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Impact absorption and force dissipation of protective mouth guards with or without titanium reinforcement

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ABSTRACT

Background. Mouth guards are used to reduce the risk of experiencing dental injuries. Various individual and commercial designs are available.
Methods. The authors prepared 20 artificial maxillae from a polyether-resin to simulate teeth, jaw bone and gingiva. They customized two designs of mouth guards by using stone models from impressions of the artificial maxillae; one (n = 10) was constructed of four layers of ethylene vinyl acetate (EVA) (total thickness = 4.0 millimeters) (group EVA), and the other (n = 10) was constructed of EVA with an intermediate layer of 1.0-mm–thick sheet titanium from the left maxillary canine to the right maxillary canine (total thickness = 4.0 mm) (group EVA-Ti). They used a drop-weight impact testing machine (DTM 1000-S, Omnipotent Instruments, Seremban, Negeri Sembilan Darui Khusus, West Malaysia) for a frontal impact with 1.7 kilograms of mass dropped at 0.34 meter per second. The force of the drop was verified by means of a laser Doppler vibrometer (laser model OFV-323 and controller model OFV-3020, Polytec, Irvine, Calif.) to calculate the absorbed energy. They used a high-speed camera (FastCam APX-RS, Photron, San Diego) to obtain images of energy dissipation over the length of the mouth guard.
Results. The mean effective total impact energy that reached the maxillae–mouth guard models was 5.66 (standard deviation [SD], 0.035) joules. The mean absorbed energy in group EVA was 4.39 (0.023) J (77.8 percent of total impact energy). The mean (SD) absorbed energy in group EVA-Ti was 4.28 (0.013) J (75.9 percent of total impact energy). The mean (SD) total dissipated energy was 1.26 (0.21) J in group EVA and 1.36 (0.11) J in group EVA-Ti. The mean (SD) transmitted energy for the mouth guards was 1.08 (0.19) J in group EVA and 0.99 (0.05) J in group EVA-Ti. There was no statistically significant difference between the groups in terms of any energy transmission or absorption.
Conclusion. The results of this study suggest that an additional intermediate titanium layer in the anterior area of a mouth guard may not have a beneficial effect on impact absorption and dissipation.
Practical Implications. The use of mouth guards is a general requirement for physical sports activities, and it should be strongly encouraged for people playing contact sports in particular. However, the authors' results indicate that the total thickness of a mouth guard is more important than is the use of an additional intermediate layer (in this case, titanium).

Key Words. Mouth guards; mouth injuries; mouth protectors.
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Mouth guards are used primarily to reduce the risk of experiencing dental injuries in contact sports.[1,2] In addition, they are used by people playing team and other noncontact sports to protect teeth, periodontal tissues and the temporomandibular joint from excessive occlusal forces.[3-5] An appropriate mouth guard design will support the vestibule and underlying bone as well as protect the alveolus. A particular mouth guard's functional ability to protect against excessive force depends on the way in which it can act as a shock absorber, specifically of forces that would be transmitted to the teeth and the supporting tissues.[6]

Most mouth guards are made from ethylene vinyl acetate (EVA), which has been shown to have physical properties suitable for mouth guard design.[7] A measurable performance factor for increased protection is the amount of energy that is absorbed by and dissipated through a mouth guard. Study findings have suggested that the thickness of EVA should be between 3 and 4 millimeters to promote adequate impact absorption.[2,8] Besides using only EVA, investigators undertook various other approaches to increase the effectiveness of mouth

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guards, including use of laminate layering, air-filled cavities, Sorbothane (Sorbothane, Kent, Ohio) inserts and hard acrylic inserts.[9-14] However, controversial results have been found for the overall energy absorption of mouth guards on and the distribution of residual energy over the maxillary arch.[14-16]

Overall, studies of athletic mouth guards vary greatly in terms of the focus of the investigation and of methodology. Knapik and colleagues[17] published a review of studies of mouth guards. In general, they found that available studies could be divided into investigations of physical properties of mouth guard materials and studies of shock-absorbing capabilities in context with mouth guard design features and the influence of particular designs on mouth guards' protective qualities.[17]

Common testing designs for the shock absorption of mouth guards include pendulum devices that measure impact energy by means of fiber Bragg grating sensors[18,19] or strain gauges.[20]

Particularly in contact and team sports, impact to jaws and teeth frequently occurs from a frontal direction, forcing a blow that directly affects the maxillary teeth. However, the actual impact on teeth and alveolar bone, such as the potential damage caused by the energy of a blow that is not absorbed by a mouth guard, is less well known.

