ORIGINAL ARTICLE

Beneficial effects of air inclusions on the performance of ethylene vinyl acetate (EVA) mouthguard material

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Br J Sports Med 2002;**36**:51–53

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Accepted 12 July 2001

Objective: To investigate the impact characteristics of an ethylene vinyl acetate (EVA) mouthguard material with regulated air inclusions, which included various air cell volumes and wall thickness between air cells. In particular, the aim was to identify the magnitude and direction of forces within the impacts.
Method: EVA mouthguard material, 4 mm thick and with and without air inclusions, was impacted with a constant force impact pendulum with an energy of 4.4 J and a velocity of 3 m/s. Transmitted forces through the EVA material were measured using an accelerometer, which also allowed the determination of force direction and magnitude within the impacts.
Results: Statistically significant reductions in the transmitted forces were observed with all the air inclusion materials when compared with EVA without air inclusions. Maximum transmitted force through one air inclusion material was reduced by 32%. Force rebound was eliminated in one material, and reduced second force impulses were observed in all the air inclusion materials.
Conclusion: The regulated air inclusions improved the impact characteristics of the EVA mouthguard material, the material most commonly used in mouthguards world wide.

Mouthguards are worn by participants in contact sports to reduce damage to the orofacial complex. As well as providing protection to teeth against chipping, fractures, displacement, and avulsion, mouthguards can reduce the incidence of pulpal damage caused by impacts. Research has shown that soft tissue injuries, jaw fractures, and concussions are also reduced in those who wear mouthguards in sports that involve heavy body contact and possible impacts from sports equipment.[1–5]

There are two main types of mouthguard. The most commonly used is the mouth formed mouthguard, which costs less and is made by the user after softening it in hot water and forming it in the mouth with pressure from fingers, tongue, and cheek. Most mouthguards sold world wide are of this type.

The second type is the custom made mouthguard. As the name suggests, it is individually fitted to the wearer and requires a dental impression, dental models, and a forming process based on either vacuum or pressure. Generally accepted by the dental profession as being more effective, this type of mouthguard has the advantage of better fit and therefore greater comfort.

Mouthguards of both types have generally been made from ethylene vinyl acetate (EVA) over the last 30 years. EVA has been shown to exhibit desirable properties for use in mouthguards, such as non-toxicity, minimal moisture absorption, elasticity, and ease of manufacture.[6]

The performance of mouthguards can be determined in three ways: (*a*) the energy absorption of the material from which the mouthguard is formed can be gauged; (*b*) the resistance to deformation can be measured; (*c*) wearer comfort can be assessed. This paper is concerned with energy absorption.

The performance of mouthguard materials can be improved by increasing energy absorption by either thickening the material[7–9] or adding air inclusions.[10] Both will improve energy absorption and reduce transmitted forces. However, increased thickness reduces wearer comfort and affects speech and breathing.[11] The addition of air inclusions improves performance by reducing transmitted forces through better energy absorption without increasing thickness.

The aim of this study was to investigate the impact characteristics and performance of EVA mouthguard materials and, in particular, to identify the magnitude and direction of forces, as well as rebound within impacts, in mouthguard materials with and without air inclusions.

MATERIALS AND METHODS

Repeated blows were applied to different areas of test samples of EVA mouthguard materials but with the same energy of impact (4.4 J) and velocity (3 m/s) using a pendulum impact machine similar to an Izod or Charpy impact pendulum as described in Australian Standards (AS1544, 1989). The force of impact tested has the equivalent energy of a cricket ball travelling at 27 mph, which is capable of damaging teeth and other tissues of the orofacial complex.

The blunt striker on the pendulum head that impacted the test materials was flat and circular with a diameter of 20 mm. The swing head of the pendulum was fitted with an accelerometer, and the transmitted forces through the test materials were determined using the formula, $f = ma$, where f = transmitted force, m = mass of impact pendulum, and a = acceleration of the impact. The accelerometer was mounted on the reverse side to the impact striker face on the pendulum head and aligned in the direction of the impact. In this study, the striker mass was constant, therefore the force transmitted was directly related to the acceleration of the pendulum head. The measurement of acceleration allowed determination of the transmitted forces through the mouthguard material.

Figure 1 shows the relation between impact force, energy absorption, and transmitted forces that occur when mouthguard materials are impacted. The impact force is reduced by the energy absorption of the material to produce a transmitted force through the mouthguard material to the underlying teeth and orofacial tissues.

