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Concussion in Rugby Union and the role of biomechanics

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INTRODUCTION

Due to the physical and high-impact nature of rugby, head impacts occur frequently within the game. This can result in the occurrence of concussion injuries as well as other moderate-to-severe head injuries.[1] Concussion is defined as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces",[1] and was found to be one of the more common brain injuries throughout the world.[2] This is particularly true in sport; it has been estimated that over half of all concussions are related to sports.[3] A systematic review of the incidence of concussion in contact sports found that Rugby Union has a higher incidence rate compared with other sports, such as American football and soccer.[4]

Unlike other sports injuries, detecting a concussion is difficult, as the neuropathological changes cannot be recognized on standard neuroimaging technology.[5,6] Therefore, if a player is suspected of having a concussion, they are removed from play for a head injury assessment (HIA). The HIA is a standardized tool for the medical assessment of concussion injuries in rugby and aims to improve detection and patient education.[7] The HIA assesses a range of degenerative concussive symptoms including memory, cognitive ability, balance, and player discomfort. This concussion diagnosis protocol therefore relies heavily on sideline medical staff to identify if a player is exhibiting concussive symptoms. A major disadvantage to this is that concussion has a variable natural history, with transient, fluctuating, delayed, and evolving signs or symptoms.[8] This means that symptoms can take up to 48 hours to become apparent.[8] It has therefore been acknowledged that the content of the HIA will be modified as the research around concussion diagnosis evolves.[8]

The reliance on sideline medical staff to accurately identify concussive symptoms means that there is a possibility that a concussed player may remain on the field; this is one problem that biomechanical research into concussion is trying to overcome. This study will give an overview of concussion in Rugby Union with a focus on incidence, severity, and protection strategies. It will discuss current biomechanical research and further research required in the area of concussion injuries in Rugby Union.

Mechanism of concussion

The brain has a high bulk modulus but a low shear modulus.[9] This means the brain has a high ability to resist changes in volume but a poor ability to resist changes in shape. The bulk modulus of brain tissue is roughly five to six times greater in magnitude than the shear modulus, meaning that it tends to deform primarily in shear when the head is impacted.[10,11] This means that brain strain has a large sensitivity to rotational loading and a small sensitivity to linear loading. Rapid head rotations result in shear forces throughout the brain causing deformation and shear-induced tissue damage. Many studies have found that rotational motion causing shear deformation is the main mechanism of concussion injury.[12–14] One study in primates found that if head motion does not include any rotational movement and is purely linear, it is difficult to cause unconsciousness.[15] However, including a rotational movement after impact significantly increases the possibility of causing concussion.[15]

Concussion in Rugby Union

Incidence

The reported incidence of concussion injuries in Rugby Union is high at 10.5 per 1000 player-hours.[16] Cross *et al.* (2015) reported an incidence of 8.9 per 1000 player-hours in the 2013–14 English Premiership season, which was a significant increase from 6.6 per 1000 player-hours in the previous season.[17] This increase may reflect a higher rate of detection as a result of increasing awareness. Concussion has been identified to account for roughly 5% of injuries in elite Rugby Union in Australia and New Zealand.[18,19] One study found that 23% of elite-level South African Rugby Union participants received a concussion in one season.[20]

A detailed epidemiological study was conducted to define the incidence, nature, severity, and causes of head injuries in professional Rugby Union players using 757 male participants from 13 English Premiership clubs over three seasons.[21] For match play, it was found that 6.6 overall head injuries per 1000 player-hours occurred, resulting in 14 days of lost time on average. Concussion injuries contributed to 4.1 injuries per 1000 players-hours, making concussion the third most common match injury for all Rugby Union players.

In 2013–14, concussion was, for the third consecutive season, the most commonly reported English Premiership match injury and constituted 12.5% of all match injuries.[16] A prospective injury surveillance study on Ulster schoolboys' rugby found the head/face as the most common site for injury (23.9%), with concussion being the second most reported injury (19%) behind muscle sprains (31.2%).[22]

Severity

Kemp *et al.* (2008) found that concussion injury resulted in 13 days of lost time but 48% of players could safely return to play within 7 days.[21] The mean severity of reported match concussions for English Premiership rugby players in 2013/14 was 11 days of lost time.[16] In Ulster schoolboys' rugby, the median time loss reported due to concussion was 24 days.[22]

Phase of play

The impact of the tackle is the most regular cause of injury in rugby.[18,23–28] Therefore, the tackle is regarded as the most dangerous facet of play in Rugby Union.[23]

