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# Sport-Related Structural Brain Injury and Return to Play: Systematic Review and Expert Insight

**BACKGROUND:** Sport-related structural brain injury (SRSBI) is intracranial pathology incurred during sport. Management mirrors that of non-sport-related brain injury. An empirical vacuum exists regarding return to play (RTP) following SRSBI.

**OBJECTIVE:** To provide key insight for operative management and RTP following SRSBI using a (1) focused systematic review and (2) survey of expert opinions.

**METHODS:** A systematic literature review of SRSBI from 2012 to present in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and a cross-sectional survey of RTP in SRSBI by 31 international neurosurgeons was conducted.

**RESULTS:** Of 27 included articles out of 241 systematically reviewed, 9 (33.0%) case reports provided RTP information for 12 athletes. To assess expert opinion, 31 of 32 neurosurgeons (96.9%) provided survey responses. For acute, asymptomatic SRSBI, 12 (38.7%) would not operate. Of the 19 (61.3%) who would operate, midline shift (63.2%) and hemorrhage size > 10 mm (52.6%) were the most common indications. Following SRSBI with resolved hemorrhage, with or without burr holes, the majority of experts (>75%) allowed RTP to high-contact/collision sports at 6 to 12 mo. Approximately 80% of experts did not endorse RTP to high-contact/collision sports for athletes with persistent hemorrhage. Following craniotomy for SRSBI, 40% to 50% of experts considered RTP at 6 to 12 mo. Linear regression revealed that experts allowed earlier RTP at higher levels of play ($\beta = -0.58$, 95% CI −0.111, −0.005, $P = .033$).

**CONCLUSION:** RTP decisions following structural brain injury in athletes are markedly heterogeneous. While individualized RTP decisions are critical, aggregated expert opinions from 31 international sports neurosurgeons provide key insight. Level of play was found to be an important consideration in RTP determinations.

**KEY WORDS:** Sports, Traumatic brain injury, Return to play, Subdural hemorrhage, Epidural hemorrhage, Football, Collision sports

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Sport-related structural brain injury (SRSBI) is defined as intracranial pathology identified on standard neuroimaging and incurred by an athlete during sport or other life activities, with a focus on medical/surgical management and return to play (RTP). Management of SRSBI ranges from clinical observation[1,2] to surgical intervention.[3] Outcomes vary considerably, from full recovery and unrestricted return to sport[4] to neurological devastation.[3,5] RTP decisions often reflect a collaborative process involving neurosurgeons, especially postoperatively, as well as sports medicine specialists, neuropsychologists, and therapists to determine when an athlete is fully asymptomatic and may safely resume sport participation.[6]

Due to the rarity of these injuries,[7] evidence-based guidelines for RTP following SRSBI do not exist, leaving neurosurgeons little guidance

**ABBREVIATIONS: EDH,** epidural hemorrhage; **IPH,** intraparenchymal hematoma/hemorrhage; **MeSH,** Medical Subject Heading; **PRISMA,** Preferred Reporting Items for Systematic Reviews and Meta-Analyses; **RTP,** return to play; **SDH,** subdural hematoma/hemorrhage; **SRC,** sport-related concussion; **SRCSBI,** sport-related concussion and structural brain injury; **SRSBI,** sport-related structural brain injury

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to manage these complex decisions. However, attempts to summarize the literature have been made. A prior systematic review summarized SRSBI across 40 studies from 1950 to 2012[8] and reported 137 cases of intracranial pathology including 69 cases of traumatic subarachnoid hemorrhage, 16 cases of epidural hematoma/hemorrhage (EDH), 34 cases of subdural hematoma/hemorrhage (SDH), and 22 cases of diffuse cerebral edema. There were 10 deaths and several patients retired from sport, yet minimal RTP information was included. Since then, a small number of reports have appeared in the literature describing a spectrum of outcomes.[3,4]

If an athlete does make a full neurological recovery after SRSBI, multiple factors affect the RTP decision-making process, such as surgery performed, future risk of high-energy head impacts, and lingering neurocognitive deficits.[6,9] Small samples (n < 5) of expert opinions have suggested that athletes wait 1 yr to RTP following SRSBI[6] whether or not craniotomy was required.[9] However, a prior survey of 98 neurosurgeons through the American Association of Neurological Surgeons found most patients were cleared by their surgeon for RTP prior to 1 yr following a craniotomy.[10] Unfortunately, RTP following nonoperative SRSBI was incompletely addressed.[10]

While RTP following concussion has received substantial attention allowing for the development of evidence-based consensus,[11-13] these guidelines do not address concepts critical to SRSBI such as RTP following craniotomy or the presence of residual imaging abnormalities. RTP following SRSBI exists in a relative empirical vacuum. The resultant lack of evidence-based recommendations may lead to generic prohibitions and allowances that are unduly restrictive to athletes or place the neurosurgeon at significant medicolegal risk.

