Review Article

Beyond the Gear: Addressing Gaps in Concussion Care in Collision Sports

Marcus Ryan

Walnut Grove High School, 3500 E First St, Prosper, TX, 75078, United States

ABSTRACT

The landscape of concussion mitigation technologies in contact sports has evolved significantly, with innovations such as Guardian Caps, G8RSkin, and the Q-Collar showing promising results in reducing concussion risk. These advancements demonstrate crucial steps that have been made toward addressing the prevalence of traumatic brain injuries and potentially mitigating the development of chronic traumatic encephalopathy (CTE) among athletes. Despite these technological advancements, significant challenges remain in standardizing concussion protocols across sports. The lack of consensus on diagnosis methods, treatment approaches, and return-to-play guidelines undermines holistic athlete protection. Current diagnosis methods remain largely subjective and dependent on self-reporting, while treatment protocols vary widely between institutions. Moving forward, emphasis must be placed not only on improving protective equipment but also on developing standardized diagnostic criteria for early CTE detection, establishing consistent treatment protocols, and implementing mandatory recovery periods following head trauma. Multifaceted approaches can significantly enhance athlete safety while preserving the integrity and future of contact sports. As technological innovation advances, we must consider whether the investment in concussion research has fulfilled athletic institutions' ethical responsibility to protect athletes without detracting from the excitement of collision sports.

Keywords: Concussions, Technology, Athletes, Protocols, CTE

INTRODUCTION

In 2015, former NFL player Chris Borland retired after just one season, fearing the long-term effects of chronic traumatic encephalopathy (CTE). If today's advanced concussion mitigation technology had been available at the time, would he have made a different choice? Cases like Borland's are not isolated. They reflect a broader, data-driven reality: the Centers for Disease Control and Prevention (CDC) estimates that approximately 3.8 million sports-related concussions occur annually in the U.S., with 5–10% of athletes sustaining a concussion each year (1, 2). Despite improvements in diagnostic tools and concussion management, traumatic brain injuries remain a persistent risk, especially in high-collision sports.

Boxer Micky Ward, whose story was depicted in the 2010 film The Fighter, began experiencing symptoms consistent with CTE just two years after his 2003 retirement (3). Olympic boxer Tony Jeffries estimated taking 40,000 to 50,000 head blows over his career before

Corresponding author: Marcus Ryan, E-mail: marcpryanjr@gmail.com.

Received May 16, 2025**; Accepted** June 25, 2025
https://doi.org/10.70251/HYJR2348.33224234

retiring in 2011 (4). The condition is so prevalent in contact sports that Boston University announced in 2023 that they had detected CTE in 345 of 367 former NFL players studied, underscoring the prevalence of the condition among contact sport athletes and the urgent need for early detection and treatment methods (5). Similarly, a NIH-funded study of 152 brains—141 male and 11 female—from contact sport athletes who passed away before the age of 30 found that over 40% had developed CTE (6).

CTE is a neurodegenerative condition caused by repeated head trauma. Currently it can only be definitively diagnosed post-mortem (7); however, ongoing research into the accumulation of hyperphosphorylated tau (p-tau) proteins in the brain is offering promising methods for early detection (8, 9). Alzheimer's disease is also characterized by a buildup of p-tau proteins, but it differs from CTE in the distribution and progression of these deposits (10, 11). Specifically, CTE is marked by more localized tau accumulation, particularly in the cortical regions (Figure 1), whereas Alzheimer's typically shows a more widespread pattern (12). Because the abnormal tau buildup in CTE is directly linked to head trauma, its long-term effects can be just as severe as those seen in Alzheimer's disease.

The detrimental effects of CTE has led to a fear of decline of historically popular contact sports. This is due in part to research showing that athletes who experience repeated head trauma in contact sports may later develop mood disorders, cognitive issues, suicidal thoughts, and aggressive behavior. Some of these athletes show postmortem signs of CTE, which is believed to be caused by concussions or subconcussive blows present in high-energy impacts from collision sports (14, 15). However, not all athletes who suffer from head injuries develop CTE, and some individuals with similar symptoms have not been exposed to repeated trauma, leading to disagreement over the true cause of these neurological conditions (16). Advancements in research, such as Boston University's Study of Axonal and Vascular Effects (Project S.A.V.E), aim to better understand the long-term effects of repetitive head trauma and develop treatment strategies (17). Continued research into CTE is crucial for potentially mitigating the condition's debilitating effects.

The necessity to mitigate concussions in contact sports has led to an increase of concussion mitigation technologies, which have proven to see success in limiting concussion rates. These tools take different approaches—external and internal—to reduce head trauma. While each method shows promising results, their adoption and effectiveness vary.

External devices, such as the Guardian Cap or G8RSkin, focus on reducing impact force. Guardian Caps are soft-shell helmet covers shown to lower both linear and rotational acceleration, leading to a 52% reduction

