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Can mouthguards prevent mandibular bone fractures and concussions? A laboratory study with an artificial skull model

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Abstract – Some sports' accidents are responsible for inflicting traumatic brain injuries and mandibular bone fractures when impacts occur to the chin. It is often thought that mouthguards can prevent many of these injuries. However, such assertions may be insufficient without adequate research. It is therefore necessary to establish a systematic method of investigation to solve this problem. In the present laboratory study, tests were performed using pendulum impact equipment and an artificial skull model connected to strain gages and accelerometers to simulate and measure the surface distortions related to bone deformation or fractures and the acceleration of the head related to concussions. As impacts, direct blows to the mandibular undersurface were applied. As a result, wearing a mouthguard decreased ($P < 0.01$) the distortion to the mandibular bone and the acceleration of the head significantly compared with not wearing a mouthguard (54.7% to the mandible – measured at a total of three different points, 18.5%: to the head measured at a total of three different points). Within the limits of this study, the following conclusions were drawn: The present measuring system in this study was able to evaluate the distortion to the mandibular and the acceleration of the head from the direct blow to the mandibular undersurface. Mouthguards can reduce distortion to the mandibular and the acceleration of the head from the same blow. So mouthguards might have the possibility to prevent mandibular bone fractures and concussions. However, further well-designed and exhaustive studies are vital to show that mouthguards reduce the incidence of concussions and mandibular bone fractures.

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The overwhelming majority of surveys stress the significant protective ability of mouthguards to teeth, soft tissue and orofacial traumas. It was the research carried out on early American football that showed it most clearly. Stenger et al. (1), reported that full facemasks reduced dental and mouth injuries to almost half and with the addition of mouthguards the number of these injuries decreased to 1.4%. Since the use of mouthguards was made compulsory for American high school football in 1962 and for American college football in 1974, the number and severity of dental injuries among these athletes have decreased (2, 3).

In other sports, Morton and Burton (4) reported that, 272 high school rugby players were fitted with custom-made mouthguards. Among the total 31 players reported receiving damage to the mouth during one season. Of these 31 players, 20 were wearing mouthguards at the time of the accident and most received soft tissue lacerations and bruising, and five suffered minor teeth fractures. On the contrary, 13 fractures were recorded in 11 players who were not wearing mouthguards. Morrow et al. (5), studied orofacial injuries among female basketball players during the 1990–1991 season. The injury rate was 2.8% for those who wore mouthguards and 30.3% for those who did not wear them. Maestrello-de moya and Promosch (6) also surveyed high school basketball players in Florida, and determined that injuries increased 6.8 times when mouthguards were not used.

Thus many researchers have showed the effectiveness of the mouthguard in sports; however the spread of suitable mouthguards is still slow. This seems to suggest that a lot of preventable dental related sports injuries continue to occur. One reason for this is that players might not recognize the advantages of mouthguards and may not have had a properly produced mouthguard for their age, the kind of sports they played, or their level of participation in sports. Knowledge is especially short concerning the relationship between mandibular bone fractures, concussion prevention and mouthguards.

It has long been thought that concussions are associated with a range of injuries that are generally diagnosed on the basis of medical signs and symptoms present at the time of an impact. A concussion has been described in clinical terms as a syndrome characterized by immediate and transient post-traumatic impairment of neural function, such as alteration of consciousness or disturbance of vision or equilibrium, and other signs and symptoms because of the involvement of the brain stem (7).

The assumed cause is a rapid distortion and movement of the brain according to acceleration as well as more critical subdural hemorrhage etc (8). However, neither the impact power nor the acceleration of the head in sports' injuries is that strong if compared with accidental falls and traffic accidents (9). Therefore, the kind of brain damage easily generated by sport is thought to be concussions. Not surprisingly, surveys seem to suggest that there are a great number of concussions found in various sports.

In contact sports, it is said that one in every 20 players experienced a concussion during a season (10). Gerberich's (11) investigation into secondary school sports' injuries and revealed that 19% of players reported having had a concussion with 69% of them returning to play sports the same day. Garon (12) reported that among junior high school athletes more than a third of the concussions were reported in sports other than football. Although this situation continues, the symptoms associated with a concussion are assumed to be transitory in general. As a result, concussions tend to be disregarded as serious injuries. However, players with a prior history of a concussion had a four to six times greater risk of a second concussion than that of the player without a prior history (11, 13–15). Furthermore, the effects of concussion seem to be cumulative, and lead to postconcussion syndrome (16). Thus, this has important implications for sports where concussion associated injuries are common.