Due to the dearth of information on RTP after SRSBI and the complexity of such decisions, the need for a preliminary framework is apparent. The objective of the current study was to derive key insights for operative indications and RTP after SRSBI utilizing (1) a systematic review of literature and (2) a cross-sectional survey of expert opinion on RTP following SRSBI. We hypothesized that low level of evidence and limited RTP information garnered from the systematic review would require us to lean on aggregate expert opinion obtained via the survey to provide summative insight.

## METHODS

### Study Design

This study combined 2 methodologies, including a focused systematic review and cross-sectional survey of international sports neurosurgical experts, in order to provide key insight and a more complete understanding of the published experience versus expert opinions on RTP after SRSBI.

#### *Systematic Review*

The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[14] The review protocol was not registered in advance with any service. As SRSBI reports from 1950 to 2012 have been previously reviewed,[8] we reviewed published titles/abstracts from 2012 to present, which were searched systematically from PubMed using relevant MeSH (Medical Subject Heading) terms and keywords (Appendix 1). Titles and abstracts were screened and full-texts reviewed for inclusion by a single author (A.R.T.). Senior author (S.L.Z.) reviewed and verified all included articles and extracted data with concerns or disagreements settled by a second senior author (A.Y.K.). Inclusion criteria consisted of the following: case report, case series, or observational study of an athlete(s) with SRSBI.

Previously, sport-related concussion and structural brain injury (SRCSBI) had been the focus of discussion[8]; however, as guidelines for RTP following concussion have been well described, SRC was omitted for the purpose of this review. The previously published SRCSBI definition[8] was refined to SRSBI—an intracranial pathology identified on standard neuroimaging (computed tomography [CT]/magnetic resonance imaging [MRI]) incurred by an athlete during sport or other life activities *that involves a focus on medical/surgical management and RTP.* Irrespective of injury mechanism, RTP decisions following both sport-related traumatic brain injury and non-sport-related injury require similar considerations assuming similar neurological outcomes. Structural brain injuries included SDH, EDH, intraparenchymal hematoma/hemorrhage (IPH), subarachnoid hemorrhage (SAH), diffuse cerebral edema, and diffuse axonal injury. Fractures alone without parenchymal damage were not considered SRSBI.[8]

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### Expert Opinion

A panel of international neurosurgeons with sport expertise was selected by identifying those in a preexisting network of professional sporting leagues, and via referrals from those experts. The network was formed based on neurosurgeons who have participated in previous international sport guidelines and consensus papers.[11,12,15] Of participating neurosurgeons, 71% were actively involved in professional sport concussion/neurotrauma protocols, 92% were either full professor or associate professor, and 29% were leading members of sport neurotrauma guidelines (Concussion in Sport Group, American Academy of Neurology Concussion Guidelines, Brain Trauma Foundation, or Centers for Disease Control TBI guidelines).

The survey was restricted to neurosurgeons given the content of structural brain injury and RTP after neurosurgical operations. The online survey consisted of 3 questions assessing the extent of respondent experience in counseling athletes following SRSBI and 13 multiple choice questions assessing operative indications for SRSBI and RTP timing in 4 scenarios at 3 levels of sport—high school, collegiate, and professional. The survey is provided in Appendix 2. For question 6, only the *asymptomatic athlete with structural brain injury* was considered. For questions 7 to 18, the same *asymptomatic athlete* was considered.

To further study how level of play affected RTP responses, the 4 scenarios (questions 7-18) that asked about increasing level of competition were collapsed into 1 variable, the *RTP Assessment Score*. Each survey answer was assigned a numerical value, indicating an increasingly conservative RTP assessment, from 1 to 6, where 1 = most lenient/least conservative and 6 = most conservative/least lenient. Specific values were: 1 = *RTP 3 mo*, 2 = *RTP 6 mo*, 3 = *RTP 9 mo*, 4 = *RTP 1 yr*, 5 = *RTP 2 yr*, 6 = *no return to original high-contact/collision sport*. These timeframes were chosen in order to provide a reasonable level of granularity while maintaining consistency between experts' answers. Though the last 2 survey responses (retire from all sports; retire from high-contact/collision sports) represent different responses, they were collapsed to one value, as neither response included an ordinal timetable for RTP. The *RTP Assessment Score* was solely meant to create a numerical continuum of answers by transforming ordinal data to a continuous variable for statistical analysis.[16] Participants who did not answer according to the choices provided were excluded. Descriptive statistics of survey responses were performed, in addition to linear regression assessing a potential relationship between *RTP Assessment Score* and level of sport. A priori statistical significance was set at $P < .05$. All analyses were performed using STATA version 14 (StataCorp LP, College Station, Texas).

