Concussions are acceleration-deceleration injuries that occur when biomechanical forces are transmitted to the cerebral tissues. By limiting acceleration of the head, enhanced cervical muscle activity derived from clenching with a mouthguard (MG) may reduce the incidence or severity of concussions following impact.

The purpose of this study was to investigate the effect of voluntary clenching with a proper MG on acceleration of the head during “heading” of a soccer ball. Eleven male high school soccer players (mean age, 16.8 years) participated in the study. Each player was given a customized MG. An automated soccer machine was used to project the ball at the participants at a constant speed. The participants headed the ball under 3 different oral conditions: drill 1, heading freely performed without instruction and without the MG; drill 2, heading performed as the subject was instructed to clench the masseter muscles tightly while not wearing the MG; drill 3, heading performed as the subject was instructed to clench tightly while wearing the MG. Each participant repeated each drill 5 times. Linear acceleration of the head was measured with a 3-axis accelerometer. Activity of the masseter and sternocleidomastoid muscles was measured by wireless electromyography. Weak masseter and sternocleidomastoid muscle activity was observed during drill 1. After the soccer players had been instructed to clench their masseter muscles (drills 2 and 3), statistically significant decreases in head acceleration and increases in masseter and sternocleidomastoid muscle activity were observed ($P < 0.05$; paired $t$ test). The effect was stronger when the players wore the MG. Dentists should encourage soccer players to habitually clench while wearing a proper mouthguard to strengthen cervical muscle resistance as a way to mitigate the damage caused by heading.

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use of an MG (equipment category); and the importance of tooth clenching during collisions (coaching and medical [dental] supervision categories).10,11

Although the preceding recommendations are valid, there has been little quantification of the effects of MGs and masticatory muscle activity on head stability during contact in actual heading. The purpose of this study was to investigate the effect of voluntary clenching with an MG on acceleration of the head and activity of the masseter and sternocleidomastoid muscles during soccer heading.

**Materials and methods**

A total of 11 male high school soccer players with an average age of 16.8 years participated in this study. The participants were healthy and had no objective or subjective abnormality of the oral cavity, temporomandibular joints, or head and neck muscles. None had a history of otolaryngological or ophthalmological disorders. The study protocol was explained in detail to all participating athletes and coaches before commencement of the experiment, and written consent was obtained from each player. The study protocol was approved by the Tokyo Dental College Ethics Committee (approval No. 437). The study adhered to the tenets of the Helsinki declaration on ethical treatment of human subjects.18

A 4-mm sheet of mouthguard material (Impact Guard, GC Corporation) was used to make a customized MG for each soccer player included in the study. A Drufomat unit (type SO, Dreve Dentamid GmbH) pressure formed the sheet on a cast of the mandibular dentition. After the form was corrected, the occlusion of the MG was checked in centric occlusion both on an articulator and in the mouth. The thickness of the MG was approximately 2 mm at the first molars (Fig. 1).

Experimental drills were conducted for 3 different oral conditions: drill 1, heading freely performed with no instruction; drill 2, heading performed as the subject was instructed to clench the masseter muscles tightly while not wearing the MG; drill 3, heading performed as the subject was instructed to clench the masseter muscles tightly while wearing the MG. Drill 1 was performed first, and drills 2 and 3 were performed in random order. Each participant repeated each drill 5 times, performing 15 drills in a row.

The JUGS Soccer Machine (JUGS Sports), which is designed to duplicate any type of pass or shot, was used to project the ball at the player’s head (Fig. 2).19 The machine has two 0.25-hp motors, and the speed can be adjusted through a dual dial on the interface. A ball is fed through the machine, resulting in a simulated shot with a maximum speed of 40 m/s and a maximum range.
of 73 m. For this study, the initial velocities were set at 28.0 (right motor) and 38.0 (left motor) m/s. The ball (HSF5F, Molten Corporation) traveled in a gentle curve because of the right and left speed difference. As a result, heading was easier for the player. The range was approximately 9.0 m. Ball speed was comparable with that shown in previous research. Heading type of ball projection was employed in this study. The participants were instructed to remain standing and not to contribute actively to the impact.

The measuring system employed in this study comprised a triaxial accelerometer and a multichannel telemetry system. The triaxial accelerometer (Wireless Sensor Module 50G, Logical Product Corporation) was put in a headband to measure head acceleration (Fig. 3). Accelerations were expressed as gravitational units (1g = 9.81 m/s²). The WEB-7000 Multichannel Telemetry system (Nihon Kohden Corporation) was used to monitor muscle activity (Fig. 4). This system mainly comprises electromyographic transmitters (ZB-150H), a BIO Repeater (ZB-700H), a receiver (ZR-700H), and a personal computer. Electromyograms were used to measure bilateral masseter and sternocleidomastoid muscle activity. The acceleration measurements and electromyograms were synchronized by digital video imaging for display by a Pixel Runner (TellusImage, Co., Ltd.); light signals were entered into a video image and trigger signals were entered into the WEB-7000, both by direct current.

