Dental Traumatology 2004; 20: 150–156
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DENTAL TRAUMATOLOGY

Are all mouthguards the same and safe to use? The influence of occlusal supporting mouthguards in decreasing bone distortion and fractures

Takeda T, Ishigami K, Ogawa T, Nakajima K, Shibusawa M, Shimada A, Regner CW. Are all mouthguards the same and safe to use? The influence of occlusal supporting mouthguards in decreasing bone distortion and fractures. Dent Traumatol 2004; 20: 150–156. © Blackwell Munksgaard, 2004.

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Abstract – The safety benefits of mouthguards have been demonstrated in many studies, with many authors and sports dentists strongly recommending the wearing of mouthguards. However, wearing a mouthguard with incorrect occlusion might cause a variety of problems. It comes as no surprise that a traumatic blow to the chin, while wearing an insufficient mouthguard lacking anterior contact, can result in severe distortions to the mandibular bone, and bone fractures. The aim of this study was to clarify how ineffective insufficient occlusal supporting mouthguards are and how dangerous they can be to use. Consequently, in this study, occlusal supportive areas were varied and accelerations of head and distortions of the mandible were measured using an artificial skull model and a pendulum impact device. As a result, the distortions of the mandible tended to increase as the supported area decreased. On the contrary, accelerations of the head decreased as the occlusion part decreased. Thus, a lot of impact energy was consumed in the distortion of the mandible; accordingly, it seemed that only a little destructive energy was transferred to the head. From this study, it would seem that wearing a mouthguard, which is insufficient in the occlusion, has the potential of causing a bone fracture of the mandible. Consequently, mouthguards should have proper occlusion.

Key words: mouthguard; occlusal supported areas; safety; bone distortion; artificial skull

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Accepted 15 October, 2003

With the number of people taking part in various sports worldwide increasing, mouthguards, as a protective equipment, has attracted the attention of athletes and many others connected with sports. Until now, the efficiency of mouthguards to protect against trauma has been demonstrated in hundreds of studies, not only in epidemiological research, but also in experimental methods (1–16). Mouthguards decrease the incidence of injuries to both the teeth and lips, and reduce the severity and prevalence of jaw fractures and concussions (14–19). Not surprisingly, many authors and sports dentists, alike, have strongly recommended the wearing of mouthguards.

As a result of the growing number of sports and participants, sports-related injuries also appear to be increasing in proportion. In the current situation, seven sports have already taken initiatives to make the wearing of mouthguards compulsory, i.e. boxing, American football, rugby, kick-boxing, karate (Kyokushin), inline hockey and women's lacrosse (except for boxing, as per the rules, mouthguards are not applied for all the ages, levels and gender) in Japan. Furthermore, in other sports, such as K-1 and sumo-wrestling, mouthguards are gradually becoming more accepted among some participants.

One negative aspect of making the wearing of mouthguards compulsory in all sports is that it would only solve part of the problem, as most players seem to wear inefficient mouthguards, such as the boil-and-bite type or the one-layer vacuum type.

In addition, it was envisaged that using these types of mouthguards might cause various problems, especially when using mouthguards with improper or insufficient occlusion. First, a traumatic blow to the chin area of a skull model was conducted, while an insufficient mouthguard lacking anterior contact (such as a canine to a canine missing occlusion) was used. Not surprisingly, severe distortions occurred in the mandibular bone, and the chance of bone fractures increased. Secondly, it was suspected that these types of mouthguards might also cause temporomandibular arthritis. To keep these types of mouthguards in position, players need to continuously clench during a game or practice. This has the potential to cause great stress or even an overload to the neuromuscular system resulting in temporomandibular arthritis.

In the present study, we concentrated on the first problem. The aim of this study was to clarify how ineffective insufficient occlusal mouthguards are and how dangerous they can be to use. Consequently, in this study, occlusal supportive areas were varied, and accelerations of head and distortion of the mandible were measured using an artificial skull model and a pendulum impact device.