Concussions occur even when there is no direct blow to the head such as in a knockout blow in boxing. While it is said that an impact to the brain is indispensable for a concussion to occur, it does not necessarily have to be a direct blow (9). One report sited that the most common cause of a concussion in sport was a blow to the mandible (17).

Therefore, the mouthguard might have some benefits in preventing concussions. The first benefit is the dissipation of the forces delivered to the maxilla, skull, and temporomandibular joint complex when the mandible receives a blow (18–22). The second benefit is the stabilization of the skull through increased neck muscle activity when clenching, which may be enhanced with the presence of a mouthguard (18, 23, 24). The third benefit is gained with an alert mandibular position by wearing a mouthguard which can distract the condyle from their fossa (1, 25).

However, as clinical evidence, only the retrospect surveys and some case study reports suggested that mouthguards may protect athletes from concussions (26, 12). In contrast, a prospective study in the American college basketball league and American football showed that custom-fitted mouthguards did not significantly affect the rates of concussion (27, 28).

When we pay attention to concerning laboratory studies now; Hickey (19) first indicated the effectiveness of the mouthguard with tests carried out on cadaver. However, ethical considerations make it difficult to duplicate or continue such experiments or to use such methods now.

With these considerations in mind, a variety of simulation experiments are being planned, and being executed. De Wet et al. (20) conducted experiments using a modal hammer with a built-in load cell and a skull model with strain gauges and accelerometer sensors mounted in various positions on the maxilla and inside an artificial skull. They could not get appropriate results concerning the deformation of bone from the strain gauges and accelerometer sensors. But only the input force with the modal hammer was able to show the mouthguards effectiveness. The impact attenuation rate after an impact, on a dry skull, was also reported and led to the assumption that there was an absorption ability to some degree (21). Sumiyoshi et al. (22) reported that after the impact to the mandibular was analyzed using a finite element method, the impact force was reduced to the maximally incisor tooth, nose and a reduction in the number of concussions when using a mouthguard. Moreover, in other papers (23, 24) it was reported that the mouthguard was effective in reducing the impact of punches to the head in boxing. However, to continue such testing methods nowadays would be fought with greater ethical difficulties than before, especially if trying to obtain dry human skulls and the necessary specialized equipment for testing.

In regard to mandibular bone fractures, a number of reports (23, 24, 29) argue on the effectiveness of using mouthguards. Takeda et al. (30) showed the possibility that a defective mouthguard in occlusion increases mandibular bone fractures, i.e. the design and or materials of the mouthguard can reduce mandibular bone fractures etc. Therefore, a lot of mandibular bone fractures can occur causing serious problems extending over one's whole life. There are many reports concerning mandibular bone fractures related to sports, which are common traumas to the maxillo-facial region and often cause additional brain damage. There are also many cases that result in types of temporomandibular disorders, after treatment has been carried out (31). When a tooth germ is in a fracture line, either abnormalities related to shape or eruption were frequently observed (32). Moreover, even if an injury does not result in a bone fracture, there is the possibility that traumatic changes will occur in the temporomandibular joint (33). Also, in children's jawbone fractures, especially in simultaneous fractures of the mandible and joint areas, dentition and jaw deformity emerged at a high rate later (34). Therefore, the influence of such injuries on everyday sports life and athletic ability, and so on after an injury, is immeasurable.

In this laboratory study, the mouthguard is examined for its effectiveness or lack of effectiveness on the surface distortion of the mandible in relation to mandibular bone fractures and the acceleration of head related to concussions by means of a pendulum impact testing device and an artificial skull model (30). At the same time, we hope to establish a systematic approach to testing that can be used in the future, and which is the basis of our present trials.

While considering further well-designed prospective studies are essential to show that mouthguards considerably reduce the incidence of concussions and mandibular bone fractures.