Kemp *et al.* (2008) found that tackling head-on was the main cause associated with match concussion (28%), which is supported by other literature.[23,27] Collisions (20%) and being tackled head-on (19%) were the second and third main cause respectively. The middle-high tackle has been isolated as the most common type of tackle to cause injury.[23]

Positions

Kemp *et al.* (2008) found that the midfield backs (fly half [#10], inside centre [#12], and outside centre [#13]) were of highest risk of sustaining a concussion.[21] Brooks *et al.* (2005) and Quarrie & Hopkins (2008) state that backs suffer from a greater number of concussions due to the high-speed nature of their role and

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are, therefore, most likely to be involved in high-speed tackles and collisions.[23,27]

On the contrary, reports have shown that forwards are more likely to sustain concussion as they engage in potentially more dangerous aspects of the game, such as rucks and mauls.[18,24,26] It was found in the 2011 Rugby World Cup that forwards suffered 8.8 concussion injuries per 1000 player-hours compared with backs who suffered 6.7 concussion injuries per 1000 player-hours.[29] Furthermore, the mean severity of injury for forwards was 12.8 days until return to safe play, more than double than that of backs at 6.2 days.[29]

Head protection equipment

In terms of biomechanics, well-designed protective headgear has the potential to prevent certain head injuries by reducing the impact force and distributing this force over a larger area of the head. However, since the brain injury metrics of concussion are still debated, headgear is still an area of contention for concussion protection. It is not compulsory to use headgear in rugby and the sanctioned headgear has no hard outer shell unlike those used in American Football and Ice Hockey. A potential reason for this is that players who wear hard-shell head gear tend to play more aggressively, resulting in them being more liable to receive severe impacts in the game.[30] Sixty-seven per cent of young rugby players (under 15 years old) felt a greater ability and confidence to tackle harder whilst wearing headgear.[31]

The headgear currently used in rugby consists of soft polyethylene 306 foam padding. McIntosh *et al.* (2009) conducted a controlled trial on the effectiveness of padded headgear in preventing head injury and concussion in rugby.[32] In total, 1493 participants (10 650 player-hours) were in the control group (no headgear), 1128 participants (8170 player-hours) were in the standard headgear group, and 1474 participants (10 650 player-hours) were in the modified headgear group. The study showed that the rate of concussion is not reduced when using padded headgear and, therefore, the study could not recommend padded headgear for use in concussion injury prevention. This is supported by laboratory studies that demonstrated the potential of standard rugby headgear to attenuate impacts.[33] However, laboratory studies have shown that modified headgear, with more padding in susceptible areas, has a greater potential to attenuate impacts than standard headgear.[30] Overall, however, padded headgear appears to offer very little protection against concussion injuries in rugby. It is recommended to be worn for the prevention of lacerations and abrasions.

Current and future biomechanics research

Even though the incidence of concussion injuries in rugby is high,[16–20] there is still insufficient knowledge on the biomechanics and specific head motion patterns that are causing concussion injuries. Since protective equipment has little influence on concussion reduction, an emphasis must be placed on prevention strategies and concussion identification techniques. It is therefore evident that a greater understanding of the mechanisms of concussion and the dynamics of head impacts is required to achieve this.

Tierney *et al.* (2016) identified that legal tackles in Rugby Union can be split into two main categories; upper body tackles (UBT) and lower body tackles (LBT).[34] A UBT is defined by the tackler's initial contact being above the ball carrier's hip and below the

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neck, whereas a LBT is defined by the tackler's initial contact being at, or below, the ball carrier's hip. It was found that, in elite-level Rugby Union, tacklers were at most risk of receiving a direct head impact and UBTs were the main cause of injury. Therefore, it is clear that the tackle is a candidate for further research, as it is a major cause of head impacts and concussion in Rugby Union.[23,34] For UBT-related head impacts, the ball carrier weighed on average 12 kg more than the tackler. This difference in mass could potentially have a psychological effect on the tackler and thus adversely affect tackling proficiency. This study also found that the majority of tackle-related head impacts occurred in the second half of a game, which may suggest a role for fatigue in injury risk. The study identified that the foot position of the tackler is a risk factor for injury. Tackler foot planting can potentially reduce tackler mobility and the chance of placing their head in a safe position, increasing the risk of injury. Therefore, keeping the feet active when tackling and placing the head away from contact were identified as effective prevention strategies against concussion.