## RESULTS

### Systematic Review

Of 241 publications from the initial query, 81 full-text sources were searched for eligibility, leading to 27 included studies (Appendix 3). The 27 eligible studies included in the current review are summarized in Table 1 (and further details of each study are described in Appendix 4).[1-4,17-39] Nearly all studies were case reports or series (level 4 evidence). Twelve reports from 9 articles (33%) that included RTP information are summarized in Table 2. Ten of these 12 cases occurred in high-school athletes or younger. The most common sport was American football (41.7%). Five (41.7%) patients were managed surgically (3 craniotomies, 1 burr hole, and 1 hemicraniectomy). One patient remained symptomatic 4 mo postinjury and was told to avoid sports until asymptomatic, and a second patient continued to have severe neurological disability. In the remaining 10 patients whose symptoms resolved completely, 3 returned to their original high-contact/collision sport with no subsequent complications noted.[1,2,4] Of the 7 athletes who did not return to their original high-contact/collision sport, 6 were approved for low-contact sports and 1 was told to not return to any sport at all.

### Expert Opinion

#### Demographics

Of 32 neurosurgeons invited to participate, 31 completed the survey (96.9% response rate). The United States (U.S.) was the most represented country (71%) among respondents. Mean years of experience treating athletes was 24.2 yr (5-50) (Table 3). Collegiate athletes (90.3%) and professional athletes (87.1%) were the most commonly treated. American football was the most common sport (77.4%) treated.

#### Operative Decision Making

In terms of the *asymptomatic* athlete with acute SRSBI, 12 (38.7%) neurosurgeons would not operate regardless of imaging (Table 4). Of the remaining 19 (61.3%) who would operate, common indications were a midline shift >10 mm (63.2%) and/or size of hemorrhage >10 mm (52.6%).

#### RTP Decisions

RTP responses were queried in 4 clinical scenarios and are summarized according to level of play (Table 5). Due to low responses at 3- and 9-mo intervals, these responses were collapsed graphically into 6 mo and 1 yr, respectively. For the *high-school athlete*, after SRSBI with resolved hemorrhage, the most common RTP times was 6 mo (33%). RTP with a persistent hemorrhage was conservative with 39% of respondents not allowing any sports and 46% of respondents recommending a low-contact sport to the athlete. After burr holes, most recommended switching to a low-contact sport (37%) or RTP at 6 mo postoperatively (37%). Craniotomy decisions were more conservative, with 7% recommending no sports at all and 50% recommending switching to low-contact sports.

For the *collegiate athlete*, after SRSBI with resolved hemorrhage, the most common RTP time was 6 mo (37%). RTP with persistent hemorrhage included a more conservative approach than resolved hemorrhage, with 41% not allowing any sports and 41% recommending a low-contact sport. RTP after burr holes was most commonly at 6 mo (33%). Post-craniotomy recommendations were more conservative, with 7% recommending no sports at all and 40% recommending a switch to low-contact sports.

For professional athlete's RTP after SRSBI with resolved hemorrhage, 0% of experts recommended retirement and most often considered RTP at 6mo (41%) and 1 year (33%). Only 7% recommended switching to a low-contact sport, lower than 22%

**TABLE 1. Sports Implicated in Cases of Sport-Related Structural Brain Injuries From 2012 to Current**

| Sport | No. of studies (%) | No. of cases (%) | Authors and year | RTP information included |
|---|---|---|---|---|
| American Football | 6 (22) | 9 (7) | Forbes et al, 2013[39]; Weinstein et al, 2013[26]; Treister et al, 2014[24]; Pascoe et al, 2015[27]; Jeon et al, 2016[25]; Yengo-Kahn et al, 2017[3] | 2/6 (33%) |
| Soccer | 5 (19) | 5 (4) | Edmondson et al, 2014[36]; Takizawa et al, 2015[18]; Ellis et al, 2018[20]; Furtado et al, 2019[35]; Mummareddy et al, 2019[4] | 3/5 (60%) |
| Ice hockey | 3 (14) | 3 (2) | Ellis et al, 2015[34]; Bonfield and Kondziolka 2016[28]; Degen et al, 2016[2] | 2/3 (67%) |
| Judo | 3 (14) | 3 (2) | Takizawa et al, 2015[18]; Yokota and Ida, 2016[29]; Scramstad et al, 2017[30] | 0/3 (0%) |
| Bicycle | 2 (9) | 2 (2) | Seddighi et al, 2012[17]; Takizawa et al, 2015[18] | 0/2 (0%) |
| Boxing | 2 (9) | 2 (2) | Falvey and McCrory, 2015[1]; Kariyanna et al, 2019[19] | 1/2 (50%) |
| Equestrian | 2 (9) | 84 (66) | Guyton et al, 2013[23]; Connor et al, 2019[22] | 0/2 (0) |
| Skiing | 2 (9) | 2 (2) | Mitsis et al, 2014[32]; Takizawa et al, 2015[18] | 0/2 (0%) |
| Dodgeball | 1 (5) | 1 (1) | Ellis et al, 2016[21] | 1/1 (100%) |
| Rugby | 1 (5) | 1 (1) | Tator et al, 2019[31] | 0/1 (0%) |
| Snowboarding | 1 (5) | 1 (1) | Takizawa et al, 2015[18] | 0/1 (0%) |
| Snowmobiling | 1 (5) | 13 (10) | Plog et al, 2014[33] | 0/1 (0%) |
| Taekwondo | 1 (5) | 1 (1) | Kertmen et al, 2012[37] | 0/1 (0%) |
| Weight-training | 1 (5) | 1 (1) | Park et al, 2013[38] | 0/1 (0%) |
| Totals | 27 | 128 | – | 9/27 (33%) |

RTP = return-to-play; bold = RTP information included.

