Sport-related Structural Brain Injury in High School and College American Football Athletes, 2002-2020: Effect of Lystedt Law

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Background: A previous report revealed an average of 7.2 (0.67 per 100,000 participants) sport-related structural brain injuries (SRSBIs) with macroscopic lesions per year in high school (HS) and college football players. The Lystedt law and other rule changes have been implemented with intent to reduce the risk of brain injury in football.

Hypothesis: To update the profile of SRSBIs in HS and college football players and evaluate the efficacy of legislation intended to reduce brain injuries.

Study Design: Descriptive epidemiology study.

Level of Evidence: Level 4.

Methods: We retrospectively reviewed 18 academic years (July 2002 through June 2020) of SRSBIs catalogued by the National Registry of Catastrophic Sports Injuries. The incidence of SRSBIs was assessed at the HS level during the pre (July 2002 through June 2009), transitional (July 2009 through June 2014), and post (July 2014 through June 2020) universal adoption time periods of the Lystedt law. In addition, the incidence of SRSBIs during the second half of the study (2011-2012 through 2019-2020) was compared with the first half of the study (2002-2003 through 2010-2011).

Results: During the study period, there was a total of 228 SRSBIs (12.7 per year, 1.01 per 100,000 participants): 212 (93%, 11.8 per year, 1.00 per 100,000) in HS athletes and 16 (7%, 0.89 per year, 1.17 per 100,000) in college athletes. There were 52 fatalities (2.9 per year, 0.22 per 100,000 participants) with 46 (2.56 per year, 0.22 per 100,000) in HS athletes and 6 (0.33 per year, 0.43/100,000) in college athletes. There was no significant difference in risk of HS total SRSBIs or fatalities during the 3 Lystedt periods. The risk of combined SRSBI cases [relative risk (RR) = 1.22, $P = 0.13$] and fatalities (RR = 1.20, $P = 0.52$) was similar in the second half of the study compared with the first half of the study.

Conclusion: Despite implementation of rule changes intended to reduce head injury, in particular the Lystedt law, the incidence of SRSBIs has remained unchanged. Further research is necessary to develop effective prevention programs for SRSBIs.

Clinical Relevance: SRSBIs remain a persistent problem in HS and college American football. The recent head injury rule changes have not been effective at reducing SRSBIs.

Keywords: fatalities; football; subdural hematoma; traumatic brain injury

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American football is the most popular sport among male participants in the United States, with an estimated 1.1 million high school (HS) and 75,000 college participants annually.[29,30] The total number of HS football participants has declined since 2009, possibly due to the risk of brain injuries.[15] Most brain injuries in football are concussions; however, football, of all school-sponsored sports, is responsible for the highest number of traumatic brain injuries (TBIs), with macroscopic lesions [sport-related structural brain injuries (SRSBIs), previously known as TBIs] which can result in permanent brain injury and fatality.[5,6,22]

With a goal of preventing brain injury (concussions, SRSBIs, and chronic traumatic encephalopathy), rule changes and policy recommendations by football oversight bodies have been mandated over the past 2 decades.[2,7,32,38] Athletes may be at increased risk of SRSBIs if they return to play before full recovery from a previous concussion.[6,21,33,39] Therefore, in May 2009, Washington State passed legislation requiring any HS athlete with a suspected concussion to be removed from play and allowed to return to sports (game or practice) only with the written permission from a licensed healthcare provider trained in the evaluation and management of concussion.[7] By 2014, similar legislation, collectively referred to as the "Lystedt law," was passed in all 50 states. While the Lystedt law has demonstrated an increased concussion diagnosis rate and a decline in the recurrent concussion rate, to our knowledge, there are no reports on whether the law has reduced SRSBI rates.[7,17,37]