Material and methods

The measuring methods and systematic approach were almost the same as our previous series of studies (30, 35, 36) i.e. the pendulum device was constructed similar to that of a Charpy or Izod impact machine with a steel ball (approximately 300 g) attached as the impact object. The axis length of the pendulum was about 50 cm and the apparatus was adjusted to hit the center surface of an acrylic resin plate fixed to the left second premolar of the mandibular bone of an artificial skull model (ZA20; 3B Scientific International, Co. Ltd, Niigata, Japan) from below. This model had the occlusion adjusted carefully and the temporomandibular space filled with acrylic resin. The mandibular was attached to the maxilla with three springs. An electromagnet was used to control the release of the impact ram in order to concentrate the force over a small area and make the distance with the target precise (Fig. 1).

Strain gauges (KFG-1-120-D171-11N30C2; Kyowa Electronic Instruments Co., Ltd, Tokyo, Japan) were applied to three labial aspects of the mandible (right premolar region, left premolar region and left mandibular angle region) to measure the surface distortion relating to bone deformation

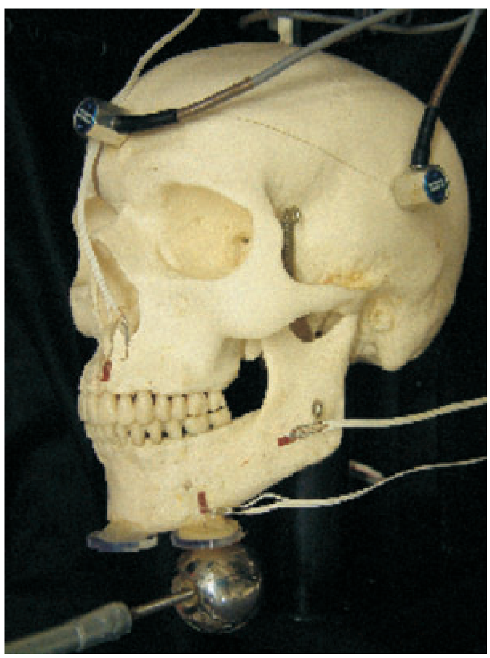

Fig. 1. Artificial skull model sensors were applied with the pendulum impact device.

or fracture. Three single-direction accelerometers (AS-A YG-2768 100G, Kyowa) were fitted to three points (the parietal region = frontal plan, the frontal region = sagittal plan, and the temporal region = horizontal plan) to measure the acceleration of the head, in relation to concussions, as three-dimensional objects (Fig. 1).

Measured mechanical forces by means of the strain gauges and the accelerometers were amplified with a Strain Amplifier (DPM-712B; Kyowa) and then converted into an electric output voltage and stored as data with an Oscillographic Recorder (RDM200A; Kyowa). Data were then analyzed with a personal computer (PC-SJ145V, Sharp Co., Ltd, Tokyo, Japan). Data were processed with tooth piece (soft wear; Ami-system Co., Ltd, Tokyo, Japan) to analyze distortion ($\mu\varepsilon$) and acceleration (g) respectively. As shown in Fig. 2, it measured the height of the impact effect of the first wave as a peak force (a maximum impact) and this was compared with calibrations. Thus, means and standard deviation were calculated for each variable evaluated. Statistical comparisons were made using a Student's t-test in each measured region ($P < 0.01$), using SPSS® (SPSS Japan Inc., Tokyo, Japan). All tests were conducted in an air-conditioned room at 25°C.

The mouthguard blanks used were Drufosoft (Dreve-Dentamid GMBH, Unna, Germany) with a 3.0 mm thickness. The mouthguard tested samples (Fig. 3) were constructed of 2-layer-laminations by means of a Dreve Drufomat (Type SO; Dreve-Dentamid) air pressure machine on a stone model impressed with alginate material. The actual thickness after lamination with adjustments made for the normal spatial relation of the teeth when the jaws were closed was approximately 3.0 mm on the first molar. To obtain uniform thickness, the same operating steps (including the constant heating time: 150 s.) were used. Three mouthguards were made and the impact test was carried out three times. Therefore, nine impacts were recorded in total.

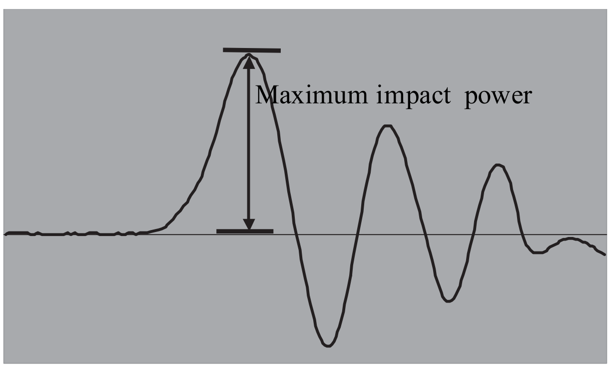

Fig. 2. It measured the impact response height of the first wave as the maximum impact power.