Materials and methods

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 point of impact. The axis length of the pendulum was about 50 cm, and the apparatus was adjusted to hit centrally a surface of the acrylic resin plate fixed on the left second premolar of the mandibular bone of an artificial model (ZA20:3B; Scientific International, Co., Ltd., Niigata, Japan) at a bottom point. The 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. The strain gauges (KFG-1-120-D171-11 N30C2; Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan) were applied to the labial aspect of the mandible (right and left premolar regions). The accelerometers (AS-A YG-2768 100G; Kyowa) were fitted to three points (parietal, frontal, temporal region) to measure the acceleration of the head as a three-dimensional object (Fig. 1). Measured mechanical forces, by means of strain gauges and accelerometers, were amplified with Strain Amplifier (DPM-712B; Kyowa), converted into an electric output voltage, stored as data on an oscillographic recorder (RDM200A; Kyowa), and then analyzed with a personal computer (PC-SJ145V; Sharp Co. Ltd., Tokyo, Japan).

Mouthguard blanks used were Drufosoft (Dreve-Dentamid GMBH, Unna, Germany) with a 3 mm thickness. Test samples were constructed of two-layer laminations by means of a Dreve Drufomat (Type SO, Dreve-Dentamid, Unna, Germany) air pressure machine on a stone model impressed with an alginate material. Actual thickness after lamination and

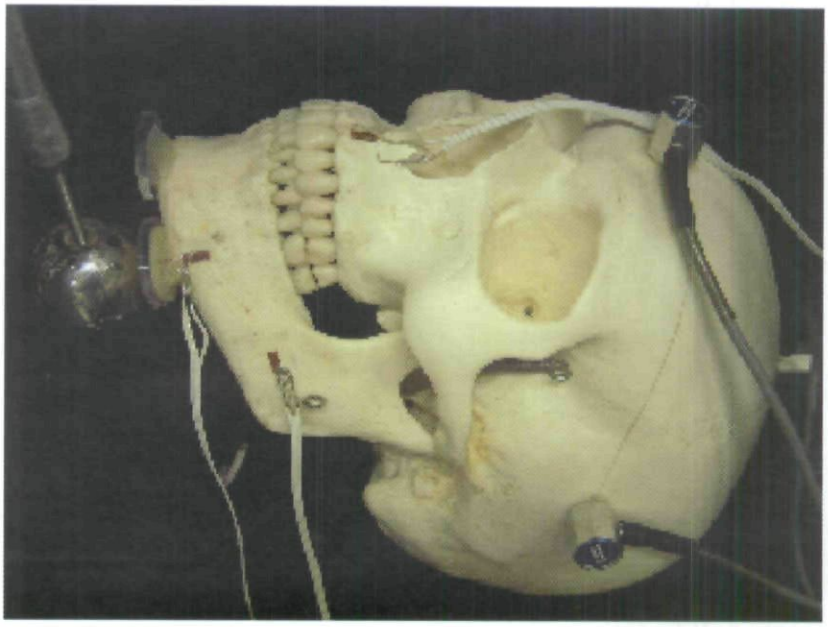

Fig. 1. The accelerometers and strain gauges were fitted to the measuring points.

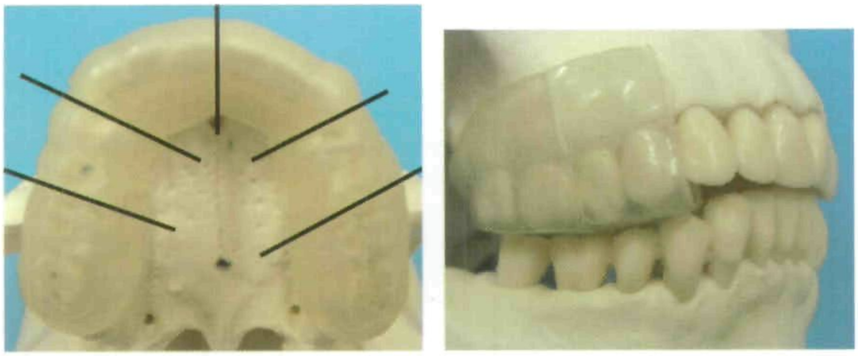

Fig. 2. The mouthguard was cut in position central, distal of left and right canine and distal of left and right second premolar, to test occlusal conditions (left) and 7-4|MG mouthguard is in position (right).

