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Case Series

Microhemorrhages in Professional Motocross Athletes: A Case Series

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Abstract

Introduction
Motocross is a sport in which riders race 250–450 cc four-stroke dirt bikes and are potentially subjected to a high frequency of head injuries starting at a very young age. The objective of this case series is to present the findings following gradient echo T2-weighted MRI (SWI) upon clinical evaluation after a concussion in 4 young professional motocross racers.

Clinical Findings
Microhemorrhages were found in 2 of 4 riders. Areas of microhemorrhages were not aligned with a previously positive CT finding from a prior concussion in 1 rider.

Conclusions
Microhemorrhages were found in 2 young motocross riders following a gradient echo T2-weighted MRI upon a clinical evaluation after a concussion. Long-term consequences of these findings are not yet known, and longitudinal studies are needed to provide further understanding to improve concussion management in motocross athletes.

Keywords
brain concussion; microhemorrhages; ImPACT; motocross; off-road motor vehicles; craniocerebral trauma; brain injuries, complications; athletic injuries, complications; intracranial hemorrhages, diagnosis; magnetic resonance imaging

Introduction

Motocross is a high-speed sport where 20–40 riders at a time race 250–450 cc four- stroke dirt bikes, which can exceed 60 miles per hour on a track with multiple large jumps. The jumps are typically between 20–100 feet apart and launch the rider, on average, 30 feet into the air. The number of participants in the sport of motocross is drastically rising in all age groups but more significantly in the 4–30 age group. The 30+ age group has increased due to the number of young racers who continue riding into their adulthood, not due to older ones who are new to the sport. This information comes from participant entries from the largest national amateur race (W. Kern, national race track owner, personal communication, December 10, 2019) Races are now broadcasted live on national television, which has increased the interest young children have in the sport. Competing at high speeds within a large group in a precarious environment may increase the rider's risk of injury. Overall, emergency room visits from injuries sustained by pediatric motocross riders at one tertiary care center servicing seven local motocross tracks were estimated to cost around $4.5 million per year.[1] The cost per injury ranged from $105 to $217,780,[1] which is substantially higher than traditional team sports. Traditional team sports cost per injury ranges from $900 to $1,800.[2]

Similar to traditional team sports, young riders practice throughout the week in preparation for weekend races with the hope of becoming a professional. Motocross, however, has both professional and amateur races consistently throughout the year, leaving little to no off season in comparison to traditional team sports. This type of commitment can be quite taxing on the athletes and imposes a significant financial burden on the parents as stock bikes cost up to $9,000, clothing and gear around $1,000 and entry fees up to $500 per class. There are also additional costs for travel and lodging.

Unlike other sports such as baseball or basketball the age to become a professional rider is 16. Therefore, the age at which a motocross rider must begin training to reach the professional level may be much younger than other sports. Many professional motocross athletes begin riding competitively around 3–4 years old. Today's top amateur riders are receiving significant monetary compensation starting around the age of 9. The aspiration for success, and over-encouragement of their parents out of monetary necessity, may drive young athletes into rigorous training schedules and could subject them to a high frequency of injuries, including head injuries, starting a very young age.[1,3-5]

In 2012, the American Motorcyclist Association (AMA) responded to increased concussion awareness by implementing a strict return-to-riding protocol at the professional level governed by a designated medical team and the AMA. To acquire a professional license, the rider must complete a baseline immediate post-concussion assessment and cognitive test (ImPACT.)[6] Following a significant crash, the rider is evaluated by the medical team. If there is a loss of consciousness or a high degree of suspicion of concussion, with a lower threshold for the younger riders under 21, the rider is put through the return-to-ride protocol once medically stable. Coaches and parents may also report behavioral changes that can warrant evaluation, but they are not always present, nor are they always the first on the scene. The protocol lasts a minimum of 8 days and consists of a thorough evaluation by an approved physician, a post-injury ImPACT testing and observation for normalization of scores and supervised progression through the protocol by the gym trainer or riding coach. Upon completion of the protocol, the rider must be evaluated by the physician at the race venue and is allowed to race the event if they receive full medical clearance. There is currently no set protocol for evaluation or return to play for amateur racers. A 2015 study reported that 48% of questioned youth riders admitted to having concussion symptoms that season and 61% of them continued racing even after experiencing a concussion symptom from a crash earlier in the day.[7]