**TABLE 2. Cases of Sport-Related Structural Brain Injuries With RTP Information**

| Authors and year | N | Sport/level | Injury | Management | Return to play |
|---|---|---|---|---|---|
| Mummareddy et al, 2019[4] | 1 | Soccer/high school | EDH (26 mm, 2 mm MLS) | Craniotomy | Returned 3 mo after surgery; no complications |
| Ellis et al, 2018[20] | 1 | Soccer/high school | Multifocal small IPH (no mass effect) | Nonoperative | Told to avoid contact/collision sports |
| Yengo-Kahn et al, 2017[3] | 3 | Football/high school | Bifrontal SDH (3 mm R, 2 mm L, 0 mm MLS); R SDH (9 mm, 8 mm MLS); L SDH (12 mm, 10 mm MLS) | Nonoperative; craniotomy; hemicraniectomy | Told to avoid contact/collision sport; no RTP any sport; incapacitated |
| Degen et al, 2016[2] | 1 | Ice hockey/ | L IPH 13 mm, L SDH 2 mm (0 mm MLS) | Nonoperative | Returned 3 mo postinjury; no complications |
| Ellis et al, 2016[21] | 1 | Dodgeball/middle school | Small L frontoparietal IPH (no mass effect) | Nonoperative | Returned to ice hockey before neurosurgical consultation; recommended to avoid contact sport after neurosurgical consultation |
| Ellis et al, 2015[34] | 1 | Ice hockey/middle school | Right occipital IPH (no mass effect) | Nonoperative | Avoid future contact/collision sports; remained symptomatic (headache, nausea, photophobia, irritability) 144 d postinjury |
| Falvey and McCrory, 2015[1] | 1 | Boxing/professional | R SDH (10 mm, 0 mm MLS) | Nonoperative | SDH resolved at 8 wk postinjury; returned to professional boxing 3 mo after SDH resolved; no complications |
| Edmondson et al, 2014[36] | 1 | Soccer/high school | L subacute SDH with arachnoid cyst (12 mm, 10 mm MLS) | Burr hole for SDH; arachnoid cyst no treatment | Placed on sports restriction until resolution of subdural hematoma; no further follow-up |
| Forbes et al, 2013[39] | 2 | Football/high school | L SDH (11 mm, 6 mm MLS); L SDH (4 mm, 0 mm MLS) | Craniotomy; nonoperative | Avoid contact/collision sport for both |

EDH = epidural/extradural hematoma, IPH = intraparenchymal hemorrhage, SDH = subdural hematoma, MLS = midline shift, ED = emergency department.

**TABLE 3. Demographics of Participating Sports Neurosurgeons**

| Characteristic | Value N = 31 |
|---|---|
| Country, n (%) | |
| United States | 22 (71.0%) |
| Australia | 4 (12.9%) |
| Canada | 2 (6.5%) |
| England | 1 (3.2%) |
| Italy | 1 (3.2%) |
| New Zealand | 1 (3.2%) |
| **Years of experience, mean (SD), range** | 23.6 (14.0); 5-50 |
| Level n (%) | |
| Youth | 21 (67.7%) |
| High school | 24 (77.4%) |
| Collegiate | 28 (90.3%) |
| Professional | 27 (87.1%) |
| Sport, n (%) | |
| American football | 24 (77.4%) |
| Soccer | 18 (58.1%) |
| Hockey | 13 (41.0%) |
| Lacrosse | 11 (35.4%) |
| Rugby | 11 (35.4%) |
| Car Racing | 6 (19.4%) |
| Boxing/mixed martial arts | 4 (12.9%) |
| Australian football | 3 (9.7%) |
| Basketball | 2 (6.5%) |
| Wrestling | 2 (6.5%) |
| Baseball | 1 (3.2%) |
| Gymnastics | 1 (3.2%) |
| Motorcross | 1 (3.2%) |
| Winter sports | 1 (3.2%) |

**TABLE 4. Operative Intervention in an Asymptomatic Athlete With SRSBI**

| Characteristic | N |
|---|---|
| If an athlete has suffered an SRSBI but remains asymptomatic, would you operate? n (%) | N = 31 |
| *No operation* if asymptomatic (regardless of imaging) | 12 (38.7%) |
| *Yes operation* though asymptomatic | 19 (61.3%) |
| Among those who would operate on an asymptomatic patient, what is your indication for operating? n (%) | N = 19 |
| Midline shift > 10 mm | 12 (63.2%) |
| Size > 10 mm | 10 (52.6%) |
| Midline shift > 5 mm | 5 (26.3%) |
| Increased size on serial imaging | 3 (15.8%) |
| Any cortical mass effect | 1 (5.3%) |
| Depends on discussion with patient | 1 (5.3%) |

and 15% for high school and collegiate athletes, respectively. RTP with persistent hemorrhage was more conservative with 41% not allowing any sports. RTP after burr holes was most commonly at 6 mo (50%). The majority allowed RTP at 6 mo (43%) post-craniotomy.