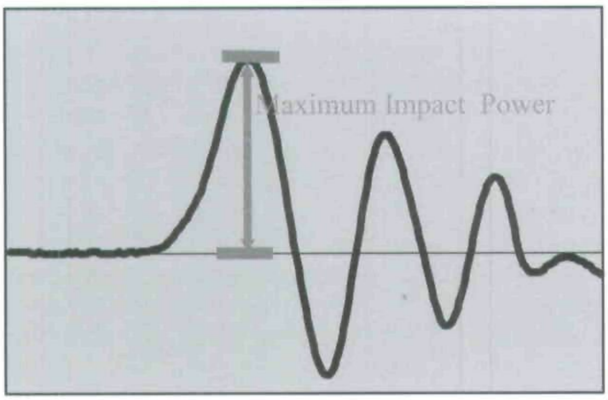

Fig. 3. Analysis method: measured the height of the biggest impact response as the maximum impact power.

occlusal adjustment was approximately 3.0 mm on the first molar. After occlusal adjustment – central, distal of left and right canine, and distal of left and right second premolar – the mouthguards were cut in position to test the following six occlusal conditions: (i) (76|MG), (ii) (7-4|MG), (iii) (7-1|MG), (iv) (7 3MG), (v) (7+5MG), (vi) (7+7MG; Fig. 2). Three mouthguards were made and impact tests were conducted three times on each one. The data were processed with Tooth Piece (Amisystem Co., Ltd., Tokyo, Japan). As shown in Fig. 3, the height of the first impact was analyzed as the maximum impact power. In addition, three different acceleration points were measured, giving the total acceleration of the head. Means and SDs were calculated for each variable evaluated. Statistical comparisons were made using a one-way analysis using the ANOVA variance test. Tukey's multiple comparison tests were used for further comparisons between occlusal areas ($P < 0.05$), using SPSS® (SPSS Japan, Inc., Tokyo, Japan). All tests were conducted in an air-conditioned room at 25°C.

Results

Distortion in the mandible

The results of two measurement points (left premolar, near the hit point; right premolar) and the total of

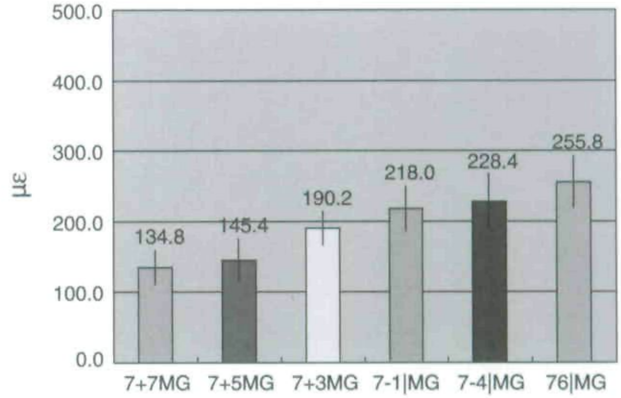

Fig. 4. Distortion in the mandible (left premolar, NHP): On the left premolar, it increased from 134.8 in 7+7MG to 255.8 in 76|MG. In addition, 76|MG showed approximately two times the amount of distortion to that of 7+7MG.

the two measured points are shown in Figs. 4–6, and the results for the ANOVA and Tukey's multiple comparison tests are illustrated in Tables 1 and 2.