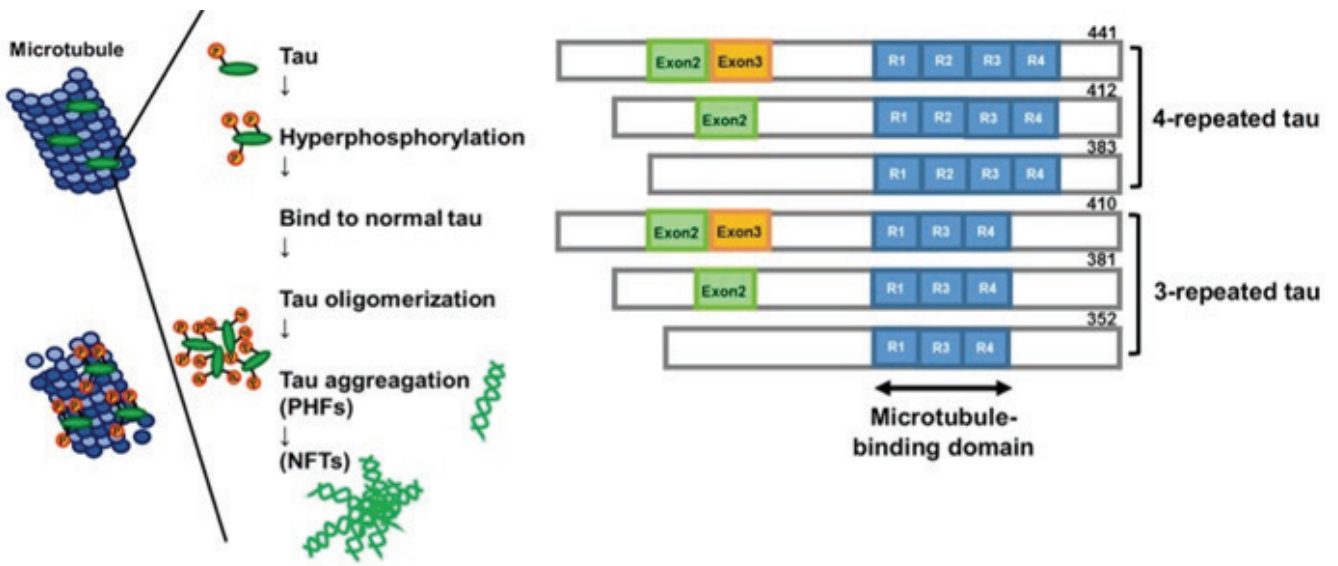

Figure 1. Hyperphosphorylated tau aggregates dissociate from microtubules and form neurofibrillary tangles in the brain, contributing to the development of CTE (11, 13).

in concussions during NFL practices and up to a 34% risk reduction in youth and high school football (18, 24). However, some players are resistant to wearing them due to discomfort and their appearance, which could affect their widespread use (29). Similarly, the *G8RSkin* uses a cross-functional protective gear that reduces concussion risk by up to 79% by absorbing and dispersing impact forces through its polymer design (19). The G8RSkin has been tested using methods like the Combined Probability of Concussion (CPC) and Head Acceleration Response Metric (HARM), showing a reduction in concussion risk by up to 82% in various impact scenarios (19, 32).

Alternatively, internal solutions target the physiological effects of impact. The *Q-Collar* applies light pressure to the neck, increasing blood volume in the brain's venous structures to prevent internal brain movement during impacts (20). As the only FDA-approved concussion mitigation device, it works alongside helmets to reduce "brain sloshing" during head impacts. While these technologies offer complementary forms of protection, challenges remain in adoption, long-term testing, and integrating them into standardized concussion prevention strategies.

Despite the high prevalence of brain injuries in sports, there is still no consensus on concussion treatment. For instance, the University of Michigan recommends light exercise during recovery, while other institutions advocate for complete rest (21, 22). The growing concern about the long-term health risks athletes face from repeated concussions in collision sports has spurred significant advancements in concussion mitigation technologies. These technologies have demonstrated success in reducing concussion rates and protecting athletes from the long-term effects of brain trauma, including CTE. However, despite these developments, the need for early diagnosis and treatment remains critical, as current methods for assessing brain injury are limited, and CTE is still diagnosable only post-mortem. While the latest concussion mitigation technologies have significantly improved athlete protection against brain injuries, further focus should be placed on early diagnosis and treatment methods to prevent long-term neurological damage and conditions similar to CTE, ultimately shifting the approach to include these factors as components of overall concussion management going forward.

GUARDIAN CAPS

Rutgers New Jersey Medical School conducted a study which examined the prevalence of head impacts in the Summit Youth Football League, where 20 children at the middle school level were equipped with *Guardian Caps*—soft-shelled helmet pads used by the NFL to reduce concussion risk—during practices (23) (Figure 2). *Guardian Caps* function independently from the helmets, allowing them to shift upon impact and disperse energy more effectively. Unlike typical helmets, the *Guardian Cap* has a soft outer shell that absorbs impact, reducing the force transferred to the hard shell and interior padding. The impact on an athlete's head is minimized, similar to the soft wall technology used by NASCAR or car airbags (24). Typically, 18.2% of middle schoolers and 14.3% of high schoolers report at least one concussion from sports or physical activity annually (25). The study revealed that *Guardian Caps*, coupled with safer tackling techniques, substantially mitigated the number of head injuries among that team (23).

Similarly, the Virginia Tech Institute evaluated football helmets with add-ons—such as the Guardian Cap XT and Guardian Cap NXT—at varsity-level impact conditions, the latter being designed for higher-impact forces at the professional level (26, 27). These add-ons reduce vibrational frequencies, mitigating impact by an average of 10-20% at NFL speeds, compared to helmets without them. The findings demonstrated that *Guardian* technology reduced both linear and rotational accelerations, thereby lowering the risk of concussions. Research from the National Center for Biotechnology Information supports this, analyzing how rotational acceleration magnitude and

Figure 2. Example of Guardian Cap. As seen here, the cap acts as a shell over the helmet but moves independently, allowing it to absorb and redirect impact forces before they reach the hard shell to reducing the overall force transferred to the player's head (18).

duration affect behavioral outcomes, such as neuromotor function, cognitive deficits, and emotional behaviors across different injury groups (28). The effects observed in the *Morris Water Maze* and *Composite Neuroscore* suggest that higher rotational acceleration leads to greater neurological dysfunction (28). As shown by the Table 1 below, *Guardian caps* reduced linear acceleration by 3-8% and rotational acceleration by 5-14% (26).

