IMPACT TESTING OF 18 ADULT MOUTHGUARDS

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Mouthguards are used by sports participants to reduce dental injuries, but there is limited evidence of effectiveness of mouthguards. This research compared biomechanical impact performance data from 18 adult mouthguards available in New Zealand. Repeated impact testing was conducted on the centre of each mouthguard mounted on a dental model. The best mouthguards when impact absorption scores were considered were Avaro International, Shock Doctor Power Hilo v4.5 (upper/lower), and Signature Proplus Gel Type 3; The worst mouthguards were Shock Tec Classic and Professional moulded 1 senior custom laminated. Our impact results seem in contrast to other studies which support the belief that custom mouthguards provide superior protection against injury than boil-and-bite mouthguards (which are all usually EVA low stiffness).

KEY WORDS: mouthguards, impact testing.

INTRODUCTION: Participants in sports such as rugby, soccer and hockey have a high risk of dental injuries. The wearing of mouthguards has been included in the laws of the game by the NZ Rugby Football Union to reduce this risk (Quarrie, Gianotti, Chalmers et al. 2005). Though the protective ability of mouthguards has been well accepted, controversy continues regarding optimal design (Cummins and Spears 2002). The Punahou School Study demonstrated that mouthguards are effective in reducing injuries to the teeth, such as avulsions, chipped teeth, fractures and luxations, jaw and soft tissues of the mouth (Beachy 2004). Regarding design however "…the necessity for custom-fitted mouthguards (versus boil-and-bite) for athletes in contact sports is brought into question."

Impact testing using drop testers and accelerometers has been conducted for protective equipment. Warnet and Greasley (2001) determined that mouthguards of variable quality had significant influence on force-time traces from impact testing. This study also displayed results that suggest that impact testing of mouthguards demonstrated high reproducibility and therefore reliability in terms of force-time profiles and the number of teeth broken.

A common material used for the construction of mouthguards is ethylene vinyl acetate (EVA). Westerman et al. (2002a) measured the magnitude and direction of forces from impacts to investigate the absorption characteristics of EVA mouthguards of varying air cell volumes and wall thickness between air cells. Using a pendulum impact machine with a velocity of 3 m/s, repeated blows were applied to different areas of EVA mouthguard materials. The impact force was of equivalent energy to a cricket ball travelling at 27 mph (4.4 J). The best mouthguard with air inclusions displayed a 32% decrease in the mean maximum transmitted forces compared with the material of similar thickness, but without air inclusions, which transmitted the largest mean maximum force of 7.56 kN. The air inclusion mouthguard (5.12 kN transmitted mean maximum force) was also the most effective in absorbing energy and reducing transmitted forces, particularly the mean maximum transmitted force in the first impact peak. This was in addition to displaying the greatest initial deceleration, and in contrast to the non-air inclusion mouthguard, no rebound force in the opposite direction, and reduced magnitude of each subsequent impact peak. These findings indicate that the inclusion of air cells has increased mouthguard elasticity.

Greasley et al. (1998) implemented an in-vitro drop test method (10 J) to compare the stock ‘boil and bite’ mouthguards with the custom made variety on a simulated upper jaw. The custom made mouthguards were more effective than stock mouthguards at reducing damage to the teeth. The control trial, where no protection was used, resulted in six broken teeth. The use of a stock mouthguard only reduced this to four and a half broken teeth, whereas the best performing custom mouthguard reduced the number of damaged teeth to only half of a tooth. The in-vitro test utilised in this trial was indeed capable of distinguishing between the performance of mouthguards containing only minor variations in material and design. Based on their results, Greasley et al. included a number of ‘best practice’ recommendations. Interestingly, one of these recommendations was in contrast to the findings of Westerman et al. (2002a), in that air pockets or cushioning devices should not be incorporated as no additional beneficial effects could be expected from them. Another recommendation was that alternating stiff and hard layers should not be used as no benefits were achieved in terms of broken teeth; again in contrast to the recommendations of Cummins and Spears’ (2002).