### *Effect of Level of Play on RTP Decisions*

After determining *RTP Assessment Scores* and aggregating all question responses to combine all levels of play, a shift in RTP responses was seen, with earlier RTP recommended for increasing level of play (Figure 1). Mean *RTP Assessment Scores* for each level of play are summarized (Figure 2A). Linear regression demonstrated that earlier RTP was recommended for increasing higher levels of play (college and professional sports) ($\beta = -0.58$, 95% CI –0.111, –0.005, $P = .033$) (Figure 2B). Of note, the dependent variable (*RTP Assessment Score*) was a categorical variable converted to an ordinal scale, and thus no numerical concluding statement was made.

## DISCUSSION

Though neurosurgeons are frequently involved in determining RTP following SRSBI, evidenced-based recommendations addressing the nuances of these injuries do not exist. A 2012 systematic review revealed little evidence to guide RTP decision making, and published expert opinion[6,9] appears to differ from what actually occurs in practice.[10] This study sought to address this complex topic through an updated literature review and expert insights, in order to provide a summary that neurosurgeons may consider when counseling athletes on RTP following SRSBI.

### Key Results

The post-2012 systematic review yielded only 12 patients suffering from SRSBI with a wide variety of RTP decisions. Of the 5 patients who underwent operations, only 1 returned to sports without restrictions, at 3 mo postoperatively following EDH evacuation. Of 7 patients managed nonoperatively, the predominant injury patterns were IPH (n = 3) or SDH varying from 2 to 10 mm in maximal thickness (n = 4). No patients with midline shift >5 mm were managed nonoperatively. Only 2 of 7 patients managed nonoperatively returned to sport (both at 3 mo postinjury) without apparent restriction, the remaining 5 were advised to avoid contact/collision sports indefinitely. These findings suggest wider variability in decision-making than the 1-yr benchmark that previously published expert opinion suggested.[6,11]

Expert survey results among 31 international sports neurosurgeons revealed a variety of important trends. While 38.7% would not operate on an acute asymptomatic SRSBI regardless of imaging, 61.3% would operate if midline shift and/or hemorrhage size >10 mm were present. Responses to each question were relatively heterogeneous, as a similar portion responded with either no RTP or return after 6 to 12 mo. Very few (~3%) respondents considered RTP prior to 6 mo post-injury in any of the scenarios. A statistically significant association between level of play and management was seen, where earlier RTP was recommended for more elite athletes.

**TABLE 5.** **RTP Time for Clinical Scenarios and Level of Sport**

| | High school | Collegiate | Professional |
|---|---|---|---|
| Previous SRSBI, asymptomatic and resolved hemorrhage, when RTP? n, (%) | N = 27 | N = 27 | N = 27 |
| No RTP to any sport | – | – | – |
| No RTP to collision; encourage less contact sport | 6 (22.2%) | 4 (14.8%) | 2 (7.4%) |
| 3 mo | – | – | – |
| 6 mo | 9 (33.3%) | 10 (37.0%) | 11 (40.7%) |
| 9 mo | – | 1 (3.7%) | 1 (3.7%) |
| 1 yr | 10 (37.0%) | 9 (33.3%) | 9 (33.3%) |
| 2 yr | 2 (7.4%) | 3 (11.1%) | 4 (14.8%) |
| Previous SRSBI, asymptomatic and hemorrhage still present, when RTP? n, (%) | N = 28 | N = 27 | N = 27 |
| No RTP to any sport | 11 (39.2%) | 11 (40.7%) | 11 (40.7%) |
| No RTP to collision; encourage less contact sport | 13 (46.4%) | 11 (40.7%) | 10 (37.0%) |
| 3 mo | 1 (3.6%) | – | – |
| 6 mo | 2 (7.1%) | 4 (14.8%) | 5 (18.5%) |
| 9 mo | 1 (3.6%) | 1 (3.7%) | 1 (3.7%) |
| 1 yr | – | – | – |
| 2 yr | – | – | – |
| Previous burr holes, asymptomatic and resolved hemorrhage, when RTP? n, (%) | N = 30 | N = 30 | N = 30 |
| No RTP to any sport | – | 1 (3.3%) | 1 (3.3%) |
| No RTP to collision; encourage less contact sport | 11 (36.7%) | 8 (26.7%) | 4 (13.3%) |
| 3 mo postop | – | 1 (3.3%) | 1 (3.3%) |
| 6 mo postop | 11 (36.7%) | 10 (33.3%) | 14 (46.7%) |
| 9 mo postop | – | 1 (3.3%) | – |
| 1 yr postop | 7 (23.3%) | 8 (26.7%) | 8 (26.7%) |
| 2 yr postop | 1 (3.3%) | 1 (3.3%) | 2 (6.7%) |
| Previous craniotomy, asymptomatic and resolved hemorrhage, when RTP? n, (%) | N = 30 | N = 30 | N = 30 |
| No RTP to any sport | 2 (6.7%) | 2 (6.7%) | 2 (6.7%) |
| No RTP to collision; encourage less contact sport | 15 (50.0%) | 12 (40.0%) | 9 (30.0%) |
| 3 mo postop | – | 1 (3.3%) | 1 (3.3%) |
| 6 mo postop | 10 (33.3%) | 12 (40.0%) | 12 (40.0%) |
| 9 mo postop | 1 (3.3%) | 1 (3.3%) | 2 (6.7%) |
| 1 yr postop | 2 (6.7%) | 2 (6.7%) | 3 (10.0%) |
| 2 yr postop | – | – | 1 (3.3%) |

