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Consequences of Repetitive Head-Impact Exposure in Sports - literature review

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ABSTRACT
Repetitive head impacts (RHIs), common in contact sports, have raised concerns about their long-term effects on brain health, potentially leading to conditions like concussions, Chronic Traumatic Encephalopathy (CTE), and other neurodegenerative diseases. CTE, a progressive tauopathy, is associated with cognitive and psychological symptoms, including memory loss and depression. While RHIs have been linked to brain changes such as white matter thinning, the mechanisms behind these changes remain unclear. This article reviews the biophysical mechanisms of concussions, the risks of CTE and chronic neurocognitive impairment (CNI), and the challenges in diagnosing and managing these conditions. It also explores gender differences in concussion incidence and recovery. The review emphasizes the need for better diagnostic tools, injury prevention strategies, and patient-centered decision-making to protect athletes.

Keywords
head injuries, brain damage, contact sports

INTRODUCTION

Millions of people globally experience repetitive head impacts (RHIs) through involvement in contact and collision sports. These impacts can lead to concussions with noticeable symptoms, as well as more common, asymptomatic non-concussive injuries. [1,2,3,4,5,6,7]. Ongoing exposure to RHIs can lead to lasting cognitive and neuropsychiatric symptoms, as well as a progressive neurodegenerative disease known as chronic traumatic encephalopathy (CTE), which is characterized by tau protein accumulation. [8,9,10,11,12,13,14,15,16,17,18,19,20]. Hyperphosphorylated tau, or p-tau, is linked to various neurodegenerative disorders collectively referred to as tauopathies. These include Alzheimer's disease (AD), frontotemporal dementia, Parkinson's disease (PD), progressive supranuclear palsy (PSP), corticobasal degeneration, multiple system atrophy, and other similar conditions.

In the last 20 years, there has been a significant shift in how sport-related concussion (SRC) is viewed by the scientific community, sports organizations, athletes, lawmakers, and the general public. Researchers have made important advances in concussion science, helping to clarify the immediate effects of these injuries on brain structure and function, which contribute to the typical signs and symptoms. [21]

Recent data reveal structural changes in white matter on magnetic resonance imaging (MRI) in young, active, and recently retired contact sport athletes exposed to RHI. However, the underlying pathological condition responsible for these changes remains unclear. [1,2,23,24,25] Exposure to RHI is linked to the thinning of white matter, a decrease in myelin-associated proteins, and the loss of oligodendrocytes. [26,27,28,29,30]

This article will explore the current state of research on the long-term risks associated with repeated concussions and head impacts in sports. Specifically, we will examine the potential link between RHIs and neurodegenerative conditions such as CTE, as well as other cognitive and neuropsychiatric disorders. By reviewing existing studies on the biophysical mechanisms of brain injury and the impact of repeated head trauma on brain health, we aim to provide a comprehensive overview of the risks involved in contact sports and the implications for athletes' long-term well-being. Additionally, we will discuss the role of gender, age, and developmental factors in injury outcomes, and how these considerations can inform strategies for prevention, diagnosis, and management of sports-related head injuries.

MATERIALS AND METHODS

To review the literature on the topic of the role of Repetitive Head-Impact Exposure in Sports PubMed, Cochrane Library, and Google Scholar were searched using the following keywords: head injuries, brain damage and contact sports. Articles published between 2000-2023 were selected.

BIOPHYSICAL MECHANISMS IN CONTACT SPORTS

The primary cause of concussion and subconcussion is the rapid acceleration and deceleration forces on the brain, whether linear or rotational. Rotational acceleration, such as the impact from hook punches in boxing, tends to cause concussions more often than linear acceleration from straight punches or head impacts in other sports. When exposed to rapid acceleration, deceleration, and rotational forces, the brain and its components - such as neurons, glial cells, and blood vessels - are stretched, potentially disrupting their normal functioning. Axons, especially those that extend over long distances from the cell bodies, are particularly vulnerable to stretching, which can result in diffuse axonal injury, a key factor behind the symptoms seen in concussions.[35]

In sports, particularly contact or collision sports, the head can be struck in various ways, each involving distinct impact parameters. Early studies often found that impacts to the side of the head (i.e., in the mediolateral direction) were associated with the most severe injuries. More recent studies have found that linear head accelerations are highest from front and side impacts, while rotational accelerations are most significant from side and rear head impacts. Noncentric impacts, which are oblique and occur outside the head's center of gravity, have consistently been shown to be particularly hazardous. [48]

