kapur[3]

[1]Department of Pedodontics and Preventive Dentistry, Genesis Institute of Dental Sciences and Research Institute, Ferozepur, Punjab, India; [2]Department of Pedodontics and Preventive Dentistry, Punjab Government Dental College and Hospital, Amritsar, Punjab, India; [3]Central Scientific Instruments Organisation, Council of Scientific and Industrial Research, Chandigarh, New Delhi, India; [4]Pyrodynamics, Bangaluru, Karnataka, India

Key words: mouthguard; malocclusion; fiber Bragg grating; impact absorption; contact sports

Correspondence to: Ashish Bhalla, Department of Pedodontics and Preventive Dentistry, Genesis Institute of Dental Sciences and Research Institute, Ferozepur, Punjab 152001, India
Tel.: 0161-6540164
e-mail: drash_b@yahoo.co.in

Accepted 11 May, 2012

Abstract – *Purpose*: The majority of orofacial injuries affect the upper jaw, with the maxillary incisors being most prone to injury, often accounting for as many as 80% of all cases. Children with malocclusion in the anterior segment of the maxilla are more prone to traumatic injuries than those exhibiting normal occlusion, because most often the damaging force impacts directly against the maxillary anterior teeth. Hence, because of the difference of dissipation of the impact force because of the presence or absence of malocclusion, the mouthguard's shock absorption capacity would be influenced by certain factors. In the present study, a unique *in vitro* experiment utilizing fiber Bragg Grating (FBG) as distributed strain sensors was carried out to evaluate the shock absorption ability of laminate customized mouthguards in two different malocclusions compared with normal occlusion. *Material and methods*: The impact was produced using a customized pendulum device with three interchangeable impact objects on typhodont models with two different malocclusions and normal occlusion from different heights. Response of gratings was monitored using an optical spectrum analyzer. Strain induced because each impact was determined from the Bragg's wavelength shifts for each grating. For every model, 12 impact strikes were measured using three different impact objects on the two specified sites by releasing the object from two different heights. *Results and conclusions*: The laminated mouthguards showed significant variation in shock absorption ability when different malocclusions were compared. Hence, modifications in the original design of the laminated mouthguards should be considered for athletic competitors with malocclusion to provide adequate protection against impact. FBG sensor has shown the unique advantage of high sensitivity to strain measurement and can be used in further studies. The height of the impact is an important variable in determining the shock absorption ability of mouthguards.

Introduction

Orofacial injuries have widespread and problematic implications. Such injuries may impact physical, psychological, social, and economic aspects of life. The majority of injuries affect the upper jaw, with the maxillary incisors often accounting for as many as 80% of all cases (1). Physically, orofacial injuries can result in abnormal primary teeth exfoliation, failure in permanent teeth eruption, unfavorable color changes in teeth, development of painful abscesses, and tooth loss resulting in unaesthetic gaps in the mouth of the injured person (2). In addition to the damage caused by a traumatic impact to the dento-alveolar structures, damage can also result in facial bone fracture and more seriously, neck or brain injury resulting from increased cranial pressure and deformation (3–5). Fortunately, most of these types of injuries can be prevented with the use of properly fitted protective athletic mouth equipment, that is, the mouthguard.

The American Society for Testing and Materials (ASTM) classifies mouthguards into three categories (6):

1 Type I – Stock mouthguards
2 Type II – Mouth-formed, also known as 'boil-and-bite' mouthguards
3 Type III – Custom-fabricated mouthguards.