In addition to the Lystedt law, other rule changes have been implemented to decrease brain injuries in football by reducing the number of head impacts.[2,32] The targeting rules, which penalize any forcible contact to an opponent above the shoulders, were implemented by the National Collegiate Athletic Association (NCAA) in 2008 and the National Federation for State High School Association (NFHS) in 2014.[2,31] In 2013, the NCAA strengthened the targeting rule with an automatic ejection in addition to the 15 yard penalty. Previous reports have also documented a disproportionate number of catastrophic brain injuries during special team plays.[6,38] Therefore, the kickoff line was moved 5 yards forward to the 35 yard line in college[38] to increase the number of kicks landing in the end zone or fair catches and thereby reduce the number of kickoff returns. At the HS level, the 40 yard kickoff position has not changed over the past 80 years. However, rules to prevent hitting a defenseless player during kickoffs and penalties for a pop-up kickoff (driving the ball into the ground so it jumps up during an onside kick) were implemented in 2017. Finally, there has been a trend toward reducing head contact during practice sessions by limiting the number of contact practices.[34] While the targeting, kickoff, and limited contact during practice rules have all shown promise at reducing the number of concussions,[31,32,34,38] the effect of these rule changes on SRSBI incidence is unknown.

Over the past 20 years, there has been a plethora of reports on concussions, but only limited information on SRSBIs and whether the new head injury prevention rules have been effective at reducing SRSBIs in football. Therefore, the primary purpose of this study was to perform an analysis of all HS and college football SRSBI cases between the 18 academic years of 2002-2003 through 2019-2020 to determine recent trends in incidence, fatality, mechanism, diagnosis, and outcome. The secondary aim of this study was to determine if the brain injury prevention rule changes, in particular the Lystedt law, were effective at reducing SRSBIs in order to guide future prevention strategies.

METHODS

This study was exempted from institutional review board approval.

Injury Definitions

The National Registry of Catastrophic Sports Injuries (NRCSI) classifies SRSBIs, also referred to as catastrophic head injury, as brain injuries with macroscopic lesions.[27] Inclusion criteria were the presence of brain hemorrhage, swelling, or ischemia, with a diagnosis of subdural hematoma, epidural hematoma, arteriovenous malformation (AVM or other vascular malformations), ruptured aneurysm, diffuse axonal injury, diffuse cerebral edema, dural hemorrhage, and stroke occurring while playing football. Athletes with concussions, functional brain injury without structural abnormality, were excluded from the study. SRSBI was subdivided by the functional status of the athlete after the injury: fatal (the injury causes death of the athlete), permanent (the injury causes a permanent functional neurologic deficit), and serious (while severely injured, the athlete has no permanent functional neurologic disability).

Study Design and Sample

From July 2002 through June 2019, 1 of the authors collected SRSBI case information (name, date of injury, diagnosis, and level of play) from organized, supervised school-sponsored football at the HS and collegiate levels, compiling the data into the NRCSI. Sources for event occurrence were media reports and newspaper clippings, autopsy reports, certificates of death, school-sponsored investigations, and published medical literature. In 2019 and 2020, the authors retrospectively gathered additional investigative data (mechanism of injury, previous head injury, position played, recovery, treatment, game or practice, month of injury, special teams vs offensive or defensive player, cause, and treatment). The study was limited to HS and college male athletes injured while participating in a team setting (practice or game). Mechanisms were classified by action of the injured player at the time of suspected injury, and include whether they were tackling, tackled, blocking, blocked, other, or unknown.

Statistical Analysis

Excel and SAS 9.2 software were employed for the statistical analysis and graphical summary. Annual and overall incidence was calculated as the total number of injuries per time period divided by the total number of participants at the combined, HS, and college levels. Incidence proportions were calculated per 100,000 athletes.

