Concussions in ice hockey: mixed methods study including assessment of concussions on games missed and cap hit among National Hockey League players, systematic review, and concussion protocol analysis

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OBJECTIVE Concussions can occur at any level of ice hockey. Incidence estimates of concussions in ice hockey vary, and optimal prevention strategies and return-to-play (RTP) considerations have remained in evolution. The authors performed a mixed-methods study with the aim of elucidating the landscape of concussion in ice hockey and catalyzing initiatives to standardize preventative mechanisms and RTP considerations.

METHODS The authors performed a five-part mixed-methods study that includes: 1) an analysis of the impact of concussions on games missed and income for National Hockey League (NHL) players using a publicly available database, 2) a systematic review of the incidence of concussion in ice hockey, 3) a systematic review of preventative strategies, 4) a systematic review of RTP, and 5) a policy review of documents from major governing bodies related to concussions in sports with a focus on ice hockey. The PubMed, Embase, and Scopus databases were used for the systematic reviews and focused on any level of hockey.

RESULTS In the NHL, 689 players had 1054 concussions from the 2000–2001 to 2022–2023 seasons. A concussion led to a mean of 13.77 ± 19.23 (range 1–82) games missed during the same season. After cap hit per game data became available in 2008–2009, players missed 10,024 games due to 668 concussions (mean 15.13 ± 3.81 per concussion, range 8.81–22.60 per concussion), with a cap hit per game missed of $35,880.85 ± $25,010.48 (range $5792.68–$134,146.30). The total cap hit of all missed games was $385,960,790.00, equating to $577,635.91 per concussion and $25,724,052.70 per NHL season. On systematic review, the incidence of concussions was 0.54–1.18 per 1000 athlete-exposures. Prevention mechanisms involved education, behavioral and cognitive interventions, protective equipment, biomechanical studies, and policy/rule changes. Rules prohibiting body checking in youth players were most effective. Determination of RTP was variable. Concussion protocols from both North American governing bodies and two leagues mandated that a player suspected of having a concussion be removed from play and undergo a six-step RTP strategy. The 6th International Conference on Concussion in Sport recommended the use of mouthguards for children and adolescents and disallowing body checking for all children and most levels of adolescents.

CONCLUSIONS Concussions in ice hockey lead to substantial missed time from play. The authors strongly encourage all hockey leagues to adopt and adhere to age-appropriate rules to limit hits to the head, increase compliance in wearing protective equipment, and utilize high-quality concussion protocols.

KEYWORDS head injury; return to play; sports-related concussion; TBI; traumatic brain injury

SPORTS-RELATED concussion is a traumatic brain injury resulting from biomechanical forces leading to complex pathophysiological processes that occur during sports play. Sports-related concussion can occur during ice hockey, a fast-paced sport with aggressive play during which players may reach speeds as high as 50 km/hr and rubber pucks may accelerate up to 160 km/hr. Concussions may result from collisions with players, sticks,
boards, and goalposts.\textsuperscript{2} Body checking, the act of hitting a player who has the puck in an attempt to steal the puck, is frequently responsible for concussions;\textsuperscript{2} especially when checks are made to the head.\textsuperscript{5}

The incidence of concussion in hockey is concerning, given the immediate pain, discomfort, and cognitive difficulties and association with long-term cognitive deficits and mental health problems, especially in individuals who have sustained multiple concussions.\textsuperscript{6} Concussions are also associated with financial loss among professional players.\textsuperscript{7} As a result, neurosurgeons, neurologists, neuropsychologists, public health experts, scientists, hockey players, and hockey league representatives have sought to prevent concussions through protective equipment, policies and rule changes, and training and educational curricula.\textsuperscript{8} Multidisciplinary teams have also sought to characterize the burden of concussions and return-to-play (RTP) considerations once concussions occur to mitigate injury and financial loss.

Incidence estimates of concussion in ice hockey may not be current, and optimal prevention strategies and RTP considerations have not been well-defined in ice hockey. We performed a five-part mixed-methods study involving an analysis of a publicly available dataset of National Hockey League (NHL) players, three systematic reviews, and a concussion protocol analysis with the aim of elucidating the landscape of concussion in hockey and catalyzing initiatives to standardize preventative mechanisms and RTP considerations.

