Properties of an Experimental Mouthguard Material

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Purpose: The purpose of the present study was to evaluate some important mechanical properties of an experimental silicone material (PM1) to assess its potential as a mouthguard material. **Materials and Methods:** The hardness, tear strength, tensile properties, and energy absorption properties of the silicone material were determined and compared with those of 2 commercially available materials (Bioplast, a polyvinylacetate polyethylene, and Polyshield, a silicone). **Results:** Bioplast was significantly harder than Polyshield and PM1. Polyshield was significantly harder than PM1. Bioplast had a significantly higher tear strength than both Polyshield and PM1. The tensile strength of Bioplast was significantly greater than that of Polyshield and PM1. PM1 had a significantly higher tensile strength than Polyshield. Bioplast had a significantly lower energy absorption capacity at 500 N than both Polyshield and PM1, with PM1 having a significantly higher value than Polyshield. At 1,000 and 1,500 N, Bioplast had a significantly higher energy absorption than both Polyshield and PM1. **Conclusion:** It was concluded that PM1 showed better energy absorption properties than Polyshield and better energy absorption properties than Bioplast at lower impact forces. PM1 was softer and had better tear and tensile properties than Polyshield. The results of the present study suggest that the new material has a good potential for use as a mouthguard material. *Int J Prosthodont 2000;13:416–419.*

Mouthguards are now widely used in contact sports to prevent damage to teeth and oral tissues. Polyvinylacetate polyethylene (PVAc-PE) copolymer is commonly used as a mouthguard material. Silicone rubbers are less frequently used, although Auroy et al[1] showed that silicone rubbers absorb shock efficiently. The construction of silicone rubber mouthguards has been described.[2,3]

Milward[4] investigated the energy absorption properties of a commercially available silicone rubber mouthguard material and compared them with those of a PVAc-PE mouthguard material. He concluded that the silicone material showed better energy absorption capacity at 500 N at all thicknesses tested. The PVAc-PE material, however, performed better at higher loads of 1,000 and 1,500 N at all thicknesses tested.

Silicone rubbers contain fillers embedded in a polymeric matrix, and their properties can be modified readily by varying cross linking, polymer molecular weight, and filler content. Preliminary studies investigated the energy absorption properties of a range of room temperature–vulcanizing silicone formulations to determine their potential for use as mouthguard materials.[4] One of the experimental formulations showed good energy absorption properties, and it was considered to have potential for further development.

The purpose of the present study was to evaluate some important mechanical properties of that experimental formulation. The hardness, tear strength, tensile properties, and energy absorption properties were determined. The same properties of 2 commercially available mouthguard materials (one a PVAc-PE material, the other a silicone) were also determined and

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compared with the properties of the experimental material to further assess the potential of the new formulation as a mouthguard material.

Materials and Methods

The constituents of the experimental material (PM1) were: *(1)* a polymer, hydroxy end-blocked poly (dimethyl siloxane) (C50, Principality Medical Products); *(2)* a filler, Aerosil R812 (Degussa); *(3)* a cross-linking agent that was a mixture of organofunctional silanes (Principality Medical Products); and *(4)* a catalyst that was a dilute solution of alkyl tin compound in silicone oil (Principality Medical Products). The commercial mouthguard materials tested were Bioplast (Eurodontic), a PVAc-PE material, and Polyshield (Orthomax), a poly(dimethyl siloxane) heat-vulcanizing silicone rubber mouthguard material.

Polyshield and PM1 specimens were prepared using a dough-molding technique. Perspex blanks (ICI) of the required dimensions were invested in dental flasks using a 50/50 plaster of Paris and dental stone mix to produce molds in which to pack the material. When the mix had set, the flask was opened and the Perspex sheet was removed. The mold was then coated with a separating medium. Polyshield was packed into the molds and cured at 100°C for 2 hours and then allowed to cool before deflasking the specimens from the mold. PM1 was cured for 24 hours at room temperature before deflasking. Bioplast specimens were cut to the required dimensions from sheets of the appropriate thicknesses. Dimensions were confirmed using a micrometer (Cadar Microstat Measurement and Control Systems).

