This article has been updated from its originally published version to correct sentences in the *Abstract* and *Discussion*.

See the corresponding erratum notice in the November 2010 issue for full details.

Neurosurg Focus 29 (5):E4, 2010

A prospective study of physician-observed concussions during junior ice hockey: implications for incidence rates

Paul Sean Echlin, M.D.,[1] Charles H. Tator, M.D., Ph.D.,[2] Michael D. Cusimano, M.D., Ph.D.,[2] Robert C. Cantu, M.D.,[3] Jack E. Taunton, M.D.,[4] Ross E. G. Upshur, M.D.,[5] Craig R. Hall, Ph.D.,[6] Andrew M. Johnson, Ph.D.,[7] Lorie A. Forwell, M.Sc.P.T.,[8] and Elaine N. Skopelja, M.A.L.S.[9]

[1]AIM Health Group Family Medicine, London, Ontario; [2]Division of Neurosurgery, University of Toronto, Ontario, Canada; [3]Department of Neurosurgery, Boston University Medical School, Boston, Massachusetts; [4]Division of Sports Medicine, Faculty of Medicine and School of Human Kinetics, University of British Columbia, Vancouver; [5]Departments of Family and Community Medicine, University of Toronto, Ontario; [6]School of Kinesiology, [7]Faculty of Health Sciences, and [8]Department of Physiotherapy, University of Western Ontario, London, Ontario, Canada; and [9]School of Medicine Library, Indiana University, Indianapolis, Indiana

Object. The objective of this study was to measure the incidence of concussion (scaled relative to number of athlete exposures) and recurrent concussion within 2 teams of fourth-tier junior ice hockey players (16–21 years old) during 1 regular season.

Methods. A prospective cohort study called the Hockey Concussion Education Project was conducted during 1 junior ice hockey regular season (2009–2010) involving 67 male fourth-tier ice hockey players (mean age 18.2 ± 1.2 years, range 16–21 years) from 2 teams. Prior to the start of the season, every player underwent baseline assessments using the Sideline Concussion Assessment Tool 2 (SCAT2) and the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT). The study protocol also required players who entered the study during the season to complete baseline SCAT2 and ImPACT testing. If the protocol was not followed, the postinjury test results of a player without true baseline test results would be compared against previously established age and gender group normative levels. Each regular season game was observed by a qualified physician and at least 1 other neutral nonphysician observer. Players who suffered a suspected concussion were evaluated at the game. If a concussion diagnosis was made, the player was subsequently examined in the physician's office for a full clinical evaluation and the SCAT2 and ImPACT were repeated. Based on these evaluations, players were counseled on the decision of when to return to play. Athlete exposure was defined as 1 game played by 1 athlete.

Results. Twenty-one concussions occurred during the 52 physician-observed games (incidence 21.5 concussions per 1000 athlete exposures). Five players experienced repeat concussions. No concussions were reported during practice sessions. A concussion was diagnosed by the physician in 19 (36.5%) of the 52 observed games. One of the 5 individuals who suffered a repeat concussion sustained his initial concussion in a regular season game that was not observed by a physician, and as a result this single case was not included in the total of 21 total concussions. This initial concussion of the player was identified during baseline testing 2 days after the injury and was subsequently medically diagnosed and treated.

Conclusions. The incidence of game-related concussions (per 100 athlete exposures) in these fourth-tier junior ice hockey players was 7 times higher than the highest rate previously reported in the literature. This difference may be the result of the use of standardized direct physician observation, diagnosis, and subsequent treatment. The results of this study demonstrate the need for follow-up studies involving larger and more diverse sample groups to reflect generalizability of the findings. These follow-up studies should involve other contact sports (for example football and rugby) and also include the full spectrum of gender, age, and skill levels. *(DOI: 10.3171/2010.9.FOCUS10186)*

Key Words • **concussion** • **ice hockey** • **incidence** • **Canada**

Current literature on ice hockey concussion incidence does not use a single agreed-upon definition or methodology. Very few studies use direct physician-based data collection, and an internationally agreed-upon return-to-play protocol.[19] This research inconsistency may result in a paucity of significant concussion incidence data and contribute to an underreporting of the true incidence of this important injury.

