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Cervical Spine Injuries in the Ice Hockey Player: Current Concepts in Epidemiology, Management and Prevention

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Abstract

Study Design: This review article examines the biomechanics that underly hockey-related cervical spine injuries, the preventative measures to curtail them, optimal management strategies for the injured player and return to play criteria.

Objective: Hockey is a sport with one of the highest rates of cervical spine injury, but by understanding the underlying pathophysiology and context in which these injuries can occur, it is possible to reduce their incidence and successfully manage the injured player.

Methods: Multiple online databases including PubMed, Google Scholar, Columbia Libraries Catalog, Cochrane Library and Ovid MEDLINE were queried for original articles concerning spinal injuries in ice hockey. All relevant papers were screened and subsequently organized for discussion in our subtopics.

Results: Cervical fractures in ice hockey most often occur due to an increased axial load, with a check from behind the most common precipitating event.

Conclusions: Despite the recognized risk for cervical spine trauma in ice hockey, further research is still needed to optimize protocols for both mitigating injury risk and managing injured players.

Keywords

cervical spine, ice hockey, spine trauma, burst fracture, rink-side management, sports injury, cervical spine management, return to play

Introduction

Ice hockey is a sport played by over 77 nations with greater than 350,000 players under the age of 18 registered with USA hockey alone.[1] Hockey is the national sport of Canada and it is quickly becoming one of the most popular sports played in all of North America.[2,3] However, some of the most exciting aspects of hockey, including the speed and aggression of players, also generate the potential for serious injury. Current trends reveal that players are only getting bigger, heavier and faster, thus intensifying these risks.[4] Within the United States, an estimated 20,000 players present to the emergency room annually with a hockey-related injury.[5] In the 2010 Winter Olympics, ice hockey had the highest rate of injuries per player compared to any other sport at the competition.[6] While any type of injury is unfortunate, some can be especially devastating, such as cervical spine injuries. Since 1990, sporting events have been the fourth leading cause of spinal cord injury just behind motor vehicle accidents, violence and falls.[7] In fact, sports are the second leading cause of spinal cord injuries for individuals under the age of 30.[8] While American football receives the majority of attention regarding cervical spine injuries, ice hockey players are 3 times more likely to experience a cervical spine injury than football players.[9] Literature has shown that ice hockey has the highest incidence of cervical spine injury of any sport.[1]

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Despite the numerous interventions throughout the history of ice hockey, spinal cord injuries remain an important consideration in ice hockey.[10] This review article will examine the history, epidemiology, biomechanics, rink-side management and return-to-play considerations as related to cervical spinal injuries in ice hockey.

Methods

A comprehensive literature review search was conducted across a number of platforms to amass the utilized data. The platforms and databases used to collect the referenced sources included PubMed, Google Scholar, Columbia Libraries Catalog, Cochrane Library and Ovid MEDLINE. A number of independent searches were conducted for each of the subtopics included in this article. The initial search criteria utilized "spine injury ice hockey." After manually screening the results via the abstracts for relevance, further searches were conducted for specific subtopics. This was accomplished by using key phrases or keyword-based advanced searches. These phrases (or keyword/synonym combinations) included "return to play criteria," "ice hockey spine fracture biomechanics," "ice hockey injuries," and "injured ice hockey player management." All papers, irrespective of their publish date, were included in the search criteria. Our data collection process was completed in April of 2020 and therefore this literature review contains information up until that date.

Articles were selected based on their relevance to any of the subtopics within this review. Many articles were necessary to cover the individual subtopics within this review in adequate depth. No significant exclusion criteria were established, allowing for all relevant material to be considered. Any paper offering significant input was analyzed and incorporated to achieve the greatest depth and scope possible.

History of Preventative Measures

In the 1980s there was a dramatic and unexpected rise in spinal cord injuries in ice hockey.[11] In 1984 it was shown that the major precipitating event for a spine injury was checking from behind.[12,13] In an effort to curtail these injuries, the Canadian Amateur Hockey Association established a 10-minute major penalty for checking from behind in the 1985-1986 season. This penalty served as a major deterrent and subsequently reduced the incidence of cervical spine injuries drastically.[11,14] Since that first intervention, a number of other preventative measures have been enacted to further reduce cervical spine injuries. As previously mentioned, the primary mechanism for cervical spine injury in ice hockey is a check/push from behind, thus propelling a person forward, most often colliding headfirst with the boards.[9] Equipped with this information, organizations have used targeted campaigns to reduce the frequency and likelihood of this situation. USA hockey began the "Heads Up, Don't Duck" program in 1995 to prevent checking positions that risked generating an axial load to the top of the head.[15] The Fair Play Program was also established to prevent injuries[16] and utilized a point system to reward teams who committed minimal penalties.[17] Fair Play was shown to reduce penalties and had some evidence that it reduced injuries as well.[17,18] Other educational measures to reduce injuries have included "Smart Hockey: More Safety, More Fun!,"[10] Safety Towards Other Players (STOP), and many others targeting players, coaches and parents.[14]

