The Role of Intraoral Protective Appliances in the Reduction of Mild Traumatic Brain Injury

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Abstract

Intraoral appliances (mouthguards) have long been used and mandated for several sports, with good results on the reduction of dentition injury. Recently claims have arisen that mouthguards prevent brain injury. This article reviews the data on such claims, the basic science that has been conducted, and how an intraoral appliance may in the future become part of an engineered system to reduce transfer of energy from impacts to specific locations on the head, in an effort to mitigate some types of mild traumatic brain injury.

Intraoral appliances, or mouthguards, designed to protect the dentition have been in use for many years and mandated in most collision sports for some time.[1] These devices have demonstrated some degree of effectiveness in limiting certain types of dental injuries.[2] Recently, research has attempted to demonstrate that mouthguards prevent mild traumatic brain injury (MTBI). This interest stems from growing emphasis on the causes, incidents, and identification of MTBI, as well as potential preventive interventions associated with MTBI. Some of this science is based on acceleration measurements of the empty skull, while some is ascertained from field data.[3] While skull measurement research is of interest, the magnitude of the impact and thus the impulse is necessarily low. Although the data show some attenuation of energy, it is insufficient to make any claims. The field data also fall short of providing proof of any meaningful reduction in MTBI. A more recent controlled study of neurologic impairment and recovery showed no change in outcome with the use of mouthguards.[4]

This lack of data is not unexpected: to understand these issues, the mechanics of MTBI and the use of the term “mouthguard” should be examined. The term “mouthguard” seems to refer to anything from a “buy them by the hundreds” boil and bite device that has little to no functional effect on occlusion, to professionally made custom appliances, which may offer functional occlusion limits with a wide variety of possible mandible positions and which can be made from different materials. While many of these custom appliances have a good track record of dental injury reduction, there is no standard for determining the function of these appliances in MTBI, and they are functionally useless in MTBI prevention.[5] The construction and fit of these custom appliances is as variable as the practitioners and laboratories that create them. In addition, other “in between” devices, which make various safety claims and offer insurance plans, can be purchased at retail and sporting goods stores and are sold by the millions. These devices sometimes use the word “brain” in the product name or include illustrated claims of MTBI reduction or even prevention.[6,7] Scientific data show these claims to be misleading at best, and fraudulent at worst.

The previously mentioned studies often lack a description of the actual devices employed at the time of data collection; this is particularly true of retrospective cohort studies in which athletes are polled after the fact to see if they were wearing an appliance. The data is of little value, except that it offers no evidence of mitigation in the MTBI event. Other recent data suggest that some appliances may even increase the transferred energy of an impact.[5] In this author's opinion, medically trained individuals should not believe that a device placed between the mandible and the maxilla will somehow mitigate the energy from blows to any location on the head that result in MTBI. At best, placing a simple "boil and bite" appliance in the space between the mandible and maxilla may effectively prevent interdigitation, but it could also provide a slippery surface for the dentition of the mandible.

Consider typical athletes in contact sports: they are given a helmet, a face protector, a chin cup, and a "boil and bite" mouthguard. They are told repeatedly to "keep their head up" or "hit with the face." What happens when athletes follow these rules? The energy from an impact is transferred from the face protector to the chin cup, then to the mandible, the dentition of which is on that slippery surface. The mandible is then allowed to transfer to the rear with considerable force. The mechanics of this event, while not likely to cause MTBI or dentition injuries, will probably cause mandibular injury. This type of event can also endanger the delicate areas of the intercondylar space, perhaps leading to basilar skull fractures or penetration of the glenoid fossa. As this is not a typical consideration for which the athlete is examined, and the problem may not present clinically for years, the claim for the successful prevention of dentition injury persists. From an engineering or biomechanics point of view, one of the basics of any intervention is to understand how it will impact the surrounding tissues and structures. In this case, the simple mechanics of the above impact scenario makes the potential for injury obvious.

Mechanics of the MTBI

To understand MTBI, and any role a mouthguard may play in the prevention of such injury, the mechanics of the MTBI should be examined. While the pathophysiology is only now being understood, the mechanism of tissue distortion that triggers these cascades is better comprehended.[8] The basic mechanical properties of the brain, while a very complex issue, are outlined here for the purposes of this discussion. The brain—within the confines of the cranial vault and protected by the dura mater, pia mater and arachnoid sheath, bathed in cerebral spinal fluid—is divided into approximate halves separated by the falx, a very tough layer that limits the motion of the brain as a unit. Interspersed with the functional grey and white matter is the blood supply. If one could hold the blood supply of the brain intact in one hand, and the grey and white matter with the falx in the other, one would appear to be holding two brains. This intimate and complex system of tissues is at times very different in the way it reacts to impacts and impulses that demand a response from this viscous system.

As the system is combined of materials with different mechanical properties, the issue of tissue distortion becomes apparent. Imagine shaking this complex, and visualize the neuronal axons of the grey and white matter distorting around the more rigid materials of the falx and blood supply. One can see how tissue distortion can be highly variable based on several factors, not the least of which is the magnitude and direction of the impact or force vector. It also becomes clear that rotational or angular forces are the most likely to invoke problems at low levels. These kinds of insults do not require an actual impact to the head itself but can be the result of rapid non-impact motion.[9] More likely, there is an impact component at either the beginning or the end of the event.[9] Therefore, both linear and rotational forces are at work in almost all events that result in

MTBI. For this reason, helmets demonstrate mixed and limited usefulness in the prevention of MTBI and diffuse axonal injury (DAI).

