www.BokSmart.com ***/BokSmart*** ***@BokSmart***

Long-term effects of concussion in rugby union versus other contact sports

Authors: Nicholas Burger, Shameemah Abrahams, James Brown, Sharief Hendricks, Sarah McFie, Jon Patricios

Authors' affiliations:

Nicholas Burger

Nicholas is a doctoral candidate at the University of Cape Town. His research is founded on injury epidemiology and performance analysis in rugby union and his focus is the relationship between tackle performance and risk of injury. Nicholas has published his work in international peer-reviewed journals and has presented at both local and international conferences.

Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa. Email: nicholas.burger@uct.ac.za Twitter: @it_is_burger

Shameemah Abrahams

Shameemah is a PhD candidate at UCT and her PhD project focusses on the non-genetic and genetic predisposing factors for concussion risk in South African rugby union.

Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa. Email: abrsha028@myuct.ac.za

Dr James Brown

James is a Post-Doctoral Fellow for BokSmart and the Chris Burger/Petro Jackson Players' Fund and has a joint PhD from UCT, and VU University, Amsterdam. His PhD was on evaluating the effectiveness of the BokSmart nationwide injury prevention programme.

Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa; Department of Public & Occupational Health and the EMGO Institute for Health and Care Research, VU University Medical Center, Amsterdam, The Netherlands. Email: jamesbrown06@gmail.com.

Dr Sharief Hendricks

Sharief is a Research Fellow at the University of Cape Town. In his short academic career, Sharief has published over 30 international peer-review articles, a book chapter, and has contributed significantly to national strategic documents for sport in South Africa. In addition, he has presented at a number of international and local conferences.

Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa. Email: sharief.hendricks01@gmail.com Twitter: @Sharief_H

Sarah McFie

Sarah is a PhD candidate at UCT and her PhD focuses on identifying the incidence and potential modulating factors for concussion risk, severity, and recovery in South African Rugby Union players.

Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences University of Cape Town, Cape Town, South Africa. Email: sarah.mcfie@gmail.com

Dr Jon Patricios

Jon is a Johannesburg-based sports physician and consultant to BokSmart, SA Rugby and World Rugby.

Extraordinary lecturer in the Section of Sports Medicine, Faculty of Health Sciences, University of Pretoria, Honorary lecturer in the Department of Emergency Medicine, Faculty of Health Sciences, University of the Witwatersrand. Email: jpat@mweb.co.za

Corresponding author – Nicholas Burger:

Tel: +2782 3121234; Email: nicholas.burger@uct.ac.za

Introduction

The incidence of concussion is the highest in sports that involve frequent high-impact collisions, for example those seen in rugby union,[1-3] in comparison to other team sports such as soccer.[4,5] Certain facets of play, as well as specific tactics and strategies in contact and collision sports predispose athletes to a greater chance of sustaining a concussion.[1] For example the tackle phase of play in rugby union has a higher association with concussion events.[3,6,7]

Because of this greater exposure, it has been proposed that athletes who participate in these sports may be at risk for developing long-term alterations in brain function and subsequent neurodegenerative complications, such as chronic traumatic encephalopathy (CTE).

This has recently been the focus of much media attention as it has been identified in several deceased professional and amateur contact sport athletes.[8-10]

CTE may develop as a result of physiological stress and residual damage of the brain caused by a single mild traumatic brain injury (TBI)[11] or repetitive concussive and sub-concussive episodes (often experienced in contact and collision sports) over a prolonged period of time.[10-13] There is currently no official consensus-based ante-mortem clinical diagnosis for CTE, although this chronic brain disease is associated with the development of cognitive dysfunction, behavioural changes, memory loss, changes in personality, early-onset dementia and motor neuron disease.[14] These symptoms do not always follow a predictable course which makes it difficult to identify.[15] CTE is currently only diagnosed post-mortem[10,16] and is marked by atrophy of the cortical brain and augmented levels of hyperphosphorylated microtubule associated tau protein in the cerebral cortex.[16,17]

These changes may occur as part of the normal aging process and are also evident in several other neurodegenerative diseases including Alzheimer's disease, Parkinson's disease and amyotrophic lateral sclerosis that have no specific association with participation in contact sports.[8,18] It is also proposed that genetic factors, for example the presence of the apolipoprotein E (APOE) ε4 gene allele, may predispose certain individuals to the development of CTE.[13,19] The role of genetics, gender, physiological stress, pre-existing mental illness, alcohol consumption, narcotics and performance-enhancing drugs in the development of neurodegenerative disease, such as CTE, also requires further exploration, as these may also be predisposing risks.[9,20,21] These have been found to play a role in the manifestation of CTE in professional athletes of the National Hockey League (NHL) and the National Football League (NFL).[13]

There is currently inconclusive evidence to support a direct causal relationship between a head injury and the development of long-term neurodegenerative disease, and any potential association must therefore be examined with caution, until more is known.[8,9,20,22] The dose-response relationship, or accumulated volume and severity of repetitive brain injury required to cause these circumstances is also not fully understood.[8,9,15]

What is known, is that between 40-50% of athletes who experience a moderate-to-severe TBI are likely to experience acute neurological deficits and the manifestation of neurodegenerative complications.[9,23]

It is in the interest of athletes' health that representatives from all prominent contact sports must combine to develop an objective and consistent message pertaining to the long-term neurodegenerative health risks associated with concussion.[9,13] To this end, a review of CTE in contact and collision sport will

be one of the key focus questions discussed at the 5th International Conference on Concussion in Sport, in Berlin, 2016. Moreover, due to the seriousness of the situation, national and international governing bodies of specific contact sports have taken action by implementing rules and regulations to attenuate those factors associated with concussion and to improve concussion recognition and management. This may help reduce the incidence and potential long-term effects of concussion at various levels of play.[1,9]

The purpose of this narrative review is (1) to assess and compare the available literature pertinent to concussion incidence and documented cases of neurodegenerative disease (particularly CTE) in popular team contact sports, and (2) to highlight the injury prevention strategies in place to reduce the rate of these injuries and potential risk of developing these conditions.