Epidemiology

Ice hockey has 3-6 times the incidence of cervical spine injuries and spinal cord damage compared to American football.[7,19,20] Over 1/3 of all cervical spine injuries were the result of a check from behind.[9,14] A number of studies have shown that injuries, including cervical spine damage, occur at a much higher rate during competition as compared to practice,[21-27] likely due to the elevated intensity of gameplay.[23,28] One study examined 241 ice hockey players who suffered spinal fractures or dislocations. They found that 52% of injuries in players with cervical spine trauma resulted in permanent spinal cord injury with 25% of the subjects experiencing a complete spinal cord injury.[7,29] Tragically, 4% of these injuries were fatal. Previously, the hockey community debated whether the mandatory use of helmets paradoxically increased the rate of cervical spine injuries as a result of the players pushing their limits due to the sense of safety. This notion has since been debunked and multiple studies refute the hypothesis that helmets increase head or neck injuries.[30-32]

Some of the initial landmark analyses of cervical spinal injuries in ice hockey were completed by Tator et al. looking back to 1966. Tator examined major spinal injuries, which he defined as any fracture or dislocation of the spine of a hockey player with or without injury to the spinal cord or nerve roots.[33,34] From 1966 to 1993 an average 8.9 of these major spinal injuries took place per year in Canada.[29] Injuries between the years 1982 and 1993 increased to an average of 16.6.[33] Concerningly, these studies also found that 64% of major spinal injuries in ice hockey were experienced by players between the ages of 11 and 20 years old. Another 19% of injuries were suffered by players between the ages of 21 and 30. Tator's third study published in 2009 revealed an average of 6.7 major spinal injuries occurred per year between 2000 and 2005.[13] A fourth Tator study published in 2016 demonstrated an average of 7.3 major spinal injuries occurred per year between 2006 and 2011.[14]

Based off NCAA data from 2009 to 2014, a number of more recent studies examined subsets of ice hockey players and their unique risk/incidence of cervical spine injury. This dataset showed that during this 2009-2014 period men and women suffered 226 and 97 back/neck/spine injuries, respectively.[34] It is worth noting the larger number of injuries experienced by men is influenced by the larger absolute population of men playing ice hockey. Another interpretation of this data is that men and women experience back/neck/spine injuries at a rate of 56 and 65 per 100,000 athlete exposures. Of the 226 back/neck/spine injuries in the male cohort, 39% of these injuries were in the cervical region. This study also revealed that Division III athletes (for both sexes) had a higher injury rate than Division I athletes. Using a similar dataset, Simmons et al. built on previous findings and postulated that the differences in injury rates between men and women were due to the difference in body checking.[21] This hypothesis is in line with the finding that fewer injuries occur in practice than in competition, considering fewer body checks are delivered in practice in unpredictable ways. Of note, despite not being allowed in legal play, body checking can and does still occur in female competition and can contribute to injury rates.

Most recently, Deckey et al. published a study in 2020 examining neck and cervical spine injuries in athletes.[27] This study again utilized the data from the NCAA-Injury Surveillance Program. Using the database, Deckey et al. estimated that 11,510 neck and cervical spine injuries took place over the 5-year period for all NCAA sports. Within ice hockey alone, neck or cervical spine injury occurred at a rate of 14.67 and 11.51 (male and female, respectively) per 100,000 athlete exposures. This cervical spine injury rate was over double that compared to the all-sport average. Lastly, a recent study showed that high school cervical spine injuries in ice hockey occurred at a rate of 2.44 per 100,000 athlete exposures.[26] This was also much higher than any other sport.