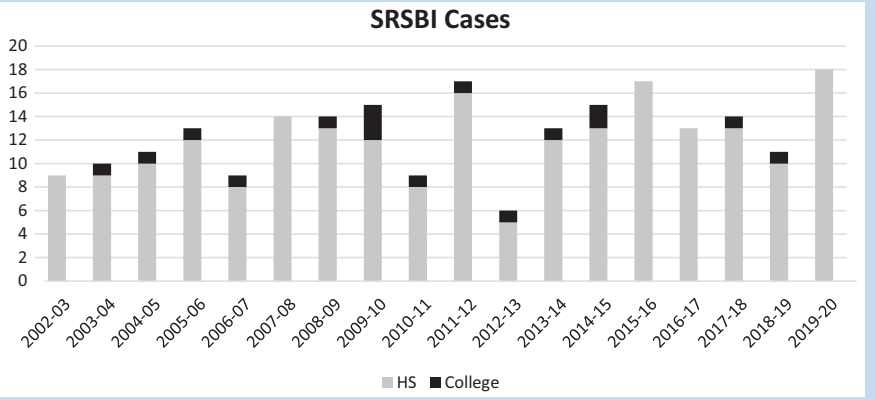

Figure 1. Number of HS and college SRSBIs per academic year, 2002-2003 through 2019-2020. HS, high school; SRSBIs, sport-related structural brain injuries.

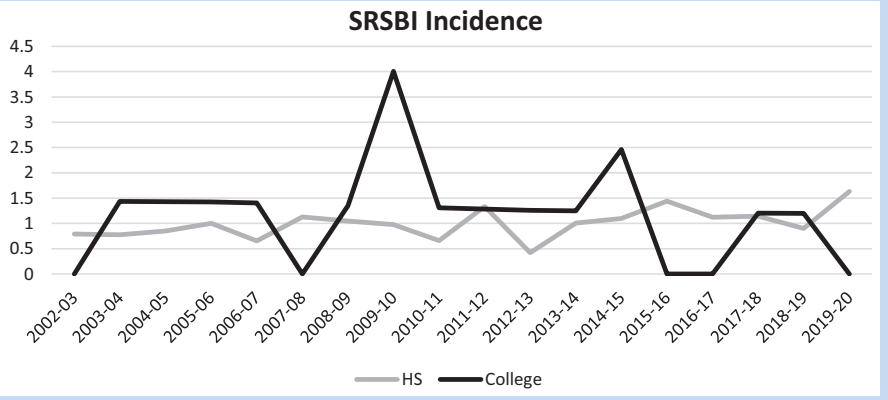

Figure 2. Annual incidence of SRSBIs in HS and college football players per 100,000 participants from 2002-2003 through 2019-2020. HS, high school; SRSBIs, sport-related structural brain injuries.

A logistic regression model was used to model (r/n) grouped data (cases and fatalities), where r represents the number of events (cases and fatalities) and n represents the total population of HS and college. The relative risk (RR), 95% CI, *P* value, and chi-square were reported for college compared with HS per total cases and fatalities. The calculations were performed to compare the pre (2002-2003 through 2008-2009), transitional (2009-2010 through 2013-2014), and post (2014-2015 through 2019-2020) universal adoption eras of the Lystedt law per total HS cases and fatalities. The same calculations were computed to compare the data from the second half of the study (2011-2012 through 2019-2020) versus the first half of the study (2002-2003 through 2010-2011) per all cases, fatalities, HS cases, HS fatalities, college cases, and college fatalities. Each position played and diagnosis was assessed compared with all other positions and diagnoses, respectively, to determine risk factors for fatal SRSBIs.

Participation Numbers

Participation numbers for HS were based on NFHS data plus an additional 100,000 players each year for the private schools that do not participate with the NFHS.[30] College participation numbers were determined by data provided by the NCAA, National Junior College Athletic Association, National Association of Intercollegiate Athletics, and the Christian colleges.[6,29]

RESULTS

Epidemiologic Patterns

During the study period there were 21,273,496 HS and 1,384,503 college players, of which 228 (12.7 per year, 1.01 per 100,000 participants) sustained a SRSBI: 212 (93%, 11.8 per year, 1.00 per 100,000) in HS athletes and 16 (7%, 0.89 per year, 1.17 per 100,000) in college athletes (Figures 1 and 2). The RR (1.16)

Table 1. Statistical comparisons in current study

				95% CI	
	Chi-square	*P* Value	Relative Risk	Lower Limit	Upper Limit
College vs HS Total Cases	0.33	0.57	1.16	0.70	1.93
College vs HS Fatalities	2.57	0.11	2.01	0.86	4.69
H-2 vs H-1 Total SRSBI Cases	2.25	0.13	1.22	0.94	1.58
H-2 vs H-1 Total Fatalities	0.41	0.52	1.20	0.69	2.06
H-2 vs H-1 HS Cases	3.06	0.08	1.27	0.97	1.67
H-2 vs H-1 HS Fatalities	0.49	0.48	1.23	0.69	2.20
H-2 vs H-1 College Cases	0.56	0.46	0.69	0.26	1.84
H-2 vs H-1 College Fatalities	0.02	0.88	0.88	0.18	4.37