Initially, most players used boil-and-bite-type mouth guards because they were inexpensive and readily available. However, these type of mouth guards offer a very low level of protection to the wearer (7). Therefore, it is strongly recommended to use a mouthguard that is custom-made (8). The shock absorption ability is proportional to the thickness (9) of the mouthguard. It is also necessary to maintain adequate thickness on the occlusal surface to establish suitable occlusion and

© 2012 John Wiley & Sons A/S

protect from the impact of force applied on the mandible (10). The vacuumed-type mouthguards most commonly used currently have been reported to undergo decrease in thickness during fabrication because of heating and vacuuming. Therefore, it is difficult for this type of mouthguard to ensure the adequate thickness required to demonstrate the ability to absorb impact forces after it has been manufactured. Conversely, laminated-type mouthguards have higher shock absorption ability as they are fused with another sheet of material, which restrains the shrinkage and provides adequate thickness to the specific part where dental injuries often occur. Hence, the application of laminated-type mouthguards is considered to be necessary from the standpoint of safety and comfort (11).

The majority of injuries affect the upper arch, with the maxillary incisors often accounting for as many as 80% of all cases (1). Children with malocclusion in the anterior segment of the maxilla are also more prone to traumatic injuries (12). The presence or absence of malocclusion of the maxillary teeth would certainly influence the mouthguard's shock absorption capacity because of the differences of dissipation of striking force.

The shock absorption ability of mouthguards has been researched using different types of impact materials and sensors. It was found that shock absorption abilities vary with different impact objects and sensors. It is recommended to test more than one impact object to select appropriate material for each sport (10). It was also found that the strain gauge is one of the most sensitive sensors to measure the shock absorption ability of mouthguards (13). Fiber Bragg Grating sensor is a new breed of optical sensors, which are being used in measuring strain and temperature changes (14). The strain measurement using FBG sensor has been found to be in close agreements with those measured with the strain gauges (15). Because these fiber optic sensors offer some unique advantages, like long-term stability, immunity to electromagnetic interference, and compatibility with medical and dental composite materials (16), they are increasingly being used to study strain changes in dental research studies.

Therefore, an *in vitro* comparative study was carried out to evaluate the shock absorption ability of laminate mouthguards using FBG sensor in two different malocclusions and normal occlusion using three different impact objects released from two different heights and made to strike at two different sites (anterior and posterior).

Materials and methods

A pendulum device apparatus was constructed for the experiment by Pyrodynamics similar to that of a Charpy or Izod impact machine with interchangeable impact objects (Fig. 1). The axis length of the pendulum was 50 cm, and the apparatus was adjusted to hit the most prominent tooth on the typhodont model (Fig. 2). Two rods were designed for the pendulum apparatus axis arm such that one of the rods had the capability for interchangeably attaching the cricket and hockey ball where as a separate rod for the attachment of steel ball was fabricated because of the small diameter of the steel ball as compared to the other two. A metallic base was placed where the typhodont models could be fixed with the help of screws. (Figs 3–5)

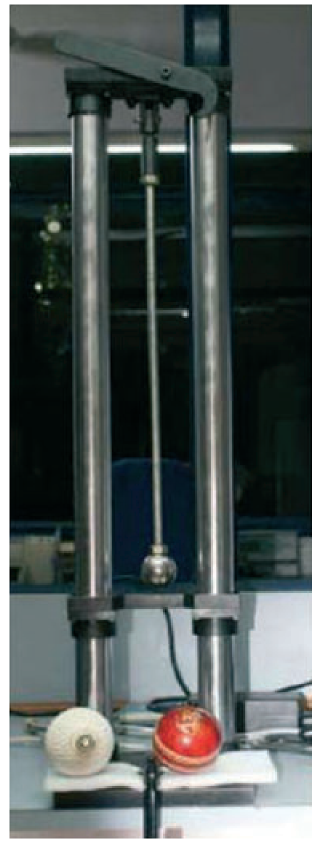

Fig. 1. Pendulum device apparatus.