Cervical Spine Fracture Biomechanics

Various studies have shown that the most common mechanism by which an ice hockey player suffers a cervical fracture is due to an increased axial load. In the vast majority of cervical spine fractures, the precipitating event is a check from behind which propelled the player into an object.[12,13,19] The most common object for this player to collide with is the boards. Additionally, when the player is first checked from behind, their head/neck is often slightly flexed as they are looking down at the puck on the ice.[19] Once the player is in motion toward the boards, the first point of contact becomes the top of their head. As the player's head strikes the boards, the head stops almost instantaneously, and is only minimally aided in deceleration by the padding contained within the helmet.[35] The remainder of the player's body, however, has yet to decelerate and continues to move toward the boards. The cervical spine therefore becomes subjected to the body's momentum and is ultimately responsible for generating the force to decelerate the remainder of the body. This subjects the cervical spine to enormous forces and subsequent compression.[29,36,37] Simulations and studies have shown collision speeds of just 1.8 m/s can cause cervical fractures in 75% of collisions,[35] and that 3.1 m/s *always* causes cervical fractures.[38] This is concerning when considering players can skate above 12 m/s, and when sliding, can reach speeds of 6.7 m/s, both of which are well above the speed needed to consistently induce cervical fractures.[39]

The slight flexion of the player's neck when colliding with the boards dramatically increases the risk of cervical fracture. In its normal lordotic position, the cervical spine has a greater capacity to absorb and disperse an axial load and utilize elasticity of the surrounding paravertebral musculature and vertebral ligaments.[37] When the neck is slightly flexed, the cervical lordosis is lost, and the cervical vertebrae become arranged linearly. In a linear arrangement, the force vector from an axial load travels parallel with the cervical spine, subjecting the vertebral bodies to extremely high forces and compression.[37,40] Under these conditions, the cervical spine is susceptible to suffering a burst fracture.

Given this biomechanical sequence, it is not surprising that the most common cervical fractures in ice hockey are burst fractures[7,35,41,42] in the C5-C7 vertebrae.[35,43-45] Fracture-dislocations, flexion teardrop fractures and disk herniations are also relatively common.[7,43] Facet dislocations are more commonly the result of hyperextension in the sagittal plane, subjecting the ligamentous structures to high tensile forces.[46-48] An axial rotation force is also capable of producing a facet dislocation. An important consideration that will be critical to both rink-side management and return-to-play decisions is whether the injury is stable. An osseous or ligamentous injury can be considered unstable if the spine no longer has the capacity to maintain its premorbid patterns of motion without causing additional injury under physiological loads.[49]

Non-Fracture Spine-Related Injuries

Outside of fractures and dislocations, there are a couple of injuries related to the spine and spinal cord worth mentioning. Burners or stingers are transient sensory and/or motor disturbances involving the arms or the legs.[50] These are often temporary and last <24 hours.[51] The temporary stretching or compression of the spinal cord or nerve roots, leading to a transient alteration of membrane permeability and calcium regulation, is believed to be the pathophysiology underlying stingers.[52] Athletes with developmental or acquired cervical stenosis are especially at risk for this phenomenon considering higher likelihood of spinal cord compression.[53-55] Transient quadriparesis is a phenomenon that occurs as a result of this same pathophysiology.[56,57] As the name suggests, transient quadriparesis is a temporary loss of all motor function in the limbs.[58] Again, this is the result of a transient physiological conduction block rather than an anatomical disruption. More than 1 clinical entity can take place at the same time, however, which may make an immediate diagnosis difficult. One case study examined an ice hockey player who suffered a teardrop fracture with retropulsion at C5. This player experienced complete neurapraxia with a full recovery following cervical stabilization and surgical decompression.[42] As previously mentioned, disk herniations also commonly occur, with the same underlying mechanism as cervical fractures.[7] These too can lead to neurological dysfunction and may require surgical decompression.

Rink-Side Management

Successful management of the injured athlete, and especially the athlete with a neck injury, depends on a few critical items.

First off, protocols and pre-planned functions should exist for the personnel on the care team. Second, the necessary equipment for on-field management of the injured athlete should be properly organized. Third, a hospital and transportation system should be in place in case an immediate intervention is necessary. The first steps of assessing an injured player's status, as in all sports, remains the same. Checking the patient's airway, breathing, circulation, disability (neurologic deficit), and exposure (ABCDE) is critical regardless of the scenario.[59] Unfortunately, following this initial assessment, the consensus on proper management techniques for the hockey player with a cervical spine injury seems nonexistent.