The *Guardian Cap NXT* emerged as the most effective, reducing concussion risk by up to 34%. Virginia Tech developed the *STAR* (Summation of Tests for the Analysis of Risk) rating system to assess the effectiveness of football helmets in mitigating concussions. When evaluated, the *Guardian Cap NXT* enhanced the *Riddell SpeedFlex helmet's* performance by 72%. Given these results, it is unsurprising that, according to *Guardian's* website, the NFL has mandated *Guardian Caps* in contact practices since the 2022 season, excluding kickers and quarterbacks (24). The technology was also made optionally available to players during regular-season games. During that time period, the NFL documented a 52% reduction in concussions compared to the previous three seasons (24). Although *Guardian Caps* offer significant benefits in concussion prevention, an *ESPN article* reveals mixed feedback from NFL players. Some find the caps uncomfortable, especially in hot weather, as they trap heat and hinder ventilation within the helmet. Others criticize the appearance, with players such as Rashod Bateman and Lloyd Cushenberry expressing concerns over the unattractive natures of the caps (29). Despite their proven effectiveness in reducing concussion risk, some players remain hesitant to wear the caps during games due to discomfort in practice and their lack of visual appeal. This resistance raises concerns over whether teams will fully utilize the technology. While *Guardian Caps* show great potential in addressing the risk of developing CTE, their success depends on balancing safety with player satisfaction to ensure widespread adoption and sustained use.

G8RTECH

Unlike *Guardian Cap* technology which is limited to sports that require helmets, *G8Rtech* technology is cross-functional and can be used in any activity, protecting the neck and head area as a way of mitigating concussion risk by up to 79% (30) (Figure 3). The *G8RSkin,* a protective sheisty made of impact-absorbing polymer, was developed through continuous testing and refinement, incorporating athlete feedback and expert input to improve durable protection and comfort. The *G8RSkin* helps alleviate concussion risk by absorbing and dispersing impact forces. When a player gets hit, the helmet takes the initial force and distributes it across a larger area. Then, the *G8RSkin* absorbs the leftover impact, briefly hardening to further dissipate energy before softening again almost instantly. Its special materials and design helps spread energy more effectively, reducing force on the head, thereby minimizing the risk of concussions and long-term brain injuries such as CTE.

Data collected at an independent laboratory tested the effectiveness of the technology using two main

Figure 3. G8Rtech is a cross-functional technology designed to protect the neck and head area, reducing concussion risk by up to 79% using impact-absorbing polymers (31).

Table 1. Average Percent Reductions with Add-Ons

Add-On	Linear Accel.	Rotatinal Accel.	Concussion Risk
Guardian XT	3%	5%	15%
SAFR	4%	9%	25%
Guardian NXT	8%	14%	34%

Guardian Caps reduce the force incurred by limiting the impacts of both linear and rotational acceleration, ultimately lowering the risk of concussion (26).

methodologies. The Virginia Tech Helmet Lab, as part of their STAR testing system, developed the first method, the Combined Probability of Concussion (CPC), which measures the sustained linear and rotational acceleration a player's head experiences in a hit and calculates the risk of a concussion based on those forces. The second method, HARM (Head Acceleration Response Metric), is used by the NFL and Biocore to analyze head impacts. *HARM* combines two measurements: *HIC* (which looks at linear acceleration forces) and *DAMAGE* (which looks at rotational acceleration forces) (19) (Figure 4). The tests were conducted using a 15.6 kg (roughly the weight of a large bowling ball) ± 3% linear ram that strikes a headform—both with and without *G8Rskin* technology—mounted on a sliding carriage with the ram constrained to translational movement along its axis (32) (Figure 5).

$$HARM = C_1 HIC + C_2 DAMAGE$$

Figure 4. HARM, the Head Acceleration Response Metric, is calculated using a linear combination of HIC and DAMAGE values, where a lower HARM value indicates better helmet performance, with DAMAGE derived from a multibody model using rotational acceleration inputs (32).

The setup allowed a 6-axis load cell, capable of measuring forces in multiple directions, to capture detailed impact data. The headform's positioning was adjusted at specific angles to simulate various impact scenarios (32). The tests found that the *G8RSkin* technology lowered the HARM value by up to 36.5%, significantly mitigating the causative forces that contribute to concussions. Compared to a bare helmet, *G8RSkin* technology showed a relative concussion reduction of 79.68% on the upper side, 56.66% on the facemask side, 37.08% on the offset front, and 31.14% on the rear offset (19).

To interpret the numbers, it is helpful to understand that the impact speeds used in the test are comparable to those in football tackles, which typically range between 3 m/s to 6 m/s. This real-world comparison helps researchers assess the product's effectiveness in reducing injuries within sports contexts. The technology was created by former Johns Hopkins football player Carter Hogg as a way to prevent the dangers of tackling which he has experienced firsthand. Hogg tested the technology on himself and his teammates, with one of them claiming, "*Having taken hits like that before, I've gotten up very slowly. I've taken several seconds to get my bearings. But this time I took the hit — and it wasn't pleasant — but I was able to pop up immediately. I felt completely fine*" (33). Hogg points out that in juxtaposition to the constricting