## Interpretation

The systematic review confirmed the scarcity of published evidence and heterogeneity of RTP recommendations provided. Our survey of experts confirmed the wide-ranging neurosurgical opinions for these complex decisions. In terms of operative management, the fact that nearly 40% of neurosurgeons surveyed would not operate acutely on an *asymptomatic* athlete with structural brain injury irrespective of imaging findings emphasizes the unique clinical considerations in this population. However, most respondents utilized imaging indications for surgery similar to guidelines published for acute SDH, >10 mm in thickness or >5 mm of midline shift, though the majority considered midline shift >10 mm.[40] The systematic review suggested published cases adhered to these guidelines as nearly all patients with SDH meeting these criteria underwent surgical interventions and those with smaller hemorrhages did not.

In considering RTP decisions, numerous consensus and evidence-based guidelines exist for RTP following SRC and general pediatric mild traumatic brain injury.[12,41,42] These guidelines almost uniformly recommend a RTP process involving a graduated activity paradigm once the athlete has achieved asymptomatic status. While these guidelines should be followed in the context of SRSBI, they do not adequately address the additional nuances of structural brain injuries. These nuances include whether there has been resolution of imaging abnormalities, whether a craniotomy was performed, and what degree of risk of subsequent structural injury is acceptable. Previously, authors have sought to provide limited expert opinion on some of these topics through case discussions[9] and narrative reviews.[6,43] Generally, these authors required athletes to be asymptomatic with resolution of intracranial hemorrhage as well as brain re-expansion in the case of SDH. Additionally, as Davis et al[9] described, return to collision sports prior to 1 yr was not advisable following craniotomy as this is the length of time required for full bony fusion. Overall, these prior works do well to set the stage for needed guidance on SRSBI, but limitations in their scope necessitate the more direct approach used in the current study.