The proper rink-side management of cervical spine injuries in ice hockey continues to incite debate. The overall objective of rink-side management is to stabilize the patient and allow for safe transport to the hospital.[60] The majority of the disagreement, however, revolves around the removal of the player's equipment. A number of studies and organizations have stated removing the helmet is safest[60] while many others have advocated for keeping it on.[41,61,62] Unlike American football helmets, hockey helmets have significantly different fits and therefore require separate testing and protocols.[60]

Studies have shown that the removal of the helmet from a hockey player in the supine position significantly increases the degree of cervical lordosis.[41,61,62] One study examined the degree of cervical lordosis with different combinations of equipment. The investigators measured that the greatest degree of cervical displacement occurred when the player was wearing no helmet with shoulder pads. The players with a helmet and shoulder pads, or no helmet and no shoulder pads, showed no difference in cervical displacement.[41] This suggests that removing the helmet from a player wearing shoulder pads puts the player's cervical spine at risk. Second, the act of removing the helmet itself greatly increases the angular displacement of the cervical vertebrae.[62]

Alternatively, other compelling evidence strongly encourages the removal of the player's helmet. This evidence mostly revolves around the safety of transporting the player. It is well known that hockey players often wear their helmets loosely. One study showed that 100% of players who participated did not fit their helmets to the proper criteria, with many of them able to remove the helmet all together without unbuckling any straps.[60] The loose fit of the helmet is important to consider when attempting to stabilize the patient for transport. The first step in preparing a player for transport is getting them onto a spine board. As a result of the check from behind leading to the cervical injury, these players are often found in the prone position on the ice. This requires a log roll procedure to get them onto the spine board. One study examined the degree of cervical motion during the log roll maneuver and found that, despite the degree of fit of the helmet, cervical motion was vastly larger when the helmet was kept on the player.[60] Additionally, the use of an extrication cervical collar has not been shown to reduce this cervical motion.[63] Given the significant evidence for both sides of the helmet argument, more studies on the management of cervical spine injuries specifically focused on ice hockey are needed to establish the optimal protocol.

Return-to-Play Criteria

Advising players to return or abstain from their sport following an injury can be extremely challenging. Especially in the case of a spine injury, the stakes are even higher. The risk of a catastrophic spinal reinjury after returning to ice hockey is a factor that needs to be appropriately addressed and measured. This process is further complicated by the variability in guidelines and frequent deviation from them. Ultimately, the decision making behind return-to-play recommendations put forth by physicians has been very heterogenous.

One of the original guidelines developed by Watkins et al.[64] specifically looked at neck injuries in football players. These guidelines were developed based off relative risk stratification and anecdotal evidence which examined rates of reinjury and permanent damage. Not long after the Watkins guidelines were released, Torg et al. created a more nuanced model for return to play criteria.[65] These criteria put players in a "no contraindication," "relative contraindication" or "absolute contraindication" bucket based off their clinical presentation. While the purpose of these guidelines was valuable, much of the data was based off the author's experience rather than objective meta-analyses.[66]

Since Watkins and Torg, guidelines have continued to be developed and revised. Despite the continued efforts to establish a best-practice protocol for return-to-play decision making, there is no consensus when it comes to handling cervical spine injuries in most sports, let alone specific to ice hockey.[67] While details differ, 4 fundamental criteria remain true across all protocols. The player should be pain-free, the player should have a full range of motion in the cervical spine, the player should have full strength, and finally the player should have no evidence of residual neurological deficits.[66,68,69]

Lastly, one significant factor contributing to variability of return-to-play recommendations/decisions is the physician's bias. Recent studies examining a physician's bias in decision making demonstrated that clinical experiences, personal experiences and personality traits significantly influenced diagnostics and management.[70] A study published by Ukogy et al. in 2020 specifically examined physician bias in return-to-play decisions following a cervical spine injury.[71] This study gave physicians 15 clinical scenarios and recorded their recommendations, along with the physician's background information. Not only did the physicians fail to adhere to the guidelines proposed by Watkins and Torg, but large variations existed between physicians. Some physicians recommended increased restriction from play, while others deviated to allow return-to-play more quickly. Factors found to significantly influence the physician's decision-making include years in practice, the type of athlete most frequently treated, previous athletic experience, and orthopedic board certification status.[67,71] These inconsistencies in decision making may subject players with the same

Table 1. Composite Return-to-Play Guidelines for Cervical Spine Injuries in Ice Hockey by Popkin et al., Am J Orthop (Belle Mead NJ), 2017. **46**(3): p. 123-134.

No Contraindications	Relative Contraindications	Absolute Contraindications
Asymptomatic cervical disc herniation treated conservatively	Healed 2 Level ACDF or posterior spinal fusion	History or exam findings of cervical myelopathy
Single level healed ACDF	$\geq$ 3 stingers in the same season	C1-C2 fusion
Two stingers within same season	Prolonged burner/stinger Longer than 24 hours	3-level cervical fusion
Healed fracture C1-C7 that meets general criteria; no sagittal malalignment	-	Asymptomatic ligamentous laxity $>11°$ kyphosis compared to adjacent vertebrae or 3.5mm movement on lateral flexion/extension views; C1-C2 hypermobility
Asymptomatic clay shoveler's fracture	Transient quadriparesis with full recovery of strength and ROM	Healed fracture with sagittal malalignment
Healed Stable C1 or C2 fracture; normal ROM	-	Symptomatic disc herniation
Torg ratio <0.8 in an asymptomatic player	-	2 episodes of transient quadriparesis
-	-	Spinal canal compromise from retropulsed bony fragments

injury to either overly aggressive or insufficient protection following cervical spine trauma.