1. American Football

American Football ("football") is the most popular sport at high schools in the United States of America.[24] It is synonymous with a high incidence of concussion as a result of the physicality and frequent high impact collisions associated with the game. Players are exposed to numerous head impacts over successive playing seasons.[25-28] The helmets and extensive padding worn by participants may also negatively affect player behaviour resulting in players acting dangerously and sometimes even using their protective gear as weapons to impede opposition players.[29,30]

Concussion incidence in football

Professional NFL football has a concussion incidence rate of 18.2 injuries per 1000 player-exposure hours.[31] Similarly, football has been shown to have the highest incidence of concussion in American high school athletes playing a variety of sports,[32] although rugby union was not included in this particular analysis.

CTE cases in football

To date, CTE has most frequently been reported in American football players.[21] The prevalence of the disease was first confirmed via autopsy in three former National Football League (NFL) players in 2005, 2006 and 2010.[33-35] This was followed by CTE diagnoses in thirty-three former professional players, one

semi-professional player, seven high school players, and nine college level players.[11,12,21] Furthermore, CTE was found in four former Canadian Football League players who had all coincidentally experienced repeated concussions.[12,36] However, currently, the true incidence of CTE and other neurodegenerative diseases in football still remains unknown.

Concussion prevention initiatives in football

The NFL have implemented several law changes to eliminate dangerous play to thereby reduce the risk of sustaining head injuries, and any potential long-term effects that may be related to them.[37] For example, it is considered a foul, and will be penalised, if a player initiates unnecessary contact against another player who is deemed to be in a defenceless position (article 9).[37] An example of this is when a receiver that is attempting to catch a pass or who has just completed a catch, is not aware of the impending contact and has subsequently not had sufficient time to protect or brace himself. However, if the receiver is capable of avoiding or fending off the contact, at the discretion of the match officials, he is no longer deemed a defenceless player. Lack of player awareness of impending contact has previously been identified as a potential risk factor for concussion in rugby.[38] In addition, offensive blockers and defensive players may not hit an opponent on their head, neck, or face with their hands (article 4 and article 6).[37] The NFL have also adjusted the kick-off rule to increase the number of touchbacks (when the ball crosses the 'dead ball' line and play is restarted in an orderly fashion at the first down) and to reduce the number of kick returns (a chaotic, fast-paced phase of play with a potential for high-impact collisions and concussion).

In the USA, the Zackery Lystedt Law was passed in the Washington State in 2009, subsequent to a life-altering injury sustained by a teenage football player.[39] The main purpose of this law was to combat negligence associated with concussion recognition and its management, and also to attenuate concussion incidence.[40]

The remaining States have since then followed Washington's example and there are currently laws regulating concussion in all 50 American States.[41]

These laws stipulate that an athlete must receive, acknowledge and sign a concussion information sheet at the start of each new season. This information sheet makes them aware that they must be removed from the field of play if they are in any way suspected of having a concussion, and must not return to play

until they have followed the standardized return-to-play protocols, and have been appropriately cleared by a clinician. These laws also advocate concussion education for players, parents and coaches.

In addition to this, the Centers for Disease Control and Prevention (CDC) in the USA has initiated the "Heads Up" concussion education programme and the NFL has also developed an informative website (http://www.nflevolution.com). These were developed in an effort to reduce the incidence of concussion, by encouraging safe behaviour and proper contact techniques, and to promote the correct management of athletes who have sustained head injuries.[15,32]

2. Ice hockey

There is great potential for concussions in ice hockey, due to the high speed of play and the forceful impacts that occur when opposing players collide with each other i.e. body-checking, or when players make contact with the hard surface of the ice or with the solid boards surrounding the area of play.[1,42,43]

Concussion incidence in ice hockey

Previous research in professional Swedish ice hockey players noted a concussion rate of 6.5 injuries per 1000 player-exposure hours.[44] The NHL-NHLPA concussion programme (a collaboration between the National Hockey League and NHL Players Association (NHLPA)) was initiated in 1997 to monitor the nature and incidence of concussion injuries in professional ice-hockey.[45] This programme calculated a concussion incidence rate of 1.8 injuries per 1000 player-exposure hours.

CTE cases in ice hockey

CTE has been identified in the brains of five former ice hockey players, including four former NHL players.[21] The incidence of CTE and other neurodegenerative diseases in ice hockey players cannot be calculated due to a lack of longitudinal research, lack of calculating player exposure, and due to inconsistent data reporting.