\textbf{Methods}

\textbf{Study Rationale}

We performed a five-part mixed-methods study: 1) an analysis of the impact of concussions on games missed and income for NHL players, 2) a systematic review of concussion incidence in hockey, 3) a systematic review of preventative strategies, 4) a systematic review of RTP, and 5) a policy review of documents from major governing bodies related to the systematic review with a focus on hockey. This study was exempt from institutional review board approval. Patient consent was neither required nor sought, as no patient data were collected.

\textbf{NHL Player Analysis}

The publicly available NHL Injury Viz database (https://nhlinjuryviz.blogspot.com/2015/11/nhl-injury-database.html), which aggregates injury absence data and cap hit of injured players from injury reports on publicly available websites, was accessed in January 2024. This database has injury report data from the regular season and playoffs of the 2000–2001 season to the 2023–2024 season, apart from the 2004–2005 season, which was cancelled due to a lockout,\textsuperscript{9} and cap hit data from the 2008–2009 season to the 2023–2024 season. Cap hit of injured players represents the per-game salary cap charge of missing a game (i.e., the salary for the year divided by the number of games in the season). The database was filtered by injury type for players listed as having a “concussion.” The injury type of “head” was excluded due to its nonspecific description, potentially including lacerations or headaches rather than concussions. The database was imported into Stata 17 (StataCorp LLC), where the 2023–2024 season data were eliminated as the current season at the time of this paper’s writing. Summary statistics were produced at the level of the entire cohort and players. Cap hit values are presented as US dollars ($) at the time of injury.

\textbf{Systematic Reviews}

Systematic reviews were performed according PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.\textsuperscript{10} Systematic reviews were not registered; no protocols were prepared. All steps of the systematic reviews were performed separately for each systematic review. PubMed, Embase, and Scopus databases were searched in January 2024 using the search terms listed in Supplemental Tables 1–3, without restrictions on date, article type, or language. Deduplication was performed using the automated deduplication feature in Endnote X9 (Clarivate).

Articles were screened by title/abstract for relevance by two independent reviewers. Articles selected for full-text review were screened by two independent reviewers according to predetermined inclusion and exclusion criteria. Conflicts were reconciled by discussion. Inclusion criteria were population of ice hockey players, any level of play, any sex, any region, focused on concussion, peer-reviewed journal articles presenting quantitative primary data, and published in or translated into the English language. Exclusion criteria were abstracts, posters, chapters, conference papers, case reports, case series, reviews, and inability to differentiate the outcomes of ice hockey players from other athletes.

The epidemiology study involved additional inclusion criteria of reporting the incidence of concussions in hockey players in athlete-hours (person-hours) or athlete-exposures (person-exposures) in games, practice, or both settings, and studies with large registries. An additional exclusion criterion was unrepresentative populations, such as those presenting to an emergency department. These incidence outcomes were selected to be consistent with a previous systematic review.\textsuperscript{2} Studies that allowed calculation of the incidence metrics but did not present them were included. The prevention study had inclusion criteria of published after 2000; assessing outcomes of protective gear, rule changes/policies, behavioral/cognitive interventions, or other ideas or interventions intended to reduce the risk of concussion; educational programs; biomechanical studies; or current state of prevention initiatives. The RTP study had the extra inclusion criterion of investigating the impact of concussion on games missed, criteria or biomarkers for RTP, and interventions to reduce RTP time.

Articles selected for final inclusion were assessed for bibliographic data, study design, participants, interventions, and outcomes. No meta-analyses were performed due to the heterogeneity between included studies. The quality of included studies was denoted using GRADE (Grading of Recommendations, Assessment, Development and Evaluations).\textsuperscript{11} The ROBINS-I (Risk of Bias in Non-Randomized Studies--of Interventions) tool was used
to designate the risk of bias for included studies. The risk of bias for each systematic review was determined by aggregating the risk of bias of the included studies.