A recent review by Popkin et al.[72] was able to generate return-to-play criteria for cervical spine injuries in ice hockey based off a composite of multiple studies. The criteria can be found in **Table 1**. This criteria utilizes guidelines presented by Torg and Cantu[50] and was modified from *Sports Health*.[66] The table also includes specific symptoms such as stingers to aid in the decision making. There are several important elements worth highlighting. A player with any permanent neurological injury should completely abstain from contact sports.[73] Players with a stable fracture that has healed, along with a complete return to clinical baseline, are generally allowed to return the following season. The presence of spinal stenosis and transient quadriplegia further complicate the return-to-play decision. Functional spinal stenosis, which can occur following a spine injury, is described as the loss of cerebrospinal fluid around the spinal cord.[74] It is currently debated whether functional stenosis increases the risk of future permanent neurological injury and thus should impact return-to-play decision making. Many investigators both support[68,69,75,76] and deny this claim.[77,78] Overall, it would seem that a single episode of transient neurological dysfunction or neurapraxia does not increase the risk of spinal cord injury, but that one of these episodes in addition to the finding of cervical stenosis does increase risk of future spinal cord injury.[79] Given the small sample size of patients and continued debate, however, this interpretation should be received with caution.

Future Direction & Prevention Efforts

Over the past decade efforts have increased to track, address and prevent cervical spine injuries in ice hockey. Fundamental to this process is a more precise and in-depth method of tracking of these injuries. An important recent development was the establishment of the Mayo Injury Registry for Ice Hockey. This registry was formed by the Mayo Clinic Sports Medicine Center and USA hockey to track injury data in the United States. With a more robust surveillance system in place, these organizations will be better equipped to provide valuable insight and protocols for reducing injury rates. One area that can use significant improvement is the standardization and rink-side management of players with a cervical spine injury in the acute setting. With a better understanding of when and how these injuries occur, new prevention guidelines and rule changes will continue to build on the many already in place, further increasing player safety.

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References

1. Vartiainen MV, Holm A, Peltonen K, Luoto TM, Iverson GL, Hokkanen L. King-Devick test normative reference values for professional male ice hockey players. *Scand J Med Sci Sports*. 2015;25(3):e327-e330.
2. Council on Sports Medicine and Fitness; Brooks A, Loud KJ, et al. Reducing injury risk from body checking in boys' youth ice hockey. *Pediatrics*. 2014;133(6):1151-1157.
3. Polites SF, Sebastian AS, Habermann EB, Iqbal CW, Stuart MJ, Ishitani MB. Youth ice hockey injuries over 16 years at a pediatric trauma center. *Pediatrics*. 2014;133(6):e1601-e1607.