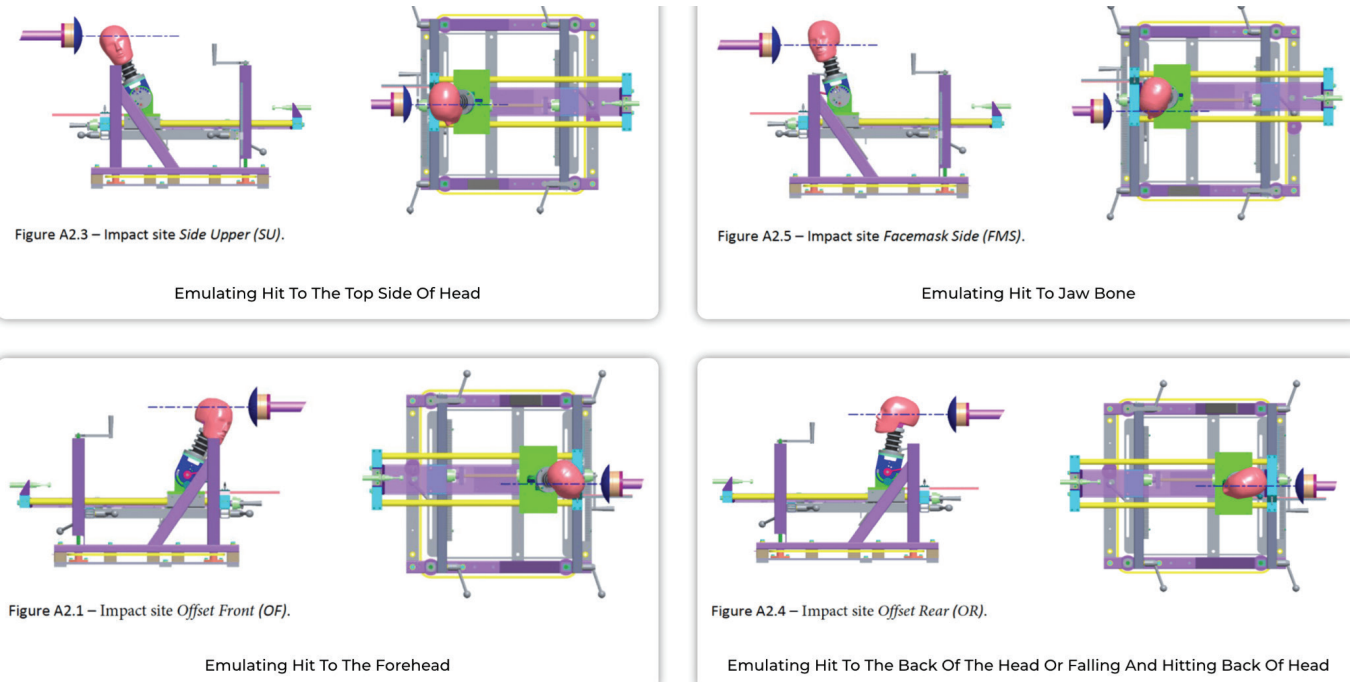

Figure 5. The G8RSkin saw up to an 82.19% reduction in relative concussion risk at different hit locations and speeds, as measured by HARM metrics, indicating it could serve as a valuable concussion mitigation application (19).

nature of *Guardian Cap* technology, "*it's not going to restrict the movement of the player whatsoever during normal play. But when you do take that hit, it actively hardens, and in doing so resists the skull's movement so that the acceleration of the head itself is reduced drastically*" (33). The G8Rskin's innovative design allows for flexibility and comfort during play while actively reducing the forces on the head during collisions. This lightweight, flexible design makes it easier to wear in-game compared to bulkier concussion protection devices, contributing to its growing popularity among athletes. G8RSkin technology provides a highly effective solution for mitigating concussion risk by absorbing and spreading impact energy. Since its launch in May of 2024, it will be interesting to see how data from actual NFL games either reinforce or refute the claims made by the developers of the device. Additionally, studies evaluating players who only wore the G8RSkin would be worth conducting to determine if concussion mitigation technologies are additive in effect or if risk can only be limited to a certain extent no matter the technologies at play.

Q-COLLAR

Unlike other concussion mitigation technologies which aim to reduce the linear and rotational accelerations of forces impacting the brain, Q30 has developed the Q-Collar, an innovative device that applies light pressure to the sides of the neck, increasing blood volume in the brain's venous structures to reduce internal movement of the brain, helping prevent injury (Figure 6). Currently, the Q-Collar is the only FDA-approved concussion mitigation technology, which underscores the product's validity and confirms its efficacy in reducing concussion risk (34). The technology is designed to be worn alongside helmets in order to prevent "brain sloshing" (the internal movement of the brain within the skull during an impact), and protect athletes' brains during head impacts.

The Naval Medical Research Center conducted a rat blast wave model study, to assess whether compressing the internal jugular vein (IJV) could reduce brain damage from blast waves. In the study, venous compression in the neck significantly reduced the extent of axonal injury by around 83% compared to the control group which did not undergo compression. The results indicated that reducing "brain slosh" through IJV compression led to decreased brain trauma, demonstrating that the Q-Collar can help protect the brain from high-pressure blasts (36, 37). A separate study conducted at Cincinnati Children's Hospital examined high school football players over a season using diffusion tensor imaging (DTI) – a brain imaging technique that measures water diffusion in brain tissue to assess white matter structure and connectivity (38). The study found that players who did not wear the Q-Collar exhibited significant brain changes associated with repeated impacts, while those who wore the device experienced much less damage. These findings reinforce that the Q-Collar could prevent long-term brain injuries in contact sports (34, 36). Beyond its effectiveness, the technology seems to be well-received among athletes, with Jesse Bernhardt, professional lacrosse player and coach, claiming, "*The Q-Collar is just another piece of equipment keeping me healthy on the field, taking care of my body with my brain; I want to be successful in my future when Lacrosse is over, whether that's coaching, being a good husband, or being a good father*" (37). As the *Q-Collar* offers a new approach beyond traditional helmets, and as more athletes and studies support its effectiveness, it could soon become a standard in contact sports safety.