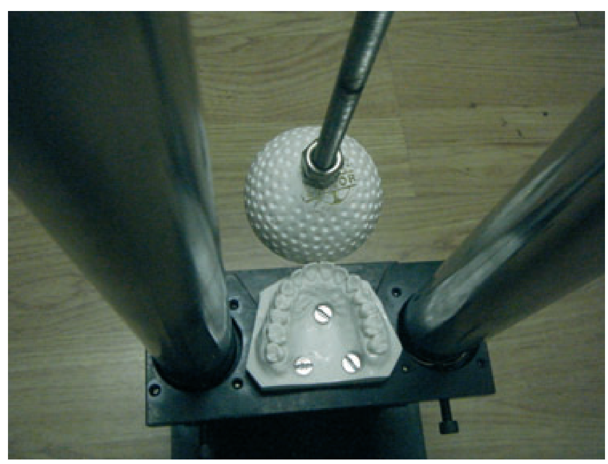

Fig. 2. Ball apparatus hitting the most prominent tooth on the typhodont model.

Three balls were selected for the study (Figs 6–8):

1. Cricket ball with the weight of 130 g and diameter of 78 mm.

© 2012 John Wiley & Sons A/S

Fig. 3. Nissin typhodont model D1-01BN: Class I molar relation with normal occlusion.

Fig. 4. Nissin typhodont model D1-01C: Class I molar relation with crowding in maxillary anterior teeth.

Fig. 5. Nissin typhodont model D1-01B: Class I molar relation with proclined maxillary central incisors.

Fig. 6. Cricket ball.

2 Hockey ball with the weight of 120 g and diameter of 78 mm.
3 Steel ball with the weight of 210 g and diameter of 37 mm.

Three typhodont models were selected:

1 Nissin Typhodont Model D1-01BN: Class I molar relation with normal occlusion.
2 Nissin Typhodont Model D1-01C: Class I molar relation with crowding in maxillary anterior teeth.
3 Nissin Typhodont Model D1-01B: Class I molar relation with proclined maxillary central incisors.

Fiber Bragg Grating sensors for the study were fabricated at Central Scientific Instruments Organization (Council of Scientific and Industrial Research, New Delhi, Chandigarh). Figure 9 FBG sensors were used for each location to measure the effect of respective impacts on the jaw model and the mouthguard. The FBGs were fabricated by exposing the core of hydrogenated photosensitive fiber to intense UV light from a KrF excimer laser at 248 nm using standard 'phase mask technique'. All the FBGs had their Bragg wavelength λ_B between 1545 and 1550 nm with grating length approximately 10 mm and similar reflectivities. These FBGs were recoated for strength and thermally annealed at 150°C for 24 h to stabilize their properties.

Custom-made laminate mouthguards were prepared for the selected jaw models by making accurate impressions and pouring in die stone material. The prepared models were sent to Buy-Dent Agencies Laboratory in Hyderabad for fabrication of the laminated custom-made mouthguard (Erkodent). Mouthguards were fabricated to a thickness with the top layer being colored, (2 mm thick) and base kept transparent (2 mm thick).

The impact strikes of a cricket ball, hockey ball, and a steel ball on the anterior and posterior teeth of the selected typhodont models were measured using the FBG sensor. The buccal surfaces of the teeth on the typhodont model and external surface of the mouthguard were first cleaned with acetone for bonding of the FBG sensor. The FBG sensor was surface mounted/bonded on the entire external surface of the mouthguard and all the buccal surfaces of the teeth on the typhodont model at middle third level using EA-2A

© 2012 John Wiley & Sons A/S

Fig. 7. Hockey ball.

Fig. 8. Steel ball.

Epoxy resin adhesive (Fig. 10). These specimens were left in an air-conditioned room with the temperature maintained at 25°C for 24 h for the adhesive to cure and bond the FBG sensor to both the specimens. Before placing the model on the pendulum apparatus, the Bragg wavelengths were measured using commercially available interrogator (OSA) (Fig. 11), so that the measure was standardized. The typhodont model with the mouthguard fitted over it along with the FBG sensor was placed very carefully on the base of the pendulum apparatus and was fixed by means of screws such that the arm of the apparatus along with the ball should hit the target area (Fig. 12). The FBG sensors were attached to the interrogator again and the interrogator was in turn attached to a computer with software to detect the shift in wavelength of the FBG sensor on the mouthguard as well as the typhodont model (Fig. 13).

