Helmets and Mouth Guards: The Role of Personal Equipment in Preventing Sport-Related Concussions

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Because the brain is freely floating within the cerebrospinal fluid, it moves at a rate that is different from that of the skull in response to a collision.[1] This discrepancy can result in a collision between the brain and skull, either on the side of the impact, coup, or opposite the impact, contrecoup.[2] The high-speed deceleration associated with these impacts may also result in stretching of the long axons at the base of the brain, resulting in diffuse axonal injury.[3] Depending on the extent of these injuries, neurologic dysfunction may be observed.[4]

Every year, approximately 1.7 million people in the United States are hospitalized or die as a result of a traumatic brain injury (TBI).[5] These figures, however, are thought to

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drastically underrepresent the total incidence of TBI, as many individuals with mild or moderate TBI do not seek medical care.[5,6] A portion of these brain injuries are considered concussions, meaning that a direct or indirect blow to the head, face, neck, or body results in an alteration of mental status or produces 1 or more of 25 recognized postconcussion symptoms.[7] It has been estimated that 1.6 million to 3.8 million of these concussions occur annually as a direct result of participation in athletics.[5,6,8] The changes in neurologic function associated with concussion often present rapidly and resolve spontaneously.[9] As such, many concussions are unreported and unrecognized by coaches, trainers, or the athletes themselves.[10–13] A further confounding factor resulting in underreporting the total incidence of concussions is the desire of the athlete to return to play.[14]

Most symptoms associated with concussions are transient; however, there are several ways in which concussions can have lasting symptoms. For example, in some cases of concussion, memory impairment has been shown to last for months.[4] Furthermore, postconcussion syndrome (PCS) may occur, especially in situations in which an athlete is not properly treated after a concussion. PCS presents with physical, cognitive, emotional, and behavioral symptoms that can take months or even years to resolve.[15,16] If an athlete returns to play before symptoms resolve, the athlete risks a rare but sometimes fatal event known as second impact syndrome.[17,18] In addition, repetitive concussive and subconcussive blows can cause chronic traumatic encephalopathy or chronic traumatic encephalomyelopathy.[19,20]

The importance of understanding and preventing these impacts is increasing because athletes have been getting bigger, faster, and stronger, leading to more forceful collisions, which are more likely to cause concussions.[21,22] The mechanisms underlying these concussions, as well as methods of prevention, have been investigated both in the laboratory and in the field. The simplest of these preventative measures seem to be rule changes, rule enforcement, and player and coach education.[10] In addition to these suggestions, equipment changes have been proposed in an attempt to help prevent concussions, including modifications of helmets and mouth guards. This equipment has been critical for injury prevention; helmets have been shown to protect against skull fracture, severe TBI, and death, whereas mouth guards protect against oral and dental injury.[23–25] However, the specific effects of helmets and mouth guards on concussion incidence and severity are less clear.

HELMETS AND HEADGEAR

Protective headgear and helmets decrease the potential for severe TBI after a collision by reducing the acceleration of the head on impact, thereby decreasing the brain-skull collision and the sudden deceleration-induced axonal injury.[26] The energy-absorbing material within a helmet accomplishes this by compressing to absorb force during the collision and slowly restoring to its original shape. This compression and restoration prolongs the duration of the collision and reduces the total momentum transferred to the head.[27] There is variation in helmet design based on the demands and constraints of each sport. Although helmets and headgear in most sports are good at mediating the high-impact collisions responsible for severe TBI, the question remains as to what extent the helmets and headgear of each sport are able to respond to the lower-impact collisions responsible for concussion.

American Football

Early helmets

There has been a great deal of focus on the protection afforded by helmets in football. The primary intent of early football helmets, first reported in use during an Army-Navy game in 1893 and constantly evolving throughout the 1900s, was to prevent catastrophic head injury and the resultant morbidity and mortality.[28] These early helmets, then nothing more than leather padding, were slowly phased out as metal and plastics were added to provide additional protection. However, even these basic helmets were not required for college play until 1939 and were not mandated until 1940 for athletes in the National Football League (NFL).[28] Despite these innovations throughout the early twentieth century, the incidence of head injuries continued to increase, prompting the formation of the National Operating Committee on Standards for Athletic Equipment (NOCSAE) in 1969 to initiate research efforts for head protection and to implement the first football helmet safety standards in 1973.[29]

