Dental Traumatology

Dental Traumatology 2013; **29**: 303–306; doi: 10.1111/j.1600-9657.2012.01171.x

A novel dual material mouthguard for patients with dental implants

Takayuki Miyahara[1,2,3], Christer Dahlin[1,3,4], Silvia Galli[1], Shima Parsafar[1,3,5], Hiroyasu Koizumi[6], Shohei Kasugai[2,7]

[1]Department of Biomaterials, Sahlgrenska Academy at University of Gothenburg, Göteborg Sweden; [2]Oral Implantology and Regenerative Dental Medicine, Department of Masticatory Function Rehabilitation, Tokyo Medical and Dental University, Tokyo Japan; [3]BIOMATCELL VINN Excellence Center of Biomaterials and Cell Therapy, Göteborg; [4]Department of ENT/ Oral & Maxillofacial Surgery, NÄL Medical Centre Hospital, Trollhättan; [5]Department of Chemical and Biological Engineering, Chalmers University of Technology, Göteborg Sweden; [6]Department of Fixed Prosthodontics, Nihon University School of Dentistry; [7]Global Centre of Excellence (GCOE) Programme, International Research Centre for Molecular Science in Tooth and Bone Diseases, Tokyo Medical and Dental University, Tokyo Japan

Abstract – *Aim*: Dental implant–supported reconstructions demonstrate significantly less physiological flexibility for loading and traumatic forces compared with a normal dentition because of their rigid integration with the adjacent bone. Ethylene vinyl acetate (EVA) material has become widely accepted as a mouthguard material; however, many studies indicate the necessity of improving the impact absorption ability by considering the design and developing new materials. The aim of this study was to compare the shock-absorbing ability of a novel dual component material comprising EVA and porous rubber with that of EVA alone. *Materials and methods*: Three groups of samples were tested: Group 1 = EVA (thickness, 4 mm), Group 2 = type 1 material (2-mm thick porous rubber sheet sandwiched between two sheets of 1-mm thick EVA sheets), and Group 3 = type 2 material (1-mm thick porous rubber sheet sandwiched between EVA sheets with 1 and 2-mm thickness, respectively). Shock absorption was determined by means of a hammer impact testing device equipped with strain gauge, accelerator, and load cell. *Results*: The value of shock-absorbing ability of group 2 (40.6 ± 12.5%) was significantly higher than those of group 1 (15.6 ± 2.1%) and group 3 (21.2 ± 9.2%). The material with thicker rubber sheet showed significantly higher shock-absorbing ability compared with that of the material with thinner rubber sheet. *Conclusions*: The novel dual material was superior to conventional EVA material in shock-absorbing ability depending on the thickness of porous rubber, and it may be potentially effective as mouthguard material, in particular, for patients wearing implant-supported constructions.

Key words: mouthguard; dental implant; contact sports; porous rubber; shock absorber; dental trauma

Correspondence to: Takayuki Miyahara, Oral Implantology and Regenerative Dental Medicine, Department of Masticatory Function Rehabilitation, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8549, Japan
Tel.: +81 3 5803 4092
Fax: +81 3 5803 4664
e-mail: miyahara.irm@tmd.ac.jp

Accepted 3 June, 2012

The use of mouthguards can reduce the incidence and severity of sports-related oral injuries involving teeth, soft tissue, alveolar bone, and the temporomandibular joint by providing a resilient and protective surface to distribute and dissipate transmitted forces on impact (1–5). Although it seems that mouthguards can decrease the incidence of brain injury or concussion, there is no empirical evidence to support this claim (6–9).

Risk of dental trauma in some sports with non-intentional contact among participants can be as high as that occurring in some full-contact sports, where the use of mouthguards is mandatory already. Therefore, the use of mouthguards should be strongly considered and recommended even in sports, with non-intentional or limited contact among participants (10). Ethylene vinyl acetate (EVA) has become widely accepted as a mouthguard material, albeit many studies indicate the necessity of improving the impact absorption ability of mouthguards by reconsidering their design and developing new materials (11–14).