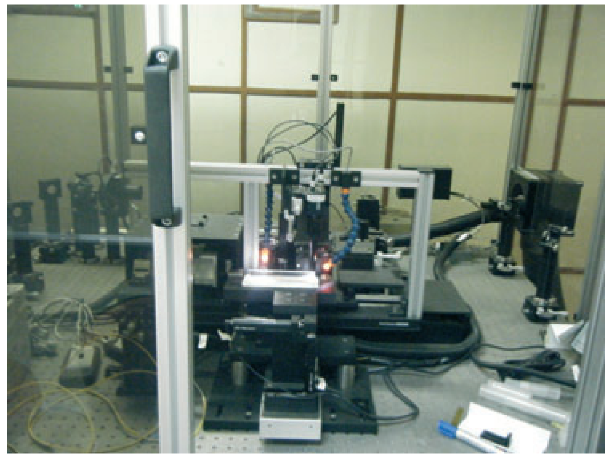

Fig. 9. Fiber Bragg Grating sensor writing system (C.S.I.O Chandigarh).

Fig. 10. Fiber Bragg Grating sensor surface mounted on the mouthguard and typhodont using EA-2A Epoxy resin Adhesive.

Each model was tested separately in two different regions:

1 Maxillary anterior region
2 Maxillary 1st molar region

The impact was carried out by releasing the impact object from two different heights, that is, 24 and 48 cm from the ground level (Fig. 14). Thus, for every model, 12 impact strikes were given using three different impact objects on the two specified sites by releasing the object from two different heights. A total of 36 impact strikes were carried out in this study.

With each impact strike, the shift in the wavelength of the FBG sensor was measured for the typhodont model and the mouthguard using the Optical Spectrum Analyzer Interrogator. The shifts in wavelength of the FBG sensors were recorded in as follows:

1 Shift in wavelength ($\Delta\lambda$): Calculated as the difference in magnitude of the reference and the impact wavelength of the FBG sensor.

© 2012 John Wiley & Sons A/S

Fig. 11. Interrogator: Optical spectrum analyzer (OSA) used for measuring wavelength shift in fibre bragg grating sensor.

Fig. 12. The typhodont along with mouthguard with Fiber Bragg Grating sensor mounted secured to the base of the pendulum apparatus using screws.

The readings were recorded separately for the mouthguards and labial/buccal surfaces of teeth on the typhodont model. The shock absorption energy was calculated from the reduction in strain developing on the teeth on the typhodont model because of the presence of mouthguard using the following formula:

$$\text{Shock absorption energy} = \frac{\mu \in_M - \mu \in_T}{\mu \in_M} \times 100$$

Where $\mu\epsilon_M$= MICRO-STRAIN ON MOUTHGUARD and $\mu\epsilon_T$= MICRO-STRAIN ON TEETH ON THE TYPHODONT MODEL.

The data were compiled, and shock absorption energy in two commonly occurring malocclusions was compared with the normal occlusion (control model) using the above technique. The values obtained were subjected to statistical analysis.

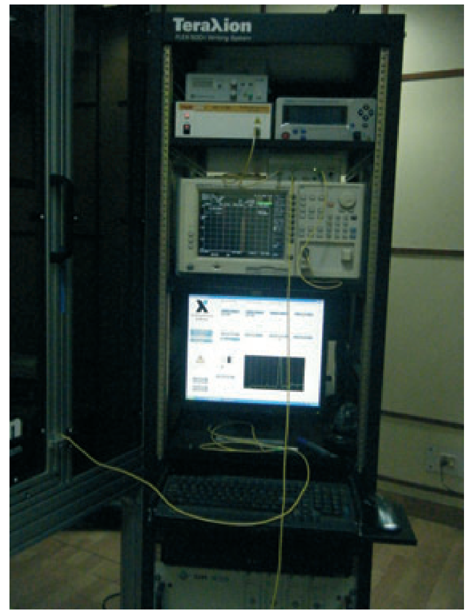

Fig. 13. Optical spectrum analyzer attached to a computer to record each impact strike separately.