REPETITIVE HEAD-IMPACT EXPOSURE IN SPORTS

As mentioned previously, there have been concerns regarding the possible neurobehavioral effects of repeated head impacts, especially those linked to contact sports like American football, ice hockey, and combat sports.[34] Concerns about the potential harm of repetitive head impacts are supported by evidence from animal studies, which have shown that mild head impacts, typically not linked to cellular injury, can still cause damage when repeated multiple times within a short period. [36,37] Emerging research from studies in American football and ice hockey, using helmet-mounted accelerometers, has measured the frequency and intensity of head impacts in contact sports and their subsequent effects on brain structure and function. [38,39]

Dementia and cognitive decline in retired athletes can be associated by a variety of factors, including neurodegenerative dementias, dementia-plus conditions, leukodystrophies, lysosomal storage diseases, vascular disorders, brain tumors, hydrocephalus, severe brain injuries, mitochondrial diseases, basal ganglia disorders, prion diseases, infectious dementias, inflammatory autoimmune diseases, and toxic-metabolic dementias. The neurodegenerative category encompasses conditions like Alzheimer's disease, dementia with Lewy bodies, and tauopathies, including frontotemporal dementia and corticobasal syndrome.

Epidemiological studies suggest that traumatic brain injury (TBI) is a risk factor for Alzheimer's disease (AD), with individuals who have experienced severe TBI facing a significantly higher risk. However, it is still uncertain whether this link also applies to milder brain injuries, particularly in cases of sports-related concussions (SRC).[42]

Head impact exposure and repeated concussions are linked to long-term neurological consequences, including chronic traumatic encephalopathy (CTE) and chronic neurocognitive impairment (CNI). However, no established relationship exists between CTE and CNI.

CTE is a neurodegenerative condition associated with repetitive brain trauma, characterized by the accumulation of τ protein in specific brain regions. This condition leads to symptoms such as executive dysfunction, memory loss, depression, and poor impulse control. Historically, chronic traumatic encephalopathy (CTE) or dementia pugilistica (Classic CTE) referred to a small group of professional boxers who sustained repeated head trauma over extended periods and later developed a neurodegenerative condition. Postmortem examinations revealed macroscopic brain injury, such as cavum septum pellucidum with septal fenestration, along with characteristic neuropathological changes, including neurofibrillary tangles (NFT) and amyloid beta deposition throughout the brain.

CTE can only be diagnosed postmortem through histopathological analysis, and its prevalence remains unknown. Recent studies have identified CTE-related brain changes during postmortem examinations of athletes, suggesting a connection between neuroanatomical damage and observed neurobehavioral patterns before death. CTE is distinct from postconcussion syndrome or acute concussion symptoms, as it typically develops decades after initial exposure. Interestingly, not all athletes diagnosed with CTE postmortem reported concussions during their careers, raising the possibility that sub-concussive impacts might contribute to its development. Given the small number of confirmed cases relative to the large population of contact sport athletes, genetic predisposition and other factors are likely to play a role in its onset. A systematic review has been conducted on all published cases, highlighting the differences between classical CTE and modern CTE. [45-47] Chronic traumatic encephalopathy is regarded as a neurodegenerative disorder marked by the buildup of hyperphosphorylated tau protein in neurons and astrocytes. [43,44]

CNI, on the other hand, may manifest as part of postconcussive syndrome or appear years after a symptom-free period. Neuropsychological testing can identify CNI symptoms and behaviors. While some studies suggest an association between previous concussions and chronic cognitive dysfunction, others have found no such link, highlighting the variability in outcomes and the need for further research.[41]

Gender and Age as Key Factors in Sports-Related Head Injury Risks

Gender has been recognized as an independent predictor of survival after brain injury. Following moderate to severe traumatic brain injury, females had a 1.28 times greater risk of mortality compared to males. Moreover, females were 1.57 times more likely than males to experience adverse outcomes, such as severe disability or a persistent vegetative state. [22]

Gender plays a significant role in the occurrence and reporting of sports-related head and neck injuries. The majority of research on sports-related concussions has focused on male athletes, even though female participation in sports has grown significantly over the past two decades. [32,33]

Anatomical and physiological differences between males and females can contribute to varying injury risks and outcomes. For instance, females generally have smaller head-to-ball ratios, weaker neck muscles, and less head and neck mass compared to males. These factors result in greater angular acceleration of the head and neck during impact, increasing the likelihood of injury. Cultural and psychological factors further differentiate the way male and female athletes respond to injuries. Male athletes are often influenced by societal expectations that prioritize toughness and perseverance. As a result, they may continue playing despite injuries or avoid reporting symptoms altogether. [31,32] Some boys with head injuries may withhold information about their condition due to fears of being sidelined. This reluctance can lead to exacerbated injuries and long-term health consequences. In contrast, female athletes tend to prioritize their long-term health and are more likely to report injuries honestly. [22] They are often less influenced by cultural pressures to continue playing when injured and may accept being removed from play more readily than their male counterparts.[31] This difference in attitudes may stem from a greater concern about the potential impact of injuries on their future well-being. These disparities highlight the need for gender-specific approaches to injury prevention, management, and education in sports. Understanding these differences can help coaches, medical professionals, and athletes make informed decisions that prioritize safety and health.