4. Mall NA, Buchowski J, Zebala L, Brophy RH, Wright RW, Matava MJ. Spine and axial skeleton injuries in the National Football League. *Am J Sports Med*. 2012;40(8):1755-1761.
5. Deits J, Yard EE, Collins CL, Fields SK, Comstock RD. Patients with ice hockey injuries presenting to US emergency departments, 1990-2006. *J Athl Train*. 2010;45(5):467-474.
6. Engebretsen L, Steffen K, Alonso JM, et al. Sports injuries and illnesses during the Winter Olympic Games 2010. *Br J Sports Med*. 2010;44(11):772-780.
7. Banerjee R, Palumbo MA, Fadale PD. Catastrophic cervical spine injuries in the collision sport athlete, part 1: epidemiology, functional anatomy, and diagnosis. *Am J Sports Med*. 2004;32(4): 1077-1087.
8. Nobunaga AI, Go BK, Karunas RB. Recent demographic and injury trends in people served by the Model Spinal Cord Injury Care Systems. *Arch Phys Med Rehabil*. 1999;80(11): 1372-1382.
9. Tator CH, Edmonds VE, Lapczak L, Tator IB. Spinal injuries in ice hockey players, 1966-1987. *Can J Surg*. 1991;34(1):63-69.
10. Cook DJ, Cusimano MD, Tator CH, Chipman ML. Evaluation of the ThinkFirst Canada, Smart Hockey, brain and spinal cord injury prevention video. *Inj Prev*. 2003;9(4):361-366.
11. Tator CH, Provvidenza CF, Lapczak L, Carson J, Raymond D. Spinal injuries in Canadian ice hockey: documentation of injuries sustained from 1943-1999. *Can J Neurol Sci*. 2004;31(4): 460-466.
12. Tator CH, Edmonds VE. National survey of spinal injuries in hockey players. *Can Med Assoc J*. 1984;130(7):875-880.
13. Tator CH, Provvidenza C, Cassidy JD. Spinal injuries in Canadian ice hockey: an update to 2005. *Clin J Sport Med*. 2009;19(6): 451-456.
14. Tator CH, Provvidenza C, Cassidy JD. Update and overview of spinal injuries in Canadian ice hockey, 1943 to 2011: the continuing need for injury prevention and education. *Clin J Sport Med*. 2016;26(3):232-238.
15. Anderson GR, Melugin HP, Stuart MJ. Epidemiology of Injuries in Ice Hockey. *Sports Health*. 2019;11(6):514-519.
16. Smith AM, Alford PA, Aubry M, et al. Proceedings from the ice hockey summit III: action on concussion. *Clin J Sport Med*. 2019; 18(1):23-34.
17. Roberts WO, Brust JD, Leonard B, Hebert BJ. Fair-play rules and injury reduction in ice hockey. *Arch Pediatr Adolesc Med*. 1996; 150(2):140-145.
18. Cusimano MD, Nastis S, Zuccaro L. Effectiveness of interventions to reduce aggression and injuries among ice hockey players: a systematic review. *CMAJ* 2013;185(1):E57-E69.
19. Reynen PD, Clancy WG Jr. Cervical spine injury, hockey helmets, and face masks. *Am J Sports Med*. 1994;22(2):167-170.
20. Flik K, Lyman S, Marx RG. American collegiate men's ice hockey: an analysis of injuries. *Am J Sports Med*. 2005;33(2): 183-187.
21. Simmons MM, Swedler DI, Kerr ZY. Injury surveillance of head, neck, and facial injuries in collegiate ice hockey players, 2009-2010 through 2013-2014 academic years. *J Athl Train*. 2017; 52(8):776-784.
22. Agel J, Harvey EJ. A 7-year review of men's and women's ice hockey injuries in the NCAA. *Can J Surg*. 2010;53(5):319-323.
23. Agel J, Dompier TP, Dick R, Marshall SW. Descriptive epidemiology of collegiate men's ice hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train*. 2007;42(2):241-248.
24. Agel J, Dick R, Nelson B, Marshall SW, Dompier TP. Descriptive epidemiology of collegiate women's ice hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 2000-2001 through 2003-2004. *J Athl Train*. 2007;42(2):249-254.
25. Lynall RC, Mihalik JP, Pierpoint LA. The first decade of web-based sports injury surveillance: descriptive epidemiology of injuries in US high school boys' ice hockey (2008-2009 through 2013-2014) and National Collegiate Athletic Association Men's and Women's Ice Hockey (2004-2005 through 2013-2014). *J Athl Train*. 2018;53(12):1129-1142.
26. Meron A, McMullen C, Laker SR, Currie D, Comstock RD. Epidemiology of cervical spine injuries in high school athletes over a ten-year period. *PM R* 2018;10(4):365-372.
27. Deckey DG, Makovicka JL, Chung AS, et al. Neck and cervical spine injuries in national college athletic association athletes: a 5-year epidemiologic study. *Spine (Phila Pa 1976)*. 2020;45(1): 55-64.
28. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42(2):311-319.
29. Tator CH, Carson JD, Edmonds VE. Spinal injuries in ice hockey. *Clin Sports Med*. 1998;17(1):183-194.
30. Stuart MJ, Smith AM, Malo-Ortiguera SA, Fischer TL, Larson DR. A comparison of facial protection and the incidence of head, neck, and facial injuries in Junior A hockey players. A function of individual playing time. *Am J Sports Med*. 2002; 30(1):39-44.
31. LaPrade RF, Burnett QM, Zarzour R, Moss R.. The effect of the mandatory use of face masks on facial lacerations and head and neck injuries in ice hockey. A prospective study. *Am J Sports Med*. 1995;23(6):773-775.
32. Benson BW, Mohtadi NG, Rose MS, Meeuwisse WH. Head and neck injuries among ice hockey players wearing full face shields vs half face shields. *JAMA*. 1999;282(24):2328-2332.
33. Tator CH, Carson JD, Edmonds VE. New spinal injuries in hockey. *Clin J Sport Med*. 1997;7(1):17-21.
34. Zupon AB, Kerr ZY, Dalton SL, Dompier TP, Gardner EC. The epidemiology of back/neck/spine injuries in National Collegiate Athletic Association men's and women's ice hockey, 2009/2010 to 2014/2015. *Res Sports Med*. 2018;26(1):13-26.
35. ASTM Committee F-8 on Sports Equipment and Facilities and American Society for Testing and Materials. *Safety in Ice Hockey, in Stp*. ASTM; 1989.
36. Torg JS. *Athletic Injuries to the Head, Neck, and Face*. Lea & Febiger; 1982:300. xiv.
37. Torg JS, Vegso JJ, O'Neill MJ, Sennett B. The epidemiologic, pathologic, biomechanical, and cinematographic analysis of football-induced cervical spine trauma. *Am J Sports Med*. 1990; 18(1):50-57.