Policy

Websites of hockey governing bodies and professional, collegiate, and major junior ice hockey leagues in North America were browsed in February 2024 for available concussion protocols. Key data elements, including when players are removed from the ice following a concussion; information on signs/symptoms, diagnosis, and management; and RTP and return-to-learn (RTL) strategies were extracted. Hockey-specific recommendations from the “Consensus statement on concussion in sport: the 6th International Conference on Concussion in Sport–Amsterdam, October 2022” were summarized.12

Results

NHL Player Analysis

A total of 689 players, including 405 forwards, 235 defensemen, and 49 goaltenders, had 1054 concussions from the 2000–2001 to 2022–2023 seasons: 959 in the regular season and 95 in the playoffs. A concussion led to a mean of 13.77 ± 19.23 games missed (range 1–82 games missed) during the same season. In the period where cap hit per game data were available from 2008–2009 to 2022–2023, players missed 10,024 games due to 668 concussions (mean 15.13 ± 3.81 per concussion, range 8.81–22.60 per concussion), with a cap hit per game missed of $35,880.85 ± $25,010.48 (range across seasons $5792.68–$134,146.30) (Table 1). The total cap hit of all missed games was $385,960,790.00, equating to $577,635.91 per concussion and $25,724,052.70 per NHL season. Among players who sustained a concussion, the mean number of concussions was 1.53 ± 1.18 (range 1–18 concussions; Table 2), leading to a mean number of games missed due to concussion of 21.07 ± 47.51 (range 1–627) and cap hit due to missed games per player of $872,998.20 ± $2,756,081.00 (range across seasons $7926.83–$30,232,770.00). Data by position are displayed in Table 3.

Systematic Reviews

PRISMA flowcharts for the systematic reviews are presented in Figs. 1–3. For all systematic reviews, included studies were of moderate quality and moderate risk of bias, predisposing them to a moderate risk of bias overall. Full results with citations are included in the Supplemental Results.

Epidemiology

Of 1066 articles on epidemiology, 40 were included (Fig. 1 and Supplemental Table 4). Study periods extended from 1997 to 2018. Twenty-one (52.5%) studies focused on...
men, 4 (10%) on women, and 15 (37.5%) on both. Twenty-five (62.5%) studies examined adults, 14 (35.0%) youth, and one (2.5%) both. Of the studies examining adults only, 11 (44.0%) focused on college leagues such as the National Collegiate Athletics Association (NCAA), 9 (36.0%) professional leagues such as the NHL or international tournaments, 3 (12.0%) junior leagues, 1 (12.0%) amateur, and 1 (12.0%) multiple.

Fifteen studies reported an overall incidence ranging from 0.54 to 1.18 concussions per 1000 athlete-exposures. Twenty-three studies indicated 0.51 to 21.5 concussions per 1000 athlete-exposures for games, of which 15 studies reported between 1.45 and 3.07 concussions per 1000 athlete-exposures for games. Fifteen articles yielded 0.11 to 1.17 per 1000 athlete-exposures for practice, of which 14 articles reported an incidence of between 0.11 and 0.45 per 1000 athlete-exposures for practice.

Thirteen studies found an overall incidence of 0 to 24.30 concussions per 1000 athlete-hours, with an incidence of 0.58 to 4.70 in 11 of the studies. Five articles yielded 1.48 to 38.0 concussions per 1000 athlete-hours for games, with an incidence of 2.7 to 6.76 in 4 studies. Two reported 0.30 to 1.50 concussions per 1000 athlete-hours for practices.

Prevention

Of 1870 resultant articles on prevention, 46 were included (Fig. 2 and Supplemental Table 5). Four studies focused on education. A survey of NCAA women’s hockey players uncovered that only 65.3% received preseason concussion education. Three studies about educational curricula or videos emphasized that although there was an increase in knowledge following the intervention, there was no change in beliefs or intended behavior on the ice. The increase in knowledge was short-lived in one study. Two studies examined cognitive intervention, reporting that computerized cognitive training reduces head impacts but 3D multiple object tracking leads to more severe head impacts for forward. Two studies examining behaviors reported that physical activity is protective, while aggression is a risk factor for high head impact.