Concussion prevention initiatives in ice hockey

The Canadian Academy of Sport and Exercise Medicine submitted a proposal to eliminate body checking at all levels of minor ice hockey except in elite leagues and for players aged 16 and older.[46] It was postulated that the physical collisions associated with body-checking in ice hockey exposed players to an increased risk of concussions, and that by removing body-checking one would lower this risk substantially. However, recent research has shown that Bantam league ice hockey players (age 13-14) that are introduced to body-checking at a later stage (age 13 as opposed to age 11) may in fact be at an increased risk of sustaining a concussion, compared to those players who had already experienced body-checking at an earlier age.[47]

This finding may be due to lower levels of contact technique proficiency or skill, with bigger bodies and greater collisions, when introduced at a later stage. The optimal age at which youth ice hockey players need first introduction to certain contact skills, requires further investigation and should be considered when designing and implementing injury prevention programmes. This is a topical consideration that has wide-ranging implications for all contact-sports, and for balancing the risk of concussion, contact skill development, and short- and long-term player health, welfare and safety implications.

The governing body for ice hockey in North America, USA Hockey, have concussion guidelines available online[48] that highlight the potential signs and symptoms that children may display if they are concussed and also provide effective management strategies. There are also educational resources advocating proper playing technique and the use of functional safety equipment.[49] These guidelines may help players, coaches, parents and other stakeholders to prevent concussion, to better identify injured athletes and prevent them from sustaining further damage. Similarly, Hockey Canada also have online resources advocating concussion prevention and effective management.[50]

3. Rugby league and Australian Rules football

Australian Rules football and rugby league are two popular contact sports and both carry a high risk of injury and concussion.[51] Rugby league has similar attributes to rugby union and requires similar technical skills and physical abilities, for example tackling, whereas Australian Rules football involves a greater proportion of jumping and kicking of the ball.

Concussion incidence in rugby league and Australian Rules football

The incidence of concussion in professional rugby league for both ball-carriers and tacklers was reported at 9.8 injuries per 1000 player-exposure hours,[52] and 12.0 injuries per 1000 player-exposure hours for ball-carriers and 8.0 injuries per 1000 player-exposure hours for tacklers.[53]

Two studies that focused on injuries in youth rugby league showed that concussion rates ranged from 4.6-14.7 concussions per 1000 player-exposure hours.[54,55] In addition to this, research has shown that 5-7 concussions occur per team per season in elite Australian Rules football and rugby league in Australia.[56,57]

CTE cases in rugby league and Australian Rules football

A recent case of advanced stage CTE was confirmed during an autopsy of a former professional Australian Rules football player.[21] There are no other cases of CTE or other severe debilitating neurodegenerative diseases reported in the scientific literature for the sport.

Concussion prevention initiatives in rugby league and Australian Rules football

Concussion management guidelines have been developed by both the National Rugby League (NRL) in Australia and the Australian Football League (AFL), based on the Zurich Consensus Statement on Concussion in Sport, to raise awareness of these injuries and to reduce head contact.[56,58] The NRL guidelines include information for recognising and diagnosing concussion, for example, identification of visible cues including (but not limited to) loss of consciousness, lack of steadiness on feet/balance problems, holding of the head, a dazed/vacant expression and confusion. The guidelines also direct stakeholders on the immediate management and removal of the player from the field of play and highlight adherence to first aid rules, including the assessment and monitoring (by a healthcare professional) of the airway, breathing and circulation, and spinal immobilisation. The NRL also stipulate that the concussed player should be referred to a qualified medical practitioner for further assessment, and must follow and pass a graded return-to-play protocol under the supervision of a medical practitioner before returning to play. The AFL guidelines reiterate these important steps.

4. Rugby Union

Rugby union is the most popular contact sport in the world[3] and is associated with a high overall rate of injury.[59] As a result of the nature of play, particularly in the contest for possession, concussion injuries are quite common.[13]

Concussion incidence in rugby union

Research has shown that the incidence of concussion in professional men's 15s rugby union ranges from 4.1-4.5 concussions per 1000 player-exposure hours and 8.3 concussions per 1000 player-exposure hours in professional 7s rugby.[3,60] The incidence of concussion in high-level under-18 South African rugby union players was calculated at 5.8 concussions per 1000 player-exposure hours[38] and an incidence of 6.8 concussions per 1000 player-exposure hours was observed across four South African youth week rugby tournaments (under-13, under-16, and under-18).[61] The younger cohorts (under-13 and under-16) in this study had a higher incidence of concussion in comparison to the under-18 players. An addition to these findings, a systematic review on injuries in youth rugby union showed that concussion rates range from 0.2-6.9 concussions per 1000 player-exposure hours.[62] Interestingly, overall concussion rates (game and practice combined) in American collegiate rugby union players was recently shown to be significantly higher than that in collegiate football players.[63]

CTE cases in rugby union

A recent case confirmed the first report of CTE in a former rugby player who experienced several concussions during the course of his career.[10,64] He was not hospitalised for any of his injuries. Two cases of CTE have been identified in individuals who participated in rugby union in addition to high school and college American football.[12] Therefore, it is equivocal whether participation in one particular sport or a combination of the different sports contributed to the manifestation of CTE in these players.