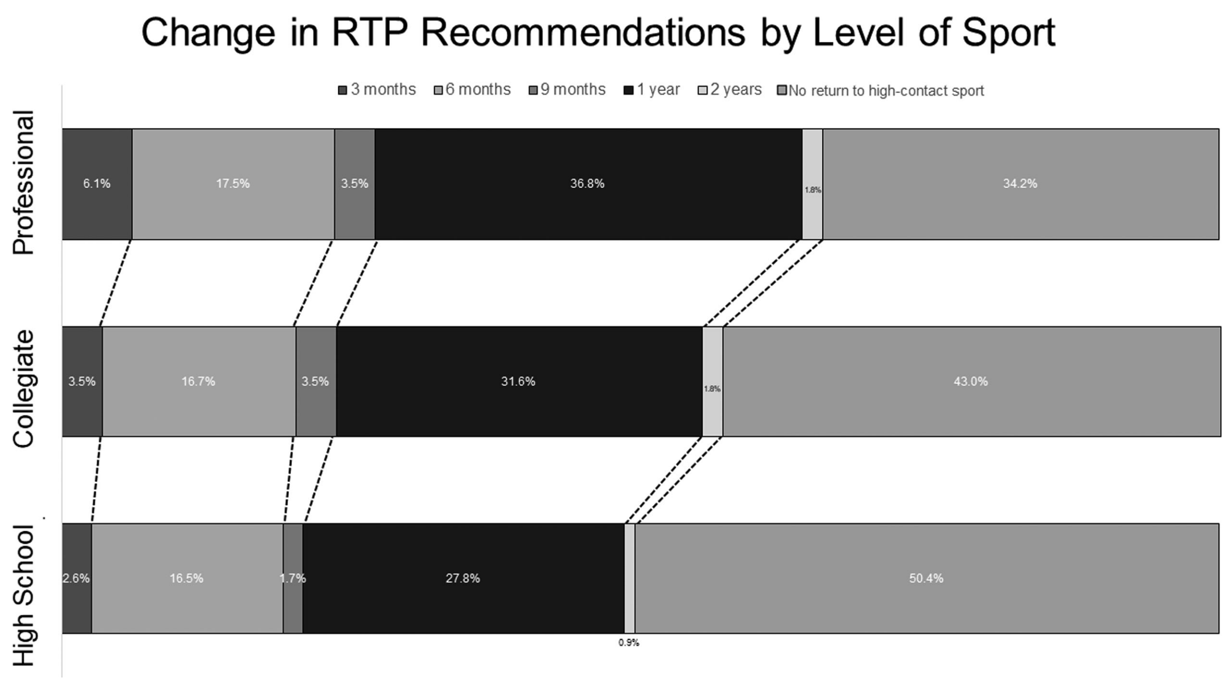


**FIGURE 1.** *Change in return-to-play recommendations by level of sport.*

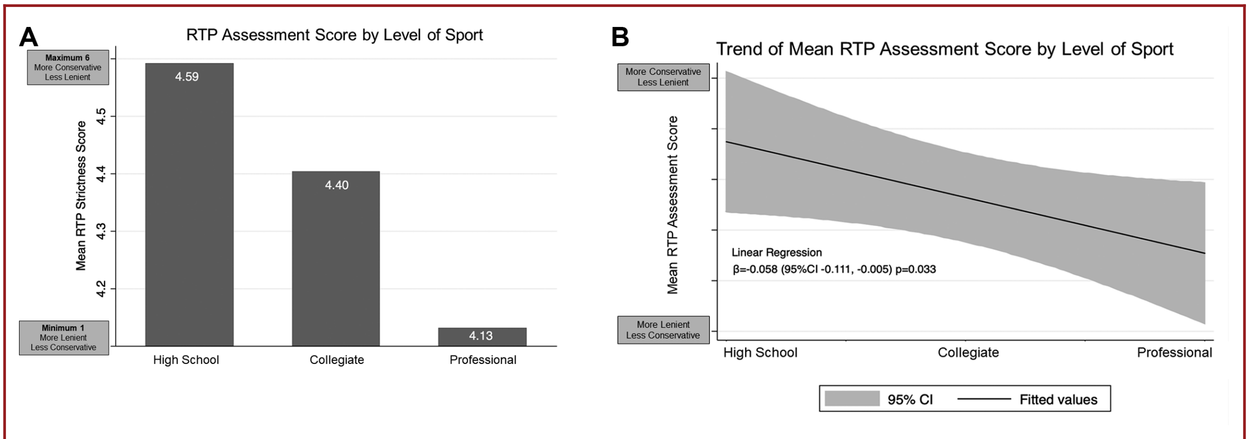


**FIGURE 2.** **A**, *RTP assessment score by level of sport;* **B**, *trend of mean RTP assessment score by level of sport with linear regression confirming increasing leniency (less conservative) return-to-play recommendations as level of sport increases.*

Our survey respondents were nearly split on whether to allow RTP to collision sports following craniotomy with resolution of symptoms and hemorrhage, with most respondents allowing RTP at 6 mo rather than 1 yr. These responses are more consistent with a prior survey of American Association of Neurological Surgeons members' cases of children who RTP after craniotomy for any reason in which over 30% reported RTP clearance at 3 to 6 mo following craniotomy and nearly all respondents reported RTP clearance before 1 yr.[10]

The results of the systematic review expectedly mirrored the heterogeneity of our survey results and previously published work. Of the 12 athletes included in the systematic review with RTP information, the 3 who returned to their original sport were cleared after 3 mo, a faster timeline than would be considered by most respondents to our survey. One high-school soccer player was returned 3 mo after a craniotomy, which was not recommended by any expert surveyed. The 2 remaining athletes who returned to their high-contact/collision sport were professionals. Moreover, 4 younger athletes who recovered entirely following nonoperative management were withheld from contact/collision sports indefinitely, which was recommended only by less than a quarter of survey respondents. Additionally, prior expert opinion would also suggest that these athletes would generally be allowed to RTP by 1 yr postinjury.[6,9] These results confirm the sparse evidence-based guidance at the neurosurgeon's disposal, and underscore the heterogeneity of sequalae and management.

## Key Insight for Return to Play After SRSBI

Given the heterogeneity of RTP practices, a multimodal approach to the RTP decision is warranted, including neuropsychological testing, validated symptom checklists, postural stability testing, vestibular and oculomotor testing, and a thorough physical exam. These decisions should also consider the patient's initial clinical presentation, past medical and concussion history, and results from other investigations where applicable, such as visual field testing. Furthermore, the usual stepwise RTP process used after a concussion[12] should be followed after SRSBI. In the context of this survey, it was assumed that the athletes in question were asymptomatic without any lingering deficits and had already passed graded exertional protocols.

