Braz Dent J (2007) 18(4): 324-328 ISSN 0103-6440

Mechanical Behavior of Ethylene Vinyl Acetate Copolymer (EVA) Used for Fabrication of Mouthguards and Interocclusal Splints

Neide Pena COTO[1]
Reinaldo BRITO E DIAS[1]
Ricardo Aurélio COSTA[2]
Tatiana Fioresi ANTONIAZZI[1]
Eduardo Pena Coto de CARVALHO[3]

[1]*Department of Oral and Maxillofacial Prosthodontics, School of Dentistry, University of São Paulo, São Paulo, SP, Brazil*
[2]*Department of Materials, Educational Foundation "Inaciana Padre Sabóia de Medeiros", São Paulo, SP, Brazil*
[3]*Department of Electrical Engineering, Polytechnic School, University of São Paulo, São Paulo, SP, Brazil*

In the present investigation, an experimental dental arch model fabricated in epoxy was assayed in Kratos universal testing machine to study the mechanical behavior of ethylene and vinyl acetate copolymer (EVA) in the form of mouthguard for sports and flat plate. The following variables were considered: thickness (3 and 4-mm plates), temperature (room and mouth temperature) and presence/absence of artificial saliva. Mechanical properties of EVA were tested under compressive strength: apparent absorbed energy (J.mm-1), maximum tension (N.mm-1), maximum dislocation (mm) and maximum strength (N). Data were recorded and modeled mathematically. Regarding the absorbed energy, maximum tension and maximum force, it was verified that the higher the thickness of the mouthguards, the better the results of force dissipation and redirection to the system and to several regions of the dental arch. In the presence of saliva and close to mouth temperature, the material responded positively to these alterations, resenting increased ductibility as well as improved mechanical responses. Regarding maximum dislocation, it was observed a better accommodation of the occlusion under conditions that simulate those observed in the oral environment. In conclusion, EVA proved to be an adequate material for fabrication of mouthguards and interocclusal splints. In addition, EVA showed good results in force dissipation and demonstrated a shock-absorbing capacity and a great protection potential.

Key Words: mouthguard, interocclusal splint, EVA, experimental model, oral and maxillofacial prosthodontics.

INTRODUCTION

With the increase in the practice of indoor/outdoor extreme sports and the engagement of more and more youngsters in these activities with a high risk of impacts and accidents, the use of mouthguards has become mandatory to prevent injuries to the teeth and mouth in case of shocks to head and dentofacial region (1-3).

In 1981, the ASTM (American Standards of Testing of Materials) F697-80 standard (4) was issued to regulate the types of mouthguards and stated that they should preferably be custom-made devices prepared and fitted by dentists according to specific fabrication and cutting guidelines.

The material used for preparation of these devices is a major issue. Several materials have been proposed for such purpose, but an effective protection relies on the material's mechanical properties, geometry and applications (5,6). When an impact occurs, the sudden transference of kinetic energy to the material may cause severe damages depending on the extension of its deformation. The most frequently observed damages in polymeric materials after impacts include per-

Correspondence: Dra. Neide Pena Coto, Rua Poetisa Colombina, 143, apto 21, Jardim Bonfiglioli, 05593-010 São Paulo, SP, Brasil. Tel: +55-11-3721-3919. Fax: +55 -11-3721-4477. e-mail: npcoto@usp.br

manent deformation, tear or fracture, delamination and holes (7,8).

Polymers have a great potential for fabrication of mouthguards because they have excellent mechanical properties and can be easily conformed at low temperatures. Furthermore, different types of polymers can be combined with other materials in order to enhance the mechanical characteristics, which yield innumerable possibilities of applications, adding important benefits to their properties, reproducibility and homogeneity (9). Another factor that must be taken into account is the final cost of the product, which is determinant for the choice of a mouthguard by non-professional players and athletes.

Ethylene vinyl acetate copolymer (EVA) has interesting characteristics for the construction of sports mouthguards and interocclusal splints, both from a mechanical standpoint and for its conformability at low temperatures. This material complies with the international standards that regulate the fabrication of mouthguards and have demonstrated satisfactory results under compressive and shear forces, in addition to having a low cost (10,11).

