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EVA mouthguards: how thick should they be?

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Abstract – A major consideration in the performance of mouthguards is their ability to absorb energy and reduce transmitted forces when impacted. This is especially important to participants in contact sports such as hockey or football. The thickness of mouthguard materials is directly related to energy absorption and inversely related to transmitted forces when impacted. However, wearer comfort is also an important factor in their use. Thicker mouthguards are not user-friendly. While thickness of material over incisal edges and cusps of teeth is critical, just how thick should a mouthguard be and especially in these two areas? Transmitted forces through different thicknesses of the most commonly used mouthguard material, ethylene vinyl acetate (EVA) (Shore A Hardness of 80) were compared when impacted with identical forces which were capable of damaging the oro-facial complex. The constant impact force used in the tests was produced by a pendulum and had an energy of 4.4 joules and a velocity of 3 meters per second. Improvements in energy absorption and reductions in transmitted forces were observed with increasing thickness. However, these improvements lessened when the mouthguard material thickness was greater than 4 mm. The results show that the optimal thickness for EVA mouthguard material with a Shore A Hardness of 80 is around 4 mm. Increased thickness, while improving performance marginally, results in less wearer comfort and acceptance.

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Key words: EVA; mouthguards; thickness; transmitted forces

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Mouthguards are used to reduce injuries to the oro-facial complex of participants in contact sports. Broken teeth, soft-tissue injuries, bone fractures and brain concussion are all reduced in wearers of mouthguards participating in sports which produce impacts between players and/or sporting implements (1–6). The method of manufacture can be used to define the two main types of mouthguards currently used in contact sports. The mouth-formed mouthguard is an appliance which is manufactured by the user. The custom-made mouthguard, on the other hand, requires a dental impression, plaster model of the teeth and specialised manufacturing techniques for the fomation of an individual-specific mouthguard. There is little doubt that the superior fit of the custom-made technique provides a more acceptable mouthguard for active sports. However, cost can influence the wearer's choice of a mouthguard. Both mouth-formed and custom-made types are generally made with ethylene vinyl acetate (EVA), which has been shown to have appropriate physical properties for mouthguards (7).

The performance of mouthguards in terms of energy absorption and transmitted forces has been shown to improve with thickness (8, 9) or the inclusion of air-cells (10). Greater thickness detracts from wearer comfort while air-inclusions increase energy absorption without increasing thickness. Thicker mouthguards reduce the capacity for speech as well as interfering with respiratory efficiency (11).

The thickness of finished mouthguards can also be influenced by their fabrication. While the thickness of a mouth-formed mouthguard is influenced by the fabrication to a certain degree, the finished thickness of custom-made mouthguards can be determined accurately and modified during fabrication.

Single-sheet EVA materials with thicknesses between 3 mm and 5 mm are commonly used in the fabrication of custom-made mouthguards. Thickness can be adjusted by removing materials during finishing or limiting thinning during manufacture. The pressure-laminated manufacturing process allows the thickness of finished mouthguards to be adjusted with extra laminates or by material removal during formation. The manufacturing process can also directly influence the thickness of materials over the incisal edges and cusps in custom-made mouthguards either by thinning when heating the material or by stretching the mouthguard material on pull-down.

Various authorities have identified what they consider to be ideal thicknesses of mouthguards, particularly inthe areas of high impact stress, the incisal edges and cusps. The question which needs to be asked, however, "is there an ideal thickness of EVA materials in these two areas?" The aim of this study was to compare the transmitted forces through various thicknesses of the most commonly used EVA mouthguard materials, when impacted with identical forces capable of damaging the oro-facial complex.

