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Are all mouthguards the same and safe to use? Part 2. The influence of anterior occlusion against a direct impact on maxillary incisors

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Abstract – The purpose of this study was to clarify the influence anterior occlusion, of mouthguards, has on protecting against a direct collision to the maxillary anterior teeth. In other words, the support mandibular dentition has when wearing a mouthguard. Two types of mouthguards were used for this study, one with an appropriate anterior occlusion or a mouthguard with positive anterior occlusion (MGAO+) and another which was a single-layer mouthguard lacking the same occlusion or a mouthguard with negative anterior occlusion (MGAO−) but with the same thickness on the buccal side. The instruments used for testing were a pendulum-type impact device with two interchangeable impact objects (a steel ball and a baseball), with a plastic jaw model having artificial teeth. Four testing conditions were observed: one with the jaw open without a mouthguard (Open NoMG), the second with the jaw clenching (loaded with 30 kg weight) without a mouthguard (Clench. NoMG), the third with the jaw clenching with MGAO− (Clench. MGAO−) and the last with the jaw clenching with MGAO+ (Clench. MGAO+). The results are as follows: both types of mouthguards showed the effects in reducing the distortion of the teeth. However, the effect was significantly obvious (steel ball = about 57% shock absorption ability, baseball = about 26%) in the mouthguard with anterior occlusion or support by lower dentition through mouthguard (Clench. MGAO+) than Clench. MGAO−. Thus, the influence of anterior occlusion of mouthguards or the support of mandibular dentition through wearing a mouthguard (MGAO+) is indispensable in reducing the impact force and tooth distortion. The results of this research should further contribute to the establishment of guidelines for safer mouthguards.

It has been reported that, during a single athletic season, there is a 1 in 10 chance of suffering a facial or dental injury, and the lifetime risk of such an injury is estimated to be 45% (1). It is also estimated that an athlete is 60 times more likely to sustain a dental injury while not wearing a mouthguard (1). Thus, there is an expectation that mouthguards can help prevent these types of injuries. The positive effects of wearing a mouthguard are indicated in various epidemiological surveys (2–6) and experiments (7–30) (Table 1). These previous findings can be classified into three categories: testing the impact absorption ability of the mouthguard material itself (7–18), testing the mouthguards' effect against a direct blow to the dentition (19–22) and testing the effect of a mouthguard against an indirect blow to the mandible and so on (23–30). Most of these studies revealed that various mouthguards have, to some degree, an injury-preventing effect. Nevertheless, many sports-related dental and oro-facial injuries can still occur regardless of whether a mouthguard is worn or not. The obvious cause of injury in mouthguard-wearing cases is when the impact force far exceeds the protective capability of a mouthguard. However, the ordinal impact power in sports is estimated to be smaller than that found in traffic accidents, etc. (31). Because of this, many sports-related oro-facial injuries are assumed to be preventable by the use of an appropriate mouthguard.

It is also well known that approximately 90% or more of oro-facial injuries involve the incisors of the maxilla (2–6). The injury prevention characteristics of mouthguards against frequent injures, which are often caused by a direct blow to the teeth, have three factors that are thought to be effective: first, the impact absorption or dissipation effects through the mouthguard material itself, which covers the maxillary incisors' buccal surface (mandibular incisors when a mouthguard is used in mandibular for severe mandibular protrusion cases); secondly, the reinforcement effect of the mouthguard material covering the lingual surface of the maxillary incisors; and thirdly, the support of the maxillary teeth, dentitions and the alveolar bones by the mandibular dentition through the mouthguard. This third effect can be achieved only when mouthguards have a fully balanced occlusion and used while clenching as one of the action of a risk hedge. Thus, there might be a problem in the injury prevention effects of commonly used mouthguards, as many of them being used now are the boil and bite types made by the players themselves, so a maximum degree of safety cannot be achieved using such a method. In other words, a custom-fit or vacuum-type mouthguards do not necessarily provide appropriate occlusion, especially, when players have malocclusion such as an elongated molar or premolar tooth, an open bite, a large overjet or maxillary protrusion, etc. Therefore, in these cases, only mouthguard material added onto the lingual side will provide a third preventive effect, achieved by having an appropriate full balanced occlusion.