The epidemiology of concussions in this sport is still lacking. Increasing medical staff at training facilities and race venues along with enhancing rider and parent education may reduce the number of premature returns to racing following a suspected concussion. The majority of the prominent amateur races are a week long, with riders racing most days. Therefore, according to Luo et al.,[7] there is a probability of a high incidence of riders who hit their heads on day one, and without a bodily injury that warrants an obvious ER visit, are not going to be evaluated and will continue to ride the next day. Providing a medical team at these races, like at the professional races, would likely mitigate the number of riders racing with concussion symptoms who are at a high risk for second impact syndrome. However, providing this type of medical team is expensive and would depend on qualified physician volunteers. The amateur race owners are only affiliated with AMA, and likely lack sufficient funding to hire such qualified physicians or enforce a protocol if one were implemented.

There is currently no consensus on concussion return-to-play protocols in pediatric or adolescent patients with or without positive imaging, and any recommendations are based solely on expert experience and opinion. Children and adolescents have a tendency to be more vulnerable to head injuries during sporting events, which predisposes them to an extended duration of symptoms and prolonged recovery from concussion. Therefore, they must be managed differently.[8]

The current neuroimaging recommendation is that CT or MRI can be used for suspicion of a traumatic brain injury (TBI) or in patients with prolonged alteration in consciousness, focal deficits or persistent or worsening symptoms.[9] A newer type of imaging, gradient echo T2-weighted MRI (susceptibility weighted imaging; SWI), has been used on young adult athletes with unrelenting symptoms following a concussion.[10-15] Cerebral microhemorrhages were documented at the gray-white matter junction even with a negative CT. Neither the

Table 1. ImPACT results showing baseline scores and scores following a concussion. Raw Scores (Percentiles); CEI (Cognitive efficiency index) which measures the interaction between percent correct and reaction time; PI (Post-injury).

	Test type	Verbal memory	Visual memory	Visual motor speed	Reaction time	Impulse control	CEI
Case 1	Baseline	96 (88)	96 (97)	37.75 (35)	0.55 (55)	2	0.37
	3 weeks PI	98 (94)	85 (82)	34.35 (20)	0.66 (13)	1	0.21
Case 2	Baseline	93 (79)	92 (91)	93 (50.6)	0.60 (54)	7	0.52
	1 week PI	97 (92)	79 (64)	42 (57)	0.63 (19)	10	0.34
	2 weeks PI	95 (84)	96 (97)	50 (90)	0.56 (49)	6	0.52
Case 3	Baseline	75 (24)	85 (81)	20.45 (1)	0.91 (1)	18	0.06
	1 day PI	57 (1)	65 (23)	24.1 (1)	1.13 (1)	7	-0.13
	1 week PI	97 (97)	80 (67)	29.53 (15)	0.85 (1)	2	0.28
	2 weeks PI	98 (98)	76 (54)	29.53 (15)	1.04 (1)	2	0.15
Case 4	Baseline	91 (73)	80 (64)	28.92 (6)	0.61 (35)	9	0.38
	2 days PI	93 (79)	78 (59)	27.98 (2)	0.62 (22)	7	0.39
	1 week PI	77 (25)	64 (20)	32.05 (10)	0.58 (37)	11	0.29
	3 weeks PI	89 (67)	84 (70)	28.92 (80)	0.58 (37)	15	0.43
	3 weeks PI	89 (67)	84 (70)	28.92 (80)	0.58 (37)	15	0.43

clinical significance nor the long-term risks of cerebral microhemorrhages are well understood in young athletes, as the majority of research has focused on routine findings in the elderly, which correlates with chronic small vessel disease-related hypertension, diabetes mellitus and Alzheimer's disease.[10,15,16]

Methods

Cases were chosen based on availability from the Tallahassee Orthopedic Center Concussion Center. Written consent for record acquisition was obtained from all participants.

Four competitive motocross riders who suffered multiple head injuries throughout their careers. All began riding motorcycles between 4–13 years old. All 4 riders trained at a motocross facility full-time and completed baseline computerized neurocognitive testing (ImPACT; See **Table 1**) before the start of the season in which their discussed concussion occurred.