These initial NOCSAE guidelines, the framework of which are still in existence, were meant to develop a standard method for measuring a particular helmet's ability to endure the annual repetitive impacts associated with football in conditions as varied as freezing cold, driving rain, heavy snow, or high heat and humidity.[28,30] However, because football collisions at that time were responsible for cerebral hematoma, cervical fractures, and death, the primary concern was the helmet's response to the most acutely severe, linear, acceleration-inducing impacts, rather than its response to the wide range and types of force that could result in concussion.[31–33] Although this focus, along with rule changes, ultimately proved successful in decreasing the risk of head injury, the hard-shelled helmet that resulted may not be best suited for protecting against the lower forces that also include a component of rotational acceleration, which are thought to cause most concussions.[23,27,34,35] Furthermore, there is evidence that newly proposed helmet-testing methods, meant to encourage the development of helmets better suited to protecting against concussions, may be less accurate than the current testing methods at simulating in vivo concussive impacts.[36]

Mechanism of concussion

Many studies have attempted to measure the forces associated with different types of head impacts. Whereas most early attempts relied on sensors housed within the helmet itself, modern studies have used sensors in contact with the athlete's head.[37,38] This use of sensors has proved more accurate, as helmet acceleration does not always accurately reflect the acceleration of the head itself.[39] These studies have helped develop a better understanding of the types of impacts associated with concussion.

One modern study, examining 19,224 high school football impacts during 55 practices and 13 games, found that impacts to the top of the head were associated with the highest force and the shortest duration of impact, resulting in the largest head jerk.[40] Although these impacts to the top of the head are more associated with severe injuries to the cervical spinal cord, rotational acceleration is more closely linked to concussion.[41,42] Impacts to the front of the head resulted in the highest rotational acceleration and were the most frequent among the high schoolers.[40] A similar study of 72 collegiate football players found that these impacts to the top of the head were 10% less frequent and associated with 1g to 2g lower accelerations than lateral hits, perhaps reflecting improved tackling form or increased neck strength.[43] These findings, of fewer hits to the top of the head in collegiate athletes than in high school athletes, have been validated elsewhere and reported in studies of professional athletes as well.[27,44] Biomechanical reconstruction of recorded concussive impacts in NFL athletes underscore the large role that rotational acceleration plays in concussion, as well as the importance of neck strength in mitigating this rotation.[45] This method of experimentally replicating recorded collisions may provide additional information about the relationship between linear and angular head acceleration and injury outcome, resulting in better helmet designs.[26,45] However, more work is needed to ensure that these models properly replicate factors potentially influencing concussion, such as bracing, neck strength, and body tension.[46]

Helmet designs

Football helmets have evolved from little more than modest leather headgear to the modern designs incorporating metals, plastics, and rubber. Analyses revealed that helmets with pneumatic padding within suspension liners were most effective at absorbing the high-intensity impacts that were of early concern.[32,33] Modern football helmets incorporate similar features, with hard plastic exteriors housing materials of various stiffness to absorb the force of collision and an inflating system meant to ensure proper fit.[28] Football helmets incorporate these basic design elements in various ways, in an attempt to afford better protection to the wearer.

There are several basic designs commonly used in the NFL. One helmet design relies on a continuous tubelike inflatable air-fit system nested into a molded foam network consisting of 2 different types of foam with different absorptive properties, ethyl vinyl acetate and polyvinyl chloride nitrile rubber (vinyl nitrile). Front and back pads consist of similar inflatable systems. A second design uses die cut, rather than molded, foams placed into a case. This creates a laminar system of foam, into which air can be introduced to ensure proper fit. An interchangeable molded urethane front pad completes the system. A third design uses a different approach: although the air liner is similar to that in the second system, it is not incorporated into the foam components. Instead, a foam, molded ethyl vinyl acetate component with vinyl nitrile inserts, similar to helmet 1, separates the air-liner fit system from an inner shell of expanded polypropylene. In addition, the plastic outer shell is ventilated and lighter than in the previous 2 designs. A noninterchangeable vinyl nitrile front pad completes the padding.[28]

Helmet manufacturers have begun to design helmets specifically intended to protect against concussion. A description of several of these helmets is in **Table 1**. One such helmet incorporates distinct design features meant to improve energy attenuation in response to lateral blows. These features include an exterior shell extending anterior to and distal to traditional shell shapes along the wearer's mandible, increased offset from the interior surface of the shell to the wearer's head in this area, and a unique interior liner construction.[47] A newer helmet design creates air turbulence within specialized shock absorbers to allow for differential response to a wider range of impact levels.[48] However, the effect of these and other changes must be further studied, both in the laboratory and on the field.