Concussion prevention initiatives in rugby union

World Rugby (previously known as the International Rugby Board or IRB) has acknowledged that there is a significant risk associated with concussions, and have subsequently implemented a risk management strategy.[9] World Rugby used current scientific evidence and the 2012 international consensus statement for concussion in sport[20] to advise on concussion prevention, identification and management at various levels of play.[13,65]

An operational definition for concussion was recently developed in professional rugby to account for the often evolving and irregular course that these injuries follow during the 48 hours after the injury.[66] The method comprises three separate head injury assessment stages (HIA 1, HIA 2 and HIA 3) and makes use of certain concussion assessment tools. Stage 1 or HIA 1 is conducted using the 10-minute head injury assessment tool (HIA) immediately after the injury has occurred. Stage 2 (HIA 2) should be completed within three hours of the injury/initial assessment and makes use of the sport concussion assessment tool (SCAT3). The third stage (HIA 3) takes place between 36-48 hours after the injury and includes the symptom checklist from the SCAT3, a computerised neurocognitive assessment tool, and/or the standardised assessment of concussion tool (SAC) from the SCAT3, and an evaluation of the player's balance using the Modified Error Scoring System and tandem gait. Any abnormal assessment confirms the diagnosis of concussion and a final decision can only be made after completion of the third stage of the process.

This operational definition will continue to develop and evolve over time as scientifically-based evidence pertinent to concussion becomes available.[66] All novel or re-engineered concussion protocols are evaluated by an independent international Concussion Advisory Group that comprises of a neurosurgeon, a neuropathologist, an injury prevention researcher and a sports medicine physician, all of whom are appointed by the World Rugby chief medical officer.[13]

The "Recognise and Remove" campaign is another example of guidelines developed and established by World Rugby to combat potential negligence surrounding concussion awareness and management.[65] This campaign targets all stakeholders including referees, parents, players and coaches.[9] Recognising a potential concussion injury is the first step in the process of effectively dealing with this injury.[9] Any player with a suspected concussion must be removed immediately from play for assessment by a medical professional and must not return to play or train on the same day and until they are completely asymptomatic.[20] Once medically cleared to do so, the player must undergo a graduated return to play

protocol, and be medically cleared again before returning to full contact training or match play as instructed by the World Rugby concussion guidelines and replicated in certain national programmes.

However, it is concerning that only 39% of professional 15s players and 59% of professional 7s players who sustained a concussion, underwent any further forms of diagnostic testing.[3] In addition to this, 48% of professional 15s players and 18% of 7s players returned to play far sooner than the minimum concussion recovery time stipulated in the World Rugby guidelines at the time of the study and, in both formats of the game, a high proportion of players who sustained a concussion were not removed immediately from play. [3,60] These findings warrant further investigation and it is evident that a continued effort is required in combating negligence related to concussion recognition and management.

World Rugby has been proactive in adapting laws and sanctions, and developed guidelines to educate stakeholders (particularly referees and players) on how to eliminate dangerous play and risk of concussion from the game.[67] For example, the World Rugby Law book stipulates that contact is not permitted above the level of the shoulders[65] (Law 10.4e), and making contact with an opposing player without use of the arms is deemed as dangerous play and will be penalised (Law 10.4g).[65,68] However, concussive episodes may occur as a result of accidental head contact with an opponent's head, shoulder or lower limb and/or the ground.[13,69]

Member unions of World Rugby have also made efforts to disseminate knowledge and implement concussion awareness programmes, in conjunction with World Rugby guidelines, dedicated to educating all stakeholders involved in rugby union.[9] Examples of these guidelines can be found as part of the New Zealand Rugby Union's (NZRU) RugbySmart programme[70] and the South African Rugby Union's (SA Rugby) BokSmart National Rugby Safety Programme.[71]

In particular, the BokSmart programme disseminates its information through four main vehicles which include (1) face-to-face workshops (compulsory for coaches and referees at all levels), (2) online material, (3) a lay person focused rugby medic programme, and (4) the BokSmart 'Spineline' (a toll-free hotline available for the reporting and management of serious head, neck and spine injuries).[72]

The NZRU have demonstrated serious concern regarding concussion injuries and have subsequently initiated a longitudinal study in collaboration with World Rugby to assess the potentially adverse long-term health effects of repetitive physical collisions on the brain.[67]

Table 1. Summary of reported concussion incidence rate and cases of chronic traumatic encephalopathy (CTE) from the scientific literature.

Contact sport	Concussion incidence	Cases of CTE
American football	**National Football League (NFL)** • 18.2 injuries per 1000 player-exposure hours[31]	• Thirty-six professional players[12,33-35] • Four former Canadian Football League players[12,36] • Seven high school players[11,12] • Nine college level players[12] • Two former players who participated in rugby union and American football[12]
Ice hockey	**Professional Swedish ice hockey** • 6.5 injuries per 1000 player-exposure hours[44] **National Hockey League (NHL)** • 1.8 injuries per 1000 player-exposure hours[45]	• Five former players (including four former professionals)[21]
Australian Rules football	**Professional Australian Rules football** • 5-7 concussions per team per season[56,57] **combined with professional rugby league*	• One former professional player[21]
Rugby league	**Professional rugby league** • 9.8 injuries per 1000 player-exposure hours[52] • 20 injuries per 1000 player-exposure hours[53] • 5-7 concussions per team per season[56,57] **combined with professional Australian Rules football* **Youth rugby league** • 4.6-14.7 injuries per 1000 player-exposure hours (under 20 years)[54,55,62]	• No cases reported in scientific literature
Rugby Union and Sevens rugby	**Professional rugby union** • 4.1-4.5 injuries per 1000 player-exposure hours[3,60] **Professional 7s rugby** • 8.3 injuries per 1000 player-exposure hours[3] **Youth rugby union** • 5.8 injuries per 1000 player-exposure hours (under-18)[38] • 6.8 injuries per 1000 player-exposure hours (under-13 to under-18)[61] • 0.2-6.9 injuries per 1000 player-exposure hours (under 20 years)[62]	• One former rugby union player[10,64] • Two former players who participated in rugby union and American football[12]