Youth athletes tend to experience longer recovery periods and are at greater risk of concussions accompanied by catastrophic injuries. The physiological characteristics of the developing brain differ significantly from those of the adult brain, including variations in brain water content, myelination levels, blood volume, blood–brain barrier integrity, cerebral glucose metabolism, blood flow, synapse density, and the geometry and elasticity of skull sutures. These developmental differences may result in younger brains having less-established neural pathways and reduced cognitive reserve compared to more mature brains. This could help explain why younger athletes often take longer to recover from concussions. Comparing recovery times across different levels of play (high school, college, and professional) is challenging, as variations in recovery duration may stem from differences in study methodologies, risk tolerance, return-to-play protocols, or a combination of these factors. Additionally, recovery patterns in athletes under the age of 15 remain insufficiently studied. Younger athletes are also more likely to experience catastrophic injuries, potentially due to the physiological differences between developing and fully matured brains. [41]

PURPOSE

There is no definitive evidence identifying factors that would universally mandate retirement or cessation of participation in contact or collision sports. However, certain sports have specific medical regulations for participation clearance, such as restrictions related to retinal detachment in boxing. Decisions about retiring from or discontinuing participation in contact or collision sports are complex and require input from clinicians with expertise in traumatic brain injury and sports medicine, ideally as part of a multidisciplinary team. This process should include a thorough clinical evaluation that takes into account patient-specific, injury-specific, sport-specific, and sociocultural factors. The discussion should present athletes with the available scientific evidence and acknowledge any uncertainties surrounding their condition, weighed against the benefits of continued participation. It should also consider the athlete’s preferences, risk tolerance, and psychological readiness to ensure they are able to make an informed decision.[49]

CONCLUSIONS

The long-term consequences of repetitive head impacts (RHIs) in contact and collision sports are increasingly recognized as a significant public health concern. Repeated exposure to these impacts can result in a range of cognitive, neuropsychiatric, and neurodegenerative disorders, including Chronic Traumatic Encephalopathy (CTE), tauopathies, and chronic neurocognitive impairment (CNI). While the association between repeated concussions and these conditions has been well-documented, there remain critical gaps in understanding the underlying pathophysiology, particularly in differentiating the contributions of subconcussive impacts to neurodegeneration.

The neurobiological mechanisms driving the damage from head impacts, including axonal injury, myelin loss, and white matter degeneration, provide a foundation for understanding the structural changes observed in athletes exposed to RHIs. However, the precise thresholds at which these injuries lead to progressive brain damage are still unclear, with challenges in diagnosing conditions like CTE, which can only be confirmed postmortem. Moreover, emerging studies suggest that sub-concussive impacts—those without obvious clinical symptoms—may contribute to long-term brain changes, complicating the ability to predict who may develop neurodegenerative conditions later in life.

Gender differences play a crucial role in the incidence, reporting, and outcomes of sports-related head injuries. Female athletes, for example, may face greater injury risks due to anatomical and physiological factors, as well as differences in cultural and psychological responses to injury. These factors underline the importance of adopting gender-specific approaches in injury prevention, management, and education to ensure that both male and female athletes are adequately protected.

The risks to youth athletes are particularly concerning due to the unique characteristics of the developing brain, which may result in prolonged recovery times and an increased vulnerability to catastrophic injuries. These factors emphasize the need for more research on the effects of head impacts in young athletes and the establishment of guidelines tailored to this vulnerable population.

In light of these findings, the decision to retire from contact sports after a concussion should be individualized, involving a comprehensive assessment by a multidisciplinary team. While there are no universal criteria for determining when an athlete should cease participation, a careful evaluation of the athlete's health, injury history, sport-specific factors, and personal preferences is essential in making an informed decision.

Ultimately, the growing body of evidence linking RHIs to serious long-term health consequences calls for continued advancements in diagnostic tools, preventative strategies, and therapeutic interventions. Greater efforts to educate athletes, coaches, parents, and healthcare providers about the risks of head injuries are essential to safeguard the health and well-being of athletes across all levels of sport.

DISCLOSURE

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