Journal of Oral Rehabilitation 2002 **29**; 146–150

Properties of athletic mouth protectors and materials

R. G. CRAIG & W. C. GODWIN *School of Dentistry, University of Michigan, Ann Arbor, MI, USA*

SUMMARY The properties of a variety of mouth protectors and sheet materials used to fabricate custom mouth protectors were determined in order to recommend limits for a specification. Hardness, water sorption, water solubility, impact absorption, and tear strength were measured, and limits for these properties were suggested.

KEYWORDS: hardness, impact absorption, tear strength, standards

Introduction

A variety of athletic mouth protectors has been developed over the years including stock, boil-and-bite, latex rubber, hand-and-vacuum-formed from thermoplastic sheets, and vacuum-formed from laminated thermoplastic sheets.

The physical properties of materials for custom-made mouth protectors were reported in an early publication by Craig and Godwin (1967). The materials evaluated were polyurethane, polyvinylacetate-polyethylene, rubber latex and a vinyl plastisol. That publication reviewed the literature related to the incidence of oral injuries in contact sports and the effectiveness of various types of mouth protectors. A summary of the results of these studies concluded that any of the mouth protectors would reduce oral injuries. Although there was no agreement as to the superiority of stock or mouth-formed versus custom-made mouth protectors, opinion surveys of athletes showed a preference for custom-made protectors based on cleanliness, lack of taste and odour, retention, durability, speaking and comfort.

In spite of the fact that mouth protectors have been in use since the 1950s, no American Dental Association/American National Standards Institute or American Standards for Testing Materials specification for mouth protectors or materials has been approved, although they are being developed.

The present study of current mouth protectors and materials was undertaken to provide a basis for establishing requirements for athletic mouth protectors and materials used to fabricate such appliances.

Materials and methods

Materials

The mouth protectors evaluated and their suppliers are listed in Table 1, and the thermoplastic sheets used to fabricate custom mouth protectors are listed along with their suppliers in Table 2. The stock and mouth-formed protectors listed in Table 1 do not include all products, but do represent an adequate sample of the types available.

Some of the mouth protectors in Table 1 have a softer thermoplastic liner and a harder shell, and some do not. These protectors are heated in hot water followed by immersion in cold water to cool the surface before placing them in the mouth and biting down to make an impression of the biting surface of the teeth. Most of the thermoplastic sheets are copolymers of vinyl acetate and ethylene. Softer sheets are made from copolymers containing fewer ethylene segments.

Methods

The test methods used to evaluate thermoplastic sheets included (i) Shore 'A' hardness, (ii) tear strength, (iii) water sorption and (iv) impact testing, while the tests conducted on stock, mouth-formed, and vacuum-formed protectors were (i) Shore 'A' hardness, (ii) water sorption and (iii) impact testing.

Table 1. Stock and mouth-formed mouth protectors

Mouth protector	Supplier
Bop Stopper	Be Safe Products Inc., Roanoke, VA, USA
Den Pak	75 Research Drive, Strathford, CT, USA
Doublegard	Masel Industries Inc., Bristol, PA, USA
Jesco	Jesco Products, Summerville, SC, USA
Scott AllSports	Scott All-Sports Inc., West Monroe, LA, USA
Shield	Brimms Inc., Tonawanda, NY, USA
Tru-Fit	True-Fit Marketing Corporation, Lynn, MA, USA
Shock Doctor	E-Z Gard Industries Inc., Minneapolis, MN, USA

Table 2. Thermoplastic sheets for fabrication of athletic mouth protectors

Product	Supplier
Glidewell	Glidewell Laboratories, Newport Beach, CA, USA
Play Safe	Glidewell Laboratories, Newport Beach, CA, USA
Proform	Dental Resources Inc., Delano, MN, USA
Proform Laminate	Dental Resources Inc., Delano, MN, USA
Volara (white)	Voltek, Lawrence, MA, USA
WorldWide	WorldWide Dental Division, Clearwater, FL, USA
StaGuard	Buffalo Dental Manufacturing, Syosset, NY, USA