Nine studies focused on protective equipment. The studies found no difference in concussion rates between newer and older helmets, but rather inadequate helmet fit may increase the risk of concussions. Additionally, 5 studies investigated mouthguards of which 2 found reduced concussion rates. Store-bought mouthguards were found to be more effective in preventing concussion than custom-fit mouthguards. Three studies indicated that mouthguards are underutilized, not worn properly, and not enforced. Only 13.3% of players wear mouthguards more than 50% of the time during games; players were found to exhibit negative attitudes toward wearing mouthguards. Three studies on face shields/visors found no change in the concussion rate, while 1 study found decreased severity with a full-face shield relative to a half shield.

Seven studies focused on biomechanics of equipment or the environment. Four studies on helmet biomechanics found that helmets are generally protective against fall impacts but sometimes ineffective for shoulder and puck impacts. Two studies indicated that foam shoulder pads may be protective. Single-framed dasher boards with light, flexible protective shielding and without shielding supports are safest. Separately, 2 studies highlighted that there is a lower incidence of concussion on the larger international rinks relative to smaller North American rinks.

Twenty articles studied policy and rule changes. Of 4 studies examining bans on hits to the head, 2 studies, including 1 study on NHL Rule 48, found decreased

<table>
<thead>
<tr>
<th>Position</th>
<th>No. of Players</th>
<th>Total No. of Concussions</th>
<th>No. of Concussions per Player Over Career</th>
<th>Total No. of Games Missed by All Players in This Position Over Career</th>
<th>Mean No. of Games Missed Per Player Over Career (range)</th>
<th>Total Cost for Missed Games, $ [no. of games since salary cap hit data became available at beginning of 2008–2009 season]</th>
<th>Cost for Games Missed Per Player Over Career, $</th>
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<tr>
<td>Goaltender</td>
<td>49</td>
<td>70</td>
<td>1.43</td>
<td>701</td>
<td>14.31 ± 20.13 (1–115)</td>
<td>22,489,790 [40]</td>
<td>562,240</td>
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<tr>
<td>Forward</td>
<td>405</td>
<td>642</td>
<td>1.59</td>
<td>9,439</td>
<td>23.31 ± 53.89 (1–627)</td>
<td>261,689,100 [253]</td>
<td>1,034,340</td>
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concussion rates. One reported no change in head contacts, while another indicated increased concussion rates. Of 3 studies on fair play rules, 2 yielded no change in concussion rates, while the other reported a decreased concussion rate. The study on bans on hits to the head and fair play rules combined indicated a decrease in direct head contacts. Of 12 studies on policies disallowing body checking, 8 yielded lower concussion rates, while 3 did not. One found reduced head contacts.

Return to Play

Of 392 articles on RTP, 23 were included (Fig. 3 and Supplemental Table 6). Thirteen studies examined the time required for RTP and associated factors. Players missed a mean/median of 5.7 to 17.2 days and 3 to 7.5 games. Having one concussion was associated with a high incidence of repeat concussions within 1–2 months, with greater missed time following a subsequent concussion. Time missed increased by 2.25 times following each subsequent concussion. Longer time to seeing a physician, greater symptom severity, more severe head injuries, poorer tandem stance, more time in moderate/vigorous physical activity during the first 3 days after concussion, preexisting peer-related problems, and acute distress about concussion were associated with longer RTP. The presence of sex differences in RTP was equivocal. However, Ackery et al. indicated that 33% of those advised not to play returned to play.

Seven studies investigated determination of RTP. Only 50% of coaches and 74% of athletic trainers used sideline screening tools to determine RTP. Six studies examined biomarkers, including serum neurofilament light, serum tau, S100 calcium-binding protein B, and calpain-derived αII-spectrin N-terminal fragment in addition to salivary cortisol. Among serum markers, serum neurofilament light and tau-A were most associated with duration of postcon-
cusive symptoms. Three studies examined interventions to reduce RTP. Early head and neck cooling reduced time to RTP. No players returned to play on the same day of a suspected concussion following the 4th Consensus Statement on Concussion in Sport.