Hardness Test

The hardness test was conducted according to British and American standards BS 903 Part A26 and ASTM D-1415[5,6] using a Wallace Dead Load Hardness Tester (HW Wallace). Five specimens were tested for each mouthguard material. Ten readings in international rubber hardness degrees were taken for each specimen.

Tensile Test

Dumb-bell specimens of mouthguard material (in accordance with BS 903 type 2 test pieces[7]) were cut from 2.5-mm-thick strips of the cured material. Testing was carried out on the Lloyd LR series testing machine, connected to an IBM-compatible 386 computer to facilitate data logging and manipulation. Ten specimens of each material were tested at a constant cross-head speed of 20 mm/min. Tensile strength was calculated automatically by the computer software using the formula:

$$Ts = F/A$$

where Ts = tensile strength (MPa); F = force at failure (N); and A = original cross-sectional area. The percentage elongation at break was calculated by expressing the increase in length as a percentage of the original gauge length. The 100% modulus was calculated according to the following equation:

$$100\%\ \text{modulus} = \frac{\text{Force at 100\% elongation}}{\text{Original cross-sectional area}}$$

Tear Resistance

Tear specimens were prepared to 50 mm × 10 mm × 2 mm. Specimens had a 90-degree notch on one edge, with the width at the notch being 6 mm. Ten specimens were prepared for each test material. A modification of ASTM D-624[8] was employed. Testing was carried out using the Lloyd LR 10K series testing machine. Ten specimens were tested for each material at a constant cross-head speed of 20 mm/min. On failure of the specimen, the tear resistance of the specimen was automatically calculated by the computer software using the equation:

$$Ts = F/t$$

where Ts = tear resistance (N/mm); F = force to tear specimen (N); and t = thickness of specimen (mm).

Energy Absorption

Energy absorption specimens were 10 mm × 10 mm × 4 mm. Testing was carried out using the Lloyd LR 10K tensile machine. Ten samples were tested for each material. The samples were mounted between brass cylinders and compressed at a speed of 10 mm/min until the desired load was reached, at which point the compression cylinders returned to their original position. Loads of 500, 1,000, and 1,500 N were applied. The stiffness, resilience, and energy used were automatically calculated by the software.

Statistical Analysis

The means and standard deviations within groups were calculated for each test and material. An unpaired 2-tailed *t* test was used to evaluate differences between the means. In the case of multiple comparisons, a one-way analysis of variance (ANOVA) was used, with the Bonferroni method being used to produce correlated *P* values. An r^2 correlation coefficient

Table 1 Properties of Bioplast, Polyshield, and PM1

	Bioplast		Polyshield		PM1	
Property	Mean	SD	Mean	SD	Mean	SD
Hardness (international rubber hardness degrees)	89	0.4	56	0.3	40	1.2
Tear strength (N/mm)	35	3.4	17	4.6	19	0.8
Tensile strength (MPa)	19	0.2	5	0.4	7	0.4
Elongation (%)	2054	4	1110	66	1627	54
100% modulus	3.7	0.2	0.4	0.1	0.7	0.1

SD = standard deviation.

Table 2 Energy Absorption Values

	Stiffness (N/mm)		Energy used (J)		Resilience (J/mm^3)	
Property	Mean	SD	Mean	SD	Mean	SD
Bioplast						
500 N	390	4.4	76	4.6	0.6	0.01
1000 N	443	5.3	670	12.6	2.3	0.01
1500 N	498	8.5	1087	22.3	3.5	0.02
Polyshield						
500 N	171	6.1	221	28.6	0.9	0.07
1000 N	301	8.2	427	29.5	1.6	0.08
1500 N	425	8.8	588	42.1	2.2	0.11
PM1						
500 N	173	4.2	268	8.0	1.1	0.01
1000 N	290	4.6	475	35.4	1.6	0.09
1500 N	398	6.8	597	57.4	2.4	0.15

n = 10.

by linear regression provided a direct quantitative means of estimating the degree of association between 2 variables. All statistical analysis was undertaken using Graphpad Instat software program, version 1.13.