Cummins and Spears (2002) compared the effects of varying thickness and stiffness of the mouthguard on the magnitude of tensile stresses in the tooth-bone complex when a 500 N static load was impacted on its anterior surface. This load was assumed to be representative of a high force soft object, comparable to a boxing glove. It was found that tensile stress in the bone and enamel was reduced with increased thickness and with increased stiffness of the mouthguards. For the high-stiffness mouthguard, increasing thickness from 1 to 6 mm reduced peak tensile stress from 45 to 31 MPa in bone and 4.1 to 1.6 MPa in enamel. Whereas, for the low-stiffness mouthguards stresses fell negligibly with increases in thickness. Interestingly, the locations of these peak tensile forces were the anterior regions of alveolar bone and of cervical enamel, which Cummins and Spears stated were common fracture sites caused by frontal impacts. It was described that thicker mouthguards deform more and therefore reduce the peak force transmitted onto the tooth by increasing contact time. The finding that stiffness was an important factor in reducing shear forces was significant because most mouthguards are of the low stiffness material EVA, and increasing thickness will not have much of an effect when stiffness is low. This is of concern, considering the popularity of EVA as a mouthguard material, and seriously challenges the suitability of using it for mouthguards, even with published literature supporting EVA with air inclusions (Westerman et al. 2002a) and EVA with increased thickness up to 4 mm (Westerman, Stringfellow and Eccleston 2002b). Analysis of the clinical effectiveness and biomechanical properties of mouthguards is necessary to reduce the rate of dental and maxillofacial injuries.

This study compared the biomechanical impact performance data from 18 adult mouthguards available in New Zealand.

METHODS: Of the 49 mouthguards on the market in New Zealand including junior, youth and senior models, 18 adult mouthguards were tested. Each mouthguard was moulded to fit a Nissin dental simulation model according to the manufactures instructions (in terms of temperature of water and time in the water, and time to mould to the teeth). The custom fitted pressure laminated mouthguard was made by Dental Solutions Lab. The custom EVA mouthguard was provided by AUT’s School of Oral Health. For testing purposes the upper jaw of the dental model was attached to a customised rigid plastic base. The lower jaw of the dental model was attached to the same base via a moveable dental articulation. A series of rubber bands were used to hold the opposing jaws together with the mouthguard inserted between the jaws. These bands also acted to reduce the movement of the lower jaw when impacted such as would be provided by the skin and muscles surrounding the mouth. A drop tester was used to test a frontal central point (in line with the two upper front teeth) on each of the 18 mouthguards. Impact data were determined from the output signal of an accelerometer mounted on the 7.45 kg ‘drop heel’ of the drop tester. The drop heel was released from a height of 5 cm above the mouthguard resulting in impact energy of 12 J. The height was used to match the impact force generated in previous work which indicated that

10-12 J of energy was an appropriate force to assess the performance of mouthguards (Greasley and Karet 1997). A 12 J impact energy 'force' to the mouthguard would be equivalent to a softball hitting the mouthguard at approximately 12 m/s. For each mouthguard three acceleration-time curves were recorded allowing 30 s between drops. Means and standard deviations were calculated for the three drops for each mouthguard. The performance of each mouthguard under impact was quantified using the following measures:

- Start to peak acceleration time – Time from the moment of impact to the point of greatest deceleration for the drop heel (striking object) which indicates the ability of the mouthguard to absorb force over a period of time.
- Minimum to maximum amplitude (Fzi) – This represents the number of gravitational forces applied to the underlying tissue through the mouthguard. A lower number means that the mouthguard is dissipating a greater amount of the impact force and therefore providing better protection.
- Mean loading rate from the slope of curve start to peak (Fzi A), and Maximal loading rate from the maximum derivative from the start to peak curve (Fzi B). Loading rates should be small if underlying tissue is to be protected.

RESULTS: Mouthguards were grouped by 'most protective' (bold font), 'moderate protection' (normal font), 'least protection' (italic font) categories for each variable measured (See Table 1).