H-1, first half of study (2002-2003 through 2010-2011); H-2, second half of study (2011-2012 through 2019-2020); HS, high school; SRSBI, sport-related structural brain injury.

of SRSBIs was similar at the college compared with the HS level (Table 1). The risk of combined SRSBI cases (1.22), HS cases (1.27), and college cases (0.69) was similar in the second half of the study compared with the first half of the study (Table 1).

Fatalities

There were 52 fatalities (2.9 per year, 0.22 per 100,000 participants) with a similar risk of fatality (2.01) at the college (n = 6, 0.33 per year, 0.43/100,000) compared with the HS (n = 46, 2.56 per year, 0.22 per 100,000) levels (Figures 3 and 4) (see Table 1). The overall risk of a fatality was similar during the second half of the study compared with the first half of the study for combined cases (1.20), HS cases (1.23), and colleges cases (0.88) (see Table 1).

Effect of Lystedt Law

The HS risk of combined SRSBIs (RR = 1.36) and fatalities (RR = 1.22) was higher during the universal adoption compared with the pre-Lystedt law period; however, there was no significant difference in the risk of SRSBIs or fatalities during the 3 Lystedt periods (Table 2, Figure 5).

Demographic Patterns

The mean age at the time of injury, known in all cases, was 16.6 years (range, 13-22 years) with a mean age of 16.3 years (range, 13-18 years) in HS and 20.3 years (range, 18-22 years) in college athletes. The position played at the time of injury was determined in 157 cases: 81 (51.5%) on defense, 61 (38.9%) on offense, and 15 (9.6%) on special teams. There were 7 (HS = 6, college = 1) special team SRSBI cases in the first half of the study and 8 (HS =7, college =1) during the second half of the study, with no significant risk reduction at the combined (RR = 1.17, 95% CI 0.42-3.23; *P* = 0.76), college (RR = 0.88, 95% CI 0.06-14.11; *P* = 0.93), or HS (RR = 1.21, 95% CI 0.41-3.59; *P* = 0.74) levels during the second half of the study.

The most frequent positions played at the time of injury were defensive backs (n = 33, 23.1%), linebackers (n = 33, 23.1%), and running backs (n = 25, 17.5%), followed by special team players (n = 15, 10.5%), quarterbacks (n = 13, 9.1%), defensive linemen (n = 10, 7%), offensive linemen (n = 5, 3.5%), wide receivers (n = 5, 3.5%), and tight ends (n = 4, 2.8%). The remaining positions were unknown, were reported to play multiple positions (n = 17) without a specific position identified at the time or injury, or were practice-related during drills. None of the positions played revealed a significant risk of SRSBI fatality.

Timing of Injury

The majority (n = 160, 70.2%) of SRSBI cases occurred in the months of September (n = 90, 39.5%) and October (n = 70, 30.7%) followed by August (n = 33, 14.5%), November (n = 17, 7.5%), May (n = 6, 2.6%), March (n = 4, 1.8%), July (n = 3, 1.3%), April (n = 2, 0.9%) and February, June, and December with 1 each (0.4%). The training was determined for 225 (98.7%) cases and unknown in 3 (1.3%). Athletes were over 4 times more likely to be injured during a game (n = 182, 80.9%) than a practice (n = 43, 19.1%) session. Of the 43 practice-related injuries, at least 10 (30.3%) occurred during a scrimmage.