Dental rehabilitation of totally or partially edentulous patients with dental implants has become a routine treatment modality in the last decades with reliable long-term results (15, 16). Especially, dental implant has become the treatment of choice for replacing one missing tooth (17). Consequently, the number of athletes treated with dental implants is increasing. The physiological mobility differs between natural teeth and dental implants. An osseointegrated implant is 'rigidly' fixed to bone and may move only 10 μm, which is primarily a result of bone flexure, while a natural tooth with a healthy periodontal ligament has a mobility of 50–200 μm (18). Owing to this difference in physiological flexibility, the same amount of stress could have a more dangerous effect for dental implants than for teeth. Therefore, the shock-absorbing ability of conventional EVA mouthguards may not be enough to prevent sports-related oral injuries for patients rehabilitated with dental implants.

In the present study, a novel dual component material for mouthguards was compared with regard to the shock-absorbing ability to conventional EVA.

Material and methods

Mouthguard material

Two mouthguard materials were assessed for this study: Impact guard (GC Corp., Tokyo, Japan) and Saporous (Asahi Rubber Inc., Saitama, Japan). Impact guard was chosen as conventional EVA material. The thickness was 1, 2, and 4 mm. Saporous was thermoplastic elastomer sheet.

Three group of samples were tested: Group 1 = EVA, Group 2 = type 1 material (2-mm thick thermoplastic elastomer sheet sandwiched between two sheets of 1-mm thick EVA sheets without adhesive), and Group 3 = type 2 material (1-mm thick thermoplastic elastomer sheet sandwiched between EVA sheets with 1- and 2-mm thickness, respectively, without adhesive). Eight samples were tested per group. The size of each sample was approximately 13 mm^2 with a flat shape.

Characterization

The morphology of thermoplastic elastomer sheet was observed by a scanning electron microscope. The surfaces were coated in a vacuum evaporator (Quick Coater Type SC-701; Sanyu Denshi Inc., Tokyo, Japan), with a thin film of gold. The specimens were observed using a FE-SEM (ERA-8800FE; Elionix Ltd., Tokyo, Japan).

Experimental methods

Shock absorption was determined by means of a hammer impact testing device equipped with strain gauge, accelerator, and load cell (OMNIACE2 RA1200 TYPE-504-CA-4; NEC Avio Infrared Technologies Co., Ltd., Tokyo, Japan) (Fig. 1). The room temperature was 21.9°C with air conditioner. A single hammer impact was used. Values of shock-absorbing ability were calculated as follows:

$$\text{Shock-absorbing ability}(\%) = (\text{maximum acceleration of blank} - \text{maximum acceleration of sample})/\text{maximum acceleration of blank} \times 100.$$

Statistical analysis

The values were shown as mean + SD. Statistical analysis was performed by one-way analysis of variance test with *post hoc* multiple comparison (SPSS ver. 15.0; SPSS Inc., Chicago, IL, USA).

Results

Characterization

Figure 2 shows a representative SEM image of novel thermoplastic elastomer sheet. Topographical analysis showed that the pore size was approximately 5–50 μm. The shape of the pore was not circular but varied. The material and the pore made a layer. A high-polymer framework was observed. Figure 2c,d show the representative SEM images after single hammer impact tests. The framework was not destroyed after the test, and any relevant deformation was not observed.

Comparison of shock-absorbing ability

Figure 3 shows the shock-absorbing ability values. The value of shock-absorbing ability of group 2 (40.6 ± 12.5%) was significantly higher than those of group 1 (15.6 ± 2.1%) and group 3 (21.2 ± 9.2%). The material with thicker thermoplastic elastomer sheet showed significantly higher shock-absorbing ability compared with that of the material with thinner thermoplastic elastomer sheet ($P < 0.05$).