Sport concussions can have cumulative and long-lasting effects on memory, judgment, social conduct, reflexes, speech, balance, and coordination. Epidemiological studies have suggested an association between sport concussions and both immediate and later-life cognitive impairment.[4,5,12,13,19–21,26,27] For example, data from a small sample of retired professional football players demonstrated an increased risk and earlier onset of memory

Abbreviations used in this paper: HCEP = Hockey Concussion Education Project; ImPACT = Immediate Post-Concussion Assessment and Cognitive Test; MBESS = Modified Balance Error Scoring System; SAC = Standardized Assessment of Concussion; SCAT2 = Sideline Concussion Assessment Tool 2.

impairment, mild cognitive impairment, and Alzheimer's dementia.[12,13] Furthermore, anecdotal case reports have noted neuropathological evidence of chronic traumatic encephalopathy in some retired professional football players.[20] In 2009, there was a news release of 1 case of chronic traumatic encephalopathy in a former National Hockey League player.[27]

Investigation of the true incidence of sport concussions may require direct observation and diagnosis by an independent, trained physician. The primary goals of this study were to prospectively measure the direct physician-observed incidence of concussion (scaled relative to number of athlete exposures) and recurrent concussion within 2 teams of junior ice hockey players during 1 regular season (36 games), utilizing the concussion definition and return-to-play protocol from the 2009 Zurich consensus statement from the 3rd International Conference on Concussion in Sport.[19]

Methods

Participants and Sampling

Between September 2009 and February 2010, 67 male fourth-tier junior ice hockey players (mean age 18.2 ± 1.2 years, range 16–21 years), from 2 teams (Team A and Team B), consented to participate in the HCEP. Team A was observed during 34 of the 36 regular season games. Two games of Team A were not observed. One missed game occurred secondary to their baseline evaluations occurring after their first game. The second missed game resulted from suspension of the HCEP for 1 game after the improper return to play of a Team A player following an observed and diagnosed concussion incident. The HCEP was halted until an addendum was added to the protocol that addressed this type of event. The player involved was subsequently removed as a study participant.

Team B was observed during 21 of the 36 regular season games. Team B withdrew their participation after Game 21 of the season, because of an inability to comply with the HCEP protocol. After due process Team B was removed from the study, and ended its participation at Game 21 of the 36-game season.

Seventeen players from both teams played 5 regular season games or fewer.

Concussion Definitions

The definition of concussion for this study was derived from the 2009 Zurich consensus statement on concussions from the 3rd International Conference on Concussion in Sport.[19] Concussion was clinically diagnosed utilizing an observed or self-reported mechanism (such as a blow to the head or body), immediate or delayed neurological signs (player is unstable, lacks coordination, or is slow to return to play) or symptoms (player experiences headache, dizziness, or alteration of vision) and abnormal SCAT2 or ImPACT test results. A self-reported concussion was defined as a concussion that was not identified by the physician or nonphysician observers at an observed game. The players who self-reported concussions subsequently presented to the physician for diagnostic evaluation, either at the end of the game or in the days following that game.

Neuropsychological Measures

Two standardized concussion assessment tools, the SCAT2 and ImPACT, were administered to all players before the season began and to each player after a physician-observed and diagnosed concussion.

The SCAT2 is an accessible and free screening tool that was developed by the 3rd International Conference on Concussion in Sport held in Zurich, Switzerland, in 2008. The SCAT2 is an improved version of the original SCAT developed in 2005.[19] Although this tool has not yet been validated as a whole, individual components have been validated, such as the SAC, the Balance Error Scoring System, the Maddox Score, Glasgow Coma Scale, and the Concussion Symptom Inventory.

The ImPACT is a computerized concussion evaluation system and is (at the time of this writing) the most widely used, although it has not been independently evaluated. The ImPACT takes approximately 20 minutes to complete and measures multiple aspects of cognitive functioning in athletes including attention span, working memory, sustained and selective attention time, response variability, nonverbal problem solving, and reaction time.

