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Head injury and concussion in cricket: Incidence, current guidance, and implications of sports concussion literature

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Abstract

Concussion following head injury remains a significant cause of injury in cricket, with recent high profile events highlighting the ongoing risk of head injury in the sport and the emerging use of concussion assessments for elite players following injury. Sport-related concussion has long been recognized to present significant concerns for athletes in both the short and long term, with an increasing evidence base surrounding diagnostic and prognostic approaches to the issue. Though cricket represents one of the most participated sports worldwide, there is a lack of evidence relating to the acute management and prognosis of head injury in cricket players. In this review, we searched the literature for terms related to head injury, concussion, and cricket, summarizing the main findings regarding the incidence, mortality, acute management, diagnostic approach, and outcome of cricket-related head injury. Further, this review places these findings in the wider context of sports-related concussion literature to ascertain both the current evidence base surrounding current cricket-related concussion guidelines, and the direction of research for future approaches to sports concussion management.

KEYWORDS

biomarkers, cricket, neuroimaging, sports concussion, traumatic brain injury

1 | INTRODUCTION

A cricket ball, as defined by cricket lawmakers the Marylebone Cricket Club (MCC), should weigh between 5.5 and 5.75 ounces[1] and can be delivered by international bowlers of speeds over 90 mph/145 kph. The bouncer, or a delivery aimed to hit the batsmen in the upper torso or head, is a legitimate tactic in cricket and though efforts (notably the introduction of helmets, not routinely worn until the 1970s, the limiting to two short pitched deliveries per over in test and one-day international cricket and the introduction of concussion substitutions in international matches) have been made to minimize the potential risk, concerns remain over batsman's safety regarding head injuries from direct impact of the ball. This concern has been highlighted recently in the media, notably in 2019 after one of the game's leading batsman, Steven Smith had to miss an important match due to ongoing concussion-related symptoms.[2]

Concussion is often used to denote a form of mild traumatic brain injury (TBI) representing clinical symptoms following head injury with or without underlying pathological injury, commonly secondary to sport. Mild TBI has been defined as a traumatically induced physiological disruption of brain function with a loss of consciousness is less than 30 minutes, Glasgow Coma Score (GCS) after 30 minutes is between 13 and 15 and post-traumatic amnesia is less than

24 hours.[3] Mild TBI carries significant short- and long-term consequences, with between 10% and 25% patients having symptoms of post-concussion syndrome for months to years following injury,[4,5] and there is increasing concern over the impact of multiple concussion episodes on subsequent sporting performance alongside wider health concerns including impact on cognitive functioning and mental health in later life.[6] Sports-related concussion represents a subset of mild TBI, with a significant evidence surrounding the diagnosis, management, and prognosis of sports concussion patients emerging over the last 30 years in both the professional[7,8] and amateur[9-11] field.

We present here a narrative summary of the current literature surrounding concussion in cricket, alongside a review of the current concussion guidance and an overview of the related research from the wider sports-related concussion field of research to help inform the sporting clinician of developments in the area.

2 | EPIDEMIOLOGY OF SPORTS-RELATED CONCUSSION IN CRICKET

Sports-related TBI was found to account for 1.2%-30.3% of all TBIs with an incidence demonstrated in the literature ranging between 3.5 and 31.5 per 100 000.[12] In a systematic review and meta-analysis conducted in 2016, the overall risk of concussion in youth athletes (<18 years old) was estimated at 0.23 with the highest incidence rates in rugby (4.18) hockey (1.20) and American football (0.53).[13] In relation to cricket, the match-based incidence rate of head impact was demonstrated at 3.9 and 3.1/1000 player days in first class male and female cricket, respectively,[14] while the incidence of elite male cricket concussion injuries was estimated at a mean of 0.9 per 100 players per year.[15] A subsequent comprehensive analysis of two consecutive seasons of all head impacts and concussions requiring medical attention in elite male and female cricket players demonstrated a significantly higher match incidence of 2.3 concussions per 1000 player days.[16] The majority of concussions were termed delayed concussions, with only 30% (11) of players removed immediately following impact, 46% (17) diagnosed later in the game, and the remainder (24%) diagnosed after the game had finished.[16]