The purpose of this study was to attest the indication of EVA in dentistry as a viable material for fabrication of mouthguards and interocclusal splints, by evaluating its mechanical behavior.

MATERIAL AND METHODS

Epoxy models were obtained from original maxillomandibular dental arch impressions of the same individual. These models were attached in occlusion to a metal support. The maxillary arch was steady, while the mandibular arch was fixed in the movable part of the device. This metal support is part of the universal testing machine (Kratos, São Paulo, SP, Brazil) used for the mechanical testing and programmed to apply a compressive load of 20 kN at a crosshead speed of 42.86 mm/min. Interarch opening was controlled by an extensometer with maximum opening of 18 mm. Interarch compression was recorded using MTS data acquisition system, which was installed on the personal computer connected to the Kratos machine.

Statistical analysis determined that 40 experiments would be necessary to evaluate 3 variables in 2 levels (2^3). The 3 variables were: thickness (3- and 4-mm-thick EVA sheets); temperature (room temperature ≈ 22ºC / mouth temperature ≈ 38ºC); and immersion or not in artificial saliva. The studied factors were: absorbed energy, maximum tension, maximum force and maximum dislocation.

Mouthguards and interocclusal splints were prepared in compliance with the ASTM F697-80 standard specifications for 3- and 4-mm-thick EVA sheets submitted to measurements before and after compression in 14 different points in the mesial and palatal side of each tooth of the arch. The saturation of the mouthguards and interocclusal splints with artificial saliva was determined after observing weight gain of a specimen immersed in this solution. This specimen was weighed at 1-h intervals and measured until the weight stabilized. Saturation was reached after 12 h.

The same tests were repeated with 3- and 4-mm-thick EVA flat plates without conformation in order to generate a reference system with low levels of thickness variability. This approach aimed at controlling thickness variation within the arch caused by a 25% to 50% thickness loss during specimen fabrication, as previously reported Craig and Godwin (12) and Park et al. (13).

The EVA sheets used for mouthguard fabrication were characterized using three techniques: 1) Differential scanning calorimetry (DSC) - to measure the fusion temperature (T_f) of specimens made with 3- and 4-mm-thick EVA sheets; 2) Thermogravimetry analysis (TGA) - to determine vinyl acetate content (%VA) by weight loss at a specific temperature at which material decomposition occurs; 3) Flow index - using a plastometer or a rheometer (14).

Material characterization was essential to warrant that the mechanical behavior was investigated using a single variety of EVA, as there are innumerable commercial possibilities of this material and comparison of different percentages of EVA was not the scope of this study. Two varieties of EVA were first considered, each containing 28% and 19.5% of vinyl acetate, respectively. The second variety was chosen for the present study.

The experimental data as a function of the studied variables and their interactions were adjusted by multiple regression analysis using Statgraphics statistical software (Statistical Graphics Corp., Rockville, MD, USA). Significance level of each coefficient in the orthogonal polynomial was estimated by using the Student's t-test. The coefficient was considered significant with ≤0.05. Means and standard deviations of the thicknesses of the mouthguards/interocclusal splints and flat EVA plates and were compared by one-way analysis variance.

RESULTS

Tables 1 to 4 show the coefficients of the orthogonal polynomial adjusted for the respective standard deviations and *p* value for the properties investigated in the present study: absorbed energy *per* millimeter (E_a, J/mm; Table 1), Maximum tension (σ_{Max}, N.mm^{-1}; Table 2), Maximum force (F_{Max}, N; Table 3), Maximum Dislocation (D_{Max}, mm; Table 4).

DISCUSSION

For the factor energy absorption, the results of the present study showed that the increase of thickness, a temperature close mouth temperature, presence of saliva and the temperature/saliva and thickness/temperature/saliva interactions contributed to decrease energy absorption.

These findings are relevant because the energy absorbed in the cyclic moment of compressive deformation should reduce the locally transmitted energy and thus avoid the collapse (rupture) of the protective polymer layer. If these conditions are met, fracture of one or more teeth is unlikely because the magnitude of

Table 1. Coefficient of the orthogonal polinomy of absorbed energy (E_a) as a function of the variables thickness, temperature and saliva and their interactions.