Discussion

EVA material has become widely accepted as a mouthguard material. However, several studies (11, 13, 19) indicate the necessity of improving the impact absorption ability of EVA mouthguards, advocating either an improvement in design or development of new materials. This is of particular interest for the increasing patient group rehabilitated with dental implant–supported reconstructions. Previous mouthguard designs with regard to hardness, impact absorption, tear

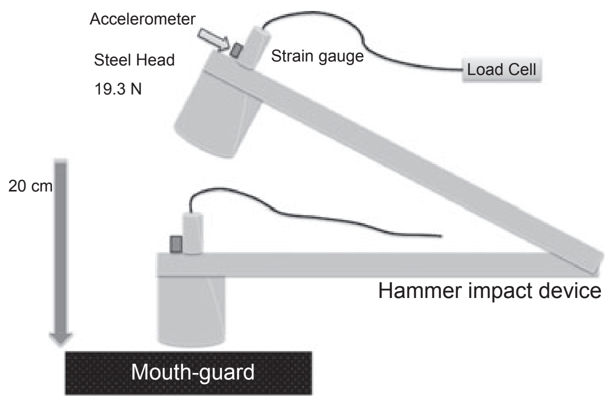

Fig. 1. Specially designed device to measure shock absorption ability of mouthguard.

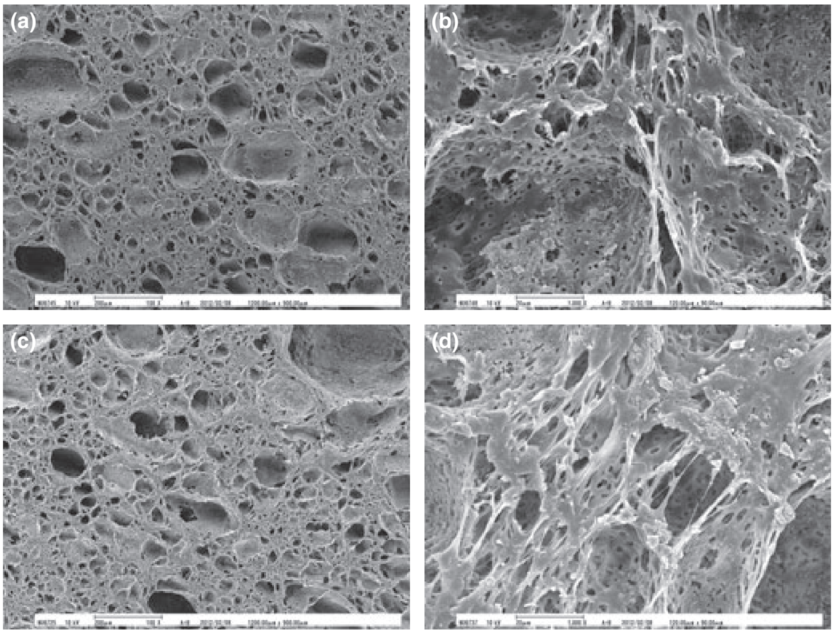

Fig. 2. (a, b) Representative SEM image of the thermoplastic elastomer sheet. (c, d) Representative one of post-testing.

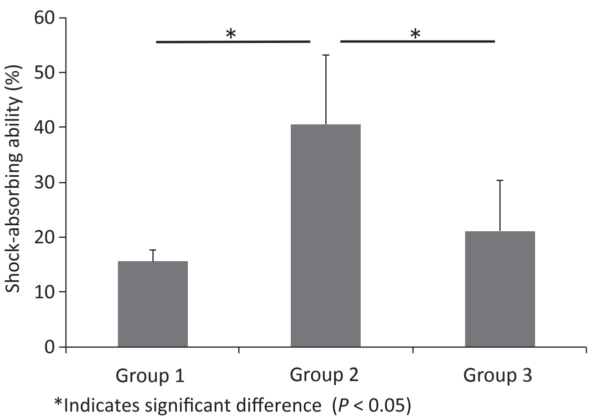

Fig. 3. Comparison of shock-absorbing ability.