The control material in the study was 4 mm thick EVA mouthguard material (Stay guard; World Wide Dental Inc, Clearwater, Florida, USA) with a Shore A Hardness of 85. This material was compared with three different samples with air

Abbreviations: EVA, ethylene vinyl acetate

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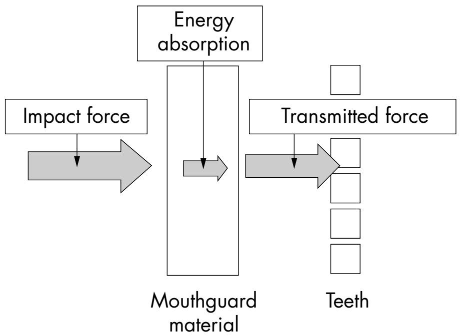

Figure 1 Impact and transmitted forces.

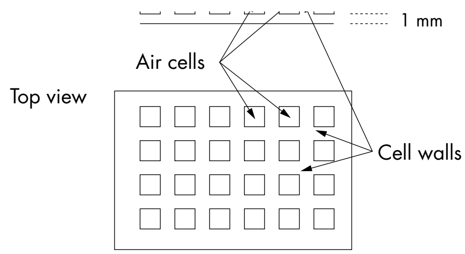

Figure 2 Construction of air inclusion materials.

inclusions of varying air cell volume and wall thickness between air cells. The samples with air inclusions were prepared from the same material as the control and were all 4 mm thick. Test samples of all materials were 50 mm in diameter, each test impact was effected on a different area of the test sample, and all tests were conducted at a room temperature of 24°C.

Figure 2 illustrates the arrangement of air cells in the air inclusion materials. Sample 1 had air cells with dimensions of 2 × 2 × 2 mm with 1 mm thick separating walls. Sample 2 also had 2 × 2 × 2 mm air cells, but the wall thickness between air cells was 2 mm. Sample 3 had larger air cells of 3 × 3 × 2 mm, but the wall thickness was 1 mm. Impacts and their accelerations and decelerations were recorded with an accelerometer (Bruel and Kjaer Australia Pty Ltd, Brisbane, Queensland, Australia), amplified (Bruel and Kjaer, type 2635), and captured on a Hewlett-Packard Digitising Oscilloscope (model 54501; Melbourne, Victoria, Australia) before data storage on a computer. Microsoft Excel (Microsoft Corporation, Seattle, Washington, USA) and Minitab (Minitab Inc, State College, Pennsylvania, USA) were used in data analysis.

RESULTS

Table 1 shows the mean maximum transmitted forces through the mouthguard materials as well as the direction of the impact forces. These transmitted forces are presented with positive or negative values indicating the direction of acceleration or deceleration respectively of the impact pendulum head. A positive value of acceleration indicates a force in the opposite direction to the main impact, while negative values illustrate deceleration of the impact head, which represents a force in the same direction as the main impact. Both acceleration and deceleration were present within the impacts. The results show a 32% reduction in the mean maximum transmitted forces through the best air cell material (sample 3) compared with the material of similar thickness but without air inclusions. The material without air inclusions transmitted the largest mean maximum force (7.56 kN) while sample 3 transmitted the smallest mean maximum force (5.12 kN).

When the acceleration values and therefore the transmitted forces are recorded in the impacts and plotted against time, they show a typical impact curve for a 4 mm thick EVA mouthguard material (fig 3). The early part of the impact shows a maximum transmitted force of 7.56 kN at point A. Within the impact at point B, there was a reversal of force direction, a rebound, and an acceleration within the impact. This was in the opposite direction to the main impact force from the pendulum and measured 1.28 kN. A further change in direction of the forces then took place when a second force impulse occurred at point C, and this measured 1.45 kN. Finally, a second but smaller acceleration took place at point D, representing a second rebound within the impact. Its strength was smaller (0.35 kN) but its direction was again opposite to the main impact force of the pendulum. Figure 4 shows the impacts to both the air inclusion and standard materials and in particular shows the differences between the materials in the forces and their directions within the impacts.