The peak acceleration in 3 axes and the activity of the masseter and sternocleidomastoid muscles on each side were recorded and analyzed. A paired t test was used to assess differences among drills 1-3. A value of P < 0.05 was considered to indicate statistical significance in all the analyses (Excel Statistics software, version 6.0, Social Survey Research Information Co., Ltd.).

Results
On waveforms of linear head acceleration and muscle activity, masseter and sternocleidomastoid muscle activity were observed even during drills without instruction (Fig. 5A). These activities started before heading. Drill 3 seemed to result in an increase in masseter and sternocleidomastoid muscle activity and reduced head acceleration (Fig. 5B). These tendencies were observed in almost all measurements.

Acceleration showed a mean gravitational force of 28.4g (SD, 7.0g) during drill 1 (Chart 1). During drill 2, clenching without an MG reduced the acceleration significantly to a mean of 23.9g (SD, 6.2g; P < 0.05). Clenching while wearing an MG (drill 3) further reduced the acceleration to 21.5g (SD, 4.6g), which was also significantly different from the force measured during drill 1 (P < 0.05).

Mean masseter muscle activity measured 44.0 (SD, 38.2) μV/s² during drill 1 (Chart 2). During drill 2, the activity significantly increased to 132.7 (SD, 76.5) μV/s² (P < 0.05). During drill 3, the activity increased further to 154.0 (SD, 99.3) μV/s², a significant difference from the activity during drill 1 (P < 0.05).

Mean sternocleidomastoid muscle activity measured 68.6 (SD, 47.7) μV/s² during drill 1 (Chart 3). This activity increased significantly to 133.5 (SD, 74.2) μV/s² during drill 2 (P < 0.05). Sternocleidomastoid muscle activity increased to 159.3 (SD, 76.8) μV/s² during drill 3. This was a statistically significant difference from the activity measured during drill 1.

Discussion
In the present study, even without instruction (drill 1), players exhibited no more than approximately 30g of head acceleration. There was no incidence of concussion or any other traumatic brain injury during the recorded periods, because the obtained acceleration was not great enough to result in a concussion and almost equal to the results of previous

Fig. 5. Typical waveforms during heading, showing linear acceleration of the head in the x-, y-, and z-axes as well as masseter muscle (MM) and sternocleidomastoid muscle (SM) activity. A. Waveforms during drill 1 (no instruction). B. Waveforms during drill 3 (instruction to clench while wearing mouthguard).
studies. The peak acceleration associated with heading a soccer ball is reported to be 54.7g. The average linear acceleration of impacts incurred is reported to be 24.89g during games and 23.39g during practice sessions. The threshold for concussion is considered approximately 100g, with an impact of at least 70g-75g.

In head-to-head impacts, contact produces enough force to result in concussive injury. Acceleration of the magnitude recorded during heading in the present study is less likely to result in concussion. However, athletes with a history of concussion are at increased risk of developing a concussion in the future. Therefore, repetitive heading may result in brain damage, and the cumulative effect of repeated subconcussive insults to the brain remains to be determined.

Generally speaking, in an impact force, the energy is great and the duration is short. Additionally, the total power is invariable, before and after the impact. If the energy of an impact force is not great enough to cause damage to a human body, the force is absorbed as heat energy by the joints or soft tissue. When the energy is much greater, it changes to a destructive energy that causes damage to soft tissues, dislocation of joints, fracture of bones, and so on. With head impacts, a force that exceeds the resistance of an athlete will result in brain injury or concussion. Fortunately, neither the impact power nor the acceleration of the head in sports injuries is that strong compared with, for example, accidental falls and traffic accidents. Therefore, clenching of the masticatory muscles to stabilize the head might have some benefit in protecting and preventing concussion in sports. In the present study, even without instruction (drill 1), each player clenched with sternocleidomastoid muscle activity during heading, even before coming into contact with the ball. However, this muscle activity was not as strong as that demonstrated during drills 2 and 3, when players were given specific instructions to clench. Even unconscious clenching, such as that as observed in the study participants during drill 1, might lessen the force transmitted to the brain. This unconscious clenching represents a form of body control that is a feed-forward mechanism acquired through training.