Each rider sustained a concussion during the season and underwent clinical evaluation, ImPACT testing, a vestibular evaluation and susceptibility weighted imaging (SWI). The vestibular evaluation included the Dizziness Handicap Inventory (DHI), Vestibular Ocular Motor Screening (VOMS) and Post-Concussion Symptoms Scale (PCSS). The DHI is a 25-item self-assessment that evaluates the self-perceived effects of dizziness, with scoring up to 100 points, where 16–34 is mild, 36–52 is moderate and over 54 is severe. The VOMS assessment includes an evaluation of five domains: smooth pursuit, horizontal and vertical saccades, near point of convergence distance, horizontal vestibular ocular reflex and visual motion sensitivity. The PCSS is a 22-item self-report that has measures rated from 0–6, with 40 being considered high with a poor prognosis for normal recovery time. An office-based neuropsychologist was involved in the treatment of these riders and administered most of the follow-up post-injury (PI) ImPACT testing, though some ImPACT testing was administered at the experienced motocross facility.

Results

Case 1

Case 1 was a 23-year-old male professional motocross rider who presented for evaluation 11 days after crashing his motorcycle during a race and hitting the temporal and posterior regions of his head. His medical history was significant for 1 prior diagnosed concussion 4 years earlier, though he reported multiple preceding suspected concussions prior to the current year. He reported most recently hitting his head in a crash 3 weeks before the latest injury, but he denied any residual symptoms or similarities to his previous concussions. In the discussed crash, he reported a loss of consciousness (LOC) of 2–3 minutes and a headache that began immediately, though the exact LOC time is not verifiable. He was transported to a local emergency department where a CT scan was performed and showed a frontal subdural hematoma (image not available). He was also treated for a fractured collarbone. At the time of in-office evaluation (11 days PI), he reported a mild lingering headache, dizziness, fatigue and some mild cognitive slowing. The DHI score was 0. He could not complete the ImPACT testing at that visit since his dominant arm was immobilized. Results from the vestibular ocular motor screening (VOMS) showed mild provocation of dizziness during the vestibular-ocular reflex (VOR), visual motion sensitivity (VMS), and horizontal saccades tests. He was referred for vestibular therapy, started a prescribed regimen of amantadine and began light exercise. He also underwent SWI imaging to assess for possible microhemorrhaging or diffuse axonal injury due to his previously positive CT.

SWI results showed multiple areas of bicerebral microhemorrhage located in the left parieto-occipital lobe and inferior frontal lobes. He also had superior microhemorrhages that were bilaterally located within the centrum semiovale (**Figure 1: A-C**). Four weeks after the initial clinical evaluation, he reported that his headache, dizziness and cognitive slowing as well as other symptoms had resolved with the completion of vestibular therapy and the