Based upon the survey results reported herein, we offer the following insight to guide the RTP process for high-contact/collision sport athletes. The survey results from 31 international neurosurgeons provide an expert perspective to guide RTP decisions after SRSBI. We acknowledge that these results reflect opinion only and do not represent formal evidence-based guidelines, consensus recommendations, or the official view of any registered neurosurgical society or organization with which the authors are affiliated. It must be strongly emphasized that the RTP decision involves much more than merely reviewing the diagnostic imaging results. Providers must ensure that athletes are apprised of all the potential short- and long-term risks associated with RTP following structural brain injury to make an informed decision, and athletes should be encouraged to seek multiple opinions.

1. In the acute management of SRSBI in an *asymptomatic patient*, operative indications are similar to nonathletes[40] and are most commonly hemorrhage size >10 mm, midline shift >10 mm, or increased size on serial imaging. It is assumed that if the athlete suffered an SRSBI and was symptomatic, operative management is pursued in accordance with Brain Trauma Foundation surgical management guidelines.[40,44]
2. Following SRSBI with resolved hemorrhage, with or without burr holes, RTP, when considered, is not recommended prior to 6 mo postinjury.
3. The majority of respondents do not recommend returning to high-contact/collision sports SRSBI with persistent hemorrhage on diagnostic imaging; however, resuming a low-contact sport may be considered. A minority of neurosurgeons allowed RTP to collision sports, most commonly at the professional level.
4. Following craniotomy for SRSBI with symptom and hemorrhage resolution, respondents most frequently recommended changing to a low-contact sport. Respondents who allowed RTP considered 6 mo the earliest time to return to high-contact/collision sports.
5. Experts recommend RTP earlier for higher level of sport, where expert medical personnel are available for all practice and game day events.

## Limitations

This study has several limitations. The systematic review was restricted to PubMed only, and it is possible that cases of SRSBI may have been missed if reported in other databases. In addition, it is also likely that cases of SRSBI exist that have not been published. The survey results were based on hypothetical patient scenarios, rather than documented clinical cases. In addition, no imaging was provided for each scenario, though this was done intentionally. While imaging would have allowed a better description of each case, it would have also limited the conclusions to that specific case, which conflicts with our objective to provide broad foundational insight on which more individualized RTP plans may be based. Conversely, the lack of imaging may have led to respondents misinterpreting questions. For example, "craniotomy" was left vague and the extent and location of the craniotomy may influence decision making, and these factors were not considered for this study. We believe that all respondents understood craniotomy to mean bone flap replacement during closure, and not decompressive hemicraniectomy, but this is another possible misinterpretation. Furthermore, the specific high-contact sport(s) in question were not outlined. The differences in frequency and amplitude of forces to the head vary significantly between sport, yet they were not accounted for in the current study.

Moreover, the sport neurosurgeons surveyed were overwhelmingly from North America without representation from South America or Africa. Thus, these results may not be applicable to sports commonly played in these regions and highlight a need to learn more about SRSBI in these areas of the world. To that end, it is possible that several experienced sport neurosurgeons may have been excluded inadvertently in the completion of this survey. Additionally, while most respondents had experience counseling all levels of athletes, experience was relatively weighted toward collegiate and professional athletes, which may have influenced responses. There were also no a priori criteria or qualifications for respondents to be included in the survey. In future studies, a codified set of clinical experience minimums may be considered.

The respondent neurosurgeons were intentionally blinded to the results of the systematic review prior to completing the survey. It is possible that some neurosurgeons may have responded differently if provided with the systematic review results prior to survey completion.

We did not explore issues such as bone union following craniotomy, encephalomalacia, parenchymal calcification, or residual parenchymal T2-weighted MRI abnormalities. Similarly, for questions regarding persistent hemorrhage, it is conceivable that responses would vary by the length of time since injury; however, this was not addressed in the survey. In addition, the RTP decision is complex and involves many variables including the patient's clinical presentation, past medical history, physical examination findings, and results of neuropsychological testing and other investigations. The nature of our survey oversimplified the RTP process, and it is likely that the RTP decision requires additional neurological information not provided.

Finally, the summary of insight provided is based on an overall low level of evidence including mainly case reports and expert opinion. These insight are meant as a starting point for neurosurgeons faced with RTP decisions with the understanding that RTP decisions are multifaceted and require individualization.

## CONCLUSION

Neurosurgeons are asked to clear athletes for return to sport after structural brain injury with little evidence-based guidance. Aggregated expert opinions based on a survey of 31 sports neurosurgeons from around the world yielded a variety of important trends regarding SRSBI and RTP, most importantly that level of play is an important factor in the RTP process. Until consensus recommendations or evidence-based guidelines are developed empirically, the resultant insight can provide preliminary guidance for all sports physicians, and specifically neurosurgeons, on a safe management paradigm to manage RTP after structural brain injury in athletes of varying levels of play.

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**Appendix 1.** Search terms used in updated systematic review.
**Appendix 2.** Survey.
**Appendix 3.** PRISMA guidelines.
**Appendix 4.** Summary of all 27 included studies.