Material and methods

The ethylene vinyl acetate mouthguard material used in this study was Drufosoft® (Dreve-Dentamid GMBH, Unna, Germany), which had a Shore A Hardness of 80. The various thicknesses tested included 1, 2, 3, 4, 5 and 6 mm sections. The test samples of each thickness were impacted eight times and each impact was on a new surface of the test material. The test impacts were produced by a pendulum impact machine similar to an Izod or Charpy impact pendulum as described in Australian Standards (AS1544, 1989). The strike face on the pendulum was flat and circular with a diameter of 12.75 mm. Transmitted forces through the EVA mouthguard materials were recorded with a force sensor (model 2084; PCB, Depew, NY, USA) with a signal amplifier, conditioner (model F484 B06; PCB, Depew) and analyser (model 2200; Diagnostic Instruments, Livingston, Scotland).

Data and statistical analysis used Microsoft Excel® (Microsoft Corporation, Seattle, WA, USA) and Minitab® (Minitab Inc, State College, PA, USA). Statistical tests were conducted at the 0.05 level of confidence. The energy of impact was 4.4 joules with a velocity of 3 meters per second. All tests were conducted in an air-conditioned room at 24°C.

Table 1. Mean maximum transmitted forces (kN)

Thickness (mm)	Mean maximum transmitted force
1	Not recorded
2	15.70
3	11.40
4	4.38
5	4.03
6	3.91

Results

Table 1 describes the mean maximum transmitted forces through the various thicknesses of mouthguard material. The greatest transmitted force was through the 1 mm samples but results were not recorded as the force exceeded the performance envelope of the force sensor. The 1 mm section material showed little energy absorption and minor reductions in trasmitted forces. The greatest recorded transmitted force was through the 2 mm material, which transmitted a force of 15.7 kN. The smallest transmitted force was through the 6 mm material, which transmitted a force of 3.91 kN. Fig. 1 shows the mean maximum transmitted forces through the materials when measured

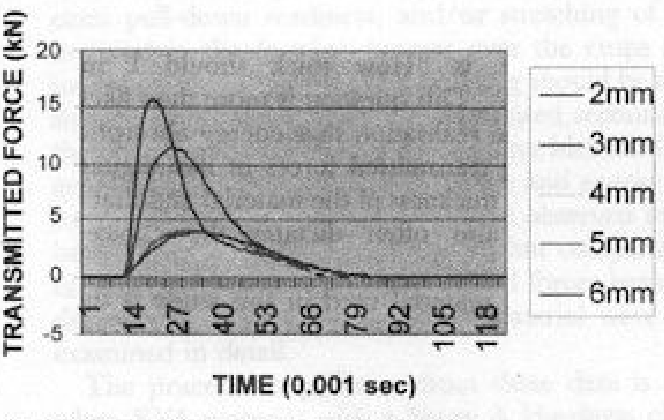

Fig. 1. Mean maximum transmitted forces (kN).

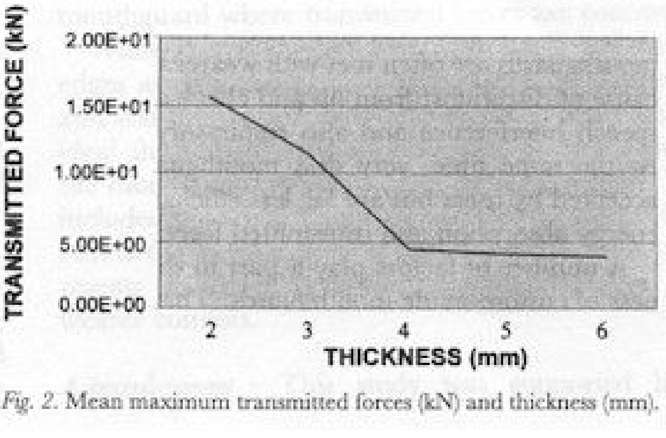

Fig. 2. Mean maximum transmitted forces (kN) and thickness (mm).

by the force sensor with time and are shown graphically.

This study shows that 2-mm-thick EVA provides little protection in terms of energy absorption, as it transmitted a force of 15.70 kN, nearly four times the force through the 4 mm material with the same impact force. Similarly, while there was an improvement of 27.4% in the transmitted forces over the 2 mm material, the thicker 3 mm material transmitted more than twice the force that was passed through the 4 mm material when impacted with the same force.