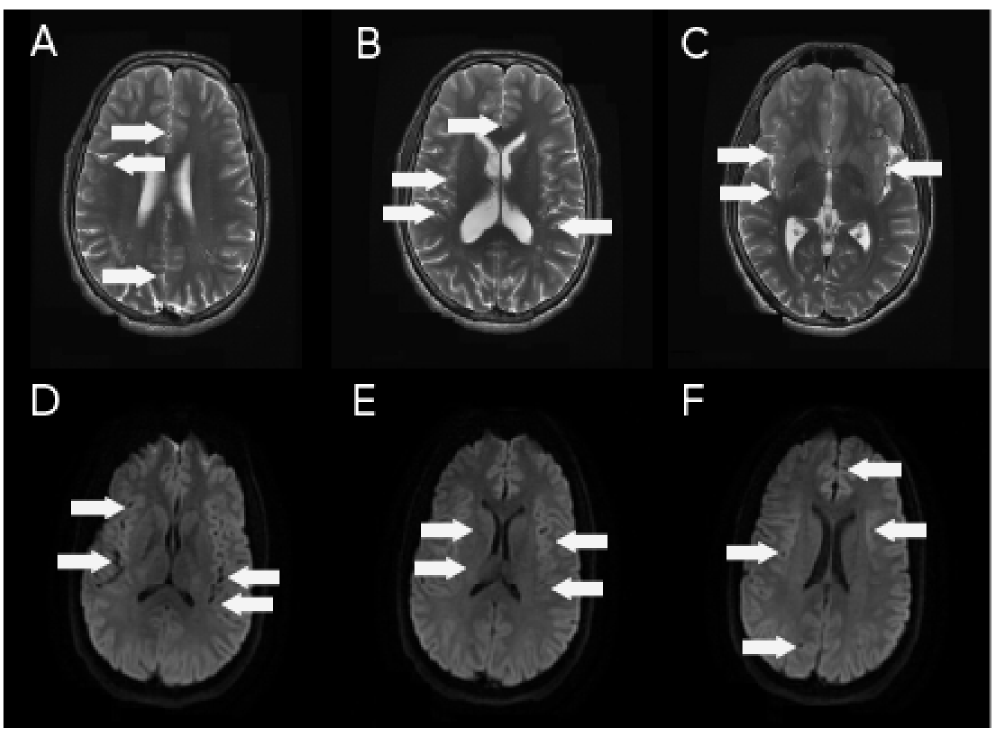

Figure 1. SWI Images. SWI results showing areas microhemorrhages in Case 1 (A-C) and Case 2 (D-F). Case 1 showed multiple areas of bicerebral microhemorrhage located in the left parieto-occipital lobe, inferior frontal lobes, and superiorly within the centrum semiovale bilaterally. Case 2 revealed areas of microhemorrhages and the right frontal lobe as well as in the subcortical regions of the left and right parietal cortex.

amantadine regimen. His DHI score remained 0. He reported no negative effects from the amantadine. Light physical activity was initiated after his initial visit and he reported no symptom provocation. The VOMS test also no longer caused dizziness. ImPACT testing performed at this visit showed an impaired reaction time percentile (76% change), but verbal memory (7% change), visual memory (15% change) and visual motor speed (43% change) percentiles were within reliable change limits of the rider's baseline performance. The post-concussion symptom scale (PCSS) total was 0. He was discharged from vestibular therapy after completion of the rehabilitation program and reported no residual symptoms. He did, however, continue to display mildly impaired neurocognitive testing. Based on the imaging results, the recommendation to cease participation in motocross was given by the treating clinician. He chose to continue and retired 3 years later.

Case 2

Case 2 involved a 20-year-old professional motocross rider with attention deficit hyperactivity disorder (ADHD), who was prescribed mixed amphetamine salts (Adderall). He presented for evaluation 1 week after he crashed his motorcycle. His medical history is significant for multiple, undocumented suspected concussions, as well as several documented ones. 11 years prior, he suffered a major head injury when he fell off a bicycle without a helmet, resulting in positive head CT findings (CT unavailable) and an extended hospital stay. He also had a documented concussion 3 years prior and 2 more in the year before the discussed concussion. In the past year since his last concussion, he started on Adderall. Following his latest concussion, he reported a LOC of about 10 seconds (witnessed) associated with significant problems with memory, disorientation and the onset of a headache. He reported initial heightened levels of emotionality and mood changes, which subsided before clinical evaluation. His DHI was 0. ImPACT testing 1 week PI showed deficits in reaction time (65% change) and impulse control (43%). He was, however, unremarkable for deficits in verbal memory (14% change), visual memory (30% change) and visual motor speed (10% change), with a PCSS total score of 0. The VOMS test provoked dizziness, fogginess and headache during VOR and VMS testing. Observable slowness during saccadic eye movements was documented. During the evaluation, it was noted that his presentation had varied from his previous evaluations. He was seen to have a lack of insight regarding his injury as well as a decreased ability to recall symptoms, which was not his normal state after previous head injuries treated by the same clinician. Following this evaluation, the clinician recommended he undergo vestibular therapy and participate in light gym activity. At this time, he also had a brain MRI, per the recommendation of his medical doctor, which was negative.

At his follow-up visit 1 week later, he reported initiating regular physical activity but refrained from riding. He also reported that vestibular therapy significantly improved his symptoms. All ImPACT percentiles returned to baseline (10% change in reaction time; 14% change in impulse control), and the VOMS was no longer provocative. His PCSS and DHI scores were 0. His personality and demeanor seemed to have returned closer to his norm. The neuropsychologist recommended that he increase his physical activity. After 2 weeks PI, he was released from vestibular therapy and was able to complete heavy workouts without symptoms, but he was not allowed to ride. It was also recommended he undergo SWI by clinical opinion due to his history of documented and undocumented concussions. SWI results revealed bilateral areas of microhemorrhages in the inferior frontal lobes, the right frontal lobe and in the subcortical regions of the left and right parietal cortex (**Figure 1: D-F**). In lieu of these results, it was recommended that he discontinue any motocross riding and obtain an extensive neuropsychological evaluation, though he had no residual symptoms. At the time of writing (5 years PI), he was still riding and did not undergo the recommended evaluation.

