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■ REVIEW ARTICLE

Helmet Modifications and Policy Changes to Mitigate Chronic Traumatic Encephalopathy in Professional Football

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ABSTRACT: Chronic Traumatic Encephalopathy (CTE) is a neurodegenerative disease caused by repetitive brain trauma, which can have symptoms of aggression, depression, and progressive dementia. Concussions, referred to as mild traumatic brain injury, happen when contact or whiplash causes the brain to shake inside the head and contact with the skull, which has been linked to the development of CTE. There are around 3.8 million sports-related concussions annually. CTE can only be definitively diagnosed (beyond limited imaging) postmortem through an analysis of the abnormal tau proteins in the brain. Unfortunately for the afflicted, there is no known cure for CTE. Preventative measures are thus paramount in reducing the incidence and severity of CTE. We present current measures being researched, including helmet modifications and neck strengthening methods and a potential policy alteration to football to reduce and/or prevent concussions (and more severe injuries such as neck fractures) and thereby mitigate CTE.

KEYWORDS: Translational Medical Sciences, Disease Prevention, Chronic Traumatic Encephalopathy, Concussions, Football.

Introduction

Chronic Traumatic Encephalopathy (CTE) is a neurodegenerative disease caused by repeated traumatic brain injuries (TBIs) or general trauma.[1] Its effects include memory loss, impaired judgment, impulse control problems, aggression, depression, suicidality, Parkinson's syndrome, and, eventually, progressive dementia.[2] The effects of CTE are progressive and are divided into four stages. Stage 1 represents the earliest signs of CTE; symptoms often include memory loss. Stage 2 has symptoms of decreased concentration and cognition and sometimes impulse control issues. Stage 3 can cause impulsive violent reactions, paranoia, and further memory loss. Stage 4 leads to symptoms like dementia. This progression of CTE from stage 1 is estimated to take around thirteen years; a high proportion of those over 60 with CTE is found to have stage 3 or stage 4.[3] CTE can only be definitively diagnosed postmortem through an analysis of the abnormal tau proteins in the brain.[4] Its signs, however, can be observed through Magnetic Resonance Imaging (MRI) testing, showing brain shrinkage in certain areas.[5] This limitation prevents the prevalence of individuals with CTE from being known. Unfortunately for the afflicted, there is no known cure for CTE at this point in time.

Preventative measures are thus paramount in reducing the incidence and severity of CTE. In professional sports, this can be achieved by preventing head trauma. Concussions are the most common mild traumatic brain injury (mTBI) in the United States of America and are the most diagnosable form of head trauma in professional sports. There are around 3.8 million sports-related concussions annually.[6] A concussion results from an impact to the head or body or a whiplash effect that jolts the brain causing damage to brain cells.[7] Symptoms include headaches, confusion, nausea, light sensitivity, ringing in the ears, and trouble understanding and/or concentrating. Concussions are diagnosed through a neurological exam that tests thinking abilities, memory/concentration, hearing, light sensitivity, vision, and eye movement.[8] Repeated concussions and traumatic brain injuries are believed to be the cause of CTE, but not all individuals who experience multiple traumatic brain injuries will be diagnosed with CTE.[6] The primary prevention strategy involving CTE must involve mitigating concussions or concussive blows by focusing on decreasing the forces involved in traumatic brain injuries. Reducing the magnitude of these impacts through policy change could also affect concussion incidence and CTE development.

Discussion

Effects of CTE on Football:

The effects of CTE on former professional players sprung into national attention after its discovery by Bennet Omalu (a Nigerian American physician, forensic pathologist, and neuropathologist). In the early 2000s, he discovered CTE after examining the head of a former professional football player. It has been diagnosed in many people, from former professional athletes to ex-military personnel.[9] It became increasingly significant after the tragic suicide of Junior Seau. He played in the National Football League (NFL) for twenty years as a linebacker and died in May 2012 of a self-inflicted gunshot. Seau was posthumously diagnosed with CTE.[10] A former teammate commented on Seau's difficulty sleeping over the years, which indicates the progressive nature of CTE. Furthermore, two years before he passed, he also owed massive debts to casinos after repeatedly playing high-stakes blackjack, potentially indicating impulsive decisions, another symptom of CTE.[11] More recently, Phillip Adams, who played six years in the NFL as a cornerback, died in April of 2021 after shooting and killing six people and then taking his own life. Adams was also posthumously diagnosed with CTE. Dr. Ann McKee, who

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analyzed the brain of Phillip Adams, diagnosed him with Stage 2 CTE. She also believed that he was suffering from paranoia and impulsive behavior symptoms.[12]