However, former studies, concerning the mouthguards' impact absorption ability, have not placed importance on how effective it is. Thus, the purpose of the present study is to clarify the influence of anterior occlusion (a fully balanced occlusion) of mouthguards, or the support of mandibular dentition through mouthguards, on safety against a direct impact force applied to the maxillary anterior teeth's buccal surface. In this study, two types of mouthguards were used, one with the appropriate anterior occlusion and the other with a commonly used one-layer-type mouthguard without appropriate occlusion but with the same thickness against the buccal sides. The testing equipment used in this study consisted of a pendulum impact testing device used in a series of studies (17, 18) and the plastic jaw model with artificial teeth. Because various impact objects influence the shock power and shock absorption ability differently, two impact objects, a steel ball with sharp impact power and a higher energy-absorbing baseball with dull impact power and a lower energy-absorbing rate (17, 18), were used. It is hoped that the results of this research will further contribute to the establishment of guidelines for the design of safer mouthguards.

Material and methods

A pendulum device apparatus was constructed similar to that of a Charpy or Izod impact machine with interchangeable impact objects (17, 18) (Fig. 1). Two mobile impact objects were selected for tests: a steel ball and a baseball. The weight and durometer hardness (except for the steel ball) were measured. The weights of the impact objects were: 172.5 g for the steel ball and 147.3 g for the baseball. The durometer hardness for the baseball was 82.5. The axis length of the pendulum was about 50 cm, and the apparatus was adjusted to hit the central surface of the right central incisor of an artificial jaw model (D18D-500H; Nisshin, Co., Ltd, Tokyo, Japan) at a bottom point. Consequently, impact forces were transmitted to acrylic resin teeth themselves or reduced by ethylene vinyl acetate (EVA) mouthguards, which were measured with a strain gage fixed on the buccal cervical aspect of the impacted tooth (Fig. 1). An electromagnet was used to control the release of the impact ram in order to concentrate the force over a small area and make a distance with the target precise (Fig. 1).

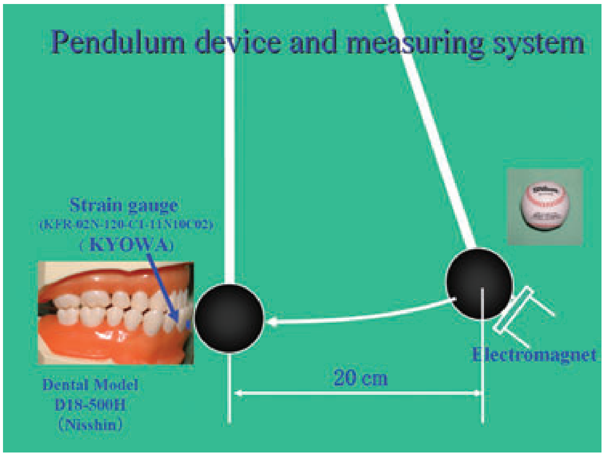

Fig. 1. Specially designed device to measure the shock absorption ability of mouthguards.

Measured mechanical forces, by means of a strain gage, were amplified with a Strain Amplifier (Kyowa DPM-712B, Tokyo, Japan) and converted into electric output voltage, which was stored as data on an Oscillographic Recorder (Kyowa RDM200A). After this, the results were first analyzed with a personal computer (PC-SJ145V; Sharp Co., Ltd, Tokyo, Japan), and then analyzed with a Tooth Piece Amisystem (Amisystem Co., Ltd, Tokyo, Japan).

