Effect of clenching with a mouthguard on head acceleration during heading of a soccer ball

Keishiro Narimatsu, DDS ▪ Tomotaka Takeda, DDS, PhD ▪ Kazunori Nakajima, DDS, PhD ▪ Michiyo Konno, DDS
Takamitsu Ozawa, DDS, PhD ▪ Keiichi Ishigami, DDS, PhD

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.

Received: January 13, 2015
Accepted: April 13, 2015

Concussion is a brain injury defined as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces."[1,2] During a traumatic impact, the brain, which floats within the cerebrospinal fluid, does not move at the same speed as the skull. The difference in velocity can result in a collision between the brain and skull. Biomechanical forces transmitted to the brain tissues during this impact cause an acceleration-deceleration injury.[2,3]

Soccer is usually identified as a sport in which participants are not at a high risk for concussions. However, as many as 46.2% of soccer players in one study had experienced symptoms of a concussion during the previous season, and 22% of all soccer injuries are concussions.[4,5] Soccer players intentionally redirect ("head") the ball with their unprotected head, and headed balls travel at high speeds before and after impact. Peak values during high school games have been reported to be in the range of 17.8 m/s, and professional players achieve higher peak values (reported variously as 25 m/s and 17-33 m/s).[6,7] During a game, a soccer player could be subjected to an average of 6 to 7 incidents of heading the ball.[8,9] Therefore, contact with the ball while heading is thought to be one cause of concussion in soccer players. Between 6% and 24% of reported concussions in soccer have been associated with heading the ball.[9] Because soccer is the most popular sport in the world—there are approximately 16 million registered players in Japan—a great number of players could suffer a concussion.

The ideal approach to concussion prevention remains controversial. Cantu suggested 5 methods for reducing the risk of mild traumatic brain injury: (1) changes in rules; (2) changes in coaching technique; (3) improved playing conditions; (4) equipment modifications; and (5) increased medical supervision.[10,11] The stability of the neck is thought to be especially important in preventing injury. The muscles in the neck play a major role in shock absorption and energy dissipation.[12] Pre-tensing of the neck muscles represents an effort to improve the union between the head and the neck and torso. Shewchenko et al reported that sternocleidomastoid and trapezius muscles are activated prior to ball impact to stabilize the head while heading.[13] Thus, appropriate cervical muscle tension is important to prevent or reduce damage to the head.

Tooth clenching to increase masseter muscle activity and wearing of a mouthguard (MG) have been understood to improve the stability of the neck. Takada reported that voluntary jaw clenching reduces reciprocal Ia inhibition of the crural muscle and suggested that clenching enhances postural stability by increasing the stiffness of all joints of a body.[14] It has been suggested that American football and rugby players employ a "bull-necked" posture, which requires clenching, during tackles.[15] Hasegawa et al reported that young male rugby players who were instructed to clench their masseter muscles demonstrated a marked decrease in head acceleration.[16] This finding may be related to the fact that the amplitude of the Hoffmann reflex increases substantially during tooth clenching.[17] Therefore, from a sports dentistry viewpoint, to reduce the incidence or severity of concussion caused by heading, dentists should emphasize the following factors (based on Cantu's previously described improvement categories): the relationship between clenching with an MG and cervical muscle activity, that is, the fact that stronger masticatory muscle activity enhances cervical muscle activity (playing conditions category); the

Fig. 1. Mouthguard used in the study.

Fig. 2. Soccer machine for duplicating passes.

Fig. 3. Triaxial accelerometer for measuring acceleration of the head.

Fig. 4. Telemetry system for monitoring activity of the muscles.