At the ice hockey rink the SCAT2 Symptom Inventory, Modified Balance Error Scoring System (MBESS), and SAC were recorded during concussion evaluation by a physician. The SCAT2 utilizes the MBESS that is performed on the ground and does not use a secondary balance platform for the 3 balance positions. At the postinjury office evaluation the ImPACT as well as the aforementioned components of the SCAT2 were tested. The ImPACT results for the HCEP were independently evaluated by a remote certified neuropsychologist. Although the ImPACT is a commonly used and relatively accessible test, it is a psychometric test whether it is computer-generated or not, and calls for a refined level of understanding available to the registered psychologist with training in psychometrics and neuropsychological diagnostic skills.[28] The remote independent neuropsychological analysis of this diagnostic tool also eliminates possible bias that may exist when a team physician is interpreting the test for an athlete that he or she works with on a regular basis.

General Procedures

Each participant signed an informed consent form, and provided a release of medical information form at the outset of the study. Each team's board of directors and the participating league's board of directors gave consent for participation in the study. The executives of both teams were asked to inform the primary investigator when a player left the team roster or was added to the roster, so that appropriate baseline testing could be performed. The Health Sciences Research Ethics Board at The University of Western Ontario approved the study.

Procedure for Concussion Surveillance

Concussion surveillance was conducted at each regular season game of the participating teams by 1 indepen-

dent physician and 1 to 3 independent, nonphysician observers. There were 6 licensed physician observers, all of whom had experience as ice hockey team physicians and 5 of whom had sports medicine certification. There were 16 nonphysician observers (5 kinesiologists, 2 certified ice hockey coaches, 5 ice hockey executives, 1 physical therapist, 1 massage therapist, 1 chiropractor, and 1 former junior ice hockey player). Independent physician and nonphysician observers were defined as individuals who were not affiliated on a regular basis with the team or teams that they were evaluating. This independence allows for the elimination of possible identification and clinical decision-making bias that may affect the evaluation and return-to-play decision due to the familiarity with the athletes and team.

Before entering the study the physician and nonphysicians were verbally instructed for 20 minutes on their observation and reporting duties. Each observer was asked to complete a 23-question descriptive form to document each observed and diagnosed concussion. The physician and the observers were placed at elevated and well-balanced positions around the ice rink, so as to have direct views of the play from a variety of vantage points. Communication between the physician and nonphysician observers, as well as the physician and team therapist/first responder/trainer was by walkie-talkie. Practice sessions were not directly observed during this study. A flowchart concerning the methods of concussion identification, treatment, and return-to-play protocol is provided in Fig. 1.

In the event of an on-ice extended period of loss of consciousness, or situations in which the player experienced neurological signs or symptoms (such as severe neck pain, limb motor/sensory changes, or seizure), play was suspended, an emergency 911 call was made, and the player was maintained with neck stabilization and trauma support until paramedics arrived for transport to the nearest hospital emergency department.

For an observed concussion that did not result in an emergency department evacuation, the team therapist/first responder was asked by the physician observer to remove the player from the game. The player was then immediately evaluated by the physician away from the locker room and ice surface, while other observers remained in place. Clinical evaluations of the player with a suspected