Discussion

Although CTE has been identified in contact and collision sport athletes, the incidence of this condition is currently unknown.[8,16,21,73,74] This is primarily due to the difficulty in identifying confounding and predisposing risk factors associated with the development of CTE and making a diagnosis in vivo.[10,75]

Furthermore, the lack of knowledge on the prevalence in normal populations, and also on the prevalence of non-CTE cases with similar concussion histories, makes it very difficult to currently compare relative risk and any direct cause-and-effect relationships.

Although, on the limited case evidence available, it would appear that the risk of developing severe long-term neurological complications such as CTE is greatest in American football.[21] It would however be dangerous to make this assumption, as cases in many other sports may go by unnoticed or undiagnosed.[10]

Therefore, it remains challenging to determine and compare the risk of CTE between the various contact and collision sports, until such time that well-designed longitudinal case-control studies can confirm any direct causal dose-response association between concussion and neurodegenerative disease.[17.73,74]

This research must also consider all potential confounding factors, for example genetic predisposition, drug, alcohol and steroid use, lifestyle habits, and pre-existing psychological conditions. There has also been limited research comparing the biomechanics of concussive head impacts in helmeted versus non-helmeted sports. Therefore, it remains unknown as to whether the long-term clinical consequences of cumulative mild traumatic brain injuries differ between these sports.[13,21]

With this said, it is important to note that, on the evidence available, the health benefits related to participation in rugby and other contact sports far out-weighs the risk of concussion and any potential long-term sequelae or neurodegenerative effects.[13] Playing sport reduces the risk of developing several adverse health conditions including cardiovascular disease, type II diabetes, hypertension, obesity and psychological-related issues.[21] Participation in regular physical activity and sport also reduces the loss of brain volume associated with the aging process, improves cognition and reduces the risk of dementia.

The governing bodies of most, if not all, major contact sports have initiated action plans to reduce the risk of concussion and improve the management of concussed athletes, thereby lowering the risk of potential long-term sequelae.

Research has also indicated that there may be an equal or even greater risk for a serious brain injury and subsequent neurodegenerative complications when taking part in other everyday activities (for example cycling, horse-riding, swimming, or driving) in comparison to participating in contact sports.[8]

It is important to note that there will always be a certain level of risk associated with participation in contact sports, but that the sporting governing bodies, should do as much as possible to lower this risk. Furthermore, it is impossible to prevent all concussions in sport. However, the potential risk of CTE and other long-term effects may be attenuated by decreasing the incidence of concussion[9] and managing each case appropriately. This may be achieved by (1) minimising the exposure to head trauma during training and matches, (2) ensuring that concussed players are removed from play and that they receive the best medical care available at the time of their injury, and (3) by encouraging stakeholders to adhere to the stipulated return-to-play protocols.

Other forms of intervention are also aimed more at the technical elements of contact sports, such as avoiding unnecessary contact, i.e. running into space, and the coaching of safe and effective contact techniques, such as tackling or ball carries.[38,76,77]

Summary

1. There is no definitive evidence that participation alone in contact and collision sports leads directly to CTE or other long-term neurodegenerative diseases
2. What predisposes certain individuals to developing CTE or other neurodegenerative diseases and what protects others, remains unknown
3. There are currently no comprehensive incidence data for CTE in contact sport
4. There is a lack of understanding of the relative risk of CTE development in those participating in contact or collision sports, compared to those who don't
5. There is currently no official consensus-based in vivo clinical diagnosis for CTE
6. Well-designed longitudinal case-control studies are required to further develop our understanding of the long-term effects of participation in contact sports

7. Representatives from contact sports must combine to develop an evidence-based objective and consistent message pertaining to the long-term neurodegenerative health risks associated with concussion and continue to update educational guidelines based on the latest scientific findings