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

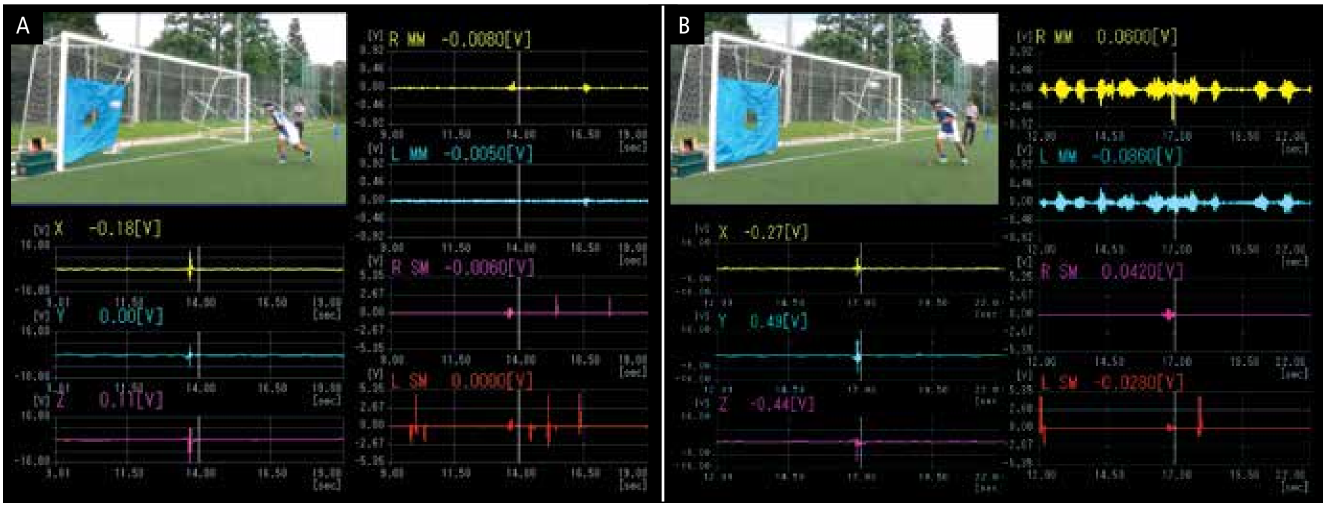


Fig. 5. Typical waveforms during heading, showing linear acceleration of the head in the x-, y-, and z-axes as well as masseter muscle (MM) and sternocleidomastoid muscle (SM) activity. A. Waveforms during drill 1 (no instruction). B. Waveforms during drill 3 (instruction to clench while wearing mouthguard).

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.[13] Heading type of ball projection was employed in this study.[12] 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 ($1g = 9.81\ m/s^2$). 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.[13] 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 28.4*g* (SD, 7.0*g*) during drill 1 (Chart 1). During drill 2, clenching without an MG reduced the acceleration significantly to a mean of 23.9*g* (SD, 6.2*g*; $P < 0.05$). Clenching while wearing an MG (drill 3) further reduced the acceleration to 21.5*g* (SD, 4.6*g*), 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) $\mu V/s^2$ during drill 1 (Chart 2). During drill 2, the activity significantly increased to 132.7 (SD, 76.5) $\mu V/s^2$ ($P < 0.05$). During drill 3, the activity increased further to 154.0 (SD, 99.3) $\mu V/s^2$, a significant difference from the activity during drill 1 ($P < 0.05$).

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

Discussion

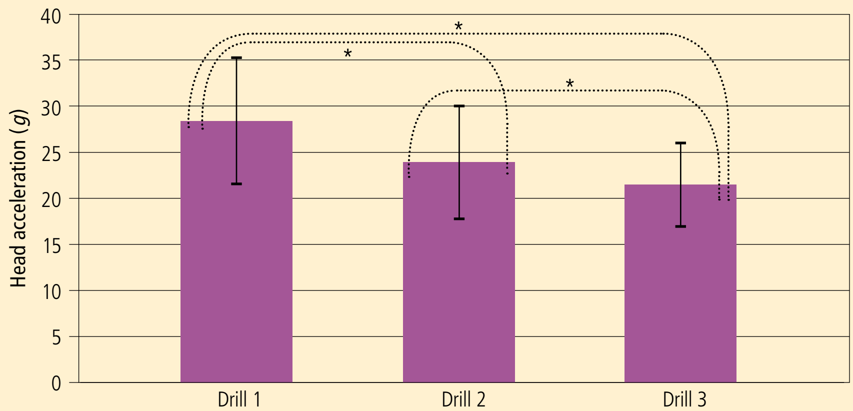
In the present study, even without instruction (drill 1), players exhibited no more than approximately 30*g* of head acceleration. There was no incidence of concussion or any other traumatic brain injury during the recorded periods, because the obtained acceleration was not great enough to result in a concussion and almost equal to the results of previous studies.[20-23] The peak acceleration associated with heading a soccer ball is reported to be 54.7*g*.[24] The average linear acceleration of impacts incurred is reported to be 24.89*g* during games and 23.39*g* during practice sessions.[25] The threshold for concussion is considered approximately 100*g*, with an impact of at least 70*g*-75*g*.[20-23]

In head-to-head impacts, contact produces enough force to result in concussive injury.[26] 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.[27] 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.[28] With head impacts, a force that exceeds the resistance of an athlete will result in brain injury or concussion.[2,3,29-32]

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.[14-17,33,34] This unconscious clenching represents a form of body control that is a feed-forward mechanism acquired through training.[16,35]

Chart 1. Mean linear acceleration of the head in 11 soccer players during heading.