Shore 'A' hardness

A Shore Type 'A' Durometer* according to ASTM Durometer Test D2240 [American Society for Testing Materials (ASTM) 1994a] was used to measure hardness. The instrument has a blunt-pointed indenter 0·8 mm in diameter that tapers to a cylindrical shaft of 1·6 mm. The indenter is attached by a lever to a pointer which indicates the hardness on a scale of 0–100. The Shore 'A' hardness was determined on as flat and as thick a surface as possible. The indenter was pressed rapidly into the surface, the maximum instantaneous value was recorded. Both sheets and protectors were stored in water at 37 °C for 7 days, the hardness measured as soon as they were removed from the water bath. Five hardness measurements were made in separate areas to determine the average Shore 'A' hardness.

Tear strength

The ASTM test for the tear resistance of rubber D624 (ASTM 1994b) with tear die 'C', was used. Test specimens were stamped from sheets using a steel die conforming to the dimensions listed in ASTM D624. The cutting edges of the die were sharp and free of nicks, and the apex of the 90° notch was honed to form a sharp corner.

Mouth protector sheets were placed on light weight cardboard supported by a smooth block of hardwood. The cutting edges of the die were positioned perpendicular to the sheets, and the anvil of the die was struck with a heavy hammer to cut and tear samples with a single blow. If the blade did not cut through the sheet with a single blow, the die was not moved and additional blows were struck. The thickness was measured in the area of the notch, and samples were stored in 37 °C water until equilibrium was reached. Specimens were removed from the water bath and immediately clamped in a universal testing machine and loaded in tension at 50 cm min^{-1} until rupture. The maximum load at rupture divided by the thickness yielded the tear strength in N cm^{-1}. Five specimens were tested to obtain the mean value and to calculate the standard deviation (s.d.).

Water sorption

Water sorption on sheet materials and mouth protectors was determined after specimens had come to constant weight (within 0·001 g) in a desiccant containing $CaSO_4$ drying agent (usually 5 days). Dried specimens were placed in 37 °C water and removed daily, dried quickly with a soft tissue, and weighed. This process was repeated until two successive weights within 0·001 g were obtained. Five specimens of sheet materials were used to calculate the mean weight percentage of water sorbed and the standard deviations. Various numbers of mouth protectors, 2–7, for each brand were used.

It should be noted that water solubility was determined on sheets for mouth protectors from two suppliers by drying water sorption samples again to equilibrium in the desiccant. Average solubility was 0·003%, and because of the low values, further testing of additional products was discontinued.

Impact testing

A pendulum impact instrument (in this study, a 10-in-pound Tinius Olsen Impact Tester with a Charpy impact pendulum) capable of providing an impact of 113 N-cm and having a striking surface of the arm of the pendulum of 1 cm wide × 1·5 cm long. The instrument had clamps and mounting for sheets or high-strength stone models supporting the custom-made

*The Shore Instrument and Manufacturing Co., Jamaica, NY, USA.

Table 3. Properties of polymer sheets for athletic mouth protectors

Product	Shore 'A' hardness at 37 °C	Water sorption wt% at 37 °C	Tear strength N cm^{-1} at 37 °C	Impact tests, room temperature % absorbed	Impact tests, room temperature N-cm absorbed
Glidewell					
Thin	76·8 (1·3)	0·14 (0·01)		90·6 (0·5)	102·4 (0·6)
Thick	76·2 (1·3)	0·14 (0·01)	565 (40)	88·0 (0·7)	99·4 (0·8)
PVC	95·0 (0)	0·30 (0·02)			
Play Safe					
Thin	79·7 (0·5)	0·22 (0·01)	471 (4)	88·8 (1·0)	100·3 (1·1)
Thick	75·2 (0·4)	0·25 (0·01)	416 (20)		
Proform	80·8 (0·7)	0·23 (0·03)	410 (14)	80·6 (1·1)	91·1 (1·2)
Proform Laminates					
Clear side	74·6 (1·4)	0·15 (0·01)	325 (16)	83·6 (0·6)*	94·5 (0·7)*
Colour side	75·8 (2·0)				
Volara (white)	25·8 (0·8)	4·1 (0·3)	68·0 (1·9)	87·1 (1·8)	98·4 (2·0)
WorldWide	79·1 (1·8)	0·19 (0·04)	414 (37)	88·3 (0·8)	99·8 (0·9)