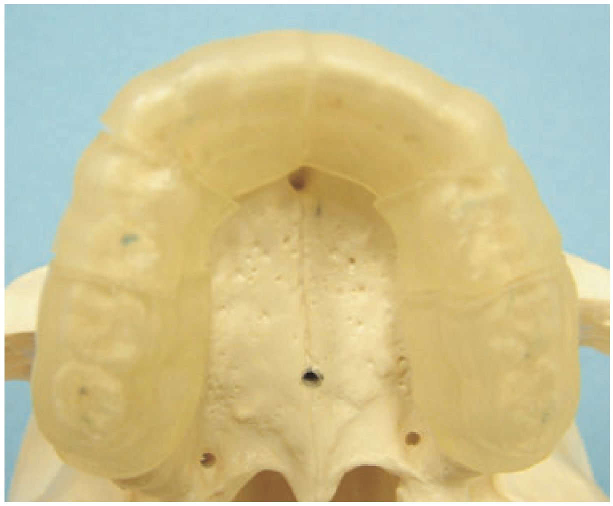

Fig. 3. Pressure laminated ethylene vinyl acetate (EVA) mouthguards were used in the experiments.

Result

The waveform from the acceleration of the head and the distortion on the mandible

Typical acceleration waveforms on the parietal region with and without mouthguards are illustrated in Figs 4 and 5. Fitting the mouthguard decreased the amplitude of the impact. Similar tendencies were observed at other measurement points.

Distortion to the mandible

The results of the three measurement points with the total shown in Fig. 6, and the results of the t-tests ($P < 0.01$) and absorption capacity (%).

The distortion recorded, without a mouthguard, to the right premolar was 149.0 $\mu\varepsilon$, the left premolar was 494.7 $\mu\varepsilon$, the left mandibular angle was 358.5 $\mu\varepsilon$, and the total was 1002.2 $\mu\varepsilon$. The distortion recorded, with the mouthguard, to the

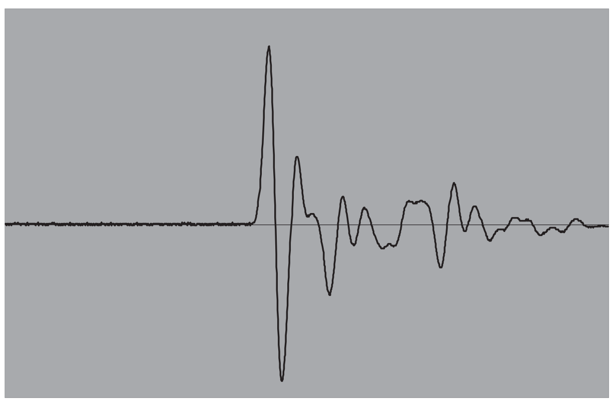

Fig. 4. Typical waveform of the acceleration of the head from the parietal region without a mouthguard.

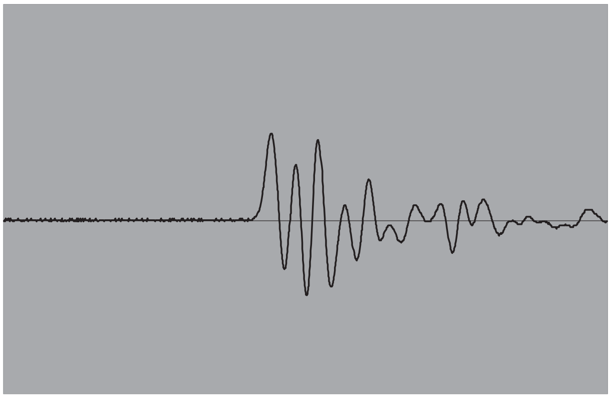

Fig. 5. Typical waveform of the acceleration of the head from the parietal region with a mouthguard. The waveform without a mouthguard was sharp and strong compared to with a mouthguard.