The objective of our study was to evaluate a novel design for testing athletic mouth guards, involving the use of artificial jaws and teeth, to compare standard EVA mouth guards with a commercially available EVA-titanium (EVA-Ti) mouth guard design for their effectiveness in absorbing and dissipating energy from an impact received from a frontal direction.

METHODS

We prepared 20 artificial maxillae from a modified polyether-based synthetic resin to simulate teeth, jawbone and gingiva (Figure 1). We mixed the polyether-resin with calcium carbonate and barium to replicate the hard-tissue structures of the teeth; the pulp chamber contained a cellulose-based filling with additions of aniline (red dye) and other organic pigments. For the bone, we used polyether-resin with an initial particle size of 0.02 mm to achieve a porous structure in the internal layers and a Shore hardness close to that of bone. The gingiva also was made of polyether-resin with aniline used as a color additive, yet in a higher-viscosity mixture (15.000 centipoise) than that used to replicate bone and with a Shore hardness of A-10 (on the Shore A Hardness Scale, a gauge of a material's hardness, human skin is 10) (IM do Brasil, São Paulo) (Figure 1). We took silicone impressions from the individual 20 maxillae by using impression material (Optosil Comfort Putty and Xantopren VL Plus, Heraeus Kulzer South America, São Paulo) and then cast stone models from the impressions. We produced custom-made mouth guards from the individual stone models.

We prepared two types of mouth guard designs (Figures 2 and 3). One type (group EVA) was made from four layers of EVA, with a total thickness of 4.0 mm (group EVA, n = 10). The other type (group EVA-Ti) also was made from EVA and had a total all-around thickness of 4.0 mm, but it incorporated an intermediate layer of sheet titanium of 1.0-mm thickness replacing one layer of EVA and of approximately 2.0-mm width (curved around the incisors) in the area from the left maxillary canine to the right maxillary canine (n = 10) (Figure 3). We produced the individual mouth guards after randomly assigning 10 stone models to each group. Both types of mouth guards were made by Forcefield, São Paulo.

We mounted the maxillae–mouth guard models in a drop-weight impact-testing machine (DTM 1000-S, Omnipotent Instruments, Seremban, Negeri Sembilan Darui Khusus, West Malaysia) by using a custom attachment. All 20 samples were subjected to impact once frontally at an identical impact zone in the anterior area by a hammer that had a mass of 1.7 kilograms and was dropped at 0.34 meter per second. Before the individual test, we used a laser unit to ensure the exact positioning of the artificial maxilla to prevent any discrepancies in impact force and direction between samples. We then verified the exact force of the final drop by using a laser Doppler vibrometer (laser model OFV-323 and controller model OFV-3020, Polytec, Irvine, Calif.) to be able to calculate the absorbed energy exactly. We used a high-speed camera (FastCam APX-RS, Photron, San Diego) to obtain images of the energy dissipation over the length of the mouth guard and to register in detail what had happened to the mouth guard during the impact. We measured results for the total impact energy, the energy absorbed by the mouth guard and the dissipated energy (from the portion of the total impact energy that the mouth guard did not absorb).

We processed the data by using data analysis software (MATLAB, MathWorks, Natick, Mass.). We performed statistical analysis by using a *t* test at a significance level of $P \leq .05$.

RESULTS

None of the mouth guards or models from either group fractured during the experiments. For both groups, the mean (standard deviation [SD]) effective total impact energy that reached the maxillae–mouth guard models as a result of the 1.7-kg hammer drop at 0.34 m/second was 5.66 (0.035) J. The mean (SD) absorbed energy in group EVA was 4.39 (0.023) J, or 77.8 percent of the total impact energy. The mean (SD) absorbed energy in group EVA-Ti was 4.28 (0.013) J, or 75.9 percent of the total impact energy. There was no statistically significant difference between the groups. The mean (SD) total dissipated energy in group EVA was 1.26 (0.21) J and in

ABBREVIATION KEY. EVA: Ethylene vinyl acetate. **EVA-Ti:** Ethylene vinyl acetate–titanium.