38. McElhaney J, Snyder RG, States JD, Gabrielsen MA. Biomechanical analysis of swimming pool neck injuries. *SAE Trans*. 1979; 88(1):494-500.
39. Sim FH, Chao EY. Injury potential in modern ice hockey. *Am J Sports Med*. 1978;6(6):378-384.
40. Clark CR, Ducker TB. Cervical Spine Research Society Editorial Committee. In *The Cervical Spine*. 3rd ed. Lippincott-Raven; 1998:1003. xx.
41. Metz CM, Kuhn JE, Greenfield ML. Cervical spine alignment in immobilized hockey players: radiographic analysis with and without helmets and shoulder pads. *Clin J Sport Med*. 1998;8(2): 92-95.
42. Yue JJ, Ivancic PC, Scott DL. Teardrop fracture following head-first impact in an ice hockey player: case report and analysis of injury mechanisms. *Int J Spine Surg*. 2016;10:9.
43. Molsa JJ, Tegner Y, laranta H, Myllynen P, Kujala UM. Spinal cord injuries in ice hockey in Finland and Sweden from 1980 to 1996. *Int J Sports Med*. 1999;20(1):64-67.
44. Torg JS, Pavlov H, O'Neill MJ, Nichols III CE, Sennett B.. The axial load teardrop fracture. A biomechanical, clinical and roentgenographic analysis. *Am J Sports Med*. 1991;19(4): 355-364.
45. Boden BP, Jarvis CG. Spinal injuries in sports. *Phys Med Rehabil Clin N Am*. 2009;20(1):55-68, vii.
46. Coelho DG, Brasil AV, Ferreira NP. Risk factors of neurological lesions in low cervical spine fractures and dislocations. *Arq Neuropsiquiatr*. 2000;58(4):1030-1034.
47. Razack N, Green BA, Levi AD. The management of traumatic cervical bilateral facet fracture-dislocations with unicortical anterior plates. *J Spinal Disord*. 2000;13(5):374-381.
48. Schmitt H, Gerner HJ. Paralysis from sport and diving accidents. *Clin J Sport Med*. 2001;11(1):17-22.
49. White AA, Panjabi MM. *Clinical Biomechanics of the Spine*. 2nd ed. Lippincott; 1990:722. xxiii.
50. Cantu RC, Li YM, Abdulhamid M, Chin LS. Return to play after cervical spine injury in sports. *Curr Sports Med Rep*. 2013;12(1): 14-17.
51. Del Bigio MR, Johnson GE. Clinical presentation of spinal cord concussion. *Spine (Phila Pa 1976)*. 1989;14(1):37-40.
52. Torg JS, Thibault L, Sennett B, Pavlov H.. The Nicolas Andry Award. The pathomechanics and pathophysiology of cervical spinal cord injury. *Clin Orthop Relat Res*. 1995;(321):259-269.
53. Thomas BE, McCullen GM, Yuan HA. Cervical spine injuries in football players. *J Am Acad Orthop Surg*. 1999;7(5):338-347.
54. Penning L. Some aspects of plain radiography of the cervical spine in chronic myelopathy. *Neurology*. 1962;12:513-519.
55. Carter JW, Mirza SK, Tencer AF, Ching RP. Canal geometry changes associated with axial compressive cervical spine fracture. *Spine (Phila Pa 1976)*. 2000;25(1):46-54.
56. Torg JS, Pavlov HE, Genuario SE, et al. Neurapraxia of the cervical spinal cord with transient quadriplegia. *J Bone Joint Surg Am*. 1986;68(9):1354-1370.
57. Nagoshi N, Tetreault L, Nakashima H, Nouri A, Fehlings MG. Return to play in athletes with spinal cord concussion: a systematic literature review. *Spine J*. 2017;17(2):291-302.
58. Schneider RC, Reifel E, Crisler HO, Oosterbaan BG. Serious and fatal football injuries involving the head and spinal cord. *JAMA*. 1961;177(6):362-367.
59. Banerjee R, Palumbo MA, Fadale PD. Catastrophic cervical spine injuries in the collision sport athlete, part 2: principles of emergency care. *Am J Sports Med*. 2004;32(7):1760-1764.