Results

The following results were obtained for the anterior and the posterior region of the typhodont model. (Table 1; Fig. 15). Computed comparative evaluation of shock absorption ability of laminated mouthguards in both anterior as well as the posterior regions of the models was made (Table 2). Two-way ANOVA test based on DOS Software was applied (17) (Table 3), and after statistical analysis, it was found that the difference in shock absorption ability of laminate mouthguards in the anterior region of three different models with malocclusion was highly significant at 1% level. On further analysis of paired comparisons through critical difference value, it was found that the critical difference in shock absorption ability of laminated mouthguards of model 1 and model 2, model 1 and model 3 was highly significant at 1% level while that for model 3 and model 2 was significant at 5% level. It was also found that the difference in shock absorption ability of laminated mouthguards was statistically insignificant in the posterior region. The difference in shock absorption ability of laminated mouthguards at two different regions, that is, anterior and posterior was found to be highly significant at 1% level of significance. The influence of the type of ball on the shock absorption ability of laminated mouthguards was found to be statistically insignificant. The influence of the type of height on the shock absorption ability of laminated mouthguards was found to be highly significant at 1% level of significance. The influence of combination of each ball for the given 2 heights for all the 3 models on two different regions on the shock absorption ability of laminated mouthguards was found to be statistically highly significant at 1% level (Table 3).

© 2012 John Wiley & Sons A/S

Fig. 14. Impact Release from height H2 = 48 cm from ground level.

Table 1. Showing%Age absorption ability of laminated mouth guards for different malocclusions using three different impact balls at two different heights, H1 and H2

		Absorption ability (%)		
Region	Balls And Height	Model 1	Model 2	Model 3
Anterior	Cricket H1	36.36	10.00	28.57
	Cricket H2	49.60	34.54	37.50
	Hockey H1	25.00	14.28	14.28
	Hockey H2	50.00	35.71	33.33
	Steel ball H1	33.33	10.00	33.33
	Steel ball H2	60.00	40.00	41.67
Posterior	Cricket H1	50.00	40.00	30.00
	Cricket H2	66.67	60.00	56.25
	Hockey H1	33.33	32.50	33.33
	Hockey H2	75.00	70.00	60.00
	Steel ball H1	25.00	36.00	42.85
	Steel ball H2	75.00	73.33	66.67

Discussion

Shock absorbing capability can be broadly defined as the reduction in the impact energy or force transmitted to the surface beneath the mouthguard material. Various techniques have been tested in the past to measure this characteristic, and one of the commonly used measures is the initial rebound of a pendulum or a dropped weight which directly impacts the mouthguard material. The degree of rebound is a marker of the amount of impact force absorbed, that is, less rebound, more shock absorption. Another direct shock absorption quantification method is the force measured on a transducer, that is, accelerometer and strain gauge beneath the mouthguard material once a known force (from a pendulum, dropped weight, or piston) is applied to the top of the material Takeda et al. (10–13). Some studies Westerman et al. (18) measured acceleration and calculated impact force as: Force = mass × acceleration, where impact mass is taken constant. Takeda et al. (19) measured only acceleration keeping the mass and the distance at which the pendulum was released constant. The change in acceleration was used to deduce the shock absorption ability. Later, Takeda et al. (20) derived the shock absorption ability by using strain gauge to record the strain developing on a dental model with and without a mouthguard separately. The present study used the same principle to derive the shock absorption ability but recorded the strain developing on teeth on the typhodont model and the mouthguard at the same time with the same impact strike, keeping in view real-life situations and the fact that impact occurs simultaneously on the teeth as well as the mouthguard.