While somewhat over-simplified, the following two scenarios are examples of the complexity of these injuries. In the first, a head relatively *not* in motion is struck with an object. The impact results in a linear acceleration followed by a rotation, as the head is tethered to the torso and can translate only a short distance. In this case, without a helmet, the person is likely, depending on the impact magnitude, to have a point load, perhaps a skull fracture and significant linear injury prior to the onset of any rotational acceleration. In this kind of event a helmet is indispensible, as it will spread the load area, which reduces the point load, thereby reducing the translation and rotational impulse as well. For this reason helmets have a stellar record of injury reduction and prevention of events such as skull fracture, subdural hematoma, and sudden death.

In the second scenario, the head is in motion: for example when a person falls from a bike, and the head hits the pavement after the shoulder lands. In this case, there is a very high rotational impulse prior to head strike because the linear portion of this event is after the rotational event. Even if a helmet is worn, serious brain damage occurs, limited to the diffuse axonal damage, which is the result of the rotation. The helmet prevents the linear impact from causing immediate death by preventing skull fracture and tissue-destroying linear impact. Although the helmet proved life-saving, the person is seriously injured. The helmet could not protect the brain; the energy that injured the brain is the result of the brain's motion, while the helmet is on the skull.[9]

These events are only two possible examples: there are many other incidents with varying degrees of magnitude. For example, if the helmet is too stiff, the impulse at the end of the rotation may exacerbate the rotational acceleration. A softer helmet may limit the rotational rebound inside the head but may have allowed the point load to take place, still resulting in serious injury, but now more from the linear rather than rotational impact. In the first scenario, a too-soft helmet can result in death.

As a final step in this introduction to MTBI, imagine these scenarios, and others, occurring at much lower impulses, so that the damage is limited to a smaller number of axons (typically farther from the center of rotation). In the case of lower magnitude insult, MTBI can occur. There are standards for the thresholds of more serious brain injuries, but not yet for MTBI.[10,11] As some MTBIs can occur without head impact, no helmet, and thus no mouthguard, can prevent them.

Preventing Injury

However, there are measures that can be taken to prevent MTBI. There is a point where the right mouthguard can limit some of the forces that might cause MTBI. Based on the above explanation, it is clear that the possibility is limited to blows that occur to or are transferred to the mandible—and only the mandible. A device that 1) interdigitates the upper and lower dentition so the mandible is fixed, 2) separates the upper and lower dentition by providing a physical barrier of deformable material with the appropriate mechanical properties, and 3) wears comfortably, will limit the acceleration of the head in impacts where the mandible is a primary point of load to the head. This device will protect the dentition and the mandible, and will limit the acceleration translated to the head, thus reducing both linear and rotational forces that result from the impact impulse.

While this is all good, it is neither a panacea or a simple process. The mechanical properties of such a device must allow it to work, via deformation, at the right time, for the maximum amount of displacement, while still maintaining interdigitation and remaining comfortable. This is not a small task. A standard must be developed to test various compounds and approaches to determine if this device could perform as needed and further to determine the range of function given the limits of materials and space. However, this author believes, based on ongoing testing, that there is a balance of mechanical properties that will result in a device that, when impacted with reasonable forces, either directly or via a chin cup, will limit head acceleration to a degree that makes this of value.[5] This device will work best when coupled with other devices that limit the impulse, such as deformable face protector systems and chin anchor systems with carefully designed properties, resulting in a system that works in harmony to limit the widest range of impulses while transferring the least amount of acceleration to the head.

Conclusion

Should such devices exist, they will be important in the tool box used to limit MTBI; however they will not be the critical component. Broad claims that such devices prevent concussion remain unsupported, and any claim that the device has some function even when the mandible is not the point of load should be discounted by the knowledgeable practitioner.

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References

1. National Collegiate Athletic Association. *2008 NCAA® Football Rules and Interpretations.* Indianapolis, IN: NCAA; 2008:32.

2. Knapik JJ, Marshall SW, Lee RB, et al. Mouthguards in sport activities: history, physical properties and injury prevention effectiveness. *Sports Med.* 2007;37(2):117-144.

3. Takeda T, Ishigami K, Hoshina S, et al. Can mouthguards prevent mandibular bone fractures and concussions? A laboratory study with an artificial skull model. *Dent Traumatol.* 2005;21(3):134-140.

4. Mihalik JP, McCaffrey MA, Rivera EM, et al. Effectiveness of mouthguards in reducing neurocognitive deficits following sports-related cerebral concussion. *DentTraumatol.* 2007;23(1):14-20.

5. Padgett K. *Evaluation of Human Performance Characteristics and Peak Head Acceleration Through the Use of Protective Mouthguards* [master's thesis]. Knoxville, Tennessee: The University of Tennessee; 2005.

6. Brain-Pad Inc. Brain-Pad Protective Solutions Technology. http://www.brainpads.com/index.php?option=com_content&view=article&id=112&Itemid=123. Accessed April 17, 2009.

7. Pro-Tekt Mouthguards. Mouthguard Facts. http://www.sportsguard.com/why-wear-mouthguards.htm . Accessed April 17, 2009.

8. Giza CC, Hovda DA. The neurometabolic cascade of concussion. *J Athl Train.* 2001;36(3):228-235.

9. Roy R. *Evaluation of Head Linear and Rotational Acceleration Response to Various Linear-Induced Impact Scenarios* [master's thesis]. Knoxville, Tennessee: The University of Tennessee; 2007.

10. Pellman EJ, Viano DC, Withnall C, et al. Concussion in professional football: helmet testing to assess impact performance—part 11. *Neurosurgery.* 2006;58(1): 78-96.

11. Torg JS. *Athletic Injuries to the Head, Neck, and Face.* Philadelphia, PA: Lea & Febiger; 1982.

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