*At 37 °C, 87·3 (0·6)% absorbed and 98·6 (0·7) N-cm absorbed.

mouth protectors. The high-strength stone models were obtained by duplicating a maxillary Dentaform model. In the testing of stock or mouth-formed protectors, tape was wrapped around the periphery to form a dam, and the protector was poured in high-strength stone. After setting, the base and heel of the high-strength stone were trimmed perpendicular using a standard dental laboratory model trimmer. The specimens were then allowed to stand until the dry strength of the high-strength stone had been reached. After mounting on the impact machine, the pendulum was raised so it provided an impact of 113 N cm and released. The amount of rebound was recorded and the percentage and the N-cm of the impact absorbed were calculated. Testing was done at room temperature for convenience as testing of Proform[†] sheets at 37 °C showed only a 4% increase in the percentage of impact absorbed over room temperature.

Results

The property data for (i) polymer sheets, (ii) custom fabricated mouth protectors and (iii) stock and mouth-formed mouth protectors are presented in Tables 3–5, respectively.

The Shore 'A' hardness values for most of the sheets were from 75 to 80 except for the PVC poly(vinyl chloride) insert for Glidewell[‡] (95·0) and the foam material Volara[§] (25·8). The hardness of the shells of the stock or mouth-formed mouth protectors varied from 57 to 81 with low values of 32 for Bop Stoppers,[¶] 57 for Shield Youth, and 63 for Den Pak;[**] the remainder had hardness values from 73 to 81. The hardness of liners of Den Pak (26), Doublegard[††] (50), Shield 2000[‡‡] (47·3), and Shock Doctor[§§] (50) were, as expected, substantially lower.

The water sorption values for all sheet materials was low, < 0·3 wt% with the exception of Volara, which was about 4 wt%. The water sorption values of stock or mouth-formed protectors were within this low value except for Bop Stopper (22·6%), made from a polymer foam and those with a liner: Den Pak (0·36%), Doublegard liner (0·98%) and Shock Doctor (0·67%).

The tear strengths of the sheet materials were high, 410–565 N cm^{-1}, except for Volara (white) with a value of 68 N cm^{-1}. Although not reported in Table 3, no significant difference was found in tear strength between dry samples at 37 °C and those at equilibrium with water at 37 °C.

Impact tests at room temperature showed that the sheet materials absorbed 80–90% of the impact and that testing at 37 °C increased the percentage absorbed

[†]Dental Resources Inc., Delano, MN, USA.
[‡]Glidewell Laboratories, Newport Beach, CA, USA.
[§]Voltek, Lawrence, MA, USA.
[¶]Be Safe Products Inc., Roanoke, VA, USA.
[**]Research Drive, Strathford, CT, USA.
[††]Masel Industries Inc., Bristol, PA, USA.
[‡‡]Brimms Inc., Tonawanda, NY, USA.
[§§]E-Z Gard Industries Inc., Minneapolis, MN, USA.

only slightly. The calculated impact absorbed ranged from 90 to 102 N-cm. Impact tests on custom-fabricated mouth protectors (Table 4) from sheets of three suppliers confirmed the values on the sheets with 83–89% absorption of impact except for Glidewell at 73% (probably because they contained the hard insert of PVCs). A recent study by Westerman *et al.* (2000) confirm the decrease when hard inserts are used. The impact absorbed ranged from 83 to 101 N-cm.