References

1. KOH, J.O., CASSIDY, J.D., WATKINSON, E.J. Incidence of concussion in contact sports: a systematic review of the evidence. Brain. Inj. 17:901-917. 2003.
2. KAPLAN, K.M., GOODWILLIE, A, STRAUSS, E.J., ET AL. Rugby Injuries: A Review of Concepts and Current Literature. Bull. NYU. Hosp. Jt. Dis. 66:86-93. 2008.
3. FULLER, C.W., TAYLOR, A, RAFTERY, M. Epidemiology of concussion in men's elite Rugby-7s (Sevens World Series) and Rugby-15s (Rugby World Cup, Junior World Championship and Rugby Trophy, Pacific Nations Cup and English Premiership). Br. J. Sports. Med. DOI:10.1136/bjsports-2013-093381. 2014.
4. JUNGE, A, CHEUNG, K, EDWARDS, T, ET AL. Injuries in youth amateur soccer and rugby players - comparison of incidence and characteristics. Br. J. Sports. Med. 38:168–172. 2004.
5. MCINTOSH, A.S., MCCRORY, P, FINCH, C.F., ET AL. Head, face and neck injury in youth rugby: incidence and risk factors. Br. J. Sports. Med. 44:188–193. 2010.
6. MCINTOSH, A.S., MCCRORY, P. Preventing head and neck injury. Br. J. Sports. Med. 39:314–18. 2005.
7. MCINTOSH, A.S. Rugby Injuries. In: Epidemiology of Pediatric Sports Injuries: Team Sports. MAFFULLI, N, CAINE, D.J., eds. Med. Sport. Sci. Basel, Karger. 120–139. 2005.
8. LOVE, S, SOLOMON, G.S. Talking With Parents of High School Football Players About Chronic Traumatic Encephalopathy: A Concise Summary. Am. J. Sports. Med. DOI:10.1177/0363546514535187. 2014.
9. RAFTERY, M. Concussion and chronic traumatic encephalopathy: International Rugby Board's response. Br. J. Sports. Med. 48:79-80. DOI:10.1136/bjsports-2013-093051. 2014.
10. STEWART, W, MCNAMARA, P.H., LAWLOR, B, ET AL. Chronic traumatic encephalopathy: a potential late and under recognized consequence of rugby union? QJM. Int. J. Med. Hcv070. 2015.
11. OMALU, B.I., BAILES, J., HAMILTON, R. L., ET AL. Emerging histomorphologic phenotypes of chronic traumatic encephalopathy in American athletes. Neurosurgery. 69(1):173-183. 2011.

12. MCKEE, A.C., STERN, R.A., NOWINSKI, C.J., ET AL. The spectrum of disease in chronic traumatic encephalopathy. Brain. 136:43-64. DOI:10.1093/brain/aws307. 2013.
13. PATRICIOS, J.S. Rugby Contact and Collisions – Clinical Challenges of a Global Game. Curr. Sports. Med. Rep. 13:326-333. 2014a.
14. MCKEE, A.C., CANTU, R.C., NOWINSKI, C.J., ET AL. Chronic traumatic encephalopathy in athletes: progressive tauopathy following repetitive head injury. J. Neuropathol. Exp. Neurol. 68:709-735. 2009.
15. KORNGOLD, C, FARRELL, H.M., FOZDAR, M. The National Football League and Chronic Traumatic Encephalopathy: Legal Implications. J. Am. Acad. Psychiatry. Law. 41:430–436. 2013.
16. MCKEE, A.C., CAIRNS, A.J., DICKSON, D.W., ET AL. The first NINDS/NIBIB consensus meeting to define neuropathological criteria for the diagnosis of chronic traumatic encephalopathy. Acta. Neuropathol. 131:75–86. 2016.
17. IVERSON, G.L., GARDNER, A.J., MCCRORY, P, ET AL. A critical review of chronic traumatic encephalopathy. Neurosci. Biobehav. R. 56:276–293. 2015.
18. LEHMAN, E.J., HEIN, M.J., BARON, S.L., ET AL. Neurodegenerative causes of death among retired National Football League players. Neurology. 79:1970–1974. 2012.
19. JORDAN, B.D. The clinical spectrum of sport-related traumatic brain injury. Nat. Rev. Neurol. 9:222–230. 2013.
20. MCCRORY, P, MEEUWISSE, W, AUBRY, M, ET AL. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. Br. J. Sports. Med. 47:250–258. 2013.
21. MCKEE, A.C., DANESHVAR, D.H., ALVAREZ, V.E., ET AL. The neuropathology of sport. Acta. Neuropathol. 127:29–51. 2014.
22. PARTRIDGE, B, HALL, W. Repeated Head Injuries in Australia's Collision Sports Highlight Ethical and Evidential Gaps in Concussion Management Policies. Neuroethics. 8:39–45. 2015.
23. JOHNSON, V.E., STEWART, J.E., BEGBIE, F.D., ET AL. Inflammation and white matter degeneration persist for years after a single traumatic brain injury. Brain. 136:28-42. 2013.
24. MCGUINE, T.A., HETZEL, S, MCCREA, M, ET AL. Protective Equipment and Player Characteristics Associated With the Incidence of Sport-Related Concussion in High School Football Players. Am. J. Sports. Med. DOI:10.1177/0363546514541926. 2014.
25. BROGLIO, S.P., MARTINI, D, KASPER, L, ET AL. Estimation of head impact exposure in high school football: implications for regulating contact practices. Am. J. Sports. Med. 41:2877–2884. 2013.