Evaluating helmets

There have been few studies evaluating the effectiveness of different helmet designs in reducing concussions. These studies have tended to be nonrandomized, retrospective analyses and have suffered from the same general pitfalls including selection bias and overreliance on subject recollection. In addition, because the guidelines for concussion assessment were not easily available until recently, many studies relying on coaches and athletic trainers to diagnose concussions may have drastically underreported the total number of concussions because only the most severe injuries would have been counted.[49,50] Even after educational outreach efforts by the Centers for Disease Control and Prevention, the Sports Legacy Institute, and others, knowledge about current concussion guidelines remains an issue.[51,52] By reporting only on the relationship between helmets and the most severe concussive injuries, these types

Table 1
Overview of material and construction of newer football helmets as compared with an older helmet design

	Riddell			Schutt		Adams	Xenith
	Original VSR-4	**New VSR-4**	**Revolution**	**Air Varsity Commander**	**DNA**	**Pro Elite**	**X1**
Forehead Pad	Molded urethane	Molded urethane	Molded urethane	Dual density VN	Skydex + CF	VN	All pads use unique Aware Flow shock absorbers in a shock bonnet
Crown Pad	VN + CF	VN	VN + CF	Comolded EVA and PE	Skydex + CF	VN/EPP + EVA CF	
Back and Sides	VN + CF	VN	VN + CF	Comolded EVA and PE	Skydex + CF	VN/EPP + EVA CF	
Jaw Pads	Interchangeable thickness CF	Interchangeable thickness CF	VN + CF	VN + CF	VN + CF	Interchangeable thickness CF	
Fit Adjustment	Crown, back, and sides padding encased in inflatable vinyl bladders	Crown, back, and sides padding encased in inflatable vinyl bladders	Crown, back, and sides padding encased in inflatable vinyl bladders	Halo-style tubular air bladder	Vinyl air bladder around CF	Vinyl air bladder covering crown, back, and sides	Fit seeker cable tightens the shock bonnet after chin straps are pulled tight. No pumps.

Abbreviations: CF, comfort foam; EPP, expanded polypropylene; EVA, ethylene vinyl acetate; PE, polyethylene; VN, vinyl nitrile.

Adapted from Viano DC, Pellman EJ, Withnall C, et al. Concussion in professional football: performance of newer helmets in reconstructed game impacts—Part 13. Neurosurgery 2006;59(3):595; with permission.

of studies risk ignoring the vast majority of concussions, which are in the mild to moderate range.[38] Studies relying on hospitalization data would have a similar bias.

Data collected by the National Athletic Injury/Illness Reporting System from a sample of high school and collegiate athletes during the 1975 to 1977 seasons showed no difference in concussion rate among 13 helmet designs. However, this study was hampered by poor concussion reporting, as a rate of only 1 concussion per 10,000 athlete exposures was reported, less than one-fourth the most conservative current rates.[53,54]

Data on helmet models used and occurrence of cerebral concussions during 5 seasons were collected from a representative sample of college football teams, consisting of a total of 8312 player-seasons and 618,596 athlete-exposures. Of the 10 models of football helmets included in the analyses, the Riddell M155 had a significantly lower-than-expected frequency of concussions, whereas the Bike Air Power had a significantly higher frequency of concussions.[55] However, the number of concussions was again less than half of current conservative estimates of concussion rates.[54] In addition, more than half of the athletic exposures in the 2 statistically significant helmet models were from schools with more than 97% of the same helmet type, exposing the study to a potential bias. Because the study relied on athletic trainer report and all but a few athletes at most schools had the same helmet type, differences in athletic trainer reporting could have had significant effects on the observed concussion rates for many of the athletes studied. To directly compare helmets, each school, and thus each athletic trainer, would have needed to have a mix of all 10 of the helmet types studied. The reported relationship is further obscured by there being a near-linear relationship between the number of athletic exposures and the rate of concussions reported; the helmets with the most exposures tended to have the highest rate of concussion exposure. This finding could be in part because of the fact that larger programs, with more athletes in total and more of the most popular helmet types, may have had staff better trained to recognize concussions.