DIAGNOSIS PROTOCOLS AND PREVENTION

Overall, technological advancements in concussion mitigation have led to the development of promising new devices aimed at reducing concussion risk. While these innovations reflect a clear and sustained initiative to limit the threat of concussion, further research is needed to better understand how CTE develops and to improve treatment strategies. For instance, Boston University

Figure 6. The Q-Collar works to increase volume in the brain's jugular structures by applying light pressure to the neck which prevents internal movement of the brain within the skull during an impact (35).

published a study suggesting a potential diagnosis method for pre-mortem CTE. By discovering a strong correlation between the buildup of p-tau proteins in the brain—especially in the frontal lobe —and cognitive, functional, and behavioral symptoms, researchers aim to establish diagnostic criteria enabling doctors to identify CTE in living patients (9, 39). Further investment in concussion research could be another method by which athletic institutions can work to limit the negative risks of contact sports and catch the early symptoms of CTE before they worsen.

Preventing concussions is essential to mitigating severe long-term consequences including CTE, memory loss, cognitive decline, and mental health issues. The recent developments in concussion mitigation technology underscore the growing scientific movement toward taking concussion prevention seriously (40).

Although concussion prevention is a critical topic for research, diagnosis and treatment could prove to be just as important. The current standard of concussion diagnosis typically includes a neurological exam assessing vision, hearing, strength, balance, coordination, and reflexes (41). However, concussion assessment in sports is often influenced by athlete bias—particularly the desire to keep playing—especially in professional combat sports, where concussion evaluations may be as minimal as shining a light in the athlete's eyes and asking if they can continue. Unlike many medical conditions with standardized diagnostic protocols, no formal consensus guidelines exist for managing concussions or determining return-to-play protocols in combat sports. As a result, in-game concussion diagnoses are often unreliable and heavily dependent on self-reporting, making them susceptible to false statements from athletes eager to continue competing. Given that head contact is intrinsic to these sports, concussion protocols must be more rigorous than in non-combat disciplines to ensure athlete safety (42).

Protocols are needed to standardize concussion reporting and enforce appropriate time off for recovery to minimize repeated head trauma. The National Library of Medicine surveyed and interviewed 25 athletes across 13 sports to assess their attitudes and behaviors regarding concussion reporting (43). While most athletes disclosed previous concussions, the interviews revealed barriers such as stigma, peer pressure, and lack of team support. The study demonstrates the need for standardized protocols and interventions to promote concussion disclosure and mitigate long-term brain injury risks in athletes.

In addition to promoting concussion disclosure, Hackensack Meridian Health stresses the importance of a carefully monitored recovery period, emphasizing that time off from physical activity is crucial to avoid worsening symptoms and prevent long-term brain damage. Returning to activity too soon—especially in contact sports—can carry major ramifications (44). A notable example is six-time UFC champion Alexander Volkanovski, who accepted a fight against power-puncher Ilia Topuria just four months after suffering a severe knockout loss to Islam Makhachev (45). Once again, Volkanovski was knocked out – this time with more serious ramifications. As demonstrated by a study conducted by the University of Oxford and the University of Exeter—the largest of its kind—repeated head trauma is generally more detrimental to neurological function than a singular head impact (46, 47). Due to the heightened risk of consecutive brain trauma, Volkanovski took a hiatus of over a year to recover. If sports such as MMA, boxing, and the NFL implemented standardized protocols—such as mandatory recovery periods following a knockout in combat sports—these preventable risks could be significantly reduced, ultimately mitigating long-term brain damage in athletes (48).

Brain imaging can often play a more objective role in concussion diagnosis, and may be recommended for individuals with severe or worsening concussion symptoms such as persistent headaches or seizures to check for bleeding or swelling in the skull. A computerized tomography (CT) scan is standard for adults immediately after injury, providing cross-sectional images of the brain using X-rays. In children, CT scans are used only if specific criteria, such as a skull fracture, are met to minimize radiation exposure. Magnetic resonance imaging (MRI) scans—which work using magnets and radio waves—may be used to detect brain changes or complications following a concussion (41). Although useful for diagnosis, CT scans and MRIs are impractical for mid-game use due to their high cost, large size, and long duration. A CT scan costs on average around $1,200 and takes about 10 minutes, while an MRI can cost up to $2,000 and lasts an hour or more, making both options too expensive and time-consuming to be used during live sporting events (49).

TREATMENT

Similar to the challenges arising from the lack of standardized diagnostic procedures, a key issue in concussion treatment is the variation in treatment protocols and beliefs among universities and organizations. The University of Michigan Health published a study

discussing the three phases of concussion recovery (50):

1. The Acute Symptomatic phase lasts from the injury until symptoms peak and begin to improve, usually lasting around three days. During this phase, rest is essential, and activities that worsen symptoms should be avoided.
2. The Recovery Phase is when symptoms gradually lessen and individuals can tolerate more cognitive and physical activities. In this phase, a structured return to normal activities is important.
3. The Recovered Phase is when the patient is symptom-free at rest and during activity, reflecting a full return to pre-injury function.

In combination with concussion prevention technologies and the need for investment in standardizing concussion diagnosis, treatment remains another area requiring improvement, with a key issue being that different institutions may treat concussions differently. For example, despite traditional concussion treatment guidelines emphasizing strict rest, a Michigan Medicine team physician is exploring new research that may suggest alternative recovery approaches (21, 22). The study assessed the effectiveness of supervised exercise in concussion recovery. An analysis of 126 patients found that those who started supervised exercise within 16 days of their concussion returned to sports without serious adverse effects, and at a 2.35 times higher likelihood of a faster recovery. These findings challenge traditional concussion recovery methods and suggest that supervised exercise during the acute symptomatic stage may lead to safer and faster return to activity.