strength, and water sorption (20–22) have taken into account the fact that a normal dentition has an 'inbuilt' flexibility of approximately 200 μm owing to the anatomical and physiological characteristics of the periodontal ligament of the teeth. A well-integrated dental implant has a physiological flexibility, which is related to the flexibility of the bone tissue, allowing a mobility of about which is only around 10 μm (18). To our knowledge, this behavioral difference has not been taken into account previously when designing optimal mouthguards for this patient population, The thermoplastic elastomer sheet in this study is a continuous pore high-polymer material and has already been used as 'Various insoles (High shock-absorbent)', 'Hip protectors for care goods (High shock-absorbent)', and 'Earplugs for the swimming (waterproof)'. According to information provided by the company, the ratio of porosity of these materials is 71%, 71%, and 66%, respectively. Takeda et al. reported a method for fabrication of mouthguards which consists of an outer and an inner EVA layer and a middle layer of acrylic resin. Such a method makes it possible to fabricate a three-layer mouthguard (19).

Several research groups have reported limitations of hammer impact tests. Tiwari et al. (23) used Fiber Bragg gratings. They tested several impact levels. In the present study, hammer impact test had been used. The disadvantage of this test is that it is impossible to adjust the impact degree. To mimic the clinical situation, impact tests from several different directions are required. A material tested as a flat sheet cannot be considered to reproduce the clinical situation where a mouthguard is shaped over curved surfaces and sharp peaks of cuspal tips. Therefore, a laboratory test which duplicates the clinical situation, comprising the performance of an impact test of convex surfaces from several directions, should be developed in further studies.

The novel materials were laminated. Hence, no analyses with regard to fracture tests were performed.

Mouthguards have been utilized by athletes who recognize the need for oral protection during their sports activities. However, the frequency of mouthguard usage is still limited. Reasons for not wearing a mouthguard are mainly the discomfort and the difficulty in breathing as well as in speaking (24). Maeda et al. (25) reported that, the necessary thickness of mouthguards to acquire a sufficient shock-absorption ability was about 4 mm in conventional EVA material. It has been claimed that thickness of material more than 4 mm for mouthguard is uncomfortable to wear (26). Therefore, the thickness of samples of present study was set at 4 mm. The shock-absorbing capacity of EVA is considered not enough even to prevent traumas even in natural teeth with periodontal ligament (25). Hence, it does not fulfill the needs of protection in athletes treated with dental implant. The amounts of vertical displacement between natural teeth and dental implants differ. The amount of vertical displacement under loading for natural teeth with periodontal ligament tissue and dental implant is about 50 and 5 μm, respectively (18). The implant structure and the abutment connection can be damaged by blunt force occurring during sports. Another aspect taken into account is that during sports, athletes tend to clench their teeth. In such a situation, it might be possible that overload might happen toward the dental implants, hereby causing potential overload and subsequent marginal bone loss. The combination of a thermoplastic elastomer sheet and dual layers of EVA demonstrated a significant higher shock-absorbing value. Hence, it could be an effective material in compensation for the different displacement under pressure of natural teeth and dental implants.

Conclusion

A novel dual component material was superior to conventional EVA material in shock-absorbing ability depending on the thickness of thermoplastic elastomer sheet, and it may be potentially effective as mouthguard material. Such a high absorbing mouthguards may be recommended for athletes with dental implants.

Acknowledgements

We would like to express special thanks to Nobukazu TAKASAWA (for making the samples of sheets for samples and prototype), Masanori SATO and Satoshi KOBAYASHI (for supplying porous rubber 'Saporous'), and Noriyuki INOUE [Business, Research and Intellectual Property Center (NUBIC) Nihon University]. This work was supported by Grant-in-Aid for GCOE Research and Grant-in-Aid for Exploratory Research from the Ministry of Education, Culture, Sports, Science and Technology, Japan, and BIOMAT-CELL VINN Excellence Center of Biomaterials and Cell Therapy, Göteborg, Sweden.

Conflict of interest

None of the authors has any conflict of interest to disclose.