Another study evaluated the effect of polyurethane helmet covers. During 3 seasons from 1992 to 1994, a total of 155 athletes identified as having purchased a polyurethane helmet cover in the previous year were surveyed relating to their concussion history in the seasons before and after using the device. Athletes who reported more concussions in the 4 years before adopting the cover also reported a higher rate of concussion reoccurrence while using the device.[56] These results reflect the findings of other studies, which report that players with a history of concussion are significantly more likely to suffer a new concussion than those with no previous history.[34,55] Therefore, the use of a polyurethane football helmet cover does not seem to provide additional protection against incurring concussions in the future. In a more recent study, one cohort of 1173 high school athletes given Riddell Revolution helmets were compared with 968 using standard helmets. All athletes were given a baseline immediate postconcussion assessment and cognitive testing (ImPACT) examination. During the next 3 years, whenever athletes experienced a potential concussive blow, they was assessed for concussive signs using the ImPACT test. During the course of the study, the concussion rate in athletes wearing the Revolution helmet was 5.3% compared with a concussion rate of 7.6% in athletes wearing the standard helmet [χ^2 (1, 2, 141) = 4.96, $P<.027$]. Athletes wearing the Revolution helmet seemed to have a 31% decreased relative risk for sustaining a diagnosed concussion compared with those who were not.[47] However, limitations in the study design diminish the strength of the findings. The players in the Revolution helmets had new helmets, whereas the standard helmets were of varying age, and helmets tend to become less effective over time. Because athletic trainers are often unaware of all but the most severe concussions, the results may have been influenced more by reporting rates of the high school staff than absolute differences in the risk of concussion. Furthermore, concussions were diagnosed by ImPACT instead of a combination of neurologic examination that includes balance testing. Finally, the study was funded by Riddell, and a Riddell employee was a lead author, which pose an obvious conflict of interest. Although there was a difference in the rate of concussion between the 2 groups, concussed athletes in the 2 groups did not differ significantly in the average number of days to recover and return to play after their concussions.

Baseball

Several new concussion-proof helmet designs have been proposed and are now being introduced into Major and Minor League Baseball, but their degree of effectiveness in preventing concussion has not yet been demonstrated in any epidemiologic study. However, the role of standard baseball helmets in preventing more serious head injuries has been well validated.[57]

Cycling

Helmets have long been shown to decrease the rates of head injury in cyclists.[58–61] However, there have been no studies evaluating the different bicycle helmet designs in response to concussive impacts.

Ice Hockey

Ice hockey, like football, is a helmeted sport associated with a significant risk of concussion. For aforementioned reasons, including an increased awareness of diagnostic criteria, the rate of diagnosed concussions has been increasing; nonetheless, helmets are largely responsible for protecting hockey players from the most catastrophic head injuries.[10,11,54] The introduction of ice hockey helmet standards and the proper use of helmets have resulted in a decrease in fatal and catastrophic head injuries but with an increase in the concussion rate.[62] Although this increase in rate is likely due in large part to better concussion awareness and recognition, aggressive play may also be responsible for this increase in rate.[63]

Concussions in hockey most commonly occur as a result of collision with an opponent or with the boards.[64] Measurements from sensors within the helmets of hockey players have found that the impacts sustained by hockey players are comparable in magnitude to those experienced by football linemen but occur at approximately one-third of the frequency.[38] Since helmets have been made mandatory in hockey, there has been little literature published comparing the protective effects of different hockey helmets. However, there is evidence that player flexion and anticipation before a collision decreases the risk of concussion, providing a potential avenue for future helmet design.[46] Newer helmet-testing methods have begun to take into account the rotational acceleration component involved in a collision, which better simulates concussive impacts.[35]