Sample 3 was the best in terms of energy absorption and reduced transmitted forces, particularly the mean maximum transmitted force at point A. The initial deceleration in the material was also longer. This indicates increased elasticity of the sample being tested. Also, with this material, no rebound occurred at B, and the second force impulse at site C was almost halved compared with that of the standard material (0.75 kN). No rebound occurred later in the impact at point D with any of the air inclusion materials.

Table 1 Mean maximum transmitted forces (kN) within impacts and direction of impact forces (positive and negative)

Impact site	Standard	Sample 1	Sample 2	Sample 3
A	–7.56	–5.50	–6.15	–5.12
B	+1.28	+0.25	+0.04	–0.10
C	–1.45	–0.58	–0.84	–0.75
D	+0.35	–0.12	–0.18	–0.19

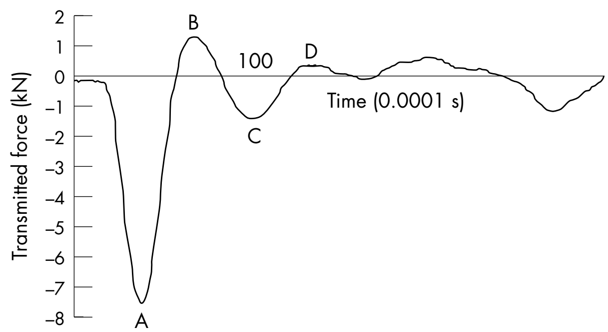

Figure 3 Forces within impacts on standard EVA mouthguard material without air inclusions.

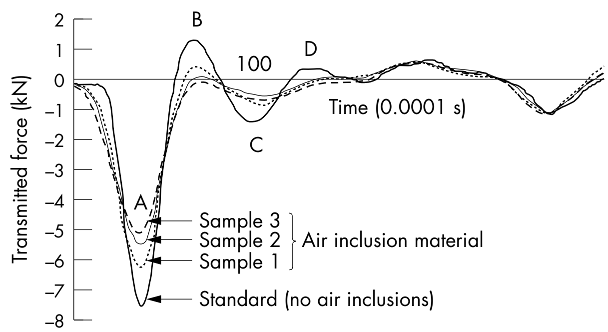

Figure 4 Forces within impacts on EVA mouthguard materials with and without air inclusions.

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A two way analysis of variance of the transmitted forces showed significant ($p<0.05$) differences between the EVA mouthguard materials with and without air at points A, B, C, and D.

DISCUSSION

There have been only relatively minor changes in mouthguards and the way they are made in the last 30 years. Early mouthguards were vacuum formed from single sheets of EVA polymer on dental models. Usually 3–5 mm thick before fabrication, these mouthguards have always provided a superior fit to the mouth formed or do it yourself mouthguards. Pressure laminated mouthguards were later introduced; these were formed by the use of pressure and heat to fuse two, three, or more laminates together on a dental model. Excellent fit, determinable thickness, and an extensive range of colours and colour combinations are features of laminated mouthguards. However, the improvement in performance of laminations is not clear. Data are not available on the energy absorption properties of these mouthguards compared with single sheet materials. It is highly questionable whether the heat and pressure fusion of laminates with the same Shore A Hardness, which is usually around 80, can alter the basic impact characteristics of EVA mouthguard materials. It is important to note that, when laminates in beams and sheet materials are used in the construction industry to resist deformation, the individual laminates have a different grain. When individual laminates are the same material, as they are in mouthguard fabrication, they are equivalent to single sheet material when they are fused together. Therefore the energy absorption, reduction of transmitted forces, and resistance to deformation at the point of impact are no different from those of a single sheet of the same EVA with the same thickness.

The inclusion in laminated mouthguards of harder layers of EVA with higher Shore A Hardness values has been claimed to transfer energy away from the point of contact to adjacent teeth and structures.[12] However, research has shown that the inclusion of a hard layer results in reduced elasticity of the EVA material and consequently a reduction in energy absorption, as well as an increase in transmitted forces at the point of impact.[13] Although promoted as showing enhanced performance,[12] the laminated mouthguards would appear to have properties equivalent to those of single sheet materials.