Greasley and Karet (21) described that to gain direct measurements of the performance characteristics of mouthguards, impact tests should be conducted on custom-made mouthguards constructed directly onto a 'standardized jaw'. Hence, the present *in vitro* compara-

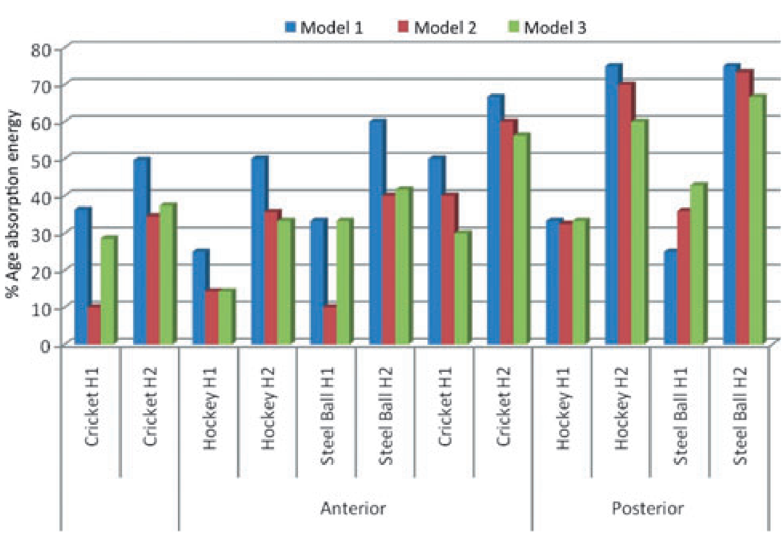

Fig. 15. Showing %age absorption ability of laminated mouthguards for different malocclusions using three different impact balls at two different heights H1 and H2.

© 2012 John Wiley & Sons A/S

Table 2. Mean, standard deviation scores, and Student's 't' test values of shock absorption ability of laminated mouth guards combined in the anterior region and the posterior region of three different models

Effects	No. of observation	Mean	Standard deviation	Coefficient of variation (%)	Standard Error of Mean	*t*-value
Treatment (type of ball × height)						
CC H1	3	24.97667	11.05732	44.3	7.81870	3.194
CC H2	3	40.54667	6.51474	16.1	4.60662	8.802
CH H1	3	17.85333	5.05346	28.3	3.57334	4.996
CH H2	3	39.68000	7.36175	18.6	5.20554	7.623
CS H1	3	25.55334	10.99787	43.0	7.77667	3.286
CS H2	3	47.22333	9.06016	19.2	6.40650	7.371
SC H1	3	40.0000	8.16497	20.4	5.77350	6.928
SC H2	3	60.97333	4.30925	7.1	3.04710	20.010
SH H1	3	33.05333	0.39146	1.2	0.27680	119.411
SH H2	3	68.33334	6.23610	9.1	4.40959	15.497
SS H1	3	34.61667	7.35259	21.2	5.19906	6.658
SS H2	3	71.66666	3.59837	5.0	2.5443	28.166

Table 3. Showing two-way ANOVA test on shock absorption ability of laminated mouthguards combined at the anterior region and the posterior region

				Variance ratio (F-values)		
					Critical	
Source of variation	Degrees of freedom	Sum of squares	Mean of squares	Computed	5%	1%
Types of typhodont models	2	718.7500	359.3750	6.602**	3.443	5.719
Treatment combinations	11	9750.6250	886.4205	16.284**	2.259	3.184
Anterior region vs Posterior region (A)	1	3181.5240	3181.5240	58.447**	4.301	7.945
Types of Balls (B)	2	155.2188	77.6094	1.426 (ns)	3.443	5.719
Types of height (C)	1	5804.1570	5804.1570	106.628**	4.301	7.945
A × B interaction	2	45.3594	22.6797	0.417 (ns)	3.443	5.719
A × C interaction	1	293.0313	293.0313	5.383*	4.301	7.945
B × C interaction	2	229.3125	114.6563	2.106 (ns)	3.443	5.719
A × B × C interaction	2	42.0234	21.0117	0.386 (ns)	3.443	5.719
Experimental Error	22	1197.5470	54.4340			
Total	35	11666.9200				

NS, Not significant.
*Significant at 5% significance level.
**Significance at 1% significance level.

tive study was attempted in two different malocclusions and normal occlusion standardized jaw models (Nissin Typhodont Model D1-01BN, D1-01C and D1-01B).