Lacrosse

In a recent study of athletic trainers, concussion was found to be the most common injury in lacrosse and was responsible for a high percentage of all injuries among boys (73%) and men (85%) than among girls (40%) and women (41%). In men, the primary injury mechanism was player-to-player contact, whereas in women, injuries primarily resulted from stick or ball contact.[65]

Although the rate of concussions has increased dramatically in many sports, some have argued that this observation in men's lacrosse may be, in part, explained by the introduction of a new helmet. One study compared the rate of concussion in the years immediately after the helmet's introduction (1996–1997 to 2003–2004) with that of the preceding years (1988–1989 to 1995–1996). In practices, the rate of concussion increased by 0.14 concussions per 1000 athletic-exposures (95% confidence interval [CI], 0.09, 0.19; $P<.01$). In games, the rate increased by 0.84 (95% CI, 0.52, 1.16; $P<.01$).[66] However, this increase is certainly due, in part, to improved detection and diagnosis of concussion during that time frame.

Rugby

Headgear in rugby consists of relatively sparse padding, and its use is not mandated. Therefore, the role of headgear in preventing concussion and head injuries can be more easily studied. In one prospective study of 294 players younger than 15 years, headgear was distributed to players. Over the course of the study, there were 1179 player-exposures with headgear and 357 without headgear. During this period, there were only 9 reported concussions, 7 of which occurred to players wearing headgear, 2 to those not wearing headgear. As a result, there was no evidence indicating a protective effect of headgear; in fact, these data showed that headgears have a nonsignificant deleterious effect.[67] However, as only concussions that were medically verified were reported, many minor concussions may have been unreported. Headgear use was not randomized, as athletes had the choice of whether or not to wear headgear. This choice produces a potential bias, as athletes more concerned about head injury are more likely to wear headgear; certainly a subset of these athletes had had prior concussions and was therefore more susceptible to having additional concussions. In another study of 304 rugby players, followed weekly, headgear was shown to have a nonsignificant protective effect on concussions but a significant protective effect on orofacial and scalp injuries.[68] However, only 22 concussions were recorded, and the study was not adequately powered to determine a suitable effect size. A survey-based study of 131 men's club rugby union participants from 8 university teams in the United States reported 76 total concussed athletes. Although 51% of the surveyed athletes were not wearing headgear, 76% of the concussed athletes reported not wearing headgear. The remaining who were concussed while wearing headgear reported that their concussions were less severe than those of the athletes not wearing headgear.[69]

However, in the most thorough study, 1493 participants from 4 rugby leagues (under 13, under 15, under 18, and under 20) were randomly assigned 1 of 2 types of headgear or no headgear and followed for 2 years. Although compliance to the random assignment was low, nearly half of all athletic exposures consisted of athletes wearing 1 of the 2 headgear types. Regardless, the use of these padded headgears did not affect the rate of concussion or the number of days missed because of concussion.[70]

These findings, which indicate that rugby headgear does not seem to have a protective effect in concussion prevention, correspond to laboratory findings indicating that headgear are maximally compressed at impacts far less intense than those likely to cause a concussion.[71] Because they are unable to absorb additional force well below the threshold at which concussions occur, they would not be expected to have a major effect on the incidence of concussion. However, this ceiling effect may be avoided in future headgear by methods such as modifying padding materials and increasing padding thickness.[72]

Besides the apparent lack of scientific justification supporting the use of rugby headgear for concussion prevention, additional barriers remain to widespread headgear adoption. Although athletes tend to report that headgear is beneficial, athletes in one survey commonly reported that the headgear caused discomfort and poor ventilation and was often grabbed by opponents during play.[69,73]

Soccer

Several studies have sought to measure the nature of impacts experienced by soccer players. Although soccer players experienced significantly fewer impacts per hour than high school football lineman or hockey players, each impact tended to be associated with higher accelerations; whereas 20% of impacts in soccer were more than 75g, approximately 5% of impacts were more than 75g in football lineman and hockey players.[38] However, the head-ball collisions that were studied are not the most common source of concussions in soccer. Most concussions in soccer occur during the act of heading as a result of head-head or head-arm collisions.[74] Another study following athletes for 3 years found that the most common site of impact in a concussion-causing collision was the temporal area of the head.[44] This finding supports those of other sports and underscores the importance of rotational acceleration in concussion.