60. Mihalik JP, Beard JR, Petschauer MA, Prentice WE, Guskiewicz KM. Effect of ice hockey helmet fit on cervical spine motion during an emergency log roll procedure. *Clin J Sport Med* 2008;18(5):394-398.
61. LaPrade RF, Schnetzler KA, Broxterman RJ, Wentorf F, Wendland E, Gilbert TJ. Cervical spine alignment in the immobilized ice hockey player. A computed tomographic analysis of the effects of helmet removal. *Am J Sports Med*. 2000;28(6): 800-803.
62. Prinsen RK, Syrotuik DG, Reid DC. Position of the cervical vertebrae during helmet removal and cervical collar application in football and hockey. *Clin J Sport Med*. 1995;5(3):155-161.
63. Del Rossi G, Heffernan TP, Horodyski M, Rechtine GR. The effectiveness of extrication collars tested during the execution of spine-board transfer techniques. *Spine J*. 2004;4(6):619-623.
64. Watkins RG. Neck injuries in football players. *Clin Sports Med*. 1986;5(2):215-246.
65. Torg JS, Ramsey-Emrhein JA. Cervical spine and brachial plexus injuries: return-to-play recommendations. *Phys Sportsmed*. 1997; 25(7):61-88.
66. Huang P, Anissipour A, McGee W, Lemak L. Return-to-play recommendations after cervical, thoracic, and lumbar spine injuries: a comprehensive review. *Sports Health*. 2016;8(1):19-25.
67. Morganti C, Sweeney CA, Albanese SA, Burak C, Hosea T, Connolly PJ. Return to play after cervical spine injury. *Spine (Phila Pa 1976)*. 2001;26(10):1131-1136.
68. Cantu RC, Bailes JE, Wilberger JE Jr. Guidelines for return to contact or collision sport after a cervical spine injury. *Clin Sports Med*. 1998;17(1):137-146.
69. Cantu RC. Stingers, transient quadriplegia, and cervical spinal stenosis: return to play criteria. *Med Sci Sports Exerc*. 1997; 29(7 Suppl):S233-S235.
70. Saposnik G, Redelmeier D, Ruff CC, Tobler PN. Cognitive biases associated with medical decisions: a systematic review. *BMC Med Inform Decis Mak*. 2016;16(1):138.
71. Ukogu C, Bienstock D, Ferrer C, et al. Physician decision-making in return to play after cervical spine injury: a descriptive analysis of survey data. *Clin Spine Surg*. 2020;33(7):E330-E336.
72. Popkin CA, Nelson BJ, Park CN, et al. Head, neck, and shoulder injuries in ice hockey: current concepts. *Am J Orthop (Belle Mead NJ)*. 2017;46(3):123-134.
73. Bailes JE, Hadley MN, Quigley MR, Sonntag VK, Cerullo LJ. Management of athletic injuries of the cervical spine and spinal cord. *Neurosurgery*. 1991;29(4):491-497.
74. Cantu RC. Functional cervical spinal stenosis: a contraindication to participation in contact sports. *Med Sci Sports Exerc*. 1993; 25(3):316-317.
75. Cantu RC. The cervical spinal stenosis controversy. *Clin Sports Med*. 1998;17(1):121-126.

76. Firooznia H, Ahn JH, Rafii M, Ragnarsson KT. Sudden quadriplegia after a minor trauma. The role of preexisting spinal stenosis. *Surg Neurol*. 1985;23(2):165-168.
77. Torg JS, Corcoran TA, Thibault LE, et al. Cervical cord neurapraxia: classification, pathomechanics, morbidity, and management guidelines. *J Neurosurg*. 1997;87(6):843-850.
78. Torg JS. Cervical spinal stenosis with cord neurapraxia: evaluations and decisions regarding participation in athletics. *Curr Sports Med Rep*. 2002;1(1):43-46.
79. Boockvar JA, Durham SR, Sun PP. Cervical spinal stenosis and sports-related cervical cord neurapraxia in children. *Spine (Phila Pa 1976)*. 2001;26(24):2709-2712; discussion 2713.