Away from the elite level, a retrospective analysis of hospital-presentation data demonstrated head injuries account for 27.8% of cricket-related ED presentations in Victoria, Australia, accounting for 28.1% of cricket-related hospital admissions.[17] A further retrospective analysis of hospital discharges and day attendances in New Zealand demonstrated a population incidence of 2.3/100 000 people of recreational injuries attributable to cricket.[18] 21% of total injuries were sustained to the head, with 77% of these being fractures, 18% contusions, and 11% concussions with open wounds and unspecified injuries constituting the remainder.[18] The widespread adoption of helmets over the last 30 years has led to a reduction in head injuries. Helmets distribute the force of impact of the ball around a greater surface area, reducing both the transmitted force on a focal area of skull and the acceleration forces on the brain, therefore lowering the risk of significant injury such as skull fracture or intracranial hemorrhage.[19] The protective benefit of helmets in amateur cricket have been demonstrated by an overall reduction in injury rates, specifically injuries of the head/neck/face, since the introduction of mandatory helmets.[20] However, though injury rates have reduced since the advent of helmet wearing, there remains a significant risk of head injuries, with significant injuries including concussion, and prolonged absences from the game observed in batters wearing a helmet following impact of the ball on the head.[21]

In reference to cricket-related mortality, when reviewing both professional and amateur cricket-related fatalities in Australia 174 deaths were found over the 154 years of study, with 52 recorded between 1965 and 2016.[22] The majority of deaths were caused by blows to the head with death recorded due to cerebral hemorrhage or other brain injury. The incidence of deaths, however, was noted to be minimal since the advent of helmet use[22]; though high profile, recent incidents demonstrate this risk is still ever-present in the game.[23]

3 | NEUROCOGNITIVE TESTING

Individuals with a mild TBI can suffer several neurocognitive deficits including poor attention, memory loss and trouble with executive functioning. There is a significant evidence base behind the use of neurocognitive testing for diagnosis and recovery monitoring in mild TBI research,[24,25] and widespread implementation of neuropsychological testing of both professional[26] and amateur[27] athletes in sports-related concussion diagnostic strategies. Immediately following head, cricketers are required to undergo an on-field assessment via standardized concussion evaluation tools, allowing for detection of objective evidence of concussion.[28] If neurocognitive deficits are detected, the player will be withdrawn from sport participation to undergo further neurocognitive testing at both an acute time point and at scheduled subsequent time points. This allows for grading of initial symptomology in the immediate post-concussion phase alongside tracking of recovery over the following days.[29-31] Neurocognitive tests often follow a model of baseline and post-concussion scoring, whereby a pre-injury baseline is established, often pre-season, with post-injury testing directly compared with this facilitating tracking of recovery to the athletes own baseline over time.[31] It has been established that neurocognitive

deficits remain following symptomatic recovery,[32,33] indicating that recurrent neurocognitive testing, rather than symptomatic improvement in isolation, should be used to guide return to activity.

The use of screening tests, such as the Standardised Assessment of Concussion (SAC), allows for rapid assessment at the time of injury and is conducted on field soon after injury. These testing questionnaires have been found to be sensitive for acute concussion[28] and are designed to provide objective evidence of concussion at the sideline, reducing subjectivity in assessment through a standardized assessment methodology allowing withdrawal from activity of the concussed athlete. Formed via expert consensus, the SCAT5 is a commonly utilized assessment tool for sports-related concussion that incorporating the SAC and designed to be used at pitch side.[34] Both the ECB head injury guidelines[35] and the Cricket Australia concussion and head trauma policy[36] advocate the use of the SCAT5, recommending a player should be removed from the field of play for SCAT5 assessment when concussion is suspected following on pitch assessment with a brief concussion recognition tool. If no concussion was detected, the player can return to the field at the next opportunity, with further assessment using the SCAT5 at the end of play or over 1 hour after the first SCAT5. The player will also have a further SCAT5 the following morning prior to play.[35] If any of these tests demonstrate a deficit, the player will be withdrawn from activity.