It is interesting that Gary Plummer, a former NFL player and Junior Seau teammate, said, "In the 1990s, I did a concussion seminar. They said a Grade 3 concussion meant you were knocked out, and a Grade 1 meant you were seeing stars after a hit, which made me burst out in laughter. As a middle linebacker in the NFL, if you don't have five of these each game, you were inactive the next game." This repeated onset of concussions, while mild, would be a factor in the development of CTE.[13]

These stories are examples of how CTE is not only a danger to the health of professional football players but also to the health of college and high school football players who experience repeated mild traumatic brain injuries or concussions. Over 1 million high school and seventy thousand college football athletes and CTE has already been observed in these groups. A retrospective study published in the Journal of Medical Association (JAMA) in 2017 found CTE in 3 out of 14 high school football players and 48 out of 53 college football players.[14] These statistics show that CTE is a growing public health issue and must be studied more closely, along with policies being enacted in football to mitigate concussions due to their link to CTE.

The Different Forces involved in Concussions and an Assessment of the Current Helmet:

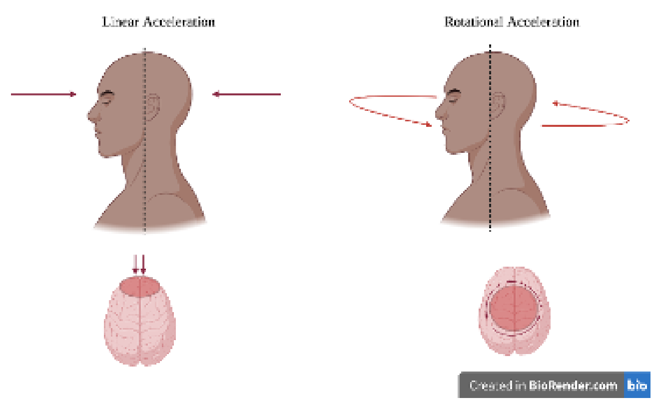

Figure 1: Visual differentiating between the linear and rotational acceleration.

During a concussion, the brain is jolted around, which stretches and damages brain cells.[7] This can damage the protectional tissue around the brain, which prevents direct contact between the brain and the skull. This can lead to bruising of the brain.[15] The main forces involved in a concussion are linear acceleration and rotational acceleration, as seen in Figure 1. Linear acceleration includes head-on impact, and injuries include intracranial hemorrhaging and skull fractures.[2] An example is when a car brakes too hard, and the passenger's head jolts forward, contacting the front of the vehicle's interior. Rotational acceleration involves the unrestricted movement of the head asynchronously to the neck and body.[2] An example would be a boxer getting punched in the side of the face, causing their neck to twist. Injuries affect the brain stem, and rotational acceleration is thought to be the leading cause of concussions. Brain stem injuries can lead to momentary paralysis and affect bodily functions and memory.[16] Most modern helmets sufficiently protect against linear acceleration but do not adequately protect against rotational acceleration. While the brain can withstand rotational acceleration up to a duration of 5 ms, typical impacts in professional football last 10-15 ms.[2] Furthermore, the rotational acceleration is dependent on the frictional coefficient. A greater frictional coefficient value would result in a greater rotational acceleration, which indicates an increased strain on the brain. The frictional coefficient represents the frictional forces between 2 objects to prevent motion; the higher the frictional coefficient, there will be less motion/slide between 2 objects. By decreasing the frictional coefficient in helmets, when contact is made, the helmets will slide on each other. Preventative measures need to limit rotational acceleration through modifications of the helmet or by decreasing the frictional coefficient of the helmet by using a different material.

Current preventative measures currently researched:

The Impact Diverting Mechanism (IDM) is a decal meant to be placed on the exterior of a football helmet.[2] The IDM Decal decreases the friction coefficient between the decal on the helmet and the impacting surface. The decal comprises four layers: the outermost layer decreases the rotational acceleration during high-speed collisions, the middle layers reduce friction between the four layers, and the innermost layer attaches to the helmet's exterior. The researchers tested this decal by comparing it to a control group (no decal). The researchers dropped helmets with decals and without and compared the rotational acceleration and velocity at a speed of 5.5 m/s.

The helmet was dropped at three impact angles at each location (15, 30, and 45 degrees) to account for the variety of hits a football player can take. They found that the decal successfully reduced rotational acceleration by amounts ranging from 27% to 77%, and rotational velocity was reduced by amounts ranging from 20% to 74%. Statistics on the durability of the IDM were not provided, and further research should investigate its feasibility. In addition, it should be noted that the researchers in this study had a conflict of interest, indicating the need for more testing to minimize the effects of bias. If the IDM consistently gets damaged, then the cost required to replace the IDM could make it impractical. This is because the IDM causes the impact to slide on the helmet, decreasing the overall magnitude of the impact by reducing the forces involved. By decreasing the frictional coefficient, the magnitude of the frictional forces involved is also reduced. Because the overall magnitude is decreased, the overall impact/jolt experienced will also be decreased, thus reducing the shock experienced by the brain. In addition, linear acceleration was also reduced (7% - 39% reduction).