Table 4. Impact tests on custom fabricated mouth protectors

Product	% absorption	N-cm absorption
Glidewell		
Clear 3-Layer Laminate	73·4 (2·3)	82·9 (2·6)
Proform		
Blue 0·15	87·0 (0·7)	98·3 (0·8)
Red 0·15	87·8 (0·4)	99·2 (0·5)
Red–White–Blue 0·15 Laminate	83·6 (0·9)	94·5 (1·0)
Red 0·2 Laminate	85·8 (1·6)	97·0 (1·8)
Orange 0·2 Laminate	84·2 (0·8)	95·1 (0·9)
Blue 0·2 Laminate	85·4 (1·7)	96·5 (1·9)
Green 0·2 Laminate	85·2 (1·1)	96·3 (1·2)
StaGuard		
Clear	83·0 (1·4)	93·8 (1·6)
Yellow	89·2 (0·8)	100·8 (0·9)
Blue	85·4 (1·1)	96·5 (1·2)

The impact values on stock and mouth-formed protectors are listed in Table 5. The percentages of impact absorbed ranged from 73 to 93%, with Bop Stopper having the highest value of 93%. The impact absorbed varied from about 80–105 N-cm.

Discussion

Based on these data and the success of these mouth protectors in preventing injuries (Craig & Godwin, 1967), we recommend the Shore 'A' hardness of sheet material and the shell of stock or mouth-formed protectors shall be between 55 and 85, and from 40 to 60 for the liners when measured at body temperature (37 °C). For comparison, Shore 'A' values for polyvinylacetate–polyethylene sheets available in the 1960s were 90 for DuraGuard, 75 for ProTex and 67 for

Table 5. Properties of stock and mouth-formed protectors

Product	Shore 'A' hardness at 37 °C	Water sorption* wt. % at 37 °C	Impact tests, room temperature* % absorbed	Impact tests, room temperature* N-cm absorbed
Bop Stopper	32 (1)	22·6 (0·9)	93 (2)	105 (3)
Den Pak				
Shell	63 (0)			
Liner	26 (1)	0·36 (0·03)	72·3 (3·0)	81·7 (3·4)
Doublegard				
Shell	78 (4)	0·17 (0·02)		
Liner	50 (3)	0·98 (0·07)	86 (0·6)	97 (0·7)
Jesco	81 (1·4)		80·1 (1·4)	90·5 (1·6)
Scott AllSports	75·5 (2·1)	0·17 (0·02)	90·7 (2·0)	102·5 (2·3)
Shield 12's #1050	72·8 (1·2)	0·18 (0·02)	91·0 (1·3)	102·8 (1·5)
Shield 25's #120	74·1 (1·9)	0·16 (0·01)	85·1 (1·0)	96·2 (1·5)
Shield 50's #180	70·9 (1·5)	0·19 (0·03)	90·2 (2·1)	101·9 (2·4)
Shield 2000				
Shell	76·9 (0·8)			
Liner	47·3 (0·5)	0·20 (0·02)	87·5 (1·2)	98·9 (1.4)
Shield Youth	57·0 (1·9)	0·24 (0·02)	92·8 (0·8)	104·9 (0·9)
Shield Lip and Mouth Protector				
Lip	74·5 (0·6)			
Mouth	75·6 (1·1)	0·20 (0·01)	73·1 (7·3)	82·6 (8·3)
Shock Doctor				
Shell	77 (1·4)			
Liner	50 (1·4)	0·69 (0·07)	87 (1)	98 (1)
Tru-fit	77·5 (0·6)	0·17 (0·05)	93·5 (2·1)	105·7 (2·4)

*Values are those for the entire mouth protector.

StaGuard.[¶¶] Gardex, a latex rubber, had a value of 35 when fabricated into a sheet (Craig & Godwin, 1967).

The impact results indicate that most of the mouth protector sheets, the fabricated mouth protectors, or the stock or mouth-formed protectors, when tested as indicated, absorbed more than 80% of the impact which corresponds to about 90 N-cm. However, based on reports of injuries (Craig & Godwin, 1967), a minimum of 70% would probably be acceptable.