On field neurocognitive testing can occur in person via medical staff or neuropsychologist evaluation. Computerized testing batteries are becoming more regularly used for subsequent testing given their similar sensitivity to acute concussion effects,[37-40] alongside ease of implementation has led to widespread adoption of the computerized testing mechanisms. There are multiple computerized neurocognitive testing batteries in current clinical usage, including the Immediate Post-concussion Assessment and Cognitive Testing (ImPACT)[41] and CogSport[33] neurocognitive tests. When directly comparing multiple mechanisms within one week of injury, a meta-analysis demonstrated a low to moderate effect size of concussion on neurocognitive functioning.[30] Of the testing mechanisms studied, the ImPACT test, a computerized battery of neurocognitive testing allowing for baseline and post-injury testing, demonstrated the highest effect size in direct comparison with other testing batteries.[30] This approach of pre-injury baseline testing, with neurocognitive testing in the acute and subacute phase post injury, has been widely accepted in the care of cricket concussions by the major cricket boards, including the England and Wales Cricket board (ECB) and Cricket Australia (CA),[35,36] and is in widespread use around the professional game.

There was limited literature assessing the impact of neurocognitive testing in elite cricketers following cricket-related concussion, with current guidelines largely following expert consensus in the wider field of sports-related concussion built upon evidence from other sports. One published abstract was found documenting CogSport, a computerized neurocognitive test designed to monitor recovery from concussion previously demonstrated as a reliable cognitive function test in young athletes in Australian Rules Football,[42] in 46 elite Australian cricket players (aged 20-29 years) following head injury with subsequent concussion diagnosis.[43] They compared the post-concussion CogSport scores with those of cricketers without head injury within one hour of match conclusion, aiming to ascertain differences between post-match fatigue and concussion on neurocognitive testing. Significant differences were shown in aspects of CogSport neurocognitive testing between these groups, indicating a level of neurocognitive deficit in concussed players as compared to standard post-match fatigue, directly validating the use of the CogSport tool in a cricketing context. The use of the CogSport Concussion test is recommended alongside the SCAT5 in the Cricket Australia concussion and head trauma policy.[36]

4 | BIOMARKERS

The use of blood born biomarkers in sports-related concussion and traumatic brain injury in general is an ever expanding field of research. The release of proteins from damaged neuronal cells, detectable in serum, could allow diagnostically for objective evidence of concussion in the acute phase, while indicating patients with worse injuries and longer recovery times, with subsequent utility guiding return to play.[44] There have been numerous studies relating to the use of serum proteomic biomarkers in sports-related concussion; however, there were no studies found relating to the use in cricket-related injury.

Diagnostically, the ability of a serum blood test to allow for further objective evidence, alongside neurocognitive testing, of athletes who have sustained a concussion offers clear benefit to the acute management following sports-related head trauma including cricket-related injury. Diagnostic utility for sports-related concussion, as highlighted in a systematic review of the subject, has been demonstrated glial fibrillary acidic protein (GFAP), S100B, neuron-specific enolase (NSE), ubiquitin C-terminal hydrolase (UCH-L1), and neurofilament light (NFL). In relation to recovery time, various studies have shown promise in biomarkers including NFL,[46] tau,[45-47] S100B,[47] calpain-derived αII-spectrin,[45] *N*-terminal fragment (SNTF),[45] quinolinic acid,[45] and prolactin[45] for detection of patients with prolonged recovery post-concussion. Of note, there have been two recent large prospective studies.[48,49] Concussed athletes have been shown to have significant elevations in GFAP, UCH-L1 and tau acutely post-injury, with a panel combining multiple biomarkers showing

adequate discrimination for detection of sports-related concussion.[48] Similarly, while on a panel of biomarkers consisting of: GFAP, UCH-L1, S100B, alpha-II-spectrin breakdown product 150, interleukin 6, interleukin 1 receptor antagonist (IL-1RA), and c-reactive protein, all proteins aside from GFAP and CRP demonstrated discrimination of concussed patients from non-concussed contact sport controls.[49]

Early prognostic prediction can help plan tailored management strategy, both for the player and for the team, giving advanced notice of players unlikely to make a fast recovery and allowing for resource allocation. There have been various studies assessing the use of blood biomarkers for this purpose in the realm of sports concussion. Acute post-injury samples of S100B and NSE have not been shown to relate to patient symptoms at 24-48 hours following injury.[50,51] However, more promise has been demonstrated by NFL, with NFL being demonstrated to differentiate between patients with prolonged symptoms and relating to return to play.[46,52] Though the evidence is mixed, there is a potential prognostic utility offered by serum biomarkers of concussion.