The best mouthguards when all impact rank scores were considered were Avaro International, Shock Doctor Power Hilo v4.5 upper/lower, and Signature Proplus Gel Type 3. The best mouthguards when impact scores and price were considered were Repaire+ Senior, Shock Doctor Adult Pro, and Signature Proplus Gel Type 3. The worst mouthguards when impact scores and price were considered were Shock Tec Classic and Professional moulded 1 senior custom laminated.

Table 1: Impact absorption and price results for the 18 adult mouthguards tested; 'most protective' (bold font), 'moderate protection' (normal font), 'least protection' (italic font).

Mouthguard	**Start to peak acceleration time (ms)**	**Min to max amplitude mean (g)**	**Min to max slope A (g/ms)**	**Min to max slope B (g/ms)**	**Price**
3M Nexcare Sports Adult	66.33	0.036	0.00054	0.00103	5.50
Avaro International	**88.00**	**0.028**	**0.00036**	0.00079	9.95
Elastoplast Adult	62.67	0.038	0.00060	0.00105	6.95
Prolon Universal	61.33	0.037	0.00059	0.00104	6.20
Reliance Custom Pro III	61.00	0.037	0.00061	0.00101	35.99
Reliance PromaX I Slimline	**68.00**	0.034	0.00052	**0.00092**	11.99
Reliance ProXtreme II Slimline	59.33	0.034	0.00058	0.00100	17.99
Repaire+ Senior	**69.67**	0.033	0.00048	0.00101	**2.95**
Shock Doctor Adult Pro	64.00	0.033	0.00051	0.00093	9.90
Shock Doctor Gel Max	60.33	0.035	0.00058	0.00102	19.90
Shock Doctor Power Hilo v4.5 (upper/lower)	58.67	**0.026**	0.00044	**0.00076**	49.90
Shock Doctor Power Ultra	**77.67**	0.038	0.00055	**0.00111**	39.90
Shock Tec Classic	59.33	*0.045*	*0.00073*	*0.00124*	6.99
Signature Pro Type 2	62.33	0.038	0.00061	0.00111	13.00
Signature Type 1	58.33	**0.030**	0.00052	0.00090	9.00
Signature Proplus Gel Type 3	59.67	**0.028**	0.00046	0.00078	29.00
Professional moulded 1 senior custom laminated	63.00	*0.041*	*0.00065*	*0.00117*	*200.00*
Professional moulded 2 senior custom EVA	59.67	0.032	0.00054	0.00092	*100.00*

DISCUSSION: Our impact results seem in contrast to some other studies which generally support the belief that custom mouthguards provide superior protection against injury than off-the-shelf boil-and-bite mouthguards (which are all usually EVA low stiffness). However, it was noted that the custom mouthguards fitted better and stayed in place better during the impact testing than the majority of boil and bite mouthguards. At least half of the other boil and bite guards moved during testing. Mouthguards made by dentists are likely to fit better, resist displacement and have more even distribution of materials for absorbing force.

Cummins and Spears (2002) stated that increasing mouthguard stiffness (for instance, laminated thermoplastic such as the Professional moulded 1 senior custom laminated) reduces tensile stress during soft-object collisions as with a heavy opponent. Low stiffness mouthguards (such as boil and bite and Professional moulded 1 senior custom EVA) absorb shock associated with hard-object collisions like baseballs. Composite materials combining characteristics may be the best solution for a variety of impacts. Future combined materials may offer the best solution for a variety of sport.

A limitation of this study which should be noted is that it only assessed the ability of a mouthguard to absorb or deflect impact from the central part of the maxilla. It is also important to consider the level of protection mouthguards provide against side impacts and blows to the chin. Custom guards may perform better due to the close adaptation to teeth, soft tissue and underlying bone, and the more uniform labial, occlusal and palatal thickness. Another limitation of the study is the validity of the values for impact testing using a mouthguard mounted on an unrealistically rigid model. The absolute values cannot be translated to a real life situation. Rather the results reflect a standardised way of testing the cushioning effect of various mouthguards.

Further research is required on the use of integral upper and lower jaw mouthguards. Although this type of mouthguard may provide better force absorption properties, wearing integral mouthguards keep the jaw open farther. This brings the condyles forward thus changing the dynamics of the temporomandibular joint.

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