Case 3

Case 3 was a 15-year-old competitive amateur motocross rider who presented for his initial evaluation 1 day after he crashed his motorcycle. He reported 3 previous concussions, with the most recent occurring 1 year prior, from which he subjectively recovered in 3 days. However, following the crash, he experienced 4 episodes of total body right-sided numbness accompanied by blurry vision and vomiting prior to recovery, which he said resolved upon falling asleep. Following his latest concussion, he reported no LOC or amnesia, but he did experience immediate and persistent blurry vision, dizziness and headache through the time of initial evaluation. His DHI score was 1.

ImPACT testing was performed the same day of the crash and showed significantly impaired verbal memory (95% change), visual memory (72% change) and impulse control (61% change), but those results were likely due to poor testing effort shown by the very low cognitive efficiency index (CEI; - 0.13). Visual motor speed and reaction time, however, were unchanged from the baseline study completed 1 month prior. It should be noted that same day testing is not advised, and it was only done due to his low DHI score. His PCSS was 36. The VOMS was unprovocative, but blurry vision was reported. During testing, he displayed abnormal and slowed smooth pursuit and saccades and abnormal VOR. He was referred to vestibular therapy.

One week later, after resuming light physical activity with mild symptoms and undergoing vestibular therapy, his PCSS was 0, but VOMS showed mild provocation of symptoms with heavy levels of VOR and VMS involvement. ImPACT testing at that time showed improved scores above baseline in all but visual memory (17% change—improved from 72% change). Due to his persistent post-concussion symptoms, he underwent SWI. While awaiting results, he resumed high-level riding activity without symptoms and vestibular therapy. Two weeks PI, he had a PCSS of 1 and completely normal VOMS. SWI results were completely benign and free of any microhemorrhages. Due to a normal SWI and normal VOMS, the neuropsychologist recommended that he continue full riding activities, but he was referred to neurology for evaluation of possible migraines as the cause of intermittent numbness, blurry vision and vomiting episodes.

Case 4

Case 4 was a 19-year-old professional motocross rider with no medical conditions and no history of concussions who presented 2 days after he crashed his motorcycle. He denied any LOC or posttraumatic amnesia, but he did report less than a minute of retrograde amnesia. He reported immediate symptoms of headache, photosensitivity, balance dysfunction, dizziness and disorientation. He also reported difficulty with focus and attention. His DHI score was 2. ImPACT testing was performed and showed no marked change in any percentile scores from baseline. He had a PCSS total score of 6. The VOMS was provocative for dizziness, abnormal convergence and slowed saccadic eye movements. He was referred for vision therapy as well as an SWI due to his remarkable visual deficit upon evaluation. One week later, he was feeling improved, but the neuropsychologist recommended he continue with vision therapy to address his persistent abnormal convergence dysfunction on the vertical plane and provoked blurry vision. The PCSS was 2 and routine repeat ImPACT testing showed an impairment in visual memory (69% change) and verbal memory (66% change) percentile scores. Results of the SWI were negative and showed no evidence of microhemorrhaging. Three weeks PI, he had been participating in light activity for 1 week, and his concussion symptoms had almost completely resolved. The PCSS was 1. The VOMS was still significant for abnormal saccades and convergence. ImPACT testing at this time showed a return to baseline in visual and verbal memory percentile scores, but his impulse control had worsened (40% change). The neuropsychologist recommended he continue visual therapy and refrain from activities with the potential for head injury until he was cleared by visual therapy. He was cleared after a total of 3 months from visual therapy (no post-therapy ImPACT available).

Discussion

This case series presents the detection of microhemorrhages using SWI imaging in 2 of 4 young motocross riders, 3 with histories of multiple concussions and all with persistent concussion symptoms and abnormal neurologic exams. (**Table 2**)

Microhemorrhages have been found in athletes as young as 15 years old, but have not been extensively studied in the pediatric and young adult populations.[12,13] Routine CT scans do not show microhemorrhages because only SWI imaging allows for detection of hemosiderin in macrophages, even years after a hemorrhage. Therefore, it is difficult to ascertain when the hemorrhage occurred.[17]

Table 1. ImPACT results showing baseline scores and scores following a concussion. Raw Scores (Percentiles); CEI (Cognitive efficiency index) which measures the interaction between percent correct and reaction time; PI (Post-injury).