When measuring the two premolar points for distortion, it was revealed that as the occlusal area decreased, the distortion increased as below. On the left premolar, it increased from 134.8 με in 7+7MG to 255.8 με in 76|MG. In addition, 76|MG showed

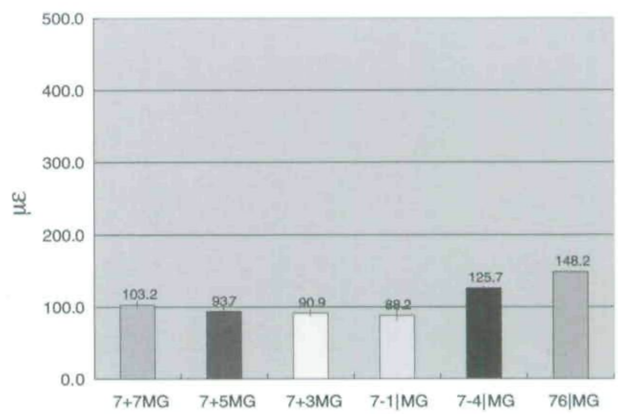

Fig. 5. Distortion in the mandible (right premolar): The right premolar showed a similar tendency with the distortion ranging from 108.2 in 7+7MG to 148.2 με in 76|MG.

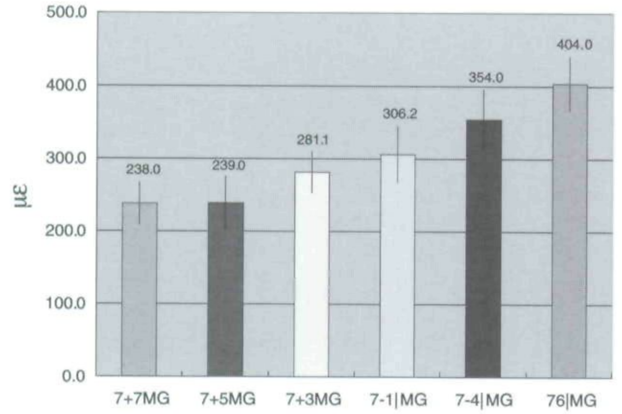

Fig. 6. Distortion in the mandible (total): As for the total, it increased from 814.8 με in 7+7MG to 1281.1 με in 76lMG.

approximately two times the amount of distortion to that of 7+7MG. The right premolar showed a similar tendency with the distortion ranging from 108.2 με in 7+7MG to 148.2 με in 76lMG. As for the total, it increased from 814.8 με in 7+7MG to 1281.1 με in 76lMG. Statistical analysis (ANOVA) showed that differences in occlusal areas effect the distortion in all two-point tests conducted, as well as the total distortion recorded ($P < 0.01$; Table 1). Furthermore, there were significant differences between 7+7MG and all other MG except for 7+5MG in left premolar and total (Tukey's test; Table 2).

Acceleration in the head

Accelerations of the head are shown in Fig. 7, and the results for the ANOVA and Tukey's significant tests are illustrated in Tables 3 and 4.

Table 1. Distortion in the mandible (ANOVA)

	Sum of squares	df	Mean square	F	Sig.
Left premolar region (NHP)					
Between groups	780858.09	6	130143.01	127.429	0.000
Within groups	57192.70	56	1021.30	–	–
Total	838050.79	62	–	–	–
Right premolar region					
Between groups	37958.30	6	6326.38	205.982	0.000
Within groups	1719.94	56	30.71	–	–
Total	39678.24	62	–	–	–
Total of mandibular distortion					
Between groups	2799418.95	6	466569.83	366.636	0.000
Within groups	71263.98	56	1272.57	–	–
Total	2870682.94	62	–	–	–

Table 2. Distortion in the mandible (the results of Tukey's honestly significant test)

	7+7	7+5	7+3	7-1l	7-4l
Left premolar region (NHP)					
7+5	–				
7+3	*	–			
7-1l	*	*	–		
7-4l	*	*	–	–	
76l	*	*	*	–	–
Right premolar region					
7+5	*				
7+3	*	–			
7-1l	*	–	–		
7-4l	*	*	*	*	
76l	*	*	*	*	*
Total					
7+5	–				
7+3	*	*			
7-1l	*	*	–		
7-4l	*	*	–	–	
76l	*	*	*	*	*

*Tukey's HSD ($P < 0.05$).