In relation to cricket, a future management strategy may involve acute biomarker sampling of a player following injury. The results of this could demonstrate which patients have suffered a concussion and require removal from participation, with either the initial biomarker concentration or serial sample levels serving to guide return to play. Further, if prognostic utility is demonstrated by biomarkers in relation to either health recovery or sporting performance, biomarker sampling could indicate players with a protracted recovery time or long-term deficits early in their injury pathway. This would allow for appropriate resource allocation both in terms of medical provision and for sporting team management.

5 | NEUROIMAGING

There were no studies found concerning the use of neuroimaging techniques in cricket-related concussion and acute neuroimaging is often not indicated in cricket concussion or in the wider realm of sports-related concussion. If there is an injury sufficient to require neuroimaging, such as a low GCS, focal neurological signs, or post-traumatic seizure, cricketers and other athletes following head injury should be conveyed to their local hospital for acute medical management. However, outside of these parameters, changes are rarely seen on structural CT,[53] and while clinical MRI may provide some benefits[54,55] standard structural imaging is not sufficient to demonstrate deficits to explain the vast array of neurocognitive deficits observed and therefore rarely forms a part of the diagnostic approach to sports-related concussion outside of a research context. Research is ongoing in the utilization of advanced imaging techniques including functional MRI (fMRI) and diffusion tensor imaging (DTI), and these may hold some potential for understanding the mechanisms underpinning ongoing deficits observed following sports-related concussion.

DTI allows for a higher sensitivity for detection of structural damage occult on standard imaging techniques with superior detection of gray and white matter damage following brain injury.[56,57] By measuring the diffusion of water molecules DTI assesses neuronal microstructure, giving indication of changes to the brain structure not otherwise identified following injury.[58] Meta-analysis of DTI in sports-related concussion has been shown to have diagnostic sensitivity in athletes following sports concussion,[59] with the white matter tract alterations following previously demonstrated to correlate clinically to symptoms and functional impairment.[60] Though results are promising, DTI serves as an experimental technique with controlled longitudinal studies required prior to establishment of DTI in clinical guidelines for sports concussion diagnosis and management.

fMRI exploits the different magnetic properties of oxyhemoglobin and deoxyhemoglobin to map activity over time. This technique can then be integrated with analyses such as functional connectivity wherein the connections—temporal covariation in time series—of discrete brain regions can be interrogated. To the best of our knowledge, no study has directly investigated the effects of cricket-related concussion on brain function. However, there is a growing interest in fMRI, especially resting-state fMRI (rsfMRI), alterations in the wider scope of sports-related concussion literature where emerging trends are apparent. First, following sports-related concussion, fMRI alterations are evident as decreased[61] connectivity, mixed[62] connectivity, and increased[63-67] connectivity. While there is no clear path, there is mounting evidence that the brain becomes hyper-connected following mTBI/SRC3 and this may serve as an adaptive mechanism of the brain.[68] It is speculated that the hyper-connected state is a transient, especially plastic state of the brain that allows areas to maintain communication and, if needed, form new connections though detours and indirect routes.[68] If the hyper-connected state is transient, it is reasonable to hypothesize that longitudinal changes should be seen. Indeed, longitudinal studies have shown different connectivity alterations in the acute phase[64,69] subacute phase[64,65] and long-term.[66] Unfortunately, this literature does not lead to a compelling conclusion on the trajectory of connectivity alterations following sports-related concussion and understanding the natural trajectory of recovery following SRC is a key area for further research.