There are various types of headgear proposed to limit the effect of concussion in soccer athletes. Although there have been nonrandomized studies of the effect of headgear on head injuries in soccer, there have been few analytic studies looking specifically at the role of headgear on concussion rate or severity,[44,75] which is a potential area of interest.

One retrospective anonymous online survey of youth soccer players, aged 12 to 17 years, studied the role of headgear on concussion symptoms. Of those eligible for the study, 216 athletes were included in the non–headgear-wearing group and 52 were included in the headgear-wearing group. This study was strengthened by the fact that it asked respondents not only how many concussions they had experienced in the prior season but also how many times they had experienced specific symptoms associated with concussions in response to a collision. About 7.2% of the athletes reported having experienced at least 1 concussion, whereas 47.8% reported having experienced concussive symptoms at least once. Athletes wearing headgear were significantly less likely to receive laceration to those areas of the scalp and face covered by the headgear. Although the group that chose to wear headgear reported having experienced more concussions before the study (42.3% had experienced at least 1 prior concussion and 26.9% had experienced more than 1, compared with 11.1% and 4.6%, respectively) and would therefore be expected to be more knowledgeable and at increased risk of having an additional concussion, it was found that not wearing headgear was associated with a 2.65 relative risk of concussion ($P<.0001$).[75] This finding might be explained in part by the fact that fewer athletes who wore headgear considered themselves to be a header (44.2% of those who wore headgear as compared with 51.4% of those who did not). Although this study is promising, it was not ideal because headgear use was nonrandomized and the retrospective study relied principally on information recollected by athletes at the end of the season. Although the anonymous nature of the survey did not allow follow-up questions of participants or verification of data, this is nonetheless a likely strength because many studies have found more accurate concussion data when athletes anonymously report their history. However, if all soccer players were to wear headgear, the effect on concussions may be complicated by risk compensation. Rule changes in football, hockey, and lacrosse have suggested that mandating headgear removes inhibitions to strike or risk strikes to the head because it reduces pain from scalp injuries and lacerations. If all players were to become accustomed to a playing style in which contact to the head was no longer off limits, the addition of headgear might result in an increase in the frequency of total collisions to the head and potentially increase the total number of concussions as well.

There is some evidence that the same headgear may not be appropriate for all athletes. One study evaluating heading kinematics found that women experienced higher acceleration than men when heading a ball.[76] Although most concussions do not occur as a result of head-ball interactions, these findings nonetheless indicate that gender differences may need to be accounted for in future headgear designs. Additional laboratory testing found that although headgear is unlikely to be effective in attenuating impact during head-ball collisions, it may decrease the impact of head-head collisions by nearly 33%.[77]

However, because there is a specific mechanism of injury associated with concussion, the simplest preventative strategy may not be newer equipment. As concussions typically occurred in both men and women as a result of contact while heading the ball, limiting this type of contact through rule changes may be appropriate.[4]

Skiing/Snowboarding

Observational studies have found that 12.1% of US skiers wear helmets.[78] However, from 1982 through 1998 at the Saint Anthony Central Hospital (Denver, CO, USA) level I trauma center only 3 of the total 1214 patients admitted for all ski-related head injuries were wearing a helmet.[79] Several studies argue that helmets may reduce risk of concussion by up to 60%.[80–83]

MOUTH GUARDS

During the 1960s and 1970s, the use of mouth guards was made mandatory in many sports, including football, ice hockey, lacrosse, field hockey, and boxing. The rationale for these rule changes was to provide additional protection against dental and orofacial injuries and to reduce a player's risk of concussion.[25,84] However, at that time, as well as now, there is little evidence that mouth guards provide protection against concussion.