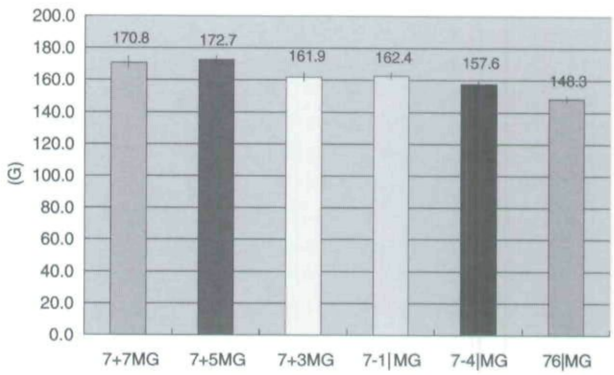

Fig. 7. Acceleration in the head: The acceleration of the head decreased as the occlusion areas decreased from 170.8G in 7+7MG to 148.3G in 76lMG.

Table 3. Acceleration in the head (ANOVA)

Total of head acceleration	Sum of squares	df	Mean square	F	Sig.
Between groups	21582.54	6	3597.09	422.899	0.000
Within groups	476.32	56	8.51	–	–
Total	22058.86	62	–	–	–

Table 4. Acceleration in the head (the results of Tukey's honestly significant test)

	Total				
	7+7	7+5	7+3	7-1I	7-4I
7+5	–				
7+3	*	*			
7-1I	*	*	–		
7-4I	*	*	*	*	
76I	*	*	*	*	*

*Tukey's HSD ($P < 0.05$).

The acceleration of the head decreased as the occlusion areas decreased from 170.8G in 7+7MG to 148.3G in 76IMG. Statistical analysis of both the ANOVA and Tukey's test showed similar results as mandibular distortions.

Discussion

The impact or shock force is thought to be the 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 great and the 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 the joint. In the case where the energy is much greater, it changes to a destructive energy that causes damage to the soft tissue, the dislocation and the fracture of teeth, fractures of the bone, and so on (20). Therefore, in many sports it is prohibited to collide with an opponent during play or to hit one's opponent with an instrument. However, in some sports a collision or blow will sometimes, accidentally or intentionally, occur. In contact sports, such as rugby, American football, boxing, and sumo-wrestling, collisions cannot be avoided as contact with opponents is expected and is a characteristic part of how they are played. Therefore, trauma is not a situation that can be avoided in all sports. The oro-facial area, where trauma to the teeth, jawbone, and so on occur frequently, is not exceptional. So, the use of mouthguards is expected to prevent injuries. Moreover, preventing concussion is also expected (1, 14–19) when using mouthguards that absorb shock energy and promote neck muscle activity (13).

However, the comfort (21), safety (1–16, 18), and so on of mouthguards are strongly influenced by the types available and the quality of manufacturing. It is impossible to assume that all types of mouthguards have the same level of protection. When a mouthguard has insufficient occlusal protection, the athlete is likely to sustain a mandibular fracture when hit in the jaw. This is likely to occur either if the mouthguard is manufactured incorrectly like many "boil and bite" types or a one layered custom made mouthguard. It is also difficult to manufacture a mouthguard correctly when the patient has an open bite or severe malocclusion (22). In addition, a mouthguard may lose occlusal protection due to wear during use. A second problem of wearing a mouthguard with insufficient occlusal protection is the possibility that the athlete would develop temporomandibular arthritis from chronic usage.