In this study, instruction to clench without an MG (drill 2) increased masseter and sternocleidomastoid muscle activity and reduced head acceleration. The increased activity of the masseter muscle along with intentional forceful clenching might facilitate activity of core and other related cervical muscles, stabilizing the head. Previous reports have demonstrated a relationship between cervical muscle strength and the severity of impacts to the head. Cervical muscle strength mitigates impact severity; the effective mass of the head-neck-trunk segment is believed to increase significantly when the cervical musculature is contracted, which reduces the force of head acceleration. This relationship is believed to play an important role during heading impacts experienced on the playing field.

In addition, clenching with a proper MG (drill 3) increased masseter muscle and sternocleidomastoid muscle activity.
even further in the participants in the present study, reducing head acceleration more than clenching without an MG. The benefit of voluntary clenching with an MG that was demonstrated by these results supports the broad use of mouthguards to protect against both concussion and damage to the intraoral structures.

A protective, but not preventive, effect in concussion may be afforded by MG use in rugby players.43 Some other studies have reported that mouthguards do little to lessen the risk of sustaining a concussion while playing rugby.49,50 Despite the lack of clear evidence to support the belief that mouthguards offer protection against concussion, Hollis et al found that consistent use of an MG reduced the incidence of traumatic brain injury among amateur rugby players by almost 50%.41 Recent research has reported that young male rugby players who were wearing a proper MG and instructed to clench during rugby practice exhibited markedly decreased head acceleration and increased masseter and sternocleidomastoid muscle activity.16

It has been reported previously that soccer players demonstrated unconscious clenching while heading a soccer ball, and the effect was strengthened when an MG was worn.34 Pre-tensed neck muscles, uniting the head better with the neck and torso, are vital for performance and safety. Furthermore, tooth clenching with a proper mouthguard strengthens the neck muscles. Therefore, every player should habitually clench while wearing a proper mouthguard to strengthen cervical muscle resistance as a way to mitigate the damage caused by heading.

A concerted educational effort by dentists to suggest this protective measure to athletes, parents, and coaches might reduce the incidence of concussion and cervical injuries to some degree. This training to clench habitually is comparable to acquiring the protective technique of responding to a throw by rolling (ukemi) in judo.42 To perform intentional clenching at the correct times, athletes must be more aware of their surroundings and better at anticipating and preparing for impending contact.51 Of primary importance are the education of athletes and coaches on appropriate techniques and the use of proper equipment.

The present study has certain limitations. Clearly, the biomechanics of concussive injury in adult and pediatric players are not the same.52 Younger players usually have less cervical muscle strength and tone than adults, so greater force may be transmitted to the cranial compartment.53 In addition, future research is needed to investigate male and female athletes of various skill levels and ages.

Future studies should also explore rotational as well as linear acceleration. Furthermore, because the posterior thickness of the MG in the present study was 2 mm, within the range of the typical interocclusal rest space, unconscious tooth clenching could occur during use of the mouthguard; therefore, a further study should assess players as they head the ball during a drill in which they receive no instruction while wearing the mouthguard.

Well-designed prospective studies are necessary to show conclusively if intentional clenching reduces the incidence of concussion. However, the present results still have value as evidence that the incidence of concussion may be reduced if players are educated about the importance of clenching when they anticipate a collision and paying attention to their surroundings during games or practice.

**Conclusion**

The activities performed while young male soccer players headed a ball involved relatively small direct head acceleration. Some masseter and sternocleidomastoid muscle activity was measured even during drills in which players received no instruction. After the players were instructed to clench their masseter muscles, a decrease in head acceleration was observed. The effect was strengthened when players clenched with a mouthguard, resulting in significant increases in masseter and sternocleidomastoid muscle activity. Clenching with a proper mouthguard should be suggested to soccer players, parents, and coaches as a means to lessen damage resulting from heading the ball.

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**Disclaimer**

The authors have no financial, economic, commercial, or professional interests related to topics presented in this article.

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![Chart 3. Mean activity of sternocleidomastoid muscles in 11 soccer players during heading.](chart.png)
References


Manufacturers

Dreve Dentamid GmbH, Utna, Germany
49.0.2303.8807.55, www.dreve.com

GC Corporation, Tokyo, Japan
81.3.3815.1815, www.gcdental.co.jp

JUGS Sports, Tualatin, OR
800.547.6843, www.jugsports.com

Logical Product Corporation, Fukuoaka, Japan
81.9.5204.7603, www.lp-d.co.jp

Molten Corporation, Hiroshima, Japan
81.3.3625.7684, www.molten.co.jp

Nihon Kohden Corporation, Tokyo, Japan
81.3.5996.8036, www.nihon.kohden.co.jp

Social Survey Research Information Co., Ltd., Tokyo, Japan
81.3.3370.2099, www.sri.co.jp

TellusImage Co., Ltd., Nara, Japan
81.4.2401.8535, www.tellusimage.co.jp