Injury Profile

The injury classification was unknown, but not fatal for 58 injuries. Of the remaining 170 injuries, 71 (42%) were classified as nonfatal (permanent neurologic deficit), 52 (31%) as fatal,

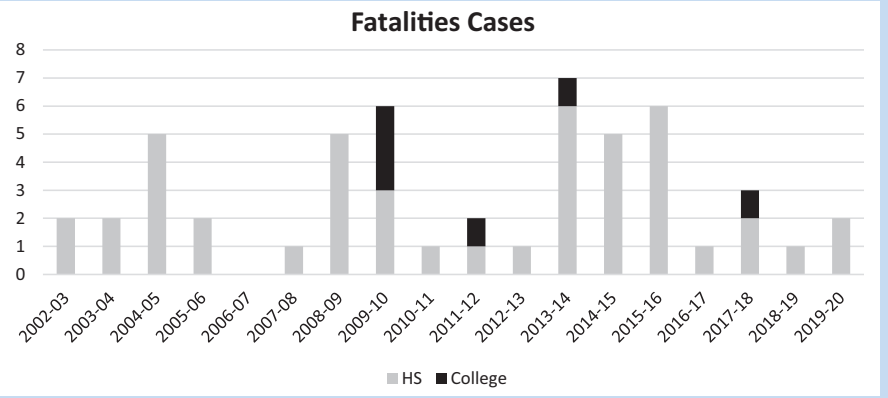

Figure 3. Number of HS and college SRSBI fatalities per academic year, 2002-2003 through 2019-2020. HS, high school; SRSBI, sport-related structural brain injury.

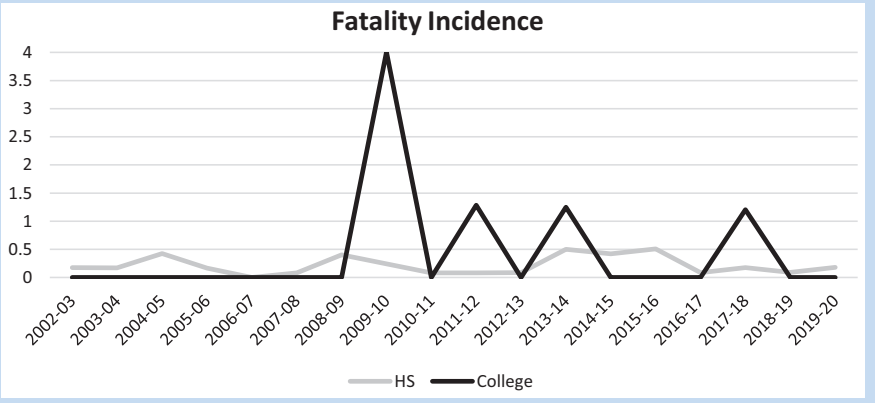

Figure 4. Annual incidence of SRSBIs in HS and college football players per 100,000 participants from 2002-2003 through 2019-2020. HS, high school; SRSBIs, sport-related structural brain injuries.

and 47 (28%) as serious (no residual neurologic deficits). The diagnosis was determined in 162 cases. The most common diagnosis was subdural hematoma (n = 104, 64.2%) followed by diffuse cerebral edema (n = 36, 22.3%), aneurysm (n = 8, 4.9%), ischemic stroke (n = 6, 3.7%), AVM (n = 2, 1.2%), diffuse axonal injury (n = 1, 0.6%), and duret hemorrhage (n = 1, 0.6%). Only 1 athlete was known to have sustained a skull fracture, in addition to diffuse cerebral edema, when the occipital portion of his helmet impacted an artificial turf field. The diagnosis was known for 42 of the 52 fatalities: subdural hematoma (n = 20, 47.6%), diffuse cerebral edema (n = 13, 30.9%), aneurysm (n = 5, 11.9%), ischemic stroke (n = 3, 7.1%), and AVM (n = 1, 2.4%). Analysis of diagnoses revealed no significant factors for the risk of fatality.

Previous Head Injuries

A minimum of 60 athletes had a previous concussion. The timing was determined to occur within 1 week in 14 cases, greater than 1 week but less than a month in 10 cases, greater than a month but less than a year in 3 cases, greater than 1 year in 4 athletes, and unknown in 29. A minimum of 15 athletes did not report the concussion, 6 were cleared to play before the SRSBI, and 2 were not cleared to play. One athlete sustained a mild subdural hematoma 17 months before the incident SRSBI. The original injury did not require surgery and he was cleared by his neurosurgeon to return to play.