Results

The results of hardness, tear, and tensile properties for PM1, Polyshield, and Bioplast are given in Table 1. Bioplast was significantly harder than Polyshield and PM1 ($P < 0.001$), with Polyshield being significantly harder than PM1 ($P < 0.001$). Bioplast had a significantly higher tear strength than both Polyshield and PM1 ($P < 0.001$). The tensile strength, percentage elongation, and 100% modulus of Bioplast were significantly higher than those of Polyshield and PM1 ($P < 0.001$), with PM1 having a significantly higher tensile strength compared to Polyshield ($P < 0.001$).

Table 2 gives the stiffness, resilience, and energy used of the materials at loads of 500, 1,000, and 1,500 N. The corrected *P* values show that at 500 and 1,000 N Bioplast had a significantly greater stiffness ($P < 0.001$) than both Polyshield and PM1, but between Polyshield and PM1 there was no significant difference ($P > 0.05$). At a load of 1,500 N there were significant differences in stiffness ($P < 0.001$) between all materials.

Bioplast had a significantly lower energy absorption capacity at 500 N than both Polyshield and PM1, with PM1 having a significantly higher value than Polyshield ($P < 0.001$). At 1,000 and 1,500 N Bioplast had a significantly higher energy absorption than both Polyshield and PM1 ($P < 0.001$).

At 500 N, Bioplast had significantly lower resilience than both Polyshield and PM1 ($P < 0.001$); however, at 1,000 and 1,500 N Bioplast had a significantly higher resilience ($P < 0.001$). There was no significant difference between Polyshield and PM1 at 1,000 N; however, the difference was significant at 500 and 1,500 N ($P < 0.001$).

Discussion

Hardness, tensile, and tear tests chosen for the comparison of PM1, Bioplast, and Polyshield have been used in previous studies that have characterized the properties of mouthguard materials.[9–13]

PM1 was significantly less hard than both Polyshield and Bioplast, which implies a lower cross-link density and elastic modulus. The ideal softness for a mouthguard material is not known; however, it is probable that PM1 would be more comfortable than Bioplast.

The evaluation of the tensile properties showed that permanent deformation occurred with all Bioplast specimens. That is, if the tensile forces were relaxed before the specimen fractured, the specimen would not return elastically to its original shape. PM1 and Polyshield exhibited deformation within their elastic limit and failed beyond a certain load by breaking. Though Bioplast had approximately twice the tensile strength of the silicone materials, the results can be misleading because the higher values did not take into account the permanent deformation of the material. This is also reflected in the percentage elongation and 100% modulus results, in which Bioplast had significantly greater values. It is likely that only small tensile forces would be exerted on mouthguards in practical use; therefore, the results suggest that all materials exhibit adequate tensile strength.

The ability of a mouthguard to resist tearing is of practical importance. If a small tear is formed in the material, it is important that it is not readily propagated through the mouthguard. The results show that Bioplast has a significantly higher tear strength than both Polyshield and PM1. The permanent deformation exhibited by Bioplast, however, results in the material breaking in the same manner as the tensile specimens. Although Bioplast has a high value for tear strength, a much lower force would in fact result in permanent deformation.

At the lowest load of 500 N, PM1 had a greater ability to absorb energy than both Bioplast and Polyshield. Therefore, it can be assumed that for loads up to 500 N, PM1 would be the superior mouthguard material in terms of its ability to protect the oral structures from the forces of impact. At the higher loadings of 1,000 and 1,500 N Bioplast absorbs a greater amount of energy than both PM1 and Polyshield, showing it to be a more effective mouthguard material under very high impact forces. The compressibility of the silicone materials appears to give them less capacity to absorb energy at the higher loadings in comparison to Bioplast.

It was concluded that PM1 showed better energy absorption properties than Polyshield and better energy absorption properties than Bioplast at lower impact forces. PM1 was softer and had better tear and tensile properties than Polyshield. The results of the present study suggest that PM1 has good potential for use as a mouthguard material. Further work to improve handling properties and to modify curing times will be carried out before use of the material by participants in contact sports is considered.

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Literature Abstract

Influence of prosthesis material on the loading of implants that support a fixed partial prosthesis: In vivo study.

