Finite Element Analysis of Football Helmet Impacts: Non-centric Impacts Cause Significantly Worse Brain Injury Compared to Central Impacts

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Introduction

American football has experienced increasing attention from media, physicians, and players alike due to the high rate of mild traumatic brain injury (mTBI) and the increasing understanding of its long-term sequelae. One method to reduce the incidence and severity of this injury is through improved helmet technology. However, progress in this area has been limited, partially due to limited helmet testing standards and performance criteria. Current helmet testing standards do not take into consideration anatomical data and over simplify impacts, discluding those occurring distant to the center of mass of the helmet. To better characterize the kinematics of non-centric impacts and understand how they may be linked to brain injury, we tested five National Football League (NFL) helmets across a range of centric and non-centric impacts to the most common concussion-causing impact location in the NFL. Helmet performance was then evaluated using a finite element model (FEM) of the brain to simulate brain injury. Five popular NFL helmets; the Riddell Speed, Riddell Speedflex, Schutt Air XP Pro, Vicis Zero1, and Xenith Epic+, were tested. Non-centric impacts displayed higher levels of simulated brain injury than centric impacts with varying levels of injury between helmets.

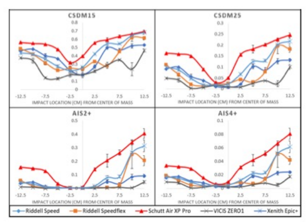
Methods

Performance tests were conducted on top performing football helmets, including the most common football helmets worn in the NFL: Riddell Speed, Riddell Speedflex, Schutt Air XP Pro, Xenith Epic+, and Vicis ZERO1. Helmets were tested using a pneumatic linear impactor at a single velocity commonly causing injury in the NFL (5.5m/s). A Hybrid III headform and neck on a linear bearing table were impacted in the approximate center of mass(CoM) and then 2.5cm away from the center of mass in the axial plane for 5 consecutive non-centric locations. The kinematics of the head following impact was then input into the Simulated Injury Monitor FEM (SIMon). The cumulative strain damage measure - 15 and 25 (CSDM15, CSDM25), correlates for diffuse axonal injury, were subsequently calculated and plotted onto previously defined abbreviated injury scale (AIS) curves to obtain a risk of varying degrees of head injury in a computational model.

Results

CSDM15 showed significantly lower values for impacts at or near the CoM, while highly non-centric impacts were associated with the most simulated brain damage. Non-centric impacts also showed the largest difference in CSDM values between all helmets (-12.5cm (p<00001), -10cm(p<0.0001), CoM(p<0.0001), +10cm(p<0.0001), +12.5cm(p<0.0001)). There was a significant difference in the risk of AIS 2 injury, i.e concussion, between all tested helmets, with a greater difference seen at impacts further from the CoM(-12.5cm(p<0.0001), -10cm(p<0.0001), CoM (p<0.0001), +10cm(p=0.0002), +12.5cm(p<0.0001)).

Figure



(Top row) CSDM15 and CSDM25, or the percentage of the brain experiencing at least 15 and 25% strain, respectively, across center of mass and increasingly noncentric impacts are shown for 5 popular football helmets worn in the NFL. (Bottom row) Risk of AIS2 injury (concussion) and AIS4 injury (DAI), as calculated from CSDM25 is shown.

Conclusions

Non-centric cranial impacts lead to higher rates of injury in a simulated brain model. As such, novel football helmet design and standards should incorporate testing of centric and non -centric impacts to decrease the risk of brain injury.

Learning Objectives

-- To understand the utility of finite element modeling for advancing helmet technology

-- To understand the types of cranial impacts leading to concussion and other forms of intracranial trauma

References

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