Mechanism of Injury

The mechanism of injury was determined in 112 cases: 49 (43.8%) were making a tackle, 39 (34.8%) were being tackled, 11 (9.8%) were being blocked, and 9 (8%) were blocking. The remaining cases were either unknown or no identifiable collisions or singular play were identified. In 59 cases, the point of impact resulting in injury was reported: 33 (55.9%) helmet-to-helmet collisions, 16 (27.1%) helmet-to-ground, 5 (8.5%) combination of helmet-to-helmet followed by impact with ground, 2 (3.4%) helmet-to-opponents shoulder, and 1 each of helmet-to-opponents knee (1.7%) and elbow (1.7%).

Table 2. Comparison of SRSBI HS cases during the pre- (L1), transition (L2), and post- (L3) Lystedt law eras

				95% CI	
Lystedt Law Period	Chi-square	*P* Value	Relative Risk	Lower Limit	Upper Limit
Total HS Cases L2 vs L1	0.010	0.92	0.98	0.69	1.40
Total HS Fatalities in L2 vs L1	0.002	0.96	0.98	0.47	2.06
Total HS Cases L3 vs L2	3.48	0.06*	1.39	0.98	1.96
Total HS Fatalities L3 vs L2	0.33	0.57	1.24	0.59	2.60
Total HS Cases L3 vs L1^{+}	3.81	0.05*	1.36	1.00	1.86
Total HS Fatalities L3 vs L1	0.33	0.57	1.22	0.62	2.38

HS, high school; L1, pre-Lystedt law; L2, transition period; L3, post-Lystedt law.
**P* value is near statistical significance.

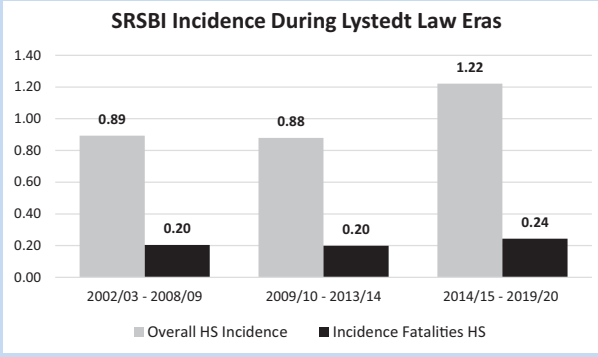

Figure 5. SRSBI incidence during pre-, transition, and postadoption of the Lystedt law for HS. HS, high school; SRSBI, sport-related structural brain injury.

Treatment and Outcomes

Information on whether surgery was performed was obtained in 121 cases, with 104 (86%) requiring surgery to decompress an intracranial bleed and 17 (14%) not requiring surgical intervention. At least 19 cases were placed in a medically induced coma. Of the 52 fatalities, 10 (19.2%) died on the day of the injury, 37 (71.2%) between the 1st and 7th day after the injury, 2 (3.8%) between the 1st week and 1st month postinjury, and 2 (3.8%) at least 1 year after the injury. The 71 permanent/nonfatal injuries resulted in a variety of residual symptoms, such as severe cognitive deficits, visual disturbances, personality changes, memory loss, difficulty walking, paraplegia (n = 2), quadriplegia (n = 1), and other medical complications.

DISCUSSION

The primary finding of this study was that the Lystedt law has not reduced the rate of SRSBIs in HS athletes. In fact, the rate of SRSBI cases and fatalities in HS participants increased 36% and 22%, respectively, during the post-Lystedt law era compared with the pre-Lystedt law period but did not reach statistical significance. There are several possible reasons why the Lystedt law has failed to reduce the rate of SRSBIs in HS athletes. The Lystedt law was not written to prevent initial brain injury and does not address the resources necessary to identify and manage concussions properly. In addition, there are no regulations concerning playing technique or rules enforcement. This study as well as other studies[6,24,39] report that previous concussions within 1 month of an SRSBI can occur in up to 20% of athletes, with many having an incomplete recovery at the time of SRSBI. The most likely explanation for the lack of injury reduction is that most SRSBIs may be caused by a single severe blow to the head, and incomplete recovery from a previous concussion is a less common predisposing factor for SRSBIs than was previously hypothesized.[6] Alternatively, there may be a higher rate of other risk factors for SRSBIs such as undiagnosed inherent abnormalities such as aneurysms, AVMs, bleeding disorders, and/or high doses of nonsteroidal usage.