American Football

There is interest in the possibility that better-designed mouth guards might help dissipate force, thereby reducing the magnitude of the impact. Because mouth guards are already mandatory equipment in football, there is an opportunity to evaluate the role of specific types of mouth guards in preventing concussion. There is some scientific rationale that custom-fit mouth guards might be more effective at measurably absorbing the force of impact.[85] A study of 28 high school and college football players suggested a decrease in the rate of concussion after the use of customized mandibular orthotics; however, this study was marked by several design flaws. Concussion rate before customized mandibular orthotics was measured by self-report, whereas concussion rate following orthotic use was calculated only based on concussions diagnosed by athletic trainers and coaches. Also, because all athletes were given orthotics, the observed decrease in the concussion rate could simply be an artifact of different styles or age of play; all athletes were necessarily older when using the custom orthotics than they were when using standard mouth guards. Finally, calculation of the rate of concussion before the use of custom orthotics was not limited to games, whereas only concussions occurring during games were counted after the use of custom orthotics.[86] No large study has been able to demonstrate a significant difference in the concussion rate depending on the type of mouth guard used. One study recruited 87 of a total of 114 Division 1 teams to participate in a study evaluating the effect of various mouth guard types on the rate of concussion. There was no statistically significant result between the different mouth guards.[87] These findings have since been replicated by other large, multicenter cohort studies.[88]

Basketball

Many are interested in the potential role of mouth guards in reducing the number of concussions in basketball. However, recent studies have found no significant differences in concussion rates between mouth guard users and nonusers.[89]

Ice Hockey

There has been some interest in the degree to which helmets, mouth guards, and visors affect concussions in athletes. There are several different hockey helmet designs that have been shown to decrease total impact experimentally; however, there have been no studies to determine their utility in reducing concussions.

Mouth guards are not mandatory in the National Hockey League (NHL) because there is a debate over the extent to which they reduce concussion incidence and severity. In a study of 1033 NHL athletes, the rate of concussion was 1.42 times greater in individuals who did not wear mouth guards compared with those who did. However, this difference was not statistically significant (95% CI, 0.90–2.25). Despite the nonsignificant finding regarding concussion rate, symptom severity was significantly decreased by the use of mouth guards. Symptom severity, measured using the modified McGill abbreviated concussion evaluation post-concussion symptom scale, was found to be significantly worse in athletes who were not wearing mouth guards than in those who were ($P<.01$).[90,91]

Rugby

In rugby, there is evidence that mouth guards protect against orofacial injuries, but a study of 304 rugby players followed weekly showed no significant effect of mouth guards on the incidence of concussions, although only 22 total concussions were observed.[68]

Soccer

One anonymous survey of 278 youth soccer players aged 12 to 17 years found no significant relationship between mouth guard use and the rate of concussion.[75]

OTHER EQUIPMENT

Facial Protection

During the l970s, full facial protection was mandated by all organized youth ice hockey associations worldwide. However, several studies have shown no significant relationship between the use of visors and the concussion rate in high school, college, or NHL athletes.[91–94]

In junior A ice hockey, full faceguards were found to provide a 4.7 times reduction in eye injuries and a nonsignificant reduction in the rate of concussion from 12.2 to 2.9 concussions per 1000 player-hours compared with no faceguard.[94] However, this study was hampered by restricted data collection for playing time and injuries, which were only recorded during home games. Therefore, injuries from away games were not included in the analysis. Also, players younger than 18 years had to wear mandatory full facial protection, whereas players older than 18 years could choose to wear a full shield, half shield, or no shield.[95] Playing style might have influenced this decision, as players with riskier playing styles may have chosen to play without visors.

In university level ice hockey, the use of full faceguards was found to reduce the number of games missed because of concussion, but not the incidence of concussion, compared with the use of half faceguard.[93] Although the use of full face shields significantly reduced players' risk of sustaining a dental injury, there was no difference in the incidence of concussions between players wearing different shield types. However, players who sustained concussions while wearing half shields required significantly more time before returning to competition than players who sustained concussions wearing full face shields.[96] One potential explanation for this finding is helmet placement. Players wearing half shields may have been tilting their helmets back to allow for an unobstructed view below the visor, thereby getting a clearer view but resulting in improper helmet placement. Alternatively, the minor visual impairment from the half shield could have led to an increased number of hits that were not foreseen by the athlete and therefore may have led to a greater number of concussions. Improper helmet alignment would causes less padding on the forehead and a loose chin strap decreasing the protective effect of the helmet. Neither of the aforementioned studies compared the incidence of concussion in athletes with visors to those without. In professional hockey, the use of a visor did not significantly reduce the prevalence of concussions. Visor use did, however, lower the prevalence of eye and nonconcussion head injuries.[92]

There is some additional interest in the potential of facial protection to mitigate concussion in other sports. In biomechanical reconstructions of professional football concussive injuries, impacts to the facemask resulted in high rotational accelerations, likely because facemasks sit outside the helmet shell and thus have an increased radius of rotation from the base of the head.[45] This may help influence future helmet designs.