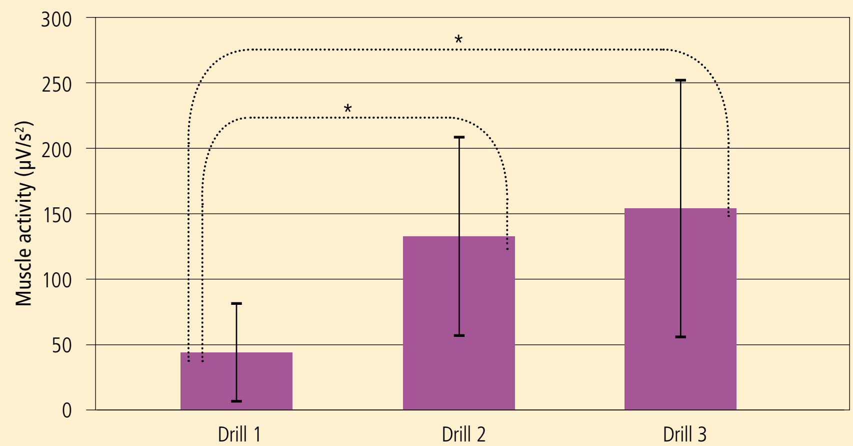


Drill 1, no instruction; drill 2, instruction to clench while not wearing mouthguard (MG); drill 3, instruction to clench while wearing MG.

Error bars represent SD.

*Statistically significant difference ($P < 0.05$; paired *t* test). Error bars represent SD.

Chart 2. Mean activity of masseter muscles in 11 soccer players during heading.



Drill 1, no instruction; drill 2, instruction to clench while not wearing MG; drill 3, instruction to clench while wearing MG.

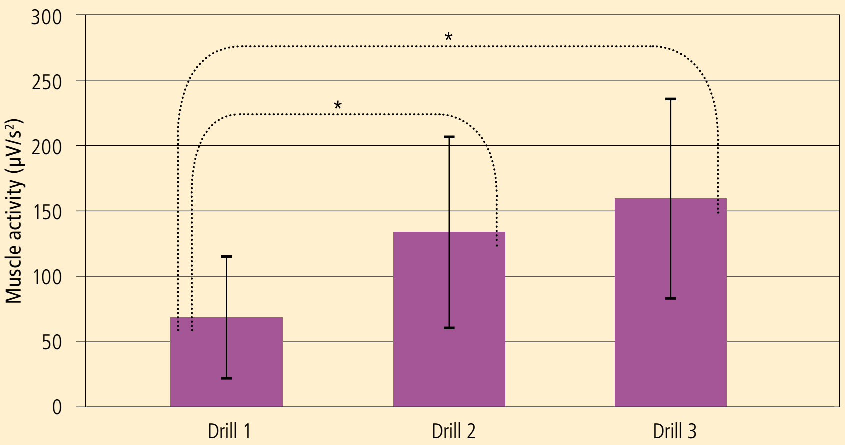
Error bars represent SD.

*Statistically significant difference ($P < 0.05$; paired *t* test).

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.[17,34,36] Previous reports have demonstrated a relationship between cervical muscle strength and the severity of impacts to the head.[16] 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.[37] 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

Chart 3. Mean activity of sternocleidomastoid muscles in 11 soccer players during heading.



Drill 1, no instruction; drill 2, instruction to clench while not wearing MG; drill 3, instruction to clench while wearing MG.

Error bars represent SD.

*Statistically significant difference ($P < 0.05$; paired t test).

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.[38] Some other studies have reported that mouthguards do little to lessen the risk of sustaining a concussion while playing rugby.[39,40] 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.[37] 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.[43] Younger players usually have less cervical muscle strength and tone than adults, so greater force may be transmitted to the cranial compartment.[44] 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.