The kinematics of direct head impacts and concussion injuries have been studied biomechanically in Rugby Union using multibody simulations,[35] computer modelling,[36] and wearable head sensors.[37] Wearable sensors could have the potential to allow reliable concussion injury predictions to be made. For example, if a player wearing a head-impact sensor receives a significant head impact above a certain injury threshold, sideline medical staff can be alerted to remove this player from the game and assess for a concussion.

Biomechanical research on concussion in Rugby Union has focused mainly on direct head impacts; however, future research must investigate the effect of non-direct head impacts on player head kinematics from legal phases of play, such as rucks and tackles. Repeated non-direct head impacts in Rugby Union may, over time, be linked to symptoms of concussion.[7,38,39] Moreover, current research using multibody simulations (**Figure 1**) have found that certain legal UBTs in Rugby Union could result in high head kinematics.[40] It is potentially these impacts, innocuous due to their legality, that could go unnoticed for concussion identification. The effects of these impacts are pertinent as a rugby player may engage in thousands of these types of impacts in their playing career without ever being diagnosed with a concussion.

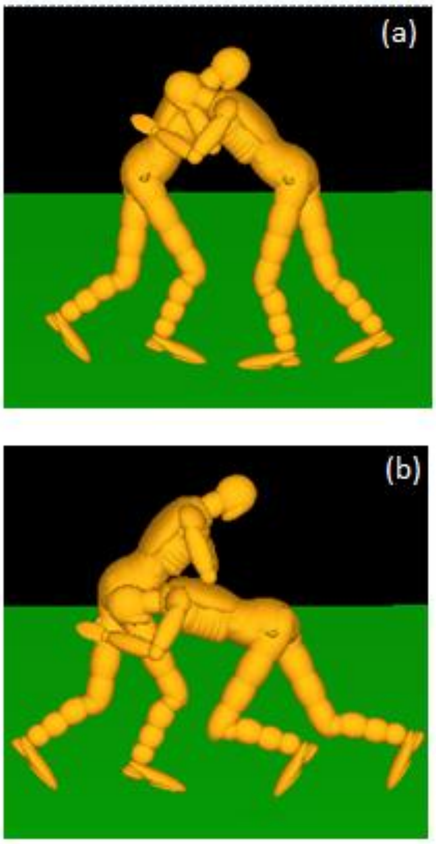

Figure 1. The multibody player-to-player configuration for (a) an upper body tackle and (b) a lower body tackle.

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There are two main contact injury models.[41] One is where a body part is overloaded from a single impact event, for example, an ankle break from a sliding tackle in football. The other is based on repetitive loading. This is where a body part is subjected to repeated loading under normal playing conditions but, over time, the body part's resistance to injury decreases due to accumulated micro-trauma to the point where normal loading conditions can no longer be tolerated. An example of this is tennis elbow. It is the latter of these models that could be of most concern to rugby players at present. Repeatedly engaging in these high-impact tackles could be reducing the brain's tolerance to injury to the point where normal tackles can no longer be tolerated. The accumulated micro-trauma may lead to long-term brain damage regardless of whether a player has a history of concussion or direct head impacts. UBTs could potentially be causing cumulative micro trauma-based damage to the brain at a higher rate than LBTs, as they cause greater head loading to the ball carrier and tackler than LBTs. Quantitative research efforts to clarify the degree of micro trauma would be beneficial for prevention strategies.

The tackle is a highly technical aspect of rugby union.[42-46] However, recent studies have found that certain techniques can reduce the risk of head impacts occurring.[34,47] This indicates the importance of coaches encompassing these techniques during tackle based training drills.

To gain a broader understanding of concussion and head impacts in rugby, future studies should combine biomechanical research with other clinical-based research such as medical imaging, blood testing, ocular micro-tremor, and genetic analysis. For on-field detection, approaches such as Model-Based Image-Matching (MBIM),[36,48,49] which measures 6 degree of freedom head kinematics of concussive events directly from broadcast video has potential. MBIM could one day be utilised during live games to assist with sideline medical staff in identifying if a player is concussed.

CONCLUSION

Concussion is a major issue in Rugby Union at present with high injury incidence and severity. Within the game, the tackle is the main cause of concussion with the tackler at highest risk. Current on-field detection methods rely heavily on sideline medical staff to identify if a player is exhibiting concussive symptoms on the field. Biomechanical research using wearable head sensors can potentially improve this identification protocol by reliably measuring concussion injury thresholds. Through three-dimensional motion analysis, computer modelling, and wearable head sensors, further research should also place emphasis on the effect of non-direct head impacts on player head kinematics from legal phases of play. Concussion is an interdisciplinary issue and therefore requires collaborative interdisciplinary research to move beyond our current understanding of the injury.

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