Another possible explanation for the lack of SRSBI reduction with the Lystedt law is poor compliance with concussion reporting and medical clearance.[20] Underreporting by players, mismanagement of injuries, and lack of awareness of concussion symptoms are all obstacles to the effective management of concussions.[1,28] Underreporting of concussions by players can be substantial, with up to 50% of athletes not reporting concussions as many symptoms may be minor or ignored due to the warrior mentality in the sport of football.[18,25] In 1 study assessing compliance with state concussion laws in Massachusetts, an estimated 12% of concussions were not reported and 25% of concussed athletes returned to play without appropriate medical clearance.[20] Less than 50% of all HSs in the state had a full-time athletic trainer or formal relationship with a school physician.[20] Therefore, renewed efforts are necessary to enforce compliance, such as removing

athletes with any concussion symptoms from play and not allowing return to play until properly cleared. Improving access to medical care is also critical. Early diagnosis and monitoring for concussion via clinical examination on the side line with a battery of concussion tests is a critical step in preventing further brain injury.[8,18] Further research is also necessary to determine when an athlete has completely recovered from a concussion. Another possible preventive strategy would require all athletes to obtain medical clearance from a healthcare provider with training in concussion assessment, or pass a neurocognitive test at the school the day before each game. In order for any implementations to be successful, a cultural change in the perception of brain injuries, and their potential for devastating consequences, by the football community is necessary.[28,35]

A second important finding in this study was no reduction in SRSBI cases or SRSBI fatalities in the second half of the study compared with the first half, indicating the overall impact of brain injury reduction strategies, in particular the targeting rule and reduction in contact practices have not had an impact on SRSBIs. In fact, 56% of the known injury mechanisms involved a helmet–to-helmet collision despite targeting rules. It is possible the targeting rules are insufficient in reducing head impacts which have been documented to be more than 2000 per season at the college level and similar at the HS level.[8,12] Alternatively compliance and enforcement may be issues that require further assessment as style of play remains unchanged. The limited contact practice rules also likely did not have a beneficial effect as SRSBIs were over 4 times more common during a game than a practice. The percentage of game injuries in the current study (81%) was also similar to a previous 13-year study (78%).[6] The rule change has shown a reduction in concussions during practice sessions, but not during games.[32] Limiting full contact practice may reduce the number of head impacts, but not necessarily the head impact burden due to increased contact intensity during the allowed contact sessions.[34] The overall percentage of SRSBI during special team plays decreased from 15% in the previous study[6] to 10% in the current study; however, there was no risk reduction during the second half of this study. As there was only 1 collegiate special team SRSBI during each half of the study and there were incomplete data for the position played, we are unable to reach a definitive conclusion on the effect of the kickoff rule change and recommend further analysis.

The overall incidence of SRSBIs increased during the 18-year period (1.01 per 100,000) in this study compared with a previous similar report[6] (0.64 per 100,000), which reviewed the 13-year period from September 1989 through June 2002. There was a more dramatic increase at the college (1.17 vs. 0.21 per 100,000) than the HS (1.00 vs. 0.54 per 100,00) level.[6] This finding is concerning and warrants further research, but may be due to improved surveillance and increased awareness of head injuries. In contrast to the present study in which the risk of SRSBIs was similar in college and HS participants, the previous 13-year study revealed a 3.3-fold higher risk in HS athletes. The higher SRSBI incidence in college athletes in the current study refutes the initial proposal[6] that HS athletes are more susceptible to SRSBIs. The reasons for the increase in SRSBI cases, especially at the college level, are unclear, but may be due to a more physical style of play. It is also possible that the trend reversal may be due to the low number of college cases with a shorter study period during the previous study leading to a statistical error.