Policy

Concussion protocols were available for both governing bodies (USA Hockey and Hockey Canada) and 2 (NHL and NCAA) of 6 leagues (Table 4). All 4 protocols mandated that a player suspected of having a concussion be removed immediately from play. All provided information on signs and symptoms and diagnosis and management protocols, although the recommended tool for diagnosis differed. All had a six-step RTP lasting > 6 days and requiring that a healthcare professional approve RTP. USA Hockey and NCAA had RTL strategies. Hockey-specific recommendations from the “Consensus statement on concussion in sport: the 6th International Conference on Concussion in Sport–Amsterdam, October 2022” included using mouthguards for children and adolescents and disallowing body checking for all children and most adolescents.12

Discussion

The long-term clinical and functional impacts of a concussion in ice hockey are significant. Many individuals have persistent symptoms lasting months or years following concussion.64 Professional ice hockey players have subtle cognitive impairment along with serious subjective complaints and psychiatric impairment,65 including depression, anxiety, and a predisposition for neurodegenerative diseases.6,66 A landmark case series found that 5 former hockey players have neuropathology consistent with chronic traumatic encephalopathy (CTE),67 with a subsequent study reporting CTE in 6 of 11 hockey players.68 Unfortunately, the burden and effect of concussion...
in hockey continues to be underrecognized. Our mixed-methods study added to this literature by analyzing missed games and salary impact, as well as characterizing the incidence of concussion, prevention measures, and RTP. We emphasize 5 key findings. 1) Concussions in the NHL lead to many missed games and have a substantial salary impact. 2) The incidence of concussion is 0.54 to 1.18 concussions per 1000 athlete-exposures when games and practices are considered together. 3) The most effective preventative mechanism in youth age groups is disallowing body checking. 4) RTP in hockey is heavily dependent on patient-specific factors and the severity of injury, with heterogeneous standards for RTP. 5) Existing concussion protocols are quite comprehensive from initial assessment to RTP or RTL. We caution that the paucity of studies and moderate bias in the systematic reviews limit generalization. Nonetheless, this article provides a comprehensive investigation of the landscape of concussion in ice hockey.

**Cost of Concussions in Professional Hockey Players**

The economic cost of missed games is substantial. Our analysis of the publicly available database builds on a previous study that reported that concussions led to a salary loss of $42.8 million/year in the 2009–2010 and 2011–2012 NHL seasons. In addition to methodological differences, the decreasing incidence of concussion over time may explain the discrepancy between estimates. Interestingly, studies of NHL players indicate that performance remains constant or decreases to a level consistent with other injuries but resolves within a short period and does not change style of play. However, a concussion can shorten a player’s career.

**Incidence of Concussions in Hockey**

Our systematic review discovered that concussions occur in hockey players of all levels and occur more frequently in games than in practices. However, the incidence of...
<table>
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<th>Governing body</th>
<th>Remove From Play Immediately After Concussion</th>
<th>Information on Signs &amp; Symptoms</th>
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<th>Management Protocol</th>
<th>RTP Strategy</th>
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AHL = American Hockey League; CRT = Concussion Recognition Tool; ImPACT = Immediate Post-Concussion Assessment and Cognitive Testing; NA = not applicable; OHL = Ontario Hockey League; PWHL = Professional Women’s Hockey League; QMJHL = Quebec Maritimes Junior Hockey League; SCAT = Sport Concussion Assessment Tool; USHL = United States Hockey League; WHL = Western Hockey League.
concussion is highly variable across studies due to differing study populations, method of diagnosing concussion, and inclusion criteria. These estimates are prone to under-reporting due to misconceptions about injury risk and a culture that reinforces and encourages players to remain in the game.73,74 A 2013 systematic review of 17 studies noted that the incidence of concussions in hockey is 0.2 to 6.5 per 1000 game-hours, 0.72 to 1.81 per 1000 athlete-exposures, and 0.1 per 1000 practice-hours.2 Our systematic review of concussion epidemiology provides updated estimates for the incidence of concussion as expressed in different metrics with greater delineation between overall, game, and practice scenarios. The previous systematic review suffers from the key limitation of limited literature on any incidence metric. It is also important to note that our systematic review has methodological strengths relative to the previous systematic review. We used more comprehensive search terms, only included peer-reviewed journal articles rather than posters and abstracts, and graded study quality and risk of bias. We note that the moderate risk of bias and heterogeneous included studies indicate caution must be exercised when interpreting incidence. Unfortunately, our study could not determine separate incidences for men and women or across different skill levels or leagues.