This study investigated the influence of prosthesis material on the distribution and magnitude of load on oral implants carrying a fixed prosthesis by an in vivo quantification and qualification of this load. Eight patients with 9 three-unit prostheses on 2 implants and 3 patients with 4 two-unit fixed prostheses on 2 implants were selected. Both metal and acrylic resin prostheses were made for the patients. Strain-gauged abutments were used to measure the load on the supporting implants during controlled application of 50 N on selected positions. A significantly better distribution of bending moments was observed with metal prostheses compared to resin prostheses. No other difference was noted. It was concluded that there may be a clinically significant increased risk of bending overload with acrylic long-span prostheses or acrylic resin prostheses with extensions.

Duyck J, Van Oosterwyck H, Vander Sloten J, De Cooman M, Naert I. *Clin Implant Dent Rel Res* 2000;2:100–109. **References:** 42. **Reprints:** Dr Ignace Naert, Department of Prosthetic Dentistry, BIOMAT Research Group, Catholic University Leuven, UZ St Raphaël, Kapucijnenvoer 33, B-3000 Leuven, Belgium—*SP*

Properties of an experimental mouthguard material. R. Jagger, P. Milward, M. Waters. Materials Science, Medicine. The International journal of prosthodontics. 1 September 2000. PURPOSE The purpose of the present study was to evaluate some important mechanical properties of an experimental silicone material (PM1) to assess its potential as a mouthguard material. MATERIALSâ€¦ Expand.Â The bimaxillary mouthguard provides enhanced protection for a participant in contact sports. This article describes the fabrication of a polyvinylacetate-polyethylene (PVAc-PE) bimaxillary mouthguardâ€¦ Expand. 8. Increasing mouthguard thickness improved the mouthguardsâ€™ shock absorption capacities. Also, adding labial inserts increased their preventive qualities in ascending order: Mouthguard with a soft insert (nylon mesh), a hard insert (PETG), air space plus a hard insert (PETG).Â Unfortunately, it is not possible to conduct an experimental in-vivo comparison of mouthguards to compare their effectiveness. In-vitro studies for mouthguard testing have also not yet been standardized [8 , 16].Â The smaller the Youngâ€™s modulus of a mouthguard material is, the softer the pendulum impact will be: Relatively soft mouthguards (i.e., BIOPLAST (EVA) with Youngâ€™s modulus = 15 MPa) absorb impact forces, while hard mouthguard materials tend to disperse the forces [33]. Comparison of Mouthguards Properties. functioning of the chewing organ (speech, food in-take, breathing), and, to an even greater degree, facial esthetics. Beside head gears protecting the head, mouthguards have become an essential fac-tor in sports injury prevention.Â 1986, 14, 77â€“84. [20] Jagger R., Milward P., Waters M.: Properties of an experimental mouthguard material. Int. J. Prosthodont. 2000, 13, 416â€“419. [21] Loehman R., Chan M., Going R.: Optimization of materials for a user â€“ formed mouthguard. Ann. Biomed. Thermal properties of material refer to characteristic behaviors of material under thermal load. Other than these properties, they do play an important role because of their physical properties.There are different thermal properties are thermal conductivity, thermal expansion, specific heat, melting point, thermal diffusivity. Melting point. Melting point is temperature at which material goes from solid to liquid state at one atmosphere.Â Electrical conductivity measure of how well material accommodates movement of an electric charge. It is ration of current density to electric field strength. Electrical conductivity is very useful property since values are affected by such things. OPRO Custom Fit Mouthguards offer the best protection for your teeth and gums. Choose your design or make your own colour choices. Buy your OPRO Custom Mouthguard.Â * D3O is a protective material that absorbs more energy at the point of impact than our standard mouthguard. With D3O, your mouthguard will be up to 50% slimmer without compromising on protection. Upgrade to D3O for just Â£11.99. No Yes.Â You can get a replacement Custom-Fit mouthguard for less than the cost of a boil and bite! To order your additional mouthguard with your OPRO Season Ticket throughout the season, please contact our dedicated OPRO Season Ticket team at info@oprogroup.com. * Discount will be applied to the cheapest mouthguard in the basket for the same wearer automatically.