Mouthguard blanks used were Drufosoft (Dreve-Dentamid GMBH, Unna, Germany) with 3-mm thickness. Two types of mouthguards were used as test samples: one was a two-layer type with proper anterior occlusion [with occlusal support of the mandibular front teeth through the use of a mouthguard, hereafter referred to as MGAO+ (Fig. 2, left)], and another was a

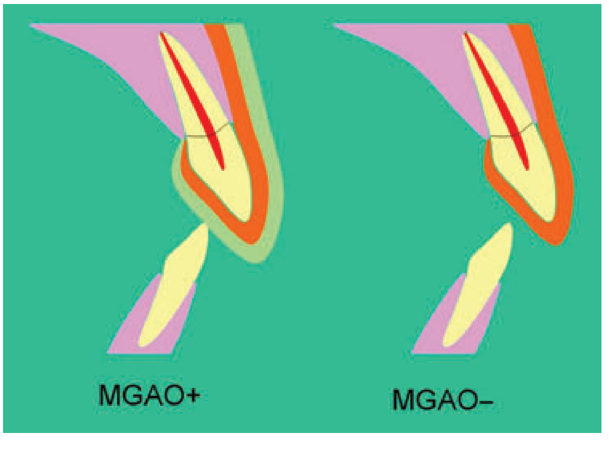

Fig. 2. Left: mouthguards with proper anterior occlusion (or the occlusion with support by the mandibular front teeth through the mouthguard – MGAO+). Right: mouthguard without those of occlusion or support (MGAO–).

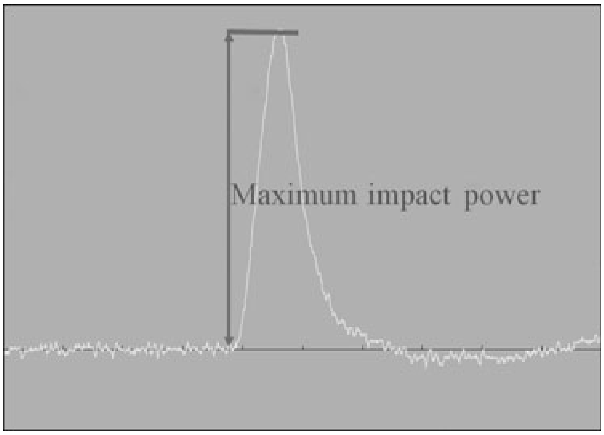

Fig. 3. Analysis method: measuring the height of the biggest impact response as the maximum impact power.

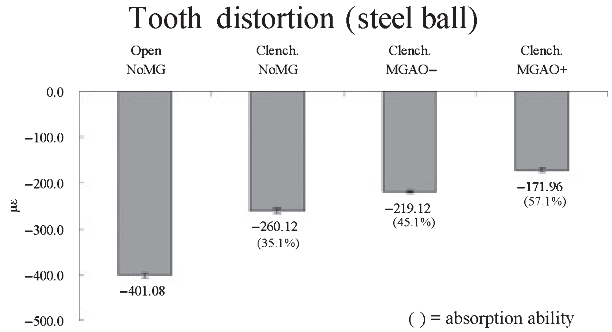

Fig. 4. Tooth distortion occurred by the impact force of a steel ball: the effects of the mouthguard and clenching were admitted. The effect was obvious in the mouthguard with Clench. MGAO + .

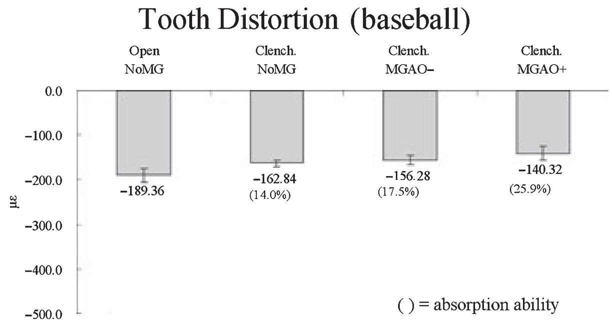

Fig. 5. Tooth distortion occurred by the baseball ball impact: the effect was a little smaller compared with the steel ball, but the tendency was almost the same.