This idea is supported by similar research including a retrospective analysis of 253 cases which found that delaying aerobic exercise negatively impacted concussion recovery time (51). Specifically, it found that those who began exercise within one day recovered significantly faster than those who waited three or more days, suggesting that strict rest may not be the most effective treatment and that early, controlled aerobic activity could improve recovery. It should be noted, however, that because this is a retrospective analysis instead of a randomized controlled trial, the findings may be subject to confounding variables – such as the likelihood that individuals who resumed activity sooner may have sustained less severe concussions. These similar studies support the growing evidence that active rehabilitation strategies are beneficial for concussion treatment, although further research is needed to determine the optimal type, intensity, and timing of exercise.

However, despite multiple findings supporting this claim, these ideas are directly conflicted by similar research at Brain Injury Association of America which claims that after a concussion, there is no circumstance where someone should return to an activity that poses a significant risk of sustaining another concussion. They recommend that while low-risk activities such as walking may be acceptable, higher-risk activities such as playing soccer, riding a bike, or skateboarding should be avoided until symptoms subside. The organization emphasizes that most concussions resolve with cognitive and physical rest alone, and additional treatment should only be considered if symptoms persist or worsen after 2-3 weeks, due to concerns that premature physical activity could lead to further complications such as a second concussion, particularly if symptoms are still present (52).

Establishing a standardized approach to concussion treatment is essential to ensure consistency in care and identify the most effective recovery methods. Consequently, variations in treatment protocols across institutions create disparities in patient outcomes and hinder the ability to determine best practices. A unified system would allow researchers to compare results more accurately and refine treatment strategies based on reliable data. Different organizations following conflicting treatment recommendations ultimately undermines progress in concussion management. Although the science of concussion treatment continues to evolve, adopting a standardized framework will ensure that all patients receive the highest quality care.

CONCLUSION

While technologies like Guardian Caps, G8RSkin, and the Q-Collar represent crucial steps in reducing concussion risk, true progress depends on more than just equipment. The lack of consensus on diagnosis methods, treatment approaches, and return-to-play guidelines undermines holistic athlete protection. To truly safeguard players, athletic institutions must prioritize the development of unified concussion protocols, including concussion mitigation strategies, standardized diagnostic criteria for early CTE detection, and consistent treatment standards. Moving forward, equal emphasis must be placed on both improving protective equipment and strengthening the medical frameworks that support athlete safety.

REFERENCES

1. Waltzman D, Womack LS, Thomas KE, Sarmiento K. Trends in Emergency Department Visits for Contact

Sports–Related Traumatic Brain Injuries Among Children — United States, 2001–2018. MMWR Morb Mortal Wkly Rep. 2020; 69: 870–874. DOI: http://dx.doi.org/10.15585/mmwr.mm6927a4

2. Mayo Clinic. Concussion. Available from: https://www.mayoclinic.org/diseases-conditions/concussion/symptoms-causes/syc-20355594 (accessed on 2025-02-17)
3. Blackford Meghan. Boxer Micky Ward Talks CTE and the Mental Health Effects. Available from: https://fherehab.com/learning/micky-ward-mental-health (accessed on 2025-03-10)
4. McRae Donald. 'Boxing is a mess': the darkness and damage of brain trauma in the ring. Available from: https://www.theguardian.com/sport/2021/may/27/time-to-find-out-who-cares-boxing-brain-damage-tris-dixon (accessed on 2025-01-30)
5. Boston University Chobanian & Avedisian School of Medicine. Researchers Find CTE in 345 of 376 Former NFL Players Studied. Available from: https://www.bumc.bu.edu/camed/2023/02/06/researchers-find-cte-in-345-of-376-former-nfl-players-studied/ (accessed on 2025-02-13)
6. U.S. Department of Health & Human Services. Chronic traumatic encephalopathy in young athletes. National Institutes of Health, 12 September 2023. Available from: https://www.nih.gov/news-events/nih-research-matters/chronic-traumatic-encephalopathy-young-athletes (accessed on 2025-03-05)
7. Mayo Clinic. Chronic traumatic encephalopathy. Available from: https://www.mayoclinic.org/diseases-conditions/chronic-traumatic-encephalopathy/symptoms-causes/syc-20370921 (accessed on 2025-01-28)
8. Mandelkow EM, Mandelkow E. Biochemistry and cell biology of tau protein in neurofibrillary degeneration. *Cold Spring Harb Perspect Med*. 2012 Jul; 2 (7): a006247. doi: 10.1101/cshperspect.a006247. PMID: 22762014; PMCID: PMC3385935.
9. Alosco ML, White M, Bell C, *et al*. Cognitive, functional, and neuropsychiatric correlates of regional tau pathology in autopsy-confirmed chronic traumatic encephalopathy. *Mol Neurodegeneration*. 2024; 19 (1): 10. https://doi.org/10.1186/s13024-023-00697-2
10. Mayo Clinic. Alzheimer's disease. Available from: https://www.mayoclinic.org/diseases-conditions/alzheimers-disease/symptoms-causes/syc-20350447 (accessed on 2025-02-21)
11. Katsumoto A, Takeuchi H, Tanaka F. Tau Pathology in Chronic Traumatic Encephalopathy and Alzheimer's Disease: Similarities and Differences. *Front Neurol*. 2019 Sep 10; 10: 980. doi: 10.3389/fneur.2019.00980. PMID: 31551922; PMCID: PMC6748163.
12. Boston University Chobanian & Avedisian School of Medicine. Researchers Identify Potential New Subtype of Chronic Traumatic Encephalopathy. Available from: https://www.bumc.bu.edu/camed/2024/02/26/researchers-identify-potential-new-subtype-of-chronic-traumatic-encephalopathy/ (accessed on 2025-03-14)
13. PubMed Central. Figure 1. National Library of Medicine, 10 September 2019. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC6748163/figure/F1/ (accessed on 2025-01-31)
14. Nicks R, Clement NF, Alvarez VE, Tripodis Y, *et al*. Repetitive head impacts and chronic traumatic encephalopathy are associated with TDP-43 inclusions and hippocampal sclerosis. *Acta Neuropathol*. 2023 Apr; 145 (4): 395-408. doi: 10.1007/s00401-023-02539-3. Epub 2023 Jan 21. PMID: 36681782; PMCID: PMC11360224.
15. McKee AC, Alosco ML, Huber BR. Repetitive Head Impacts and Chronic Traumatic Encephalopathy. *Neurosurg Clin N Am*. 2016 Oct; 27 (4): 529-35. doi: 10.1016/j.nec.2016.05.009. PMID: 27637402; PMCID: PMC5028120.
16. Meehan W 3rd, Mannix R, Zafonte R, Pascual-Leone A. Chronic traumatic encephalopathy and athletes. *Neurology*. 2015 Oct 27; 85 (17): 1504-11. doi: 10.1212/WNL.0000000000001893. Epub 2015 Aug 7. PMID: 26253448; PMCID: PMC4631072.
17. Cole-French William. DIAGNOSE CTE Research Project-II. BU Research CTE Center, Boston University. Available from: https://www.bu.edu/cte/our-research/clinical-studies/ (accessed on 2025-02-25)
18. Guardian Sports. Guardian Caps — Reducing Impact, One Hit at a Time. Available from: https://guardiansports.com/ (accessed on 2025-03-11)
19. G8rtech. Science and Testing. Available from: https://g8rtech.com/science-testing/ (accessed on 2025-02-07)
20. Q30 Innovations. Q-Collar. Available from: https://q30.com/products/q-collar?variant=46185202024690&tw_source=google&tw_adid=&tw_campaign=21379725508&gad_source=1&gclid=CjwKCAiA2cu9BhBhEiwAft6IxL9GC6NUtc9bY7E35TK-pW7HttSZGh021w1rdxXTdWN_thQxeNVgvhoCmvwQAvD_BwE (accessed on 2025-02-19)
21. Popovich M, Almeida A, Freeman J, Eckner JT, Alsalaheen B, Lorincz M, Sas A. Use of Supervised Exercise During Recovery Following Sports-Related Concussion. *Clin J Sport Med*. 2021 Mar 1; 31 (2): 127-132. doi: 10.1097/JSM.0000000000000721. PMID: 30768444.
22. Imhoff Jordyn. Study Suggests Exercise After Concussion Improves Recovery. Michigan Medicine, University of Michigan, 27 August 2019. Available from: https://www.michiganmedicine.org/health-lab/study-suggests-exercise-after-concussion-improves-recovery (accessed on 2025-03-01)
23. Heary Robert F, et al. Is Youth Football Safe? An Analysis of Youth Football Head Impact Data. Neuroscience, Rutgers New Jersey Medical School, Newark, New Jersey,