Author information

Dr. Narimatsu is a resident, Dr. Takeda is an associate professor, Dr. Nakajima is a senior assistant professor, Dr. Konno is a postgraduate student, Dr. Ozawa is a resident, and Dr. Ishigami is a professor, Department of Oral Health and Clinical Science, Division of Sports Dentistry, Tokyo Dental College, Japan.

Disclaimer

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

References

1. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: The 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med.* 2013;47(5):250-258.
2. Aubry M, Cantu R, Dvorak J, et al. Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. Recommendations for the improvement of safety and health of athletes who may suffer concussive injuries. *Br J Sports Med*. 2002;36(1):6-10.
3. Taguchi Y, Sekino H. When do you diagnose as the concussion? [in Japanese] *J Clin Sports Med.* 2002; 19(6):609-613.
4. Delaney JS, Lacroix VJ, Gagne C, Antoniou J. Concussions among university football and soccer players: a pilot study. *Clin J Sport Med.* 2001;11(4):234-240.
5. Covassin T, Swanik CB, Sachs ML. Epidemiological considerations of concussions among intercollegiate athletes. *Appl Neuropsychol.* 2003;10(1):12-22.
6. Naunheim RS, Bayly PV, Standeven J, Neubauer JS, Lewis LM, Genin GM. Linear and angular head accelerations during heading of a soccer ball. *Med Sci Sports Exerc.* 2003;35(8):1406-1412.
7. Matser JT, Kessels AG, Jordan BD, Lezak MD, Troost J. Chronic traumatic brain injury in professional soccer players. *Neurology.* 1998;51(3):791-796.
8. Jordan SE, Green GA, Galanty HL, Mandelbaum BR, Jabour BA. Acute and chronic brain injury in United States National Team soccer players. *Am J Sports Med.* 1996;24(2):205-210 [erratum: 1996;24(4)563].
9. Levy ML, Kasasbeh AS, Baird LC, Amene C, Skeen J, Marshall L. Concussions in soccer: a current understanding. *World Neurosurg.* 2012;78(5):535-544.
10. Cantu RC. Head injuries in sport. *Br J Sports Med.* 1996;30(4):289-296.
11. Cantu RC. Second-impact syndrome. *Clin Sports Med.* 1998;17(1):37-44.
12. Bauer JA, Thomas TS, Cauraugh JH, Kaminski TW, Hass CJ. Impact forces and neck muscle activity in heading by collegiate female soccer players. *J Sports Sci.* 2001; 19(3):171-179.
13. Shewchenko N, Withnall C, Keown M, Gittens R, Dvorak J. Heading in football, 1: development of biomechanical methods to investigate head response. *Br J Sports Med.* 2005;39(Suppl 1):i10-i25.
14. Takada Y. Facilitation of tibialis anterior H reflex and depression of reciprocal Ia inhibition on soleus motoneurons during teeth-clenching in man [in Japanese]. *Kokubyo Gakkai Zasshi.* 1998;65(1):64-73.
15. Tsukimura Y, Abe H. Prevention and measure of both cervical spine and cervical spinal injuries on contact sporting activities [in Japanese]. *J Jpn Soc Clin Sports Med.* 2008;16(2):172-187.
16. Hasegawa K, Takeda T, Nakajima K, et al. Does clenching reduce indirect head acceleration during rugby contact? *Dent Traumatol.* 2014;30(4)259-264.
17. Miyahara T, Hagiya N, Ohyama T, Nakamura Y. Modulation of human soleus H reflex in association with voluntary clenching of the teeth. *J Neurophysiol.* 1996; 76(3):2033-2041.
18. World Medical Association. *WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects.* Amended October 2013. Available at: http://www.wma.net/en/30publications/10policies/b3/index.html. Accessed July 31, 2015.
19. Tierney RT, Higgins M, Caswell SV, et al. Sex differences in head acceleration during heading while wearing soccer headgear. *J Athl Train.* 2008;43(6):578-584.
20. Pellman EJ, Powell JW, Viano DC, et al. Concussion in professional football: epidemiological features of game injuries and review of the literature—part 3. *Neurosurgery.* 2004;54(1):81-96.
21. Broglio SP, Schnebel B, Sosnoff JJ, et al. Biomechanical properties of concussions in high school football. *Med Sci Sports Exerc.* 2010;42(11):2064-2071.