The *in vitro* comparison of shock absorption ability of laminated mouthguards was recorded using FBG sensor for impact from the cricket ball, hockey ball, and steel ball (Table 1). The percentage shock absorption ability varied from 10% to 60% for the anterior region and 30–75% for the posterior region. The results were similar to those reported by Takeda et al. (19) 26–57%.

The purpose of the present study was to record the shock absorption ability of mouthguards when fabricated on maloccluded dentitions. The results of our study for the anterior region of the typhodont models in normal occlusion and two malocclusions (Table 1) signify that for all types of occlusion, the shock absorption energy of laminated mouthguards was more for the steel ball than corresponding values for cricket and hockey ball. A highly significant difference in shock absorption ability of laminated mouthguards was noticed at 1% level of significance for normal occlusion as compared to that with malocclusions (Table 2). The comparison between the normal and two malocclusions showed that critical difference in shock absorption ability of laminated mouthguard was more for normal and crowded occlusion (18.2933) than normal and proclined occlusion (10.9350) at 1% level of significance. Among the selected malocclusions, the laminated mouthguard on proclined incisors showed significantly more shock absorption ability than the crowded ones (7.3583) at 5% level of significance.

When comparison between the anterior and the posterior occlusions (Table 3) and the amount of shock absorption of the laminated mouthguards was made, more absorption was seen in the posterior region than the anterior region. This may be attributed to the fact that the mouthguard material undergoes more thinning in the anterior region because of the presence of malocclusion, thus resulting in decrease in the shock absorption ability of mouthguard.

© 2012 John Wiley & Sons A/S

Although in previous studies a single point release for the impact object for all strikes on the mouthguard were used, in our study we have used two release points from two different heights, that is, H1 = 24 cm and H2 = 48cm to consider any effect on the shock absorption ability of the laminated mouthguards when the impact came from different angles. It was also found that there was a highly significant difference in shock absorption ability at 1% level when the impacts were released from a greater height. Hence, as the height increased, the shock absorption ability of the laminated mouthguards improved. This was obvious from (Table 1) where the highest impact object (steel ball) showed 33–75% shock absorption.

Conclusion

Within the limitations of this *in vitro* study, the results of the present study support the following conclusions:

1 The shock absorption ability of laminated mouthguards varies with the type of malocclusion present. Hence, modifications in the original design of the laminated mouthguards should be considered for the sports participants with malocclusion to provide adequate protection against impact.
2 The laminate mouthguards of a given thickness provided greater cushion to proclined dentition than crowded dentition, although less in both the cases as compared to normal occlusion.
3 The height at which an impact object strikes is a deciding factor in concurrent shock absorption by a mouthguard.
4 The laminated mouthguards showed shock absorption ability for cricket ball 10–66.67%, hockey ball 14.28–75%, and steel ball 10–75%. Overall, the laminated mouthguards showed shock absorption ability of 10–75% with different impact object forces.
5 Fiber Bragg Grating sensor has shown unique advantage of high sensitivity to strain measurement and can be used in further studies.

Although sports mouthguards provide protection against trauma, dentoalveolar injuries still occur with a mouthguard in place. Perhaps, varying design according to existing malocclusion would improve the shock absorption capacity of laminated custom-made mouthguards. This study is suggestive to improvise mouthguard designs by adding bilaminate material on maximum shock areas in different malocclusions. Further studies are needed to discuss the effects of change in design and influence of different heights and impact objects on the shock absorption ability of laminated mouthguards.