6 January 2020. Available from: https://www.newswise.com/pdf_docs/158318026172666_Football%20paper.pdf?mc_cid=cae0a6767a&mc_eid=d44b51c69d (accessed on 2025-01-29)
24. Guardian Sports. Do Guardian Caps Reduce Concussions? 16 August 2022. Available from: https://guardiansports.com/faq-items/do-guardian-caps-reduce-concussions/ (accessed on 2025-02-03)
25. Sarmiento K, Miller GF, Jones SE. Sports-Related Concussions and Adverse Health Behaviors Among Middle and High School Students. *Am J Sports Med*. 2023 Feb; 51 (2): 503-510. doi: 10.1177/03635465221141440. Epub 2023 Jan 13. PMID: 36637145; PMCID: PMC9932634.
26. Virginia Tech Helmet Lab. FOOTBALL HELMET SHELL ADD-ON TESTING. Available from: https://www.helmet.beam.vt.edu/football-helmet-add-ons.html (accessed on 2025-03-15)
27. Stark N.E-P, Begonia MT, Jung C. *et al*. How Shell Add-On Products Influence Varsity Football Helmet Performance?. *Ann Biomed Eng*. 2024; 52: 2923–2931. https://doi.org/10.1007/s10439-024-03627-5
28. Stemper BD, Shah AS, Pintar FA, McCrea M, *et al*. Head rotational acceleration characteristics influence behavioral and diffusion tensor imaging outcomes following concussion. Ann Biomed Eng. 2015 May; 43 (5): 1071-88. doi: 10.1007/s10439-014-1171-9. Epub 2014 Oct 25. PMID: 25344352; PMCID: PMC4654450.
29. Barshop Sarah, *et al*. Guardian Caps on helmets? Why NFL players have mixed feelings. ESPN, 8 September 2024. Available from: https://www.espn.com/nfl/story/_/id/40964843/swag-safety-nfl-players-guardian-caps (accessed on 2025-03-18)
30. G8RTECH. Impact-Absorbing Polymer: Your New Safety Layer. Available from: https://g8rtech.com/about/ (accessed on 2025-01-26)
31. Businesswire. G8RTech Announces the Launch of G8RSkinIce™, A First-of-its-Kind Hockey PPE. 28 November 2023. Available from: https://www.businesswire.com/news/home/20231128494213/en/G8RTech-Announces-the-Launch-of-G8RSkin-Ice-A-First-of-its-Kind-Hockey-PPE (accessed on 2025-02-28)
32. NFL. Helmet Test Protocol. Biomechanics Consulting & Research, LLC (Biocore), 11 September 2019. Available from: https://static.www.nfl.com/image/upload/v1597314821/league/x1555pmeldebfym2qwky.pdf (accessed on 2025-03-06)
33. Rodenburg Malissa. Johns Hopkins football player Carter Hogg creates device to reduce risk of concussion. Johns Hopkins Magazine, Johns Hopkins University, 2023. Available from: https://hub.jhu.edu/magazine/2023/winter/carter-hogg-g8rskin-football/ (accessed on 2025-03-12)
34. QCOLLAR. Science and Research Briefing. Available from: https://cdn.shopify.com/s/files/1/0567/8445/3783/files/ResearchBrief_4-25-23.pdf?v=1682446232 (accessed on 2025-02-11)
35. Q30 Innovations. Q-Collar. Available from: https://q30.com/products/q-collar?variant=46185202024690&tw_source=google&tw_adid=&tw_campaign=21379725508&gad_source=1&gclid=CjwKCAiA2cu9BhBhEiwAft6IxL9GC6NUtc9bY7E35TK-pW7HttSZGh021w1rdxXTdWN_thQxeNVgvhoCmvwQAvD_BwE (accessed on 2025-02-19)
36. Q30 Innovations. selected published studies (RHI/TBI). Available from: https://cdn.shopify.com/s/files/1/0567/8445/3783/files/Q_Collar_Published_Studies_E_Book_1.10.23_Full_Booklet.pdf?v=1716487419 (accessed on 2025-03-02)
37. Q30 Innovations. Research Briefing. Available from: https://q30.com/pages/fda-reviewed?srsltid=AfmBOopXYEbp3MYstcjDbONK2VG9ZjtHOHoNYK13gu2AIA9o8-A8tHZ0 (accessed on 2025-02-16)
38. O'Donnell LJ, Westin CF. An introduction to diffusion tensor image analysis. *Neurosurg Clin N Am*. 2011 Apr; 22 (2): 185-96, viii. doi: 10.1016/j.nec.2010.12.004. PMID: 21435570; PMCID: PMC3163395.
39. Mandelkow EM, Mandelkow E. Biochemistry and cell biology of tau protein in neurofibrillary degeneration. *Cold Spring Harb Perspect Med*. 2012 Jul; 2 (7): a006247. doi: 10.1101/cshperspect.a006247. PMID: 22762014; PMCID: PMC3385935.
40. Centers for Disease Control. Preventing Concussion. 23 August 2024. Available from: https://www.cdc.gov/heads-up/prevention/index.html (accessed on 2025-03-25)
41. Mayo Clinic. Concussion — Diagnosis and Treatment. 12 January 2024. Available from: https://www.mayoclinic.org/diseases-conditions/concussion/diagnosis-treatment/drc-20355600 (accessed on 2025-02-10)
42. Neidecker J, Sethi NK, Taylor R, *et al*. Concussion management in combat sports: consensus statement from the Association of Ringside Physicians. *British Journal of Sports Medicine*. 2019; 53: 328-333. https://doi.org/10.1136/bjsports-2017-098799.
43. Kay MC, Hennink-Kaminski H, Kerr ZY, Gildner P, *et al*. Factors and expectations influencing concussion disclosure within NCAA Division I athletes: A mixed methodological approach. *J Sport Health Sci*. 2023 May; 12 (3): 388-397. doi: 10.1016/j.jshs.2021.09.006. Epub 2021 Sep 20. PMID: 34547482; PMCID: PMC10199141.
44. ChatGPT said: Greiss, Christine. When Is It Safe to Return to Sports After a Concussion? Hackensack Meridian Health, 18 October 2021. Available from: https://www.hackensackmeridianhealth.org/en/healthu/2021/10/18/when-is-it-safe-to-return-to-sports-after-a-concussion (accessed on 2025-01-27)
45. Raimondi Marc. Ilia Topuria knocks out Alexander Volkanovski at UFC 298. ESPN, 18 February 2024. Available from: https://www.espn.com/mma/story/_/id/39550497/ilia-