22. Broglio SP, Sosnoff JJ, Shin S, He X, Alcaraz C, Zimmerman J. Head impacts during high school football: a biomechanical assessment. *J Athl Train.* 2009;44(4): 342-249.
23. Guskiewicz KM, Marshall SW, Bailes J, et al. Recurrent concussion and risk of depression in retired professional football players. *Med Sci Sports Exerc.* 2007; 39(6):903-909.
24. Naunheim RS, Standeven J, Richter C, Lewis LM. Comparison of impact data in hockey, football, and soccer. *J Trauma.* 2000;48(5):938-941.
25. Broglio SP, Surma T, Ashton-Miller JA. High school and collegiate football athlete concussions: a biomechanical review. *Ann Biomed Eng.* 2012;40(1):37-46.
26. McCrory PR. Brain injury and heading in soccer. *BMJ.* 2003;327(7411):351-352.
27. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: The NCAA Concussion Study. *JAMA.* 2003;290(19):2549-2555.
28. Satoh T. Where does the impact power applied to the human body go? [in Japanese] *J Jpn Soc Biomech.* 1990;14:68-72.
29. Mihalik JP, Bell DR, Marshall SW, Guskiewicz KM. Measurement of head impacts in collegiate football players: an investigation on positional and event-type differences. *Neurosurgery.* 2007;61(6):1229-1235.
30. Guskiewicz KM, Mihalik JP, Shankar VM, et al. Measurement of head impact in collegiate football players: relationship between head impact biomechanics and acute clinical outcome after concussion. *Neurosurgery.* 2007;61(6):1244-1253.
31. Meaney DF, Smith DH. Biomechanics of concussion. *Clin Sports Med.* 2011;30(1):19-31.
32. Cusimano MD, Taback NA, McFaull SR, et al. Effect of bodychecking on rate of injuries among minor hockey players. *Open Med.* 2011;5(1):e57-e64.
33. Urbanowicz M. Alteration of vertical dimension and its effect on head and neck posture. *Cranio.* 1991;9(2): 174-179.
34. Takeda T, Ishigami K, Nakajima K, et al. Appearance of clenching at soccer heading and mouthguard effect. *J Korean Sports Dent.* 2008;4:20-32.
35. Yokoyama Y. Involuntary teeth clenching during physical exercise [in Japanese]. *J Jpn Prosthodont Soc.* 1998;42(1):90-101.
36. Sekimoto T, Kohno S, Sawada K, Minato O. Coactivation of the sternocleidomastoid muscle during clenching in the retruded mandibular position [in Japanese]. *J Jpn Prosthodont Soc.* 1999;43(3):568-574.
37. Mihalik JP, Blackburn JT, Greenwald RM, Cantu RC, Marshall SW, Guskiewicz KM. Collision type and player anticipation affect head impact severity among youth ice hockey players. *Pediatrics.* 2010;125(6): e1394-e1401.
38. Navarro RR. Protective equipment and the prevention of concussion—what is the evidence? *Curr Sports Med Rep.* 2011;10(1):27-31.
39. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on concussion in sport— the Third International Conference on Concussion in Sport held in Zurich, November 2008. *Phys Sportsmed.* 2009; 37(2):141-159.
40. Marshall SW, Loomis DP, Waller AE, et al. Evaluation of protective equipment for prevention of injuries in rugby union. *Int J Epidemiol.* 2005;34(1):113-118.
41. Hollis SJ, Stevenson MR, McIntosh AS, Shores EA, Collins MW, Taylor CB. Incidence, risk, and protective factors of mild traumatic brain injury in a cohort of Australian nonprofessional male rugby players. *Am J Sports Med.* 2009;37(12):2328-2333.
42. Ichii Y, Watanabe W. Snowboard trauma compared with skiing—recent tendency in Nigata prefecture Myoko district [in Japanese]. *J Clin Sports Med.* 1999; 16(2):234-238.
43. Kutcher JS, Eckner JT. At-risk populations in sports-related concussion. *Curr Sports Med Rep.* 2010;9(1): 16-20.
44. Neal MT, Wilson JL, Hsu W, Powers AK. Concussions: what a neurosurgeon should know about current scientific evidence and management strategies. *Surg Neurol Int.* 2012;3:16.

Manufacturers

Dreve Dentamid GmbH, Unna, 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.jugssports.com

Logical Product Corporation, Fukuoka, Japan
81.92.504.7603, www.lp-d.co.jp

Molten Corporation, Hiroshima, Japan
81.3.3625.7648, 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.ssri.com

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