The third trend that is becoming clear is that sports-related concussion is not a one-size-fits-all disorder. Existing literature suggests that differential effects of functional connectivity can be seen between individuals with more severe compared with less severe injuries,[61,66] symptomatic compared with asymptomatic[65,67] between individuals with a

short RTP compared with long RTP2, and between individuals with post-concussion syndrome compared with individuals without post-concussion syndrome.[70]

While resting-state fMRI may offer many benefits for highlighting and sub-typing injuries, especially where structural changes are not present on CT or structural MRI, it is clear that there is more research needed to assess its utility. Firstly, going forward it will be important to investigate specific groups of athletes rather than consider only the presence or absence of sports-related concussion. Secondly, while literature on the longitudinal effects of TBI on fMRI changes is growing, it will be vital to investigate in large scale, and at regular time intervals how fMRI alterations change over time. By implementing these two recommendations, authorities will be better able to implement policy with an aim of personalizing injury management rather than continuing umbrella management styles.

Advanced neuroimaging techniques offer an exciting future direction in both sports-related concussion and cricket concussion. Greater understanding of recovery trajectories and individualized diagnostic information, as could be provided by these techniques, may assist in guiding player recovery, aiding in improvement in player's health and sporting performance outcomes following concussion.

6 | LONG-TERM SEQUELAE OF CONCUSSION

Though the majority of patients will recover quickly following sports concussion, with the majority recovering within three days with return to sport within seven,[71-73] a small but significant number (1.5%-15% of sports-related concussion patients)[74,75] will have persistent symptoms, often referred to as post-concussion syndrome (PCS).[5] There was no evidence found surrounding the incidence of post-concussion syndrome following cricket-related head injuries, or the impact of concussion on subsequent cricket performance in the short or long term. However, a recent study in the analogous field of baseball demonstrated significant detriment to batting performance 1 year following concussion, that persisted through the remainder of their careers.[76] Though this is a finding that contrasted to preceding studies,[77] this potential impact of concussion on subsequent performance is an important consideration in relation to cricket injuries and represents an important question for future cricket-related research.

There is a significant body of literature, largely surrounding former professional American Football players, demonstrating that multiple concussions serve as a risk factor for early development of cognitive impairment and mental health problems.[78-80] Repetitive mild TBI can lead to the development of chronic traumatic encephalopathy, neurodegenerative disease clinically presenting 8-10 years following the concussion episodes with symptoms including irritability, personality changes, memory loss, and suicidality.[6] There has been significant media coverage concerning a possible link between heading a soccer ball, and long-term brain damage, though this remains unclear and unsubstantiated based on the current evidence.[81] There are no studies investigating whether CTE may occur secondary cricket, though the lower likelihood of recurrent concussion as compared to contact sports the CTE risk would be expected to be lower. Of interest, when assessing health outcomes in retired cricketers a higher prevalence of anxiety and depression was observed as compared to the general population. Though there are multiple potential confounders, further longitudinal studies may be able to assess shared risk factors for development of these mental health issues in cricketers, of which concussion history could be an interesting variable for analysis.[82]

7 | CONCLUSION

Head injury represents a significant cause of cricket-related injury and an ongoing risk to players. Though there is significant research surrounding sports-related concussion in contact sports, there is a comparative lack of research in non-contact sports, including cricket. Recent changes, notably the adoption of helmets, has decreased the associated risk of ball impact to the head, while the formation of clear assessment and management guidelines from international cricket boards, utilizing standardized concussion assessment tools and neurocognitive testing batteries, has helped standardize both acute assessment of injured players and return to play. However, this review highlights significant deficits in research relating to cricket-related concussion, notably the health and sporting performance impact on cricketers following single or repetitive concussion, with suggestion of poor recovery observed in corresponding sporting fields. Further, there are several exciting areas of development in the management of sports-related concussion of future importance to cricket concussion management including neurocognitive testing, advanced neuroimaging, and the use of serum biomarkers of concussion.

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AUTHOR CONTRIBUTIONS

DPW and VFJN formed the research question. DPW conducted the literature search and DPW and IRK-U drafted the

manuscript, and all authors contributed substantially to its revision.

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