In baseball, some have proposed that faceguards may reduce the risk of concussion, although this has not yet been studied. In youth baseball, facemasks have been shown to reduce the incidence of oculofacial injury in a nonrandomized prospective cohort study.[97] Overall, faceguards are also associated with a reduced risk of facial injury.[98]

Baseball Balls

In baseball, softer balls have been shown to reduce the risk of head injury compared with standard balls, but this equipment has yet to be studied in light of concussions. Theoretical biomechanical studies have indicated that baseballs with a lower mass and less stiffness have a reduced potential for injury.[99] Laboratory studies have shown that reduced-impact balls are less likely to result in head injury and skull fracture.[100] In practice, softer baseballs have been found to yield a 28% reduction in the risk of injury.[24,98,101]

Playing Surfaces

As the speed of athletes increases, the momentum transfer and impact associated with their collisions increase. The surface on which athletes play affects the player's speed and may influence the rate of concussions. In general, synthetic surfaces are harder and result in faster speeds than natural ones.[34] Some studies have found that athletes playing on synthetic fields have a higher risk of injury.[102] Laboratory studies have found that different fields have different impact attenuation properties, which would certainly be expected to at least influence head-ground collisions.[103]

DISCUSSION

Several studies have provided biomechanical evidence that the use of specific headgear or helmets reduces the impact forces to the brain. However, in most sports, these results have not translated into observed differences in rate or severity of concussion.

For some sports in which contact with hard surfaces is possible, such as skiing, snowboarding, and cycling, there is evidence that helmets greatly reduce the incidence of head injuries in general; therefore, helmets are an important part of injury prevention and should be recommended in these sports.[61,104–106]

Risk compensation is a complicating factor associated with helmet and headgear use. In many cases, protective equipment can lead to a false sense of security, resulting in a more dangerous style of play.[107] Often, the helmet itself may be used to initiate contact. This tendency to promote a more reckless style of play may help explain the higher rate of injury in children and adolescents as compared with adults.[108]

In general, helmets work best when properly used. This means that the helmets must be sized appropriately and worn with all straps correctly fastened and all padding in the proper positioning. Problems arise when helmets are older, incorrectly sized, worn improperly, or when padding is underinflated. Inclement weather also has been shown to affect a helmet's ability to absorb impacts.[28] Neck strength may be important in minimizing the risk of concussion in response to an impact. Therefore, rule changes mandating neck strength training, education about proper tackling form including prohibiting spearing, and monitoring player fatigue is warranted.[45] Encouraging practices with limited contact may also be an appropriate way to limit concussive blows in football; however, some studies indicate that helmet-only practices are associated with similar impacts as those experienced in full-contact play.[43]

Although mouth guards have been shown to be effective in preventing dental and orofacial injury, there is currently no evidence that standard or fitted mouth guards decrease the rate or severity of concussions in athletes.[85] The bulk of the evidence indicating a potential protective effect of mouth guards on concussion incidence has been based on a limited case series studies and retrospective, nonrandomized, cross-sectional surveys.[91] There is also evidence that mouth guard use does not result in any difference in neurocognitive test performance after concussion.[109] In sports such as hockey, there is no evidence that visors play a protective role in preventing or mitigating concussions.[91–94]

Many of the studies on the protective effect of equipment on concussive risk have been complicated by retrospective, nonrandomized study designs. Individuals may choose to wear specialized protective equipment based on previous injury history, which has been shown to increase risk of future injuries, or because of a risky playing style. The preponderance of evidence seems to indicate that helmets and mouth guards provide a significant benefit in protecting against many catastrophic head, neck, and orofacial injuries. However, there is not yet significant evidence to advocate their effectiveness in preventing concussion. Nonetheless, additional research is needed both in the laboratory to improve equipment design and on the field to verify findings epidemiologically. Although newer equipment remains a promising potential tool in minimizing concussion severity and incidence, other methods such as rule changes, improved concussion education, and proper coaching and training may prove more effective in the immediate future.

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