26. DANIEL, R.W., ROWSON, S, DUMA, S.M. Head impact exposure in youth football: middle school ages 12–14 years. J. Biomech. Eng. 136:094501. 2014.
27. WONG, R.H., WONG, A.K., BAILES, J.E. Frequency, magnitude, and distribution of head impacts in Pop Warner football: the cumulative burden. Clin. Neurol. Neurosurg. 118:1–4. 2014.
28. YOUNG, T.J., DANIEL, R.W., ROWSON, S, ET AL. Head impact exposure in youth football: elementary school ages 7–8 years and the effect of returning players. Clin. J. Sport Med. 24(5):416–421. 2013.
29. HAGEL, B, MEEUWISSE, W. Risk compensation: a "side effect" of sport injury prevention. Clin. J. Sport. Med. 14:193-196. 2004.
30. GILBERT, F, JOHNSON, L.S.M. The impact of American tackle football-related concussion in youth athletes. AJOB. Neurosci. 2:48-59. DOI:10.1080/21507740.2011.611125. 2011.
31. CASSON, I.R., VIANO, D.C., POWELL, J.W., ET AL. Twelve years of National Football League concussion data. Sports. Health. 2:471-483. 2010.
32. HALSTEAD, M.E., WALTER, K.D. Clinical Report – Sport-Related Concussion in Children and Adolescents. Pediatrics. 126:597-615. 2010.
33. OMALU, B.I., DEKOSKY, S.T., MINSTER, R.L., ET AL. Chronic traumatic encephalopathy in a National Football League player. Neurosurgery. 57:128–134. 2005.
34. OMALU, B.I., DEKOSKY, S.T., HAMILTON, R.L., ET AL. Chronic traumatic encephalopathy in a national football league player: part II. Neurosurgery. 59:1086–1092. 2006.
35. OMALU, B.I., HAMILTON, R.L., KAMBOH, M.I., ET AL. Chronic traumatic encephalopathy (CTE) in a National Football League Player: case report and emerging medicolegal practice questions. J. Forensic. Nurs. 6:40–46. 2010.
36. HAZRATI, L.N., TARTAGLIA, M.C., DIAMANDIS, P, ET AL. Absence of chronic traumatic encephalopathy in retired football players with multiple concussions and neurological symptomatology. Front. Hum. Neurosci. 7:222. 2013.
37. National Football League (NFL): Official Playing Rules. http://www.nfl.com/static/content/public/image/rulebook/pdfs/15_Rule12_Player_Conduct.pdf; 2014a.
38. HENDRICKS, S, O'CONNOR, S, LAMBERT, M.I., ET AL. Contact technique and concussions in the South African under-18 Coca-Cola Craven Week Rugby tournament. Eur. J. Sport. Sci. DOI: 10.1080/17461391.2015.1046192. 2015.

39. ADLER, R.H. Youth Sports and Concussions: Preventing Preventable Brain Injuries. One Client, One Cause, and A New Law. Phys. Med. Rehabil. Clin. N. Am. 22:721–728. 2011.
40. CHRISMAN, S.P., QUITIQUIT, C, RIVARA, F.P. Qualitative Study of Barriers to Concussive Symptom Reporting in High School Athletics. J. Adolesc. Health. 52:330-335; 2013.
41. National Football League (NFL): Player Health and Safety Report. http://www.nflevolution.com/article/nfl-highlights-safety-efforts-in-2014-health-&-safety-report?ref=0ap2000000250258; 2014b.
42. EMERY, C.A., KANG, J, SHRIER, I, ET AL. Risk of injury associated with body checking among youth ice hockey players. J. Amer. Med. Assoc. 303:2265-2272. 2010.
43. JOHNSON, L.S.M. Concussion in youth ice hockey: It's time to break the cycle. Can. Med. Assoc. J. 183(8):921-924. 2011.
44. TEGNER, Y, LORENTZON, R. Concussion among Swedish elite ice hockey players. Br. J. Sports. Med. 30:251–255. 1996.
45. BENSON, B.W., MEEUWISSE, W.H., RIZOS, J, ET AL. A prospective study of concussion among National Hockey League players during regular season games: the NHL-NHLPA concussion program. Can. Med. Assoc. J. 183:905-911. 2011.
46. KISSICK, J. Canadian Academy of Sport and Exercise Medicine Position Statement: violence and injuries in ice hockey. Ottawa (ON): Canadian Academy of Sport and Exercise Medicine; 2007. Available: http://casem-acmse.org/pg_Statements.php (accessed 2016 Mar. 23).
47. EMERY, C.A., KANG, J, SHRIER, I, ET AL. Risk of injury associated with body checking experience among youth hockey players. Can. Med. Assoc. J. 183:1249-1256. 2011.
48. USA Hockey. Safety Education and Concussion Information. http://www.usahockey.com/safety-concussions. 2014a.
49. USA Hockey. Safety Education and Concussion Information - TAKE 5 with USA Hockey's Jason Hodges. http://www.usahockey.com/news_article/show/435531?referrer_id=908034. 2014b.
50. Hockey Canada. http://www.hockeycanada.ca/en-ca/Hockey-Programs/Safety/Concussions, 2016.
51. WHITE, P.E., NEWTON, J.D., MAKDISSI, M, ET AL. Knowledge about sports-related concussion: is the message getting through to coaches and trainers? Br. J. Sports. Med. 48:119-124. 2014.
52. HINTON-BAYRE, A.D., GEFFEN, G., FRIIS, P. Presentation and mechanisms of concussion in professional Rugby League Football. J. Sci. Med. Sport. 7:400-404. 2004.