Further study should go into expanding the size of the decal as the size of the decal was limited to the size of conventional decals. If the IDM covers the whole helmet, greater protection can be ensured. However, the IDM could be a great addition to a football helmet due to its ability to decrease rotational acceleration, mitigating concussion prevalence and reducing CTE risk.

Liquid Shock Absorption:

The fluid-based shock absorber concept is the idea of applying a constant force to the head to minimize the risk of a concussion or an mTBI.[17] Applying a constant force to the head is optimal as it would minimize the jolt/blow to the head and therefore reduce the amount/degree that the brain shakes inside the head and contacts the skull. The researchers believe that by mitigating this effect, traumatic brain injuries would be prevented from occurring. The researchers used computational simulations to evaluate the effectiveness of this concept. While it doesn't perfectly encapsulate the conditions of an *in vivo* test, it provides a simulated outcome that can approximate the tested conditions, offering an accurate prediction/test of the model. The simulation accounted for collisions at a speed of 9.3 m/s and found that the average brain tissue strain is reduced by 27.6% (± 9.3) compared to the conventional helmet padding. The study did not explore whether this reduced moderate brain tissue strain would prevent a traumatic brain injury. However, the decreased brain tissue strain does indicate the success of the concept of the model. Thus, the model shows that it can, at the very least, mitigate the risk of a traumatic brain injury and the risk of the development of CTE.

Outer Shell Model:

The researchers in this study tested if an outer shell would decrease linear and rotational acceleration by reducing the overall forces transmitted to the brain.[18] They tested Sorbothane as the material for the outer shell due to its non-Newtonian properties. The property observed is the change in viscosity of the substance when under stress. Essentially, this is beneficial as the original impact/force from one player would cause the material in the helmet to "become more solid" and thus act as a harder shell. This shell was compared to the conventional helmet using a pneumatic ram test. A pneumatic ram test involves an air-powered ram that hits the helmet at several locations and angles. Both helmets were impacted five times at 3 locations (the front boss, the side, and the back). The shell reduced linear acceleration (5.8% at one location and 10.8% at another) and reduced rotational acceleration (49.8% at one location). Since the rotational and linear acceleration is decreased, then the overall jolt to the brain will decrease. The cost and durability of Sorbothane were not mentioned and are key when assessing the pros and cons of this model. However, the model may reduce the risk of a traumatic brain injury and thus decrease the risk of CTE by successfully reducing the forces acting upon the brain.

Ranking of Preventative Measures:

All three mechanisms successfully decrease the forces which act upon the brain and could be successful additions to the modern helmet. The IDM stands out for its ability to not only reduce rotational and linear acceleration but also to decrease the frictional coefficient. The Outer Shell model also decreases rotational and linear acceleration but only at specific locations on the helmet. The Liquid Shock Absorption Model decreased brain strain, but the concept was not physically tested, decreasing its potential compared to the other two options.

Role of Neck Muscles in Head Injuries:

Figure 2: Visual demonstrating eccentric contraction.

Another method to prevent CTE (by preventing mTBI) would be strengthening the neck muscles. This would be beneficial as it would increase stability and minimize the jolt to the head. The researchers in this study created a musculoskeletal model of the head and neck to analyze the role of muscles in the neck and posture.[19] They looked at isometric muscle strength (muscle contracts without movement), eccentric (muscle lengthens as it contracts) multiplier - athlete's ability to apply greater muscle force during eccentric contractions (See Figure 2), muscle activation patterns, and impact properties.

The researchers were interested in the effects of active neck muscles on the outcome of a head injury. By doubling the neck strength and increasing the eccentric multiplier from 1.2 to 1.8, there would be reductions of roughly 10%, 5%, and 8% for HIC (Head Injury Criterion), BrIC (Brain Injury Criterion), and HIP (Head Impact Power), respectively. HIC is a metric that focuses on linear accelerations of the skull, BrIC is a metric that focuses on peak rotational accelerations of the skull, and HIP is a metric that accounts for all movement in all six degrees of freedom of the head. However, doubling neck strength is hard and near impossible for some athletes, which makes this idea less feasible. Interestingly, the researchers found that posture was the most critical factor in head injuries, as changing the impact direction can change angular velocity by up to 30%. This shows that training athletes to "brace" or assume specific postures would better mitigate head injuries. However, it is essential to note that this training would only be effective in impacts the player sees coming; neck muscular strength would not play a significant role in mitigating injuries for unexpected impacts.