one-layer type without occlusion or support [MGAO− (Fig. 2, right)]. Both mouthguards were fabricated by means of a Dreve Drufomat (Type SO; Dreve-Dentamid) air pressure machine on a stone model impressed with an alginate material. Actual thicknesses of the buccal side at the impacted point for both the MGAO + and MGAO− after adjustment were approximately 1.5 mm. Three mouthguards were made, and impact tests were carried out three times on each mouthguard. Testing conditions were with the jaw open and without a mouthguard, as a control test (Open NoMG), with the jaw clenching (loaded by 30 kg weight) without a mouthguard (Clench. NoMG), with the jaw clenching with an MGAO− (Clench. MGAO−) and the jaw clenching with MGAO + (Clench. MGAO +). To apply the weight, the model was mounted upside down (Fig. 1).

As shown in Fig. 3, the height of the first impact was analyzed as the transmitted force (or the maximum impact). Means and SDs were calculated for each variable evaluated. Statistical comparisons were made using a one-way analysis of variance (ANOVA) test followed by a Tukey multiple comparison tests for further comparisons between sensors and impact objects [$P < 0.05$, using SPSS® (SPSS Japan Inc., Tokyo, Japan)]. All tests were conducted in an air-conditioned room at 25°C.

Results

The maximum impact force of four different tests using a steel ball and a baseball records the distortion, as shown in Figs 4 and 5. The results of the distortion diminishing rate calculated against an Open NoMG as the control are also shown. In the steel ball, maximum 401.08 $\mu\epsilon$ was obtained with Open NoMG, and Clench. NoMG was 260.12 $\mu\epsilon$ (distortion diminishing rate is = 35.1%). The effect of the mouthguard was admitted even with Clench. MGAO− was 219.12 $\mu\epsilon$ (45.4%) and Clench. MGAO + was 171.96 $\mu\epsilon$ (57.1%). In the baseball, maximum 189.36 $\mu\epsilon$ was obtained with Open NoMG, and Clench. NoMG was 164.32 $\mu\epsilon$ (14.0%). And Clench. MGAO− was 156.28 $\mu\epsilon$ (17.5%) and Clench. MGAO + was 140.32 $\mu\epsilon$ (25.9%). Statistical analysis (ANOVA) showed differences in four tested conditions in both impact objects ($P < 0.05$) (Tables 2 and 3). Furthermore, there were significant differences between all conditions except for between Clench. NoMG and Clench. MGAO− (Tukey multiple comparison tests, Tables 2 and 3).

Discussion

Most of the tests confirmed that the shock absorption ability of a mouthguard is proportional to its thickness. Therefore, it is the thickness, energy-absorption ability and how effective it is against a direct impact to the anterior teeth that determine its beneficial qualities. On the other hand, it is thought that the insufficient occlusion of a mouthguard might cause temporomandibular arthrosis, which also reduces safety (30). Problems associated with the occlusion of the mouthguard have not been considered deeply enough until now, especially based on the fact that many inexperienced players make their own mouthguards by themselves. With the market type currently available, to do this, it is difficult to give the mouthguard the appropriate occlusion needed. Moreover, even if the vacuum custom-made type with approximately 3-mm thickness was used, the material becomes thin by the heat and stretches during fabrication (13). So, an appropriate occlusion with enough anterior tooth contact cannot be