53. KING, D, HUME, P.A., CLARK, T. Nature of Tackles That Result in Injury in Professional Rugby League. Res. Sports. Med. 20:86-104. 2012.
54. GABBETT, T.J. Incidence of injury in junior rugby league players over four competitive seasons. J. Sci. Med. Sport. 11:323–328. 2008.
55. KING, D. Incidence of injuries in the 2005 New Zealand national junior rugby league competition. N. Z. J. Sports. Med. 34:21–27. 2006.
56. National Rugby League (NRL). The Management of Concussion in Rugby League. http://www.nrl.com/About/ReferenceCentre/ManagementofConcussioninRugbyLeague/tabid/10798/Default.aspx; 2014.
57. Australian Football League (AFL). The management of concussion in Australian football: With specific provision for children 5–17 years. Melbourne: AFL Research Board and AFL Medical Officers' Association. http://www.aflcommunityclub.com.au/fileadmin/user_upload/CoachAFL/Injury_Management/121 AFL_ConcussionManagement_2013_LowRes_1_.pdf. 2013a.
58. Australian Football League (AFL). Guidelines for the management of concussion in Australian football. http://aflcommunityclub.com.au/fileadmin/user_upload/Coach_AFL/Injury_Management/2013_AFL_Concussion_Guidelines__GPs_v4.pdf. 2013b.
59. BROWN, J.C., VERHAGEN, E, VILJOEN, W, ET AL. The incidence and severity of injuries at the 2011 South African Rugby Union (SARU) Youth Week tournaments. S. Afr. J. Sports. Med. 24:49–54. 2012.
60. KEMP, S.P.T., HUDSON, Z, BROOKS, J.H.M., ET AL. The Epidemiology of Head Injuries in English Professional Rugby Union. Clin. J. Sports. Med. 18:227-234. 2008.
61. MCFIE, S, BROWN, J.C., HENDRICKS, S, ET AL. Incidence and Factors Associated With Concussion Injuries at the 2011 to 2014 South African Rugby Union Youth Week Tournaments. Clin. J. Sport. Med. DOI:10.1097/JSM.0000000000000276. 2016.
62. KIRKWOOD, G, PAREKH, N, OFORI-ASENSO, R, ET AL. Concussion in youth rugby union and rugby league: a systematic review. Br. J. Sports. Med. 49:506–510. 2015.
63. WILLIGENBURG, N.W., BORCHERS, J.R., QUINCY, R, ET AL. Comparison of Injuries in American Collegiate Football and Club Rugby: A Prospective Cohort Study. Am. J. Sports. Med. DOI: 10.1177/0363546515622389. 2016.

64. HAY, J, JOHNSON, V.E., SMITH, D.H., ET AL. Chronic Traumatic Encephalopathy: The Neuropathological Legacy of Traumatic Brain Injury. Annu. Rev. Pathol. Mech. Dis. 11:21–45. 2016.
65. WORLD RUGBY: http://www.irbplayerwelfare.com/concussion. 2014.
66. RAFTERY, M, KEMP, S, PATRICIOS, J, ET AL. It is time to give concussion an operational definition: a 3-step process to diagnose (or rule out) concussion within 48 h of injury: World Rugby guideline. Br. J. Sports. Med. DOI:10.1136/bjsports-2016-095959. 2016
67. MURRAY, A.D., MURRAY, I.R., ROBSON, J. Rugby Union: faster, higher, stronger: keeping an evolving sport safe. Br. J. Sports. Med. 48:73-74. 2014.
68. FULLER, C.W., BROOKS, J.H.M., CANCEA, R.J., ET L. Contact events in rugby union and their propensity to cause injury. Br. J. Sports. Med. 41:862-867. 2007.
69. SYE, G, SULLIVAN, S.J., MCCRORY, P. High school rugby players' understanding of concussion and return to play guidelines. Br. J. Sports. Med. 40:1003-1005. 2006.
70. QUARRIE K.L., GIANOTTI S.M., HOPKINS W.G., ET AL. Effect of nationwide injury prevention programme on serious spinal injuries in New Zealand rugby union: ecological study. BMJ. 334:1150. 2007.
71. VILJOEN, W, PATRICIOS, J.S. BokSmart—implementing a National Rugby Safety Programme. Br. J. Sports. Med. 46:692–693. 2012.
72. PATRICIOS, J.S. BokSmart—South African Rugby's National Rugby Safety and Injury Prevention Program. Curr. Sports. Med. Rep. 13:142-144. 2014b.
73. GARDNER, A, IVERSON, G.L., MCCRORY, P. Chronic traumatic encephalopathy in sport: a systematic review. Br. J. Sports. Med. DOI:10.1136/bjsports-2013-092646. 2013.
74. TATOR, C.H. Chronic traumatic encephalopathy: How serious a sports problem is it? Br. J. Sports. Med. 48:81–83. 2014.
75. SUNDMAN, M, DORAISWAMY, P.M., MOREY, R.A. Neuroimaging assessment of early and late neurobiological sequelae of traumatic brain injury: implications for CTE. Front. Neurosci. DOI:10.3389/fnins.2015.00334. 2015.
76. VILJOEN W, TREU P, SWART B. SA Rugby BokSmart: safe and effective techniques in rugby—practical guidelines; 2009. Available: http://www.sarugby.co.za/boksmart/pdf/BokSmart%20-%20Safe%20Rugby%20Techniques%20Practical%20guidelines.pdf.2009 (accessed 23 May 2012).

77. BURGER, N, LAMBERT, M.I., VILJOEN, W, ET AL. Tackle-related injury rates and nature of injuries in South African Youth Week tournament rugby union players (under-13 to under-18): an observational cohort study. BMJ. Open. DOI:10.1136/bmjopen-2014-005556. 2014.