Forces transmitted through EVA mouthguard materials of different types and thickness

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Abstract

Previous studies into sporting mouthguards have been mainly attitudinal or epidemiological. The aim of the present study was to build an impact rig to measure the impact absorbed by mouthguard materials of various thicknesses. The acceleration of the pendulum of the rig was measured and used to calculate the force transmitted to the materials.

Impact tests were also performed on three commercially available mouthguard materials. Tests showed that the force transmitted through mouthguard materials was inversely related to the material thickness.

Mouthguard construction techniques with ethylene vinyl acetate (EVA) plastics should be monitored to avoid occlusal thinning especially on the incisal edges. Thinning results in reduction in the protection offered by the mouthguard.

Key words: Impact force, mouthguard, mouthguard thickness, transmitted force.

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Introduction

Many sporting people are highly competitive. When men and women strive to achieve their maximum sporting potential, injuries can occur. This is especially true in contact sports such as Rugby, Australian Rules football, and hockey where physical clashes are common. Facial injuries also occur in non-contact sports such as soccer and basketball. A three-year study of sporting injuries among soccer players in Finland, showed that 4.3 per cent of the players had sustained injuries.[1] Of these, 6.4 per cent or 552 people experienced maxillofacial and dental injuries. The cost of treating these maxillofacial and dental injuries was high accounting for 13.3 per cent of the costs of all soccer injuries.

Forty-three per cent of the 1990 Wallabies Rugby Union Team had previously sustained a maxillofacial injury.[2] Due to this high injury figure, 96.3 per cent of the team either refused to play without a mouthguard or were very reluctant to play without one. An American survey of 754 school-aged sports participants showed that 12 per cent had sustained oral injuries whilst engaged in sporting activities.[3]

Mouthguards provide a significant level of protection against maxillofacial injury in sports.[4] The purpose of sporting mouthguards is twofold. The primary function is to absorb and spread the energy of any impact. Impacts tend to be fairly localized. The force is absorbed by the mouthguard and spread over a number of teeth reducing the possibility of fractured teeth and/or tooth avulsion.

The second purpose of mouthguards is to protect the lips during an impact. Lacerations to the lips caused by the teeth are a common maxillofacial injury. As well as affording adequate protection, a mouthguard should be retained securely and comfortably, allow breathing and intelligible speech, and have an acceptable taste.[5] Players will still have a strong sense of having a foreign object in the mouth, therefore the mouthguard material should be as thin as possible while still providing adequate protection.

The aim of the present study was to measure and compare the forces absorbed by various mouthguard materials which are available in Australia. The effect of thickness on the effectiveness of the mouthguard material was also investigated.

Materials and methods

Impact testing rig

The impact testing apparatus was similar to that of a Charpy or Izod impact machine as detailed in AS 1544.§ The major difference, however, was that the test unit had

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§Methods for Impact Tests on Metals, 1989.

Table 1. Materials tested and Australian suppliers

Mouthguard material	Supplier
Stay-guard	Rudolf Gunz & Co Pty Ltd, Sydney, NSW
Proform	Bourke Dental Supplies, Moorabbin, Vic
Vangard	Prevident, Hornsby, NSW

a blunt striker and that the acceleration of the pendulum was measured to calculate the peak force transmitted through the mouthguard material. The linear acceleration of the pendulum is directly related to the force through the equation:

$$\text{force} = \text{mass} \times \text{acceleration}.$$

A base with a large mass was required to absorb the momentum of the pendulum. The base and non-swinging components had a mass ten times greater than the swinging mass. Information concerning EVA plastics and their impact characteristics was not available so the design of the swing arm and head was based on estimates. Two pendulums were constructed. The first pendulum was designed to imitate the impact of a cricket ball at around 45 km/h. The energy transmitted by the cricket ball would be approximately 13 joule. The impact face was a flat circle 10 mm in diameter.

The second pendulum was designed after the first set of impact tests caused plastic deformation of the samples rather than only elastic deformation. A pendulum of smaller mass was used to reduce the transmitted force. The energy of impact was reduced to 4 joule. The impact face was also enlarged to 20 mm diameter to reduce local pressure.

The swing arm head was fitted with a type 4335 accelerometer.‖ The accelerometer was connected to a type 2635 charge amplifier.‖ The accelerations were captured on a digitizing oscilloscope (model 54501A),¶ and a Racal Vstore-16 data recorder,** was used to store the data. From the oscilloscope, the data were transferred to a computer file using a Hewlett Packard Basic Program.

All the mouthguard materials tested were ethylene vinyl acetate plastics (EVA) and, using Fourier transform infrared (FTIR) spectroscopy, were shown to be remarkably similar plastics. Table 1 shows the materials tested and the Australian suppliers.

EVA plastics are thermoplastic materials that can be readily moulded to a desired shape after the material is heated. Thermoplastic polymers have a linear or branched type structure with no fixed network structure. The processibility and physical properties of the polymer can be varied by additions such as anti-oxidants, stabilizers, fillers, lubricants and colouring agents.