References

1. Newsome PR, Tran DC, Cooke MS. The role of the mouthguard in the prevention of sports-related dental injuries: a review. Int J Paediatr Dent 2001;11:396–404.
2. Canadian Dental Hyginist Association. CDHA position paper on sports mouthguards, putting more bite into injury prevention. Can J Dent Hygiene 2005;39:1–18.
3. Chapman PJ. Concussion in contact sports and importance of mouthguard protection. Aust J Sci Med Sports 1985;17:23–7.
4. Woodmansey KF. Athletic mouth guards prevent orofacial injuries: a review. Gen Dent 1999;47:64–9.
5. Schwartz R, Collins BJ, Fong C. Effects of a single and double commercial athletic mouthpiece on expiratory peak flow: a pilot study. Cranio 2000;18:23–9.
6. American Society for Testing and Materials. Standard practice for care and use of mouthguards. Designation: F 697-80. Philadelphia: American Society for Testing and Materials; 1986. p. 323.
7. Hoffmann J, Alfter G, Rudolph NK, Goz G. Experimental comparative study of various mouthguards. Endod Dent Traumatol 1999;15:157–63.
8. Duarte-Pereira DM, Rey-Santamaria M, Javierre-Garces C, Barbany-Cairo J, Paredes-Garcia J, Valmaseda-Castellon E, et al. Wearability and physiological effects of custom-fitted vs self-adapted mouthguards. Dent Traumatol 2008;24:439–42.
9. Maeda M, Takeda T, Nakajima K, Shibusawa M, Kurokawa K, Shimada A, et al. In search of necessary mouthguard thickness. Part 1: from the viewpoint of shock absorption ability. Nihon Hotetsu Shika Gakkai Zasshi 2008;52:211–9.
10. 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.
11. Miura J, Maeda Y, Machi H, Matsuda S. Mouthguards: difference in longitudinal dimensional stability between single- and double-laminated fabrication techniques. Dent Traumatol 2007;23:9–13.
12. Nguyen QV, Bezemer PD, Habets L, Prahl-Andersen B. A systematic review of the relationship between overjet size and traumatic dental injuries. Eur J Orthod 1999;21:503–15.
13. Takeda T, Ishigami K, Jun H, Nakajima K, Shimada A, Ogawa T. The influence of the sensor type on the measured impact absorption of mouthguard material. Dent Traumatol 2004;20:29–35.
14. Othnos A. Fiber Bragg gratings: review article. Rev Sci Instrum 1997;68:4309–41.
15. Tiwari U, Mishra V, Jain SC, Kesavan K, Ravisankar K, Singh N et al.Health monitoring of steel and concrete structures using fibre Bragg grating sensors. Curr Sci 2009;97:1539–42.
16. Anttila EJ, Krintila OH, Laurila TK, Lassila LV, Vallittu PK, Hernberg RG. Evaluation of polymerization shrinkage and hydroscopic expansion of fiber-reinforced biocomposites using optical fiber Bragg grating sensors. Dent Mater 2008;24:1720–7.
17. Snedecor GW, Cochran WG. Statistical methods, 8th edn. Ames: Iowa State University Press; 1989.
18. Westerman B, Stringfellow PM. Forces transmitted through EVA mouthguard materials of different types and thickness. Aust Den J 1995;40:389–91.
19. Takeda T, Ishigami K, Kawamura S, Nakajima K, Shimada A, Sumii T, et al. Adhesive strength and its improvement referring to the laminated-type mouthguard. Dent Traumatol 2006;22:205–14.
20. Takeda T, Ishigami K, Nakajima K, Naitoh K, Kurokawa K, Handa J, et al. Are all mouthguards the same and safe to use? Part 2. The influence of anterior occlusion against a direct impact on maxillary incisors. Dent Traumatol 2008;24:360–5.
21. Greasley A, Karet B. Towards the development of a standard test procedure for mouthguard assessment. Br J Sports Med 1997;31:31–5.

© 2012 John Wiley & Sons A/S

This document is a scanned copy of a printed document. No warranty is given about the accuracy of the copy. Users should refer to the original published version of the material.