Table 1. Shock absorption ability by the mouthguard in previous studies

Reference	Target	Impact method	Impactor	MG	Gage or method	Absorption (%)
Godwin (7)	Acrylic casts	Pendulum	Steel ball	12 types MG	Rebound angle	50–92
Going et al. (8)	Material	Pendulum	Steel head	EVA	Rebound angle	45.0–57.4
Bishop et al. (9)	Material	Drop ball	Steel ball	9 types MG	Rebound height	28.9–31.6
Yamamoto (10)	Material	Drop ball	Steel ball	Sorbosane	Accelerometer	90
Ishijima et al. (11)	Material	Drop ball	Steel ball	14 types MG	Accelerometer	3.33–33.3
Maeda (12)	Material	Drop ball	Steel ball	7 types MG	Force transducer	2–11
Park et al. (13)	Material	Drop ball	Steel ball	EVA	Force transducer	50.40
Auroy et al. (14)	Material	Pendulum	Steel stud	Silicone rubber MG EVA	Pressure transducer	7.67–19.71 13.5–16.6
Craig and Godwin (15)	Material	Pendulum	Steel head	EVA	rebound angle	80.6–90.6
Low et al. (16)	Material	Ultra micro-indentation system		4 types EVA MG	–	10–24
Takeda et al. (17)	Material	Pendulum	Steel ball, etc.	3.0 mm	Load cell	62.1 (steel ball)
Takeda et al. (18)	Material	Pendulum	Steel ball, etc.	3.0 mm	Load cell, accelerometer, strain gage	62–80
Morii (19)	Bovine Tooth	Pendulum	Steel ball	1.5–4.5 m	Strain gages, tooth back	8.1–30
Hoffmann (20)	Model jaw	Pendulum	Steel head	EVA	Integrated metal pin, a writing pad	7.5–58
Bemelmanns and Pfeiffer (21)	Simulated maxilla	Pendulum	Steel ram	Custom-made MG	Strain gages, tooth back	25.7–33.3
de Wet et al. (26)	Artificial skull	Pendulum	Impact hammer	5 types MG	Load cell on hammer	23–55
Takeda et al. (29)	Artificial skull	Pendulum	Steel ball	EVA	Accelerometer, strain gage	18.5–72.5

Table 2. Results of ANOVA and Tukey multiple comparison test (tooth distortion occurred by the steel ball impact)

	Sum of squares	Df	Mean square	*F*	Sig.
Between groups	292 880.972	3	97 626.99	4880.590	0.000
Within groups	720.112	36	20.00	–	–
Total	293 601.084	39	–	–	–

	Open NoMG	Clench. NoMG	Clench. MGAO−
Clench. NoMG	*		
Clench. MGAO−	*	*	
Clench. MGAO+	*	*	*

$^*P < 0.05$

Table 3. Results of ANOVA and Tukey multiple comparison test (tooth distortion occurred by the baseball ball impact)

	Sum of squares	d.f.	Mean square	*F*	Sig.
Between groups	12 518.56	3	4172.85	25.204	0.000
Within groups	5960.16	36	165.56	–	–
Total	18 478.72	39	–	–	–

	Open NoMG	Clench. NoMG	Clench. MGAO−
Clench. NoMG	*		
Clench. MGAO−	*	–	
Clench. MGAO+	*	*	*

$^*P < 0.05$

established in all cases, especially, in the case where dentitions have severe open-bite or elongated teeth, etc. In addition, the lingual-side mouthguard material protecting the front teeth are often made extremely thin or removed intentionally so as not to restrict comfort, easiness to speak or breathe lately. In such a mouthguard, enough protective efficacies cannot be expected as mentioned above. However, up to now, this has not been examined, and as a result sufficient proof on how accurate and important anterior occlusion or the support of the mandibular dentition is through the mouthguard has not been explored. For this reason, such effects were examined in this study.

As for the distortion of the teeth, the effects of the mouthguard, with and without anterior occlusion (a fully balanced occlusion) of mouthguards, or the supports of mandibular dentition through mouthguards were investigated with both a steel ball and a baseball. The effect was most obvious (steel ball = about 57% shock absorption ability, baseball = about 26%) in clenching MGAO+ (the mouthguard with anterior occlusion or support by lower dentition through a mouthguard). Thus, the protective ability of the mouthguard showed an improvement with the support of the mandibular tooth through the mouthguard, irrespective of the hardness of the impact object.

Although there were differences in the conditions governing the experiments, these values are compared with past results. The values are a little higher or almost equal to the results of distortion to a bovine tooth (19), a tooth in a simulated maxilla (21), load with a transmitted force (17, 18) and a mandibular bone in an artificial skull model (29), which used the steel impact object. Especially, it is meaningful to show an almost equal result to a previous test that (29) measured the effect of the mouthguard on a fixed acrylic plate.