‖Brüel and Kjaer Australia Pty Ltd, Brisbane, Queensland.
¶Hewlett Packard Australia Ltd, Blackburn, Victoria.
**Racal Electronics, Brookvale, New South Wales.

Table 2. Transmitted forces — high energy

		Transmitted force (kN)					Mean	SD
Stay-guard	4 mm	9.96	8.42	9.16	9.64	11.86	9.81	1.29
Stay-guard	3 mm	12.52	12.82	16.98	12.52	11.86	13.34	2.07
Stay-guard	2 mm	18.11	20.73	21.38	18.70	21.38	20.06	1.55
Stay-guard	1 mm	32.37	37.32	21.02	24.79	34.86	30.72	6.90

Table 3. Transmitted forces — low energy

		Transmitted force (kN)				Mean	SD
Stay-guard	3 mm	8.04	7.60	7.60	7.29	7.63	0.31
Proform	4 mm	7.29	7.29	7.29	7.29	7.29	0.80
Stay-guard	4 mm	7.08	7.02	6.91	7.21	7.05	0.12
Vangard	5 mm	5.98	5.98	5.84	5.84	5.91	0.08

Results

In all, six sample types were prepared for testing. Four types were tested with the high energy impact arm and four with the low energy impact arm. Five pieces of each sample type were tested in the high energy tests and four in the low energy tests.

The results are shown in Tables 2 and 3 along with means and standard deviations. An analysis of variance of each Table revealed significant differences between the different mouthguard materials. Further analysis using Tukey's method of paired comparisons showed, in the high energy tests, significant differences in material properties between Stay-guard materials except between the 4 mm and 3 mm samples. With the low energy tests, no significant differences were shown in the material properties between Stay-guard 3 mm, Stay-guard 4 mm and Proform 4 mm. However, Vangard 5 mm was significantly different from the other three materials.

All statistical tests were conducted at the 0.05 level of confidence.

The first set of high energy tests produced plastic deformation in all the samples. The thicker material transmitted a lower force.

The maximum force transmitted through the mouthguard material was related inversely to the material thickness. For the second set of tests with the low energy impacts, the one and two millimetre thick samples were deleted as the force transmitted through these two samples was considered excessive. Little protection would be afforded by such thin samples of material.

Stay-guard (3 mm) is not commercially available. Test samples were prepared by the authors. The Stay-guard 4 mm material showed a 2.9 per cent improvement in force absorption over the Proform 4 mm mouthguard material. The thicker (5 mm) Vanguard material showed a 16.2 per cent improvement in force absorption when compared with Stay-guard and 18.6 per cent compared with Proform.

Discussion

Three styles of mouthguards are currently available to sportspersons in Australia. The simplest and cheapest mouthguard is the off-the-shelf or stock protector. It is available in pharmacies and sporting stores in limited sizes. The mouthguard is held in place by the player clamping the teeth together. The stock mouthguard can interfere with speech and breathing. The protection it affords the user is generally considered less than that of the other types of mouthguards.

The form of mouthguard most commonly sold is the mouth-formed protector. It is heated in hot water, placed in the mouth, moulded and allowed to set around the teeth and gingivae. When fitted properly, this style of protector provides only reasonable protection but presents some advantages over the stock type. The custom-made mouthguard is fabricated over a model of the wearer's teeth. A dentist or prosthetist is required to take an impression, supervise the pouring of the cast, construct the appliance, and finally fit the mouthguard to the user's mouth. With the labour involved, these are the most expensive mouthguards. However, they are acknowledged as providing the highest level of protection and greatest comfort.

The tests performed in the study were on materials available for the construction of custom-made mouthguards. A comparison of the transmitted forces absorbed by Stay-guard, Proform and Vangard showed that the thicker Vangard was most effective. Stay-guard was superior to Proform.

If the thickness of Stay-guard 4 mm mouthguard material was reduced by 2 mm during fabrication on a dental model, the transmitted force was more than doubled. Even a small reduction in thickness of 1 mm in adaptation resulted in an increase in transmitted force of 34 per cent.

Conclusions

The impact rig was built and proved adequate in the testing of the material samples, giving repeatable impacts and reliable measures of the transmitted forces.

The impact tests showed that the thickness of the EVA plastic mouthguard material was an important factor in reducing transmitted forces to teeth. Of the materials tested, the thicker (5 mm) Vangard was the best impact absorber. A disadvantage with increased thickness, however, is the impairment of speech and awkwardness experienced by the mouthguard wearer. These results have particular relevance in mouthguard construction when adapting blanks to models. Uncontrolled or excessive heat and pressure on the occlusal surfaces can lead to thinning of the mouthguard material on the incisal edges and cusps of teeth resulting in reduced force absorption and impaired function of the mouthguard. This appears to be a greater problem with the infra-red heat/vacuum formed mouthguards than the traditional boiling water/vacuum formed mouthguards.

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