Prevention

Prevention strategies can be grouped as individual, referring to protective measures that a player may take, or system-based, defined as changes to how the game is played or its environment. Individual strategies not directly related to play, including education, cognitive training, and behavioral intervention, may not be effective. Our systematic review indicated that effective individual interventions such as protective equipment, namely well-fitting helmets and mouthguards,21,22 have limited effectiveness due to their inability to protect against certain types of hits and dependence on individual behavior.25,30–33 This is similar to a 2016 systematic review that indicated that protective equipment did not decrease concussion rates.75 It is possible that systems-based interventions are more effective, especially if they alter the rules of the game to preempt actions that lead to concussion. Most studies on disallowing body checking in hockey in youth age groups found a reduced incidence of concussion.47–54 Banning hits to the head, such as in NHL Rule 48, is effective.39,40 Fair play rules may be less effective alone because they are reactive rather than proactive in limited literature.43,44 but may be effective when combined with bans on hits to the head.56 This is especially important in hockey, where penalties are routinely leveled to punish rule-breaking and may not function as appropriate punishments. Given their different strengths, individual and systems-based strategies may be combined to develop a comprehensive prevention strategy. However, the moderate risk of bias in this systematic review indicates that further study is necessary.

Return to Play

RTP in hockey has been heterogeneous. A paucity of studies indicates that RTP is generally based on clinical signs and symptoms and an ability to tolerate a certain level of activity. Recently, investigators have sought to characterize biomarkers for RTP, although their additive utility relative to the clinical picture is questionable. Moreover, available literature on RTP is subject to moderate bias, reducing the weight of these initiatives. Fortunately, major North American governing bodies have high-quality concussion protocols illustrating steps for RTP. At present, these protocols involve six steps, with each lasting >24 hours. These protocols should be studied for effectiveness and continue to be modified as best practices for RTP are uncovered.

Limitations

The NHL database had cap hit data from 2008–2009 onward, limiting characterization of the full financial cost of games missed due to concussions. Cap hit was expressed in dollars at the time of the injury, rather than discounted to the present, due to an inability to access interest rates at the time of injury, precluding determination of the cost of missed games in present-day dollars. The policy analysis failed to retrieve 4 concussion protocols from leagues. These leagues may have internally accessible concussion protocols. The lack of access to these protocols prevented comprehensive characterization of the depth and breadth of concussion protocols in North American leagues. The systematic reviews were limited by the inclusion of published studies with full text, placing results at risk for publication bias. Literature on the process of RTP specific to hockey was limited. All studies had moderate risk of bias, reducing the weight of study findings. No meta-analysis was conducted due to heterogeneity of populations, methodologies, and outcomes, preventing determination of a point estimate and confidence interval for the incidence of concussion or the effectiveness of certain preventative measures. Studies were aggregated across skill levels, age, and sex, precluding prevention recommendations specific to certain groups.

Conclusions

In addition to medical concerns, concussion leads to substantial missed time from play financial impact for professional players. Implementation and enforcement of rules prohibiting body checking in younger age groups are the most effective intervention in reducing the incidence of concussion, while banning hits to the head, imposing strict penalties for dangerous play, and mandating consistent wearing of well-fitting helmets and mouthguards may be useful in all age groups. RTP is highly variable based on patient factors and the severity of the concussion. However, literature in our systematic reviews provided moderate bias and, for certain analyses, was limited. Major North American hockey governing bodies have high-quality concussion protocols from the time of injury to RTP or RTL. We strongly encourage hockey leagues to adopt and adhere to age-appropriate rules that limit hits to the head, increase compliance in wearing protective equipment, and utilize high-quality concussion protocols.

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**Disclosures**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

**Author Contributions**

Conception and design: Shlobin. Acquisition of data: Shlobin, Goel. Analysis and interpretation of data: Shlobin, Chen. Drafting the article: Shlobin. Critically revising the article: Goel, Chen, Kondziolka. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Shlobin. Statistical analysis: Chen. Study supervision: Kondziolka.

**Supplemental Information**

Online-Only Content

Supplemental material is available online. Supplemental Tables and Results. https://thejns.org/doi/suppl/10.3171/2024.4.FOCUS24103.

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