The incidence of a SRSBI fatality also increased for combined (0.22 vs. 0.06 per 100,000) cases compared with the previous 13-year time period.[6] The annual number of fatal SRSBI cases in the present study (2.9 per year) closely match a report of HS and college SRSBI fatalities during the 2005-2014 period (2.6 per year) performed by a separate database.[22,24] The annual number (16.7 per year) of SRSBI fatalities in football players at all football levels, including youth and professional, peaked during the 1965-1974 period.[9] The decline in SRSBI fatalities over the ensuing 25 years was likely due to the improved football helmet design and the establishment of safety standards for the helmet.[9] Additional factors include the spear-tackling rules[36] to reduce contact with the crown of the helmet, as well as improved on-field medical personnel, medical treatment, and surveillance of sports injury.[4,9] However, the trend reversal from a low of 1.8 per year during the 1994-1999 time period for all levels of football to an average of close to 3 per year for HS and college athletes in the current study is concerning, particularly as numerous new rules have been implemented over the past 20 years to reduce brain injuries, and helmet design has continued to evolve. In addition to the 52 fatalities in the current study, the percentage (42%) of non-fatal cases with a permanent neurologic deficit remains high.

The demographic patterns in this study were comparable with previous studies.[6,9,23,24] Consistent with prior reports, athletes were over 4 times more likely to be injured during a game (81%) than a practice (19%) session.[6,9,24] As most injuries occur in a game situation, it is not surprising that 70% of injuries occurred during the month of September or October. An explanation for this phenomenon is that football games are strongly associated with intense competitive situations, more so than practice. The frequency of head impacts and the magnitude of impacts at the 95th percentile have been reported to be greater at the college level in game situations compared with practice situations.[11,13] However, further analysis is necessary to determine the relationship between head impact biomechanics and the risk of SRSBIs.

Most players in this study were on defense (51.5%) or offense (38.9%) at the time of injury, and were either making a tackle or being tackled, which is comparable to other reports.[6,24] The most frequently played positions (defensive backs, linebackers, and running backs) at the time of injury in this study was also similar to prior reports.[6,24] Defensive backs may be prone to SRSBIs due to their small size compared with other players on the field as well as their high-speed open field tackles, which can lead to higher collision forces. Helmet telemetry data have demonstrated that collegiate running backs and linebackers also sustain the greatest impact magnitudes.[13] Linebackers and running backs are

also known to be involved in a high frequency of plays where they are either tackling or being tackled.[14]

Similar to previous studies[6,9] in football players, the majority of injuries in this study were subdural hematomas. The helmet standards developed in the early 1970s, and still in use today, are based on translational acceleration which has dramatically reduced the incidence of skull fractures in American football.[6,16] In this report, there was only 1 known skull fracture. However, in helmeted athletes, rotational accelerations appear to be the primary culprit for subdural hematoma.[16] Rotational accelerations in football have been shown commonly to surpass 5000 rads/s^2, a critical threshold for rupture of the bridging veins.[16] In 1 study, the top 1% of game impacts in HS and college averaged 6,990.5 rads/s^2.[19] Due to the increasing risk of SRSBIs in American football, further research is necessary to assess whether helmet modifications are capable of reducing rotational accelerations and the risk of concussion.[3,10,26]

Limitations

It is possible that not all SRSBIs were identified by the NRCSI leading to underreporting of incidents. This is unlikely as these high profile SRSBI cases, particularly deaths, are captured in the public domain with greater frequency than noncatastrophic injuries. In addition, the incidence trends and number of fatalities in this study closely mirror those of another national catastrophic injury database, which is sponsored by the NCAA and NFHS.[22,24] However, missing and potentially inaccurate data pertaining to demographics may lead to faulty conclusions. Furthermore, Health Insurance Portability Accountability Act regulations restrict access to medical records and images, so many of the exact medical diagnoses and treatments could not be confirmed.

CONCLUSION

Despite implementation of rule changes intended to reduce head injury, in particular the Lystedt law, the incidence of SRSBIs remained unchanged in HS and college football participants during the 18-year period. Of concern is that the incidence of SRSBIs has also increased in HS and college football players over the recent 18-year time span compared with the previous 13 years, reversing a downward trend that started in the 1970s.

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COMPETING INTERESTS

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