Further increases in mouthguard material thickness from 4 mm to 5 mm and 6 mm showed smaller improvements in energy absorption and transmitted forces with 8% and 10.7% less force, respectively, than the 4 mm material. This reduction in transmitted forces was not statistically significant in the thicker materials. Fig. 2 compares the transmitted forces through the materials with different thicknesses.

An analysis of variance showed there were significant differences between the transmitted forces for the various thicknesses. Further, there was a significant difference between the 2 mm and 3 mm thicknesses compared to the 4 mm, 5 mm and 6 mm thicknesses, while there was not a significant difference between the 4 mm, 5 mm and 6 mm thicknesses.

Discussion

A commonly asked question by fabricators of mouthguards is "How thick should I make a mouthguard?" This question is more than likely a response to the realisation that energy absorption and the resulting transmitted forces in mouthguards are linked to the thickness of the material and that wearer acceptance also often dictates the choice of a mouthguard.

The EVA material used in this study is the most commonly used polymer in the manufacture of mouth-formed and custom-made mouthguards world-wide. With a vinyl acetate composition which provides a Shore A Hardness of 80, its non-toxic nature, elasticity and ease of manufacture make it eminently acceptable as a mouthguard material.

The fabrication of mouthguards is often a compromise between thickness and wearer comfort. Thicker mouthguards are often met with wearer resistance because of discomfort from lip and cheek displacement, speech interference and also respiratory restrictions. At the same time, very thin mouthguards are well accepted by users but are far less efficient in terms of energy absorption and transmitted forces.

A number of factors play a part in the final thickness of custom-made mouthguards. They include the fabricator's perception of ideal thickness and the user's acceptance of the thickness of the finished mouthguard. As well, various authorities advocate different thicknesses. The Australian Dental Association (The Practical Guides, 6th edn., ISBN 0 909961 34 4, Sydney) suggests a thickness of 2 mm on the occlusal aspect of mouthguards. This recommendation is for a thickness of 2 mm over incisal edges and cusps with a 4 mm thickness over the labial surface of the mouthguard. This recommendation seems to reflect a notion that impacts to teeth will come as direct blows from an external source. Incisal edge and cusp coverage is important because of the danger not just of a direct blow to these areas but also from a indirect impact from opposing teeth. Most mouthguards cover the maxillary teeth only. However, a blow to the mandible can result in involuntary closing of the mandible with impacts onto the cusps and incisal edges of both maxillary and mandibular dentitions with resulting damage.

A laminated-mouthguard manufacturer (Playsafe, Melbourne, Australia) classifies its product range through perceived impacts in various levels of contact sports. Thicker mouthguards are advocated for the more extreme sports and for older participants.

The manufacturing process itself can directly influence the thickness of mouthguard material over cusps and incisal edges in finished mouthguards. When the mouthguard material is used as a diaphragm which separates suction or pressure and a dental model, thinning of the materials takes place either by thinning-on-heating, when "droop" indicates pull-down readiness, and/or stretching of the material in the forming process over the cusps and incisal edges. Either way, this thinning should be considered in the final product in the raised sections on the dental models. Previous studies have identified the general association between thickness and energy absorption. Thicker mouthguards were observed to be better interms of energy absorption but comparisons of energy absorption and transmitted forces between different thicknesses of the same material were not examined in detail.

The practical implication from these data is that when EVA material with a Shore A Hardness of 80 is used in mouthguard fabrication, there appears little advantage in increasing the thickness of material to more than 4 mm at any point in the formed mouthguard where transmitted forces are concerned.

While this study has identified cusps and incisal edges as critical areas in terms of energy absorption and transmitted forces, 4 mm seems to represent an ideal thickness that should be used at any point in the mouthguard which is likely to be impacted. This includes the labial flange of the mouthguard, which covers the labial aspects of anterior teeth. It also represents a useful compromise with thickness and wearer comfort.

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