Air inclusions in EVA mouthguard materials reduce transmitted forces when the material is impacted. A 4 mm thick EVA material (Shore A Hardness of 85) with air inclusions transmits 32% less force than a similar material of the same thickness but without air inclusions.[10]

Another obvious difference between single sheet EVA material and the air inclusion material is the feel of the air cell material. It is softer to finger pressure and to chewing. The air cell material has more "give". The reduction in the maximum transmitted force through improved energy absorption in air inclusion EVA material has been demonstrated, but the question remained whether there were other characteristics within the impact that were different. The use of an accelerometer rather than a force sensor and an impact pendulum allowed an internal view of the impact. Because acceleration and force are directly related when the mass of the impact pendulum is constant, measurement of various accelerations and decelerations describes the internal force directions within the impacts in the mouthguard material.

The positive/negative changes in force direction were an interesting observation in this study. While there was no rebound at site B in the best of the air inclusion materials, a reverse direction force of 1.28 kN occurred within the impact in the standard material. This was just less than one quarter of the major force in the opposite direction at point A. This rebound effect was repeated at point D in the standard material but was not present in any of the air inclusion materials.

Take home message

The impact characteristics of ethylene vinyl acetate (EVA) mouthguard material, commonly used in sporting mouthguards, can be improved by the inclusion of air cells. Regulated air inclusions with relatively large volumes and controlled cell wall thickness improve the performance of 4 mm thick material and reduce transmitted forces by 32%.

This has the effect of a positive/negative force within the material without air. The second force impulse at point C was in the same direction as the primary impact force at point A and was also greater in the standard material.

There was also an increase in the duration of the impacts in the air inclusion materials tested. The main impact force was longer in all of the air inclusion materials, particularly sample 3, than in the standard material. This is a direct result of increased elasticity of the material.

This improvement in performance represents an improved dampening effect. This is the equivalent of a crumple zone in a motor vehicle, where impact energy is reduced by metal distortion and energy absorption of the vehicle when it is involved in an accident.

Conclusions

Air inclusions in EVA mouthguard materials alter the impact characteristics and performance of this commonly used polymer. Maximum transmitted forces through 4 mm sections of EVA can be reduced by as much as 32% by air inclusions with regulated air cell volume and wall thickness. Rebound and second impulse forces are present during impacts on EVA mouthguard materials and both are reduced or eliminated by air inclusions.

Air inclusions in EVA mouthguard material result in improved dampening of impact forces.

This study was supported by a grant from the Australian Dental Research Foundation Inc.

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REFERENCES

1 **Gelbier S**. The use and construction of mouth and tooth protectors for contact sports. *Br Dent J* 1966;**120**:533–7.
2 **Wood AW**. Head protection: cranial, facial and dental in contact sports. *Oral Health* 1972;**62**:23–33.
3 **Wei SH**. Prevention of injuries to anterior teeth. *Int Dent J* 1974;**24**:30–49.
4 **Garon MW**, Merkle A, Wright JT. Mouth protectors and oral trauma: a study of adolescent football players. *J Am Dent Assoc* 1986;**12**:663–6.
5 **Hickey JC**, Morris AL, Carlson LD, *et al*. The relation of mouth protectors to cranial pressure and deformation. *J Am Dent Assoc* 1967;**74**:735–40.
6 **Bishop BM**, Davies EH, von Fraunhofer JA. Materials for mouth protectors. *J Prosthet Dent* 1985;**53**:256–61.
7 **De Wijn JR**, Vrijhoef MMA, Versteegh PA, *et al*. A mechanical investigation to the functioning of mouthguards. *Biomedics: principles and applications*. The Hague: Martinus Nijhoff Publishers, 1982.
8 **Park JB**, Shaull KL, Overton B, *et al*. Improving mouth guards. *J Prosthet Dent* 1994;**72**:373–80.
9 **Westerman B**, Stringfellow PM, Eccleston JA. Forces transmitted through EVA mouthguard materials of different types and thickness. *Aust Dent J* 1995;**40**:389–91.
10 **Westerman B**, Stringfellow PM, Eccleston JA. An improved mouthguard material. *Aust Dent J* 1997;**42**:189–91.
11 **Francis KT**, Brasher J. The physiological effects of wearing mouthguards. *Br J Sports Med* 1991;**25**:227–31.
12 **Hodges J**. Playsafe: the top player in the mouthguard arena. *Laboratory Digest (Fall)* 1996:14–17.
13 **Westerman B**, Stringfellow PM, Eccleston JA. The effect of hard inserts in laminated EVA mouthguards on energy absorption. *Aust Dent J* 2000;**45**:21–3.

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