Possible Policy changes (HS→NFL) (Kickoff/Protect Position groups):

In one study, researchers attached sensors to football players' helmets on two Canadian university teams to evaluate head accelerations.[20] Only helmet-to-helmet collisions were recorded in this study. Out of all the different play types, they found the accelerations to be the highest in kickoffs and kick returns. On kickoff coverage plays, the tackling player experienced greater linear acceleration, rotational velocity, and rotational acceleration. Meanwhile, on kickoff return plays, the player

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being tackled experienced higher experienced greater linear acceleration, rotational velocity, and rotational acceleration. For example, the linear acceleration observed in struck players on kick returns was around 53g (g is around 10 m/sec^2).

In comparison, the next highest value observed in struck players is about 22g in pass plays (highest non-kick return/cover play). Similarly, the rotational velocity and acceleration observed (34 rad/sec, 4000 rad/sec^2 (angular acceleration)) also have much higher values in kick returns than the highest non-kick return/cover play (16 rad/sec in run plays, 1500 rad/sec^2 in pass plays). The interesting thing to note is that for both kickoff coverage plays and kick return plays, these values were much higher than for any play type, indicating the potential impact of head trauma from these plays.

Concussion protocol has seen vast improvements over the past twenty years. The protocol offers a 5-step procedure for players to return to action.[21] This is positive as it provides a more personalized treatment method for players accounting for the variance in severity of concussions rather than assigning an arbitrary time restraint. The player must then be cleared by an unaffiliated neurological consultant approved by the NFL. While a player/team can bypass the evaluations and methodical procedures, the system is still a success compared to past years. Thom Mayer, the NFLPA's longtime medical director, said that "fully 50% of concussions had some element of player reporting".[21] This can be attributed to the CBA (collective bargaining agreement) in the NFL, which states that a team is obligated to continue to pay players who are rehabbing from an injury for the year in which the injury was sustained.[23]

Another triumph of concussion detection during games is the role of a UNC (Unaffiliated Neurotrauma Consultants).[24] UNCs can stand on either sideline and look for any symptoms of concussions – if they happen to see a symptom, they will diagnose if the player has a concussion or not and consequently will rule if they can continue to play in the game or not. At the same time, another UNC re-watches the game film for any signs of injury and reports back to other UNCs and team physicians if the player can play or not.

The system, however, can only help players that seek help/report their symptoms. If a player receives a concussive blow and doesn't explicitly show any symptoms, it would be up to the player to report it and get diagnosed. This system's limitation is nearly irreparable, as many players could stay in the game because of limited opportunities or competitive spirit (finishing out/winning the game).

One policy change that could be considered that can reduce the number of concussions in football would be the removal of kickoffs or altering them. The NFL has already limited the dangerous nature of kickoffs in the past by eliminating players on the kicking team from getting a running start before the ball is kicked. This decreases the possible acceleration on kickoffs, thus making it safer. However, even after these changes, the play still has the potential for severe head trauma with little game value. From 2016-2020, 60% of kickoffs resulted in touchbacks – the offense starts at the 25-yard line.[25] This means that in 3 out 5 kickoffs, nothing essential occurs. In fact, in the 2018-2019 season, there was a touchdown on a kickoff 0.02% of the time.[26] This shows that while the kickoff is one of the most dangerous plays in the game, it also has an essentially negligible impact on the final outcome. Alteration to the current rules related to kickoffs has the potential benefit of making the game safer for the players with negligible effect on the overall game.

Future studies:

For future studies, the different helmet models should continue to be tested, specifically in a game environment. This is important as it would provide the most accurate results and feedback on each helmet model. In addition, different plays should continue to be analyzed for the game's value and to see how dangerous they are. This can show if a specific type of play is too dangerous for its overall impact. These preventative measures should also be expanded to college and high school football players as they include a greater number of athletes affected by CTE and concussions.

■ Conclusion

To mitigate the effects of CTE on professional football players, traumatic brain injuries and concussions must be limited. This can be achieved in multiple ways, such as modifying the helmet, improving technique and gains in strength, and changing/altering the current rules to help make the games safer. Certain helmet modifications, such as the IDM, should continue to be tested and include some element of testing in the real game setting. This model adequately decreases the forces (rotational acceleration, frictional constant, and linear acceleration) involved in concussions and can be practically applied to the current helmet. Further testing should also assess the durability of the decal. Increasing neck muscular strength can also decrease the concussive forces on the brain, but more training on technique and posture (how to tackle) can also result in fewer concussions. Kick return plays have been found to exhibit greater rotational acceleration and velocity values indicating the increased likelihood of a concussion. Further studies are noted to examine the benefit to player health by altering the current rules on kickoff, including but not limited to starting the offense at the 25-yard line. Even though there is no known cure at this time, CTE incidence can be largely reduced in football, making it a safer American pastime.

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