Consequently, in this study, the authors concentrated on insufficient mouthguard occlusion with the purpose of examining the influence of different occlusal conditions of mouthguards on oro-facial safety. Testing was carried out using a skull model and a pendulum-type device to measure distortion to the mandible, and head acceleration.

The part mouthguards play in trauma prevention is well documented. This study illustrated that when an impact was applied to the mandible, the partial or total distortion of the mandible significantly increased as the supported area of the mouthguard decreased. In particular, a mouthguard such as 67IMG with insufficient occlusal contact showed almost double the amount of distortion compared to a mouthguard with an appropriate occlusal relationship (7+7MG). Of course, 7+7MG offered the most protection with 7+5MG at almost the same level of safety, but all other mouthguards, at 7+3MG or offering less occlusal support were viewed as being inappropriate. These results support the inference of three reports (15, 16, 18) on MG's effectiveness in protecting the mandible.

When you pay attention to the acceleration of the skull, the acceleration decreased as occlusal area decreased. On the surface, this might appear to be a positive result. However, it was viewed that wearing a mouthguard with fewer occlusal supported areas, at the time of impact, meant that a lot of energy was consumed in the distortion of the mandible. Accordingly, it appeared that only a small portion of the energy from the point of impact was transferred to the head. Thus using improper occlusal-supported mouthguards severely increased distortion, and so, logically, the possibility of bone fracture.

Mouthguards should be made by dentists to ensure good occlusal relationships. The player should have good occlusal contact over a large area when biting lightly. This can only be done if an impression of the apposing arch is made to establish occlusal relationship and incisal guidance. Mass-produced mouthguards cannot fulfill these requirements and, as mentioned above, even custom made but one-layered vacuum-type mouthguards are not adequate. Consequently, the pressure-laminated mouthguard that allows enough occlusal thickness is strongly recommended at this time. The other types of mouthguards should only be used on a temporary basis until the ideal mouthguard can be constructed.

Information and recommendations that athletes wear an appropriate mouthguard is crucial. As participation in sports is so widely spread across society, all dentists (not only those involved in sports dentistry) have an obligation to inform their patients, who participate in various sports, of the benefits of wearing a mouthguard that gives appropriate occlusion, such as the laminate type, as much as possible. It is also necessary to have players understand the importance of both having regular examinations, at least once every season, and the need for having adjustments or remakes done to their mouthguard when a transformation takes place, a hole wears through, or when any nonconformity occurs to the mouthguard while in use or after the teeth have been treated. Equally, there is a need to spread information, to dentists and dental technicians alike, as to which manufacturing methods are appropriate for mouthguards in order to carry forward the knowledge of an efficient type of mouthguard to players, teachers, trainers, coaches, and so on. Any attempts for a more complete health management system by various groups, teams, and/or school units will be a substantial contribution to reducing sports injuries. To establish an environment where players can only use an appropriate mouthguard is surely the goal we should all aim for.

Conclusion

As dentists, we recognize that an ideal mouthguard will provide significant benefits in reducing the impact force caused either by a direct or an indirect oro-facial trauma and will also reduce the occurrence of concussion to the brain. Consequently, we have recommended wearing mouthguards to athletes and continue to be active in this area. The acceptance of mouthguards and the use of them is increasing. However, regrettably, not all mouthguards are sufficient to ward off serious injuries. In this study, we took up the problem of occlusion as one of the ill effects of insufficient and inadequate mouthguards that are readily available for use by unsuspecting athletes from various sports. The results of this study suggest that wearing poor quality mouthguards increases the possibility of distortion of the mandibular bone after impact resulting in increased fracture potential. There will always be the fear of causing a bone fracture to the mandible, if athletes continue to wear mouthguards that are insufficient in the area of occlusion, and thus are inadequate to protect properly. Therefore, we should not blindly follow directives from manufacturers who promote the use of mass-produced or one-layer-type mouthguards. There is an obvious need to recommend that players should avoid using the boil-and-bite type. Again, mouthguards should have proper occlusion that is precisely adjusted by well-trained dentists.

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