Early values for percentage energy absorption are not directly comparable because the energy at impact was 55 N-cm (Craig & Godwin, 1967). However, values of percentage energy absorption on sheets of DuraGuard, ProTex, StaGuard and Gardex were 62, 84, 56 and 37%, respectively. A later study (Godwin & Craig, 1968) of the percentage energy absorption on mouth protectors reports values from 60 to 92% with most of the values being 80 ± 4 except for the latex protector at about 60%.

The tear strengths on the sheet materials, generally were greater than 400 N cm^{-1}; however, materials with values greater than 200 N cm^{-1} at 37 °C should provide adequate service life (Craig & Godwin, 1967). Again, for comparison, tear strength values of early materials were 464, 286, 250 and 286 for DuraGuard, ProTex, StaGuard and Gardex, respectively. A later laboratory study (Godwin *et al.*, 1982) of StaGuard and Proform reported tear strengths of 240 and 320 N cm^{-1}, respectively, with no significant changes in values after being worn by junior football players, ages 9–12.

The water sorption for most mouth protectors and sheets was < 0·3 wt%, and thus a maximum value of 0·5 wt% should provide reasonable freedom from penetration of oral fluids and organisms and allow for easy disinfection. The present values for water sorption cannot be compared with the earlier values because the values for Dura Guard, ProTex and StaGuard were measured in mg cm^{-2} in the earlier study (Craig & Godwin, 1967). If a density of 0·9 g cm^{-3} is taken for the sheets, estimated values for water sorption are 0·04% for Dura Guard, and 0·22% for ProTex and StaGuard.

Based on these suggestions, only Volara sheet, the Bop Stopper protector and the liner of Den Pak would be outside the limits for Shore 'A' hardness. With respect to water sorption, Volara sheet and the Bop Stopper and Shock Doctor protectors absorbed more than the recommended limit of 0·5 wt%. The minimum suggested tear strength of 200 N cm^{-1} was exceeded by all sheet material except Volara. All the sheet materials and custom fabricated protectors as well as the stock and mouth-formed protectors absorbed a greater percentage of the impact than the minimum recommended value of 70%.

The setting of the limits for the properties is based on the values that are available on most products that have a history of success. These limits are somewhat arbitrary and could be changed but additional clinical and field experience is needed before making them more restrictive.

Conclusions

Based on the properties of athletic mouth protectors and materials, recommended limits should be as follows to provide adequate service:

(i) Shore 'A' hardness: Liner 40–60 at 37 °C, Shell 55–85 at 37 °C,
(ii) Water sorption: < 0·5 wt% at 37 °C,
(iii) Water solubility: No requirement,
(iv) Impact: > 70% absorbed at room temperature,
(v) Tear strength: > 200 N cm^{-1} at 37 °C.

References

American Society for Testing Materials (1994a) Indentation hardness of rubber and plastics by means of a durometer, D2240. In ASTM Standards, Vol. 9.01, Philadelphia, PA.

American Society for Testing Materials (1994b) Strength of conventional vulcanized rubber and thermoplastic elastomers, D624-91. In ASTM Standards, Vol. 9.01, Philadelphia, PA.

Craig, R.G. & Godwin, W.C. (1967) Physical properties of materials for custom-made mouth protectors. *Michigan State Dental Journal*, **49,** 34.

Godwin, W.C. & Craig, R.G. (1968) Stress transmitted through mouth protectors. *American Dental Association Journal*, **77**, 1316.

Godwin, W.C., Craig, R.G., Koran, A., Lang, B.R. & Powers, J.M. (1982) Mouth protectors in junior football players. *Physicians Sportsmedicine*, **10,** 41.

Westerman, B., Stringfellow, P.M. & Eccleston, J.A. (2000) The effect on energy absorption of hard inserts in laminated EVA mouthguards. *Australian Dental Journal*, **45,** 21.

Correspondence: Dr Robert G Craig, Department of Biologic and Materials Science, School of Dentistry, University of Michigan, Ann Arbor, MI 48109-1078, USA.

[¶¶]Buffalo Dental Manufacturing, Syosset, NY, USA.