Coefficient	E_a (J.mm^{-1})	SD	*p* value
b_0	21.4	0.8	0.00
B_{Thick}	-8.2	1	0.00
b_T	-2.9	0.8	0.00
b_S	-1.6	0.8	0.05
$B_{Thick*T}$	-0.9	1	0.34
$B_{Thick*S}$	-1.2	1	0.23
b_{T*S}	-1.7	1	0.04
$b_{Thick*T*S}$	-2.8	1	0.00

Thick=thickness; T=temperature; S=saliva.

Table 2. Coefficient of the orthogonal polinomy of maximum tension (σ_{Max}) as a function of the variables thickness, temperature and saliva and their interactions.

Coefficient	σ_{Max} (N.mm^{-1})	SD	*p* value
b_0	844	9	0.00
B_{Thick}	-31	11	0.34
b_T	-187	9	0.00
b_S	-122	9	0.00
$B_{Thick*T}$	22	11	0.00
$B_{Thick*S}$	33	11	0.06
b_{T*S}	83	9	0.00
$b_{Thick*T*S}$	-25	11	0.00

Thick=thickness; T=temperature; S=saliva.

Table 3. Coefficient of the orthogonal polinomy of maximum force (F_{Max}) as a function of the variables thickness, temperature and saliva and their interactions.

Coefficient	F_{Max} (N)	SD	*p* value
b_0	2517	29	0.00
B_{Thick}	780	35	0.00
b_T	-560	29	0.00
b_S	-371	29	0.00
$B_{Thick*T}$	-119	35	0.00
$B_{Thick*S}$	-52	35	0.15
b_{T*S}	259	29	0.00
$b_{Thick*T*S}$	6	35	0.86

Thick=thickness; T=temperature; S=saliva.

Table 4. Coefficient of the orthogonal polinomy of maximum dislocation (D_{Max}) as a function of the variables thickness, temperature and saliva and their interactions.

Coefficient	Dislocation (mm)	DP	*p* value
b_0	5.32	1.05	0.00
B_{Thick}	1.25	1.05	0.00
b_T	0.62	1.05	0.05
b_S	0.01	1.05	0.78
$B_{Thick*T}$	0.36	1.05	0.35
$B_{Thick*S}$	0.10	1.05	0.78
b_{T*S}	0.05	1.05	0.86
$b_{Thick*T*S}$	0.17	1.05	0.66

Thick=thickness; T=temperature; S=saliva.

the energy recovered or returned by the material during its sudden decompression will not be sufficient to cause tooth fracture. Therefore, it may be stated that the lesser the recovered energy, the lesser the material's transmissibility of energy to the teeth and adjacent tissues. Materials that act this way function as a shock absorber, which ensures low transmission of energy to the teeth, which means less risk of injuries in case of trauma (15). This occurs because of EVA ductibility at oral temperature and the plasticization caused by the contact with saliva.

The factor maximum tension increased significantly at oral temperature, in the presence of saliva (saturation) in the temperature/saliva binary interaction and thickness/temperature/saliva ternary interaction. Loss of tension was recorded only for the thickness/temperature and temperature/saliva binary interactions due to the resistance to dislocation of the metal support/dental arch/mouthguard or interocclusal splint set.

Regarding the factor maximum force, the applicability of the experimental model designed for this study was confirmed because the result of the initial compression force test was 2517 N, which, according to Att (16), is sufficient to the fracture a sound, non-restored molar. It was observed that the supported force increased with the increase of the thickness of the mouthguard/interocclusal splint. The presence saliva as well as the thickness/temperature and thickness/saliva binary interactions caused a decrease in the absorbed force due to EVA ductibility and plasticization.

The maximum dislocation factor was evaluated due to a shearing movement presented by the experimental model used in this study, which interfered with the final result of EVA's mechanical behavior, and was directly influenced by a geometric variable (thickness; $p=0.00$) and a non-geometric variable (temperature; $p=0.00$).

Based on the findings of the present investigation, the following conclusions may be drawn: 1) EVA proved to be an adequate material for fabrication of mouthguards and interocclusal splints due to its excelent mechanical behavior, easy acquisition and handling and low cost; 2) When tested under conditions simulating those of the oral environment (±37.5ºC and immersion in saliva), EVA showed better results in force dissipation and demonstrated a shock-absorbing capacity and a great protection potential, which varied with the device thickness.