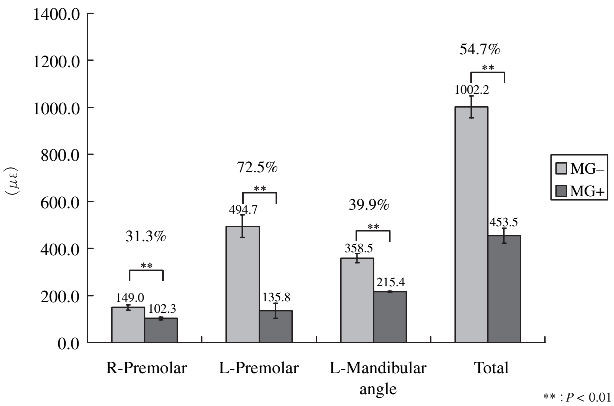

Fig. 6. Distortion of the mandible was compared with and without a mouthguard. Mouthguards can reduce the distortion from a direct blow to the mandible. The distortion recorded, without a mouthguard, to the right premolar was 149.0 με, the left premolar recorded 494.7 με, the left mandibular angle was 358.5 με, and the total was 1002.2 με. The distortion recorded, with the mouthguard, on the right premolar was 102.3 με, the left premolar recorded 135.8 με, the left mandibular angle was 215.4 με, and the total was 453.5 με. Thus, the maximum distortions were reduced when a mouthguard was fitted than without them by 31.3–72.5% at each measurement point and 54.7% approximately in total. Furthermore, the distortion to the mandible was significantly reduced, with a mouthguard, at all the measurement points as well as the total.

right premolar was 102.3 με, the left premolar was 135.8 με, the left mandibular angle was 215.4 με, and the total was 453.5 με. Thus, the maximum distortions were reduced when wearing a mouthguard than without wearing one by 31.3–72.5% at each measurement point and 54.7% approximately in total. Furthermore, the distortion to the mandible was significantly reduced, with a mouthguard, at all the measurement points including the total.

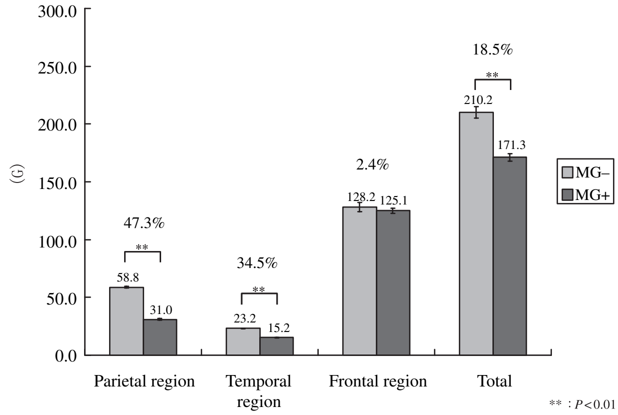

Fig. 7. Acceleration of the head compared with without and with a mouthguard. The acceleration, without a mouthguard, of parietal region was 58.8 *g*, the temporal region was 23.2 *g*, the frontal region was 128.2 *g*, and the total was 210.2 *g*. On the contrary, the acceleration, with a mouthguard, of the parietal region was 31.0 *g*, the temporal region was 15.2 *g*, the frontal region was 125.1 *g*, and the total was 171.3 *g*. Thus, the maximum acceleration was reduced when a mouthguard was worn, in contrast to the tests being conducted without them, by 2.4–47.3% at each measurement point and 18.5% approximately in total. Moreover, the acceleration was significantly reduced, with a mouthguard, in the parietal and temporal regions as well as the total.

The acceleration of the head

The results of the three measurement points and the total are shown in Fig. 7, with the results of the *t*-tests ($P < 0.01$) and absorption capacity (%).

The acceleration, without the mouthguard, of parietal region was 58.8 *g*, the temporal region was 23.2 *g*, the frontal region was 128.2 *g*, and the total was 210.2 *g*. In contrast, the acceleration, with the mouthguard, of the parietal region was 31.0 *g*, the temporal region was 15.2 *g*, the frontal region was 125.1 *g*, and the total was 171.3 *g*. Thus, the maximum acceleration was reduced when a mouthguard was fitted, in contrast to the tests being conducted without them, by 2.4–47.3% at each measurement point and 18.5% approximately in total. Moreover, the acceleration was significantly reduced, with the mouthguard, to the parietal and temporal regions.