References

1. Going RE, Loehman RE, Chan MS. Mouthguard materials: their physical and mechanical properties. J Am Dent Assoc 1974;89:132–8.
2. Bishop BM, Davies EH, von Fraunhofer JA. Materials for mouth protectors. J Prosthet Dent 1985;53:256–61.
3. Park JB, Shaull KL, Overton B, Donly KJ. Improving mouth guards. J Prosthet Dent 1994;72:373–80.
4. Cohenca N, Roges RA, Roges R. The incidence and severity of dental trauma in intercollegiate athletes. J Am Dent Assoc 2007;138:1121–6.
5. Knapik JJ, Marshall SW, Lee RB, Darakjy SS, Jones SB, Mitchener TA et al. Mouthguards in sport activities: history, physical properties and injury prevention effectiveness. Sports Med 2007;37:117–44.
6. McCrory P. Do mouthguards prevent concussion? Br J Sports Med 2001;35:81–2.
7. Wisniewski JF, Guskiewicz K, Trope M, Sigurdsson A. Incidence of cerebral concussions associated with type of mouthguard used in college football. Dent Traumatol 2004;20:143–9.
8. Mihalik JP, McCaffrey MA, Rivera EM, Pardini JE, Guskiewicz KM, Collins MW et al. Effectiveness of mouthguards in reducing neurocognitive deficits following sports-related cerebral concussion. Dent Traumatol 2007;23:14–20.
9. Gould TE, Piland SG, Shin J, McNair O, Hoyle CE, Nazarenko S. Characterization of mouthguard materials: thermal properties of commercialized products. Dent Mater 2009;25:1593–602.
10. Gould TE, Piland SG, Shin J, Hoyle CE, Nazarenko S. Characterization of mouthguard materials: physical and mechanical properties of commercialized products. Dent Mater 2009;25:771–80.
11. Jagger R, Milward P, Waters M. Properties of an experimental mouthguard material. Int J Prosthodont 2000;13:416–9.
12. Westerman B, Stringfellow PM, Eccleston JA. Beneficial effects of air inclusions on the performance of ethylene vinyl acetate (eva) mouthguard material. Br J Sports Med 2002;36:51–3.
13. Maeda Y, Kumamoto D, Yagi K, Ikebe K. Effectiveness and fabrication of mouthguards. Dent Traumatol 2009;25:556–64.
14. Andrade RA, Evans PL, Almeida AL, da Silva Jde J, Guedes AM, Guedes FR et al. Prevalence of dental trauma in pan american games athletes. Dent Traumatol 2010;26:248–53.
15. Albrektsson T, Branemark PI, Hansson HA, Lindstrom J. Osseointegrated titanium implants. Requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. Acta Orthop Scand 1981;52:155–70.
16. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11–25.
17. Pjetursson BE, Lang NP. Prosthetic treatment planning on the basis of scientific evidence. J Oral Rehabil 2008;35(Suppl. 1):72–9.
18. Burak Ozcelik T, Ersoy E, Yilmaz B. Biomechanical evaluation of tooth- and implant-supported fixed dental prostheses with various nonrigid connector positions: a finite element analysis. J Prosthodont 2011;20:16–28.
19. Takeda T, Ishigami K, Mishima O, Karasawa K, Kurokawa K, Kajima T et al. Easy fabrication of a new type of mouthguard incorporating a hard insert and space and offering improved shock absorption ability. Dent Traumatol 2011;27:489–95.
20. Craig RG, Godwin WC. Physical properties of materials for custom-made mouth protectors. J Mich State Dent Assoc 1967;49:34–40.
21. Craig RG, Godwin WC. Properties of athletic mouth protectors and materials. J Oral Rehabil 2002;29:146–50.
22. Lunt DR, Mendel DA, Brantley WA, Michael Beck F, Huja S, Schriever SD et al. Impact energy absorption of three mouthguard materials in three environments. Dent Traumatol 2010;26:23–9.
23. Tiwari U, Mishra V, Bhalla A, Singh N, Jain SC, Garg H et al.Fiber Bragg grating sensor for measurement of impact absorption capability of mouthguards. Dent Traumatol 2011;27:263–8.
24. Gardiner DM, Ranalli DN. Attitudinal factors influencing mouthguard utilization. Dent Clin North Am 2000;44:53–65.
25. 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.
26. Westerman B, Stringfellow PM, Eccleston JA. EVA mouthguards: how thick should they be? Dent Traumatol 2002;18:24–7.