Case 1	Case 2	Case 3	Case 4
• Left parietal-occipital • Inferior frontal lobes • Superior contrum semiovale bilaterally	• Right frontal • Inferior frontal lobes • Subcortical R & L parietal cortex	• Negative	• Negative

A study examining SWI findings of subjects ages 14–81 years old, with a history of varying degrees of TBI, compared non-TBI controls and reported that only 3% of control subjects had microhemorrhages versus 17% of the TBI subjects.[18] All 3 subjects that presented with microhemorrhages were over the age of 45 years old.[18] This information suggests microhemorrhages are likely a result of TBI in younger people versus a more endogenous cause, such as hypertension in older people, without a history of TBI. SWIs are not routinely attained and usually ordered only when there is a high index of suspicion for underlying pathology.[9]

The consequences of microhemorrhages are unknown, and the impact later in life, if acquired at a young age, has not yet been elucidated. The 2 cases presented with positive microhemorrhages also reported a previous history of concussions with positive CT scans. These previous injuries could be the source for the positive SWI imaging in these riders, though it is impossible to know for certain due to the undocumented concussions with obvious lack of imaging. Interestingly, case 1's positive CT findings for a frontal hematoma do not completely match the locations of the microhemorrhages found in the left parieto-occipital, inferior frontal lobes. The findings also do not match the bilateral microhemorrhages found superiorly within the centrum semiovale. Therefore, we cannot determine if all the microhemorrhages were the result of the head injury associated with a subdural hematoma or a separate injury. Unfortunately, the previous positive CT report in case 2 was not attainable to make a comparison. Another interesting finding was that case 3, despite having persistent neurological findings (right-sided numbness/tingling) and multiple concussions, and case 4, despite having persistent abnormal VOMS, both had negative SWIs.

The presence of microhemorrhages in these young athletes raises the question of whether or not SWI scans should be incorporated more often into the imaging protocols for pediatric and young adult athletes following a concussion as they do not seem to always correlate with prolonged symptoms. Furthermore, since the long-term consequences of microhemorrhages are unknown, is a positive finding in a young person enough to recommend discontinuation of the sport, even after what appears to be a complete recovery from a concussion? This question is asked among football players with these findings as well.[12] A much larger longitudinal study following the riders with positive and negative findings into adulthood, along with neuropsychological exams, would be needed to investigate the potential for microhemorrhages and to detect any related negative long-term effects. Ultimately, this correlation along with neuropsychological exam findings would be essential if SWIs were to be used as a standard screening for persistent concussion systems, with findings of microhemorrhages warranting a recommendation for a motocross rider, or any athlete with these findings, to retire.

Up to 61% of head injuries with associated concussion symptoms go unreported in the pediatric amateur motocross population.[7] Luckily, concussion education and post-concussion treatment have been receiving more attention at the amateur level as many motocross training facilities, gym trainers and riding coaches are suggesting the use of ImPACT baseline testing and enforcing evaluation and treatment after potential concussions. It is imperative that concussions in young motocross riders be further investigated, as most research focuses on traditional collegiate sports. At the minimum, the authors would strongly suggest implementation of a return-to-ride concussion protocol at the amateur races similar to the professional level. Longitudinal studies of motocross riders can help the development of more effective screening and rehabilitation protocols in a sport with a unique set of physical and mental requirements for optimal performance and provide a better understanding of any possible long-term consequences, with the ultimate goal of minimizing them.

Conflicts of Interest

The authors declare they have no conflicts of interest.