topuria-knocks-alexander-volkanovski-ufc-298 (accessed on 2025-03-20)
46. Matthew J. Lennon, Helen Brooker, Byron Creese, Tony Thayanandan, *et al*. Lifetime Traumatic Brain Injury and Cognitive Domain Deficits in Late Life: The PROTECT-TBI Cohort Study. *Journal of Neurotrauma*. 2023; 40 (13-14): 1423-1435. doi: 10.1089/neu.2022.0360.
47. University of Oxford. Three or more concussions linked with worse brain function in later life. 31 January 2023. Available from: https://www.ox.ac.uk/news/2023-01-31-three-or-more-concussions-linked-worse-brain-function-later-life (accessed on 2025-02-08)
48. Children's Hospital Colorado. Return to Play After a Concussion. Available from: https://www.childrenscolorado.org/conditions-and-advice/sports-articles/sports-injuries/concussion/play-after-concussion/ (accessed on 2025-03-09)
49. HealthImages. MRI vs. CT Scan. Available from: https://www.healthimages.com/mri-vs-ct-scan/# (accessed on 2025-02-20)
50. University of Michigan Health. Concussion Treatment and Recovery. Michigan Medicine. Available from: https://www.uofmhealth.org/conditions-treatments/brain-neurological-conditions/concussion-treatment-and-recovery#screen%20time (accessed on 2025-02-05)
51. Lawrence DW, Richards D, Comper P, Hutchison MG. Earlier time to aerobic exercise is associated with faster recovery following acute sport concussion. *PLoS ONE*. 2018; 13 (4): e0196062. https://doi.org/10.1371/journal.pone.0196062
52. Brain Injury Association of America. Follow-Up Care for Concussion. Available from: https://biausa.org/brain-injury/about-brain-injury/what-is-a-brain-injury/concussion-mtbi/follow-up-care (accessed on 2025-03-07)