RESUMO

Um modelo experimental de arco dentário, obtido em epóxi, acoplado a uma máquina universal de ensaios Kratos, foi utilizado para estudar o comportamento mecânico do copolímero de etileno e acetato de vinila (EVA), na forma de protetor bucal para esporte e placa plana. As seguintes variáveis foram observadas: espessura (lâminas de 3 e 4 mm), temperatura (ambiente e bucal) e presença ou ausência de saliva artificial. As propriedades mecânicas do EVA, foram testadas ao esforço compressivo: energia aparente absorvida ($J.mm^{-1}$), tensão máxima ($N.mm^{-1}$), deslocamento máximo (mm) e força máxima (N). Dados foram registrados e modelados matematicamente. Considerando a energia aparente absorvida, tensão máxima e força máxima, verificou-se que com o aumento da espessura dos protetores bucais houve melhores resultados de dissipação de forças compressivas e seu redirecionamento para o sistema e diversas regiões do arco dental. Com a presença de saliva e temperatura próxima a bucal o material respondeu positivamente a essas alterações aumentando sua ductibilidade apresentando assim melhora em sua resposta mecânica. Com respeito ao deslocamento máximo observou-se que houve melhor acomodação da oclusão quando em condições próximas à bucal. Conclue-se que o EVA provou ser um material adequado para a confecção de protetores bucais para esporte e placas interoclusais.O EVA mostrou melhores resultados na dissipação de forças demonstrando sua grande capacidade amortecedora e grande potencial de proteção .

REFERENCES

1. Scott J, Burke EJT, Watts DC. A review of dental injuries and the use of mouthguards in contact team sports. Br Dent J 1994;176:310-314.
2. Watermeyer GJJ, Thomas CJ, Jooste CH. The protective potential of mouthguards. J Dent Assoc South Africa 1985;40: 173-177.
3. Stenger JM, Lawson AL, Wright JM, Ricketts J. Mouthguards: Protection against shock to head, neck and teeth. J Am Dent Assoc 1964;64:273-281.
4. American Standards of Testing of Materials. ASTM F697-80 Standard Practice for Care and use of Mouthguards. In: Annual Book of ASTM Standards. Philadelphia: ASTM; 1981.
5. Stokes ANS, Croft GC, Gee D. Comparison of laboratory and intraorally formed mouth protectors. Endod Dent Traumatol 1987;3:255-258.
6. Wehner PJ, Henderson D. Maximum prevention and preservation: An achievement of intraoral mouthguards. Dent Clin of North Am 1965;493-498.
7. Kim HS, Shafig RM. Model for thickness effect with impact testing of viscoelastic material. J Appl Polymer Scien 2001; 81:1762-1767.
8. Westermam B, Stringfellow PM, Eccleston JA. Forces transmitted through EVA mouthguard materials of different types and thickness. Aust Dent J 1995;40:389-391.
9. Wong EW, White RC. Development of a shock absorbing biomedical elastomer for a new total elbow replacement design. Biomat Med Dev Art Org 1979;7:283-290.
10. Oikarinen KS, Salonen MAM, Korhonen J. Comparison of the guarding capacities of mouthguard protectors. End Dent Traumatol 1993;9:115-119.

11. Hickey JC, Morris AL, Carlson LD, Thomas ES. The relation of mouthguards to cranial pressure and deformation. J Am Dent Assoc 1967;74:735-740.
12. Craig RG, Godwin WC. Physical properties of material for custom made mouth protectors. J Mich State Dent Assoc 1967;47:34-40.
13. Park JB, Shaull KL, Overton B, Donly KJ. Improving mouthguards. J Prosthet Dent 1994;72:373-384.
14. American Standards of Testing of Materials. ASTM D 1238 Test method for flow rates of thermoplastic. In: Annual Book of ASTM Standards. Philadelphia: ASTM; 1981.
15. de Wet FA, Heyns M, Pretorius J. Shock absorption potential of different mouthguard material. J Prosthet Dent 1999;82:301-306.
16. Att VW. Fracture resistance of molars restored with different types of ceramic partial coverage restorations, an in vitro study [Dissertation] Freiburg: Albert Ludwinigs University – Germany; 2003.

Accepted June 14, 2007