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References

1. Larson AN, Stans AA, Shaughnessy WJ, Dekutoski MB, Quinn MJ, McIntosh AL. Motocross morbidity: economic cost and injury distribution in children. *J Pediatr Orthop*. 2009;29(8):847-850. https://doi.org/10.1097/bpo.0b013e3181c1e2fa
2. Kaeding C, Borchers J, Oman J, Pedroza A. Medical Expenditures in Division 1 Collegiate Athletics: Analysis by Sport and Gender. *Med Sci Sports Exerc*. 2011;43(Suppl 1):2-3. https://doi.org/10.1249/01.MSS.0000402673.23517.e6
3. Daniels DJ, Clarke MJ, Puffer R, Luo TD, McIntosh AL, Wetjen NM. High occurrence of head and spine injuries in the pediatric population following motocross accidents. *J Neurosurg Pediatr*. 2015;15(3):261-265. https://doi.org/10.3171/2014.9.peds14149
4. Arena CB, Holbert JA, Hennrikus WL. Injuries in the competitive paediatric motocross athlete. *J Child Orthop*. 2017;11(3):175-179. https://doi.org/10.1302/1863-2548.11.160262
5. Williams BA, McFadden JP, Teurlings TL, Blakemore LC. Pediatric Injuries at an Annual Motocross Competition: Rates and Severity. *J Pediatr Orthop*. 2017;37(3):e168-e173. https://doi.org/10.1097/bpo.0000000000000849
6. AMA Rulebook. https://americanmotorcyclist.com/motocross-rules/. Published 2017. Accessed July 8, 2020.
7. Luo TD, Clarke MJ, Zimmerman AK, Quinn M, Daniels DJ, McIntosh AL. Concussion symptoms in youth motocross riders: a prospective, observational study. *J Neurosurg Pediatr*. 2015;15(3):255-260. https://doi.org/10.3171/2014.11.peds14127
8. Valasek AE, McCambridge TM. Sports-Related Concussion. In: Apps JN, Walter KD, eds. *Pediatric and Adolescent Concussion: Diagnosis, Management, and Outcomes*. Springer New York; 2012:21-27. https://doi.org/10.1007/978-0-387-89545-1_3
9. Ellis MJ, Leiter J, Hall T, et al. Neuroimaging findings in pediatric sports-related concussion. *J Neurosurg Pediatr*. 2015;16(3):241-247. https://doi.org/10.3171/2015.1.peds14510
10. Pan J, Connolly ID, Dangelmajer S, Kintzing J, Ho AL, Grant G. Sports-related brain injuries: connecting pathology to diagnosis. *Neurosurg Focus*. 2016;40(4):E14. https://doi.org/10.3171/2016.1.focus15607
11. Lee JK, Wu J, Banks S, et al. Prevalence of Traumatic Findings on Routine MRI in a Large Cohort of Professional Fighters. *AJNR Am J Neuroradiol*. 2017;38(7):1303-1310. https://doi.org/10.3174/ajnr.a5175
12. Asif IM, Harmon KG, Drezner JA, O'Kane JW. Cerebral microhemorrhages in a collegiate football player: clinical implications in the management of sports concussion. *Sports Health*. 2010;2(5):391-394. https://doi.org/10.1177/1941738110374628
13. Henry LC, Burkhart SO, Elbin RJ, Agarwal V, Kontos AP. Traumatic axonal injury and persistent emotional lability in an adolescent following moderate traumatic brain injury: A case study. *J Clin Exp Neuropsychol*. 2015;37(4):439-454. https://doi.org/10.1080/13803395.2015.1025708
14. Jarrett M, Tam R, Hernández-Torres E, et al. A Prospective Pilot Investigation of Brain Volume, White Matter Hyperintensities, and Hemorrhagic Lesions after Mild Traumatic Brain Injury.

Front Neurol. 2016;7:11. Published 2016 Feb 12. https://doi.org/10.3389/fneur.2016.00011

15. Prabhu SP. The role of neuroimaging in sport-related concussion. *Clin Sports Med*. 2011;30(1):103-14. https://doi.org/10.1016/j.csm.2010.09.003
16. Ungvari Z, Tarantini S, Kirkpatrick AC, Csiszar A, Prodan CI. Cerebral microhemorrhages: mechanisms, consequences, and prevention. *Am J Physiol Heart Circ Physiol*. 2017;312(6):H1128-H1143. https://doi.org/10.1152/ajpheart.00780.2016
17. Roob G, Lechner A, Schmidt R, Flooh E, Hartung HP, Fazekas F. Frequency and location of microbleeds in patients with primary intracerebral hemorrhage. *Stroke*. 2000;31(11):2665-2669. https://doi.org/10.1161/01.str.31.11.2665
18. Trifan G, Gattu R, Haacke EM, Kou Z, Benson RR. MR imaging findings in mild traumatic brain injury with persistent neurological impairment. *Magn Reson Imaging*. 2017;37:243-251. https://doi.org/10.1016/j.mri.2016.12.009