Discussion

The impact or shock force is thought to be force that is applied to a target together with a change in speed during a short duration of time. Generally speaking, the power is very big and duration is very short. Additionally, the momentum or the total power is invariable, even before and after the impact. Therefore, when the impact power is applied to a human body, there are two quite different results. If the energy (momentum) is not great enough to cause damage to the body, it is consumed as heat energy by the viscosity characteristics of joints or soft tissue. In the case where the energy is much greater, it changes to a destructive energy which causes damage to the soft tissue, the dislocation and the fracture of teeth, fractures of the bones and so on (37, 38). Therefore, as in many sports, it is prohibited to collide with an opponent during play or to hit one's opponent with an instrument. However, accidentally or intentionally, a collision or a blow will occur in most sports. In contact sports such as rugby, American football, boxing and sumo wrestling etc., collisions cannot be avoidable, because contact is a characteristic part of how they are played. As a preventative measure the use of a mouthguard is expected to protect not only the orofacial area but also to prevent or minimize the occurrence of concussions.

The responsibility is on researchers to supply the necessary scientific proof. For that, well-designed prospective studies are necessary to show that mouthguards reduce the incidence of concussions and mandibular bone fractures. But, as a laboratory study, it is also necessary to establish a method that examines the quality and effectiveness of mouthguards.

Despite this, as described above, there is no method by which the effectiveness of the mouthguard concerning concussions and mandibular bone fractures can be easily examined.

Therefore, for the spread of mouthguards in the future, the establishment of a reliable method that can answer questions such as, 'What type of mouthguard is appropriate for preventing craniofacial injuries?' or 'How can we as dentists make reliable mouthguards for each player?' are crucial.

Thus, in the present study, the test was performed to clarify the effectiveness of mouthguards in regard to concussions and mandibular bone fractures by means of a pendulum impact testing device and skull models. As a result, wearing a mouthguard (MG+) decreased the acceleration of the head and the distortion in the mandibular bone compared with not wearing one (MG−). This was the same result as reports (1–6, 12, 18–26) suggesting that the effectiveness of mouthguards was not only to protect the teeth and dentitions but also to prevent injury to the surrounding bone and skull and reduce the likelihood of concussions. It is thought that the effectiveness of mouthguards against the impact power applied to the mandible depends on three factors as described above (1, 12, 18–26). They are the dissipation of the impact forces to the maxilla, skull, and temporomandibular joint complex when the mandible receives a blow (18–22), the stabilization of the skull through increased neck muscle activity when clenching with mouthguard (18, 23, 24), and gained with an alert mandibular position by wearing a mouthguard which can separate the condyle from their fossa. It seems that, needless to say, these results depend on the dissipation of the impact forces with mouthguard (1, 25).

Usually when the impact force to the orofacial region exceeds the physical resistance strength of an athlete's body the result is an injury. At this time, a large amount of kinetic energy is caused in the body. To absorb this energy, the teeth, periodontal tissue, the bones or the temporomandibular joints, etc. are destroyed (37). Therefore, we only have to decrease the amount of kinetic energy in the body, to prevent injuries, by using mouthguards.

Furthermore, the impact power depends on certain conditions, such as the type of sports' participation, gender, age and so on. Consequently, the necessary thickness, hardness and everything else associated with mouthguards will depend on each athlete and or sport. In other words, each sport and each player that plays in each sport requires an individualized mouthguard that is made from appropriate materials and designs custom made by a learned sports-dentist. Any mouthguard materials and designs available should always be examined and considered in light of the newest study methods available.

Conclusion

Some sports have been responsible for traumatic brain injuries and mandibular bone fractures caused by repeated blows to the chin. It is commonly believed that the mouthguard protects against these injuries. However, this revelation by itself is not sufficient. Therefore, it is necessary to establish a standardized method of experimentation to solve this problem. In the present laboratory study, the tests were performed using pendulum impact equipment and an artificial skull model. However, it is necessary to take further well-designed prospective studies into consideration to show that mouthguards reduce the incidence of concussions and mandibular bone fractures.

Within the limits of this study, the following conclusions were drawn: (i) The present measuring system in this study was able to evaluate the distortion to the mandibular and the acceleration of the head from a direct blow to the mandible. (ii) Mouthguards can reduce distortion to the mandibular and the acceleration of the head from a direct blow to the mandible in the artificial skull model. (iii) Mouthguards might have the possibility of preventing mandibular bone fractures and concussions.

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