Two impact forces were estimated for the experiments. The first estimated was a hockey puck, a 6-ounce piece of inch-thick rubber that can reach 120 mph and hit with an impact force of 1.250 lb (about 566 kgf) (32). The second was a baseball pitcher's fastball that can travel at more than 90 mph with a similar impact force. It was (33) reported that the impact force reached about 890 kgf with the baseball bat and 526 kgf with the baseball. So it seems that a free-standing tooth or teeth in present alveolar bone fractures or other severe injuries occur easily. Also mouthguard material on the buccal surface could not protect the teeth against injuries. Then, to prevent the injury, it is important that the upper and lower dentitions are integrated to distribute and absorb the impact power. In addition, when wearing a mouthguard, it is thought that occlusion can be firmly (34) established early (35). When players perceive danger, they should immediately clench with enough strength to prevent injuries. In fact, players should also use an appropriate mouthguard (Fig. 2, left) at all times during play.

Moreover, the impact absorption ability of the mouthguard is thought to be affected by the differences in the impact objects' hardness, which is high in a hard impact object such as a steel ball, etc., although it is low in comparative terms to many soft balls, etc., commonly used in sports (16, 17). Although few would disagree that low-stiffness guards absorb shock during hard-object collisions (e.g. baseballs), they may not protect the tooth–bone during soft-object collisions (e.g. using boxing gloves) (15). So the effect against a soft object has been doubted. However, from the present results dealing with tooth distortion, the support of the mandibular tooth through the mouthguard improved the effect of the mouthguard in a collision with a soft impact object, although the effect of the mouthguard with a softer baseball was smaller than that of a harder steel ball. Therefore, an appropriate mouthguard had an injury prevention effect regardless of the impact object's hardness.

Therefore, to achieve enough protection, the mouthguard, in any dentition, must secure enough thickness for the maxillary front teeth and lingual sides to establish sufficient occlusion. In addition, considering previous reports (36, 37) that described the frequency, the range and the level of injuries became appalling as the overjet strengthened. An appropriate occlusal mouthguard as well as orthodontic treatment are strongly recommended for many cases with malalignment. In any case, it is important not to use the market-type or the one-layer vacuum-type mouthguard, which cannot secure anterior tooth occlusion if used.

Although impractical for many sports, these kinds of injuries are preventable with a full-face guard such as in American football, boy's lacrosse, etc. If this is the case, then injuries from a direct blow can be prevented by using a face guard. Not surprisingly, the support of the mandibular teeth through the mouthguard is not necessarily essential for only these games. However, when teeth fractures happen by traumatic jaw closures, the mouthguard is still necessary to provide balanced occlusion for the posterior teeth (31). It is also necessary to devise a material and to design for when players cannot perceive the danger of an imminent impact at any given time and when the teeth are not clenched.

Conclusion

To clarify the influence of anterior occlusion (achieved by full balanced occlusion) of the mouthguard or the support by mandibular dentition through mouthguard on safety against the direct impact force applied to the maxillary anterior teeth, two types of mouthguards were used in this study. One is with the appropriate anterior occlusion and the other was a single-layer type lacking the same degree of occlusion but with the same thickness on the buccal side. A pendulum-type impact testing device with two interchangeable impact objects and a plastic jaw model with artificial teeth were used.

As for the distortion of the tooth, the effects of the mouthguard while clenching (loaded with a 30 kg weight) were administered with both a steel ball and a baseball. The effects were more beneficially obvious, wearing the mouthguard with anterior occlusion or support with lower dentition through the mouthguard. Therefore, it is necessary to make players wear custom-made mouthguards with enough protection, i.e. anterior occlusion. Not surprisingly, sports' dentists are well placed to promote the use of appropriate custom-made mouthguards and also have the necessary expertise to ensure that such mouthguards are appropriate for their intended use.

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