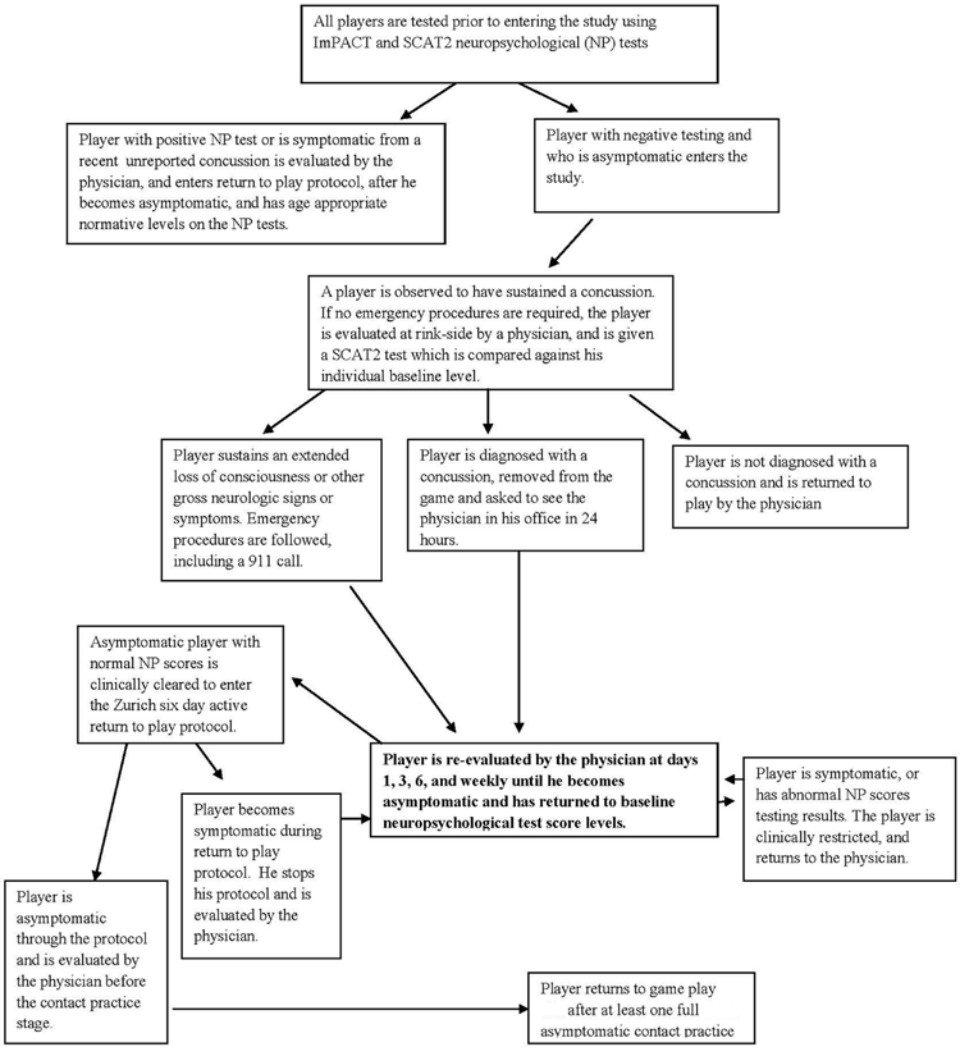

Fig. 1. Flowchart of the methods of concussion identification, treatment, and return-to-play protocol.

concussion included SCAT2 testing at the rink. If a concussion diagnosis was made, instructions regarding precautions were given to both the player and a responsible adult (such as a coach or parent). Both individuals were requested to attend a follow-up evaluation the next day in the office of the primary investigator who is a physician.

All players involved in on-ice fights who were observed to sustain a blow to the head were removed from the game and after a "cool-down" period of 30 to 60 minutes were clinically assessed by the game physician, involving a neurological examination and SCAT2. These players were also asked to complete an ImPACT the following day at the medical office of the primary investigator. Clinical office evaluations (after the rinkside diagnosis of the concussion) were performed on Days 1, 3, and 6, and then weekly as needed until the player was cleared to return to play.

Clinical Definition of Return to Play

All return-to-play decisions were made by the primary investigator on the basis of clinical judgment. The physician also drew upon the results of the SCAT2 objective components and ImPACT scores to determine when test results returned to the previously recorded baseline levels. If a baseline ImPACT had not been performed, the athlete was compared against established age-group normative levels. After clinical and neuropsychological clearance was obtained, each injured player returned to competitive play only after successfully completing the 6-day progressive and active return-to-play protocol defined in the consensus statement of international expert opinion at the 3rd International Conference on Concussion in Sport.[19] Teams that played in opposition to an HCEP-observed team and game officials were made aware of the physician at each game, and of their availability to evaluate any injuries. Two players from opposing HCEP teams were identified, diagnosed, and treated by the game physician for concussion during the 52 observed games. In both cases the physicians had to actively offer their services to the opposing team after the observed injury. Concussions identified in this fashion were not included in the incidence calculations.

Statistical Analysis

The incidence of concussion was calculated as the number of observed or self-reported concussions occurring during observed games, divided by the total number of athlete exposures. Athlete exposures were defined within this sample as the sum of all games played, and were summed for all players. This method of determining the denominator for the incidence calculation is deliberately conservative, and includes all athlete exposures, regardless of the length of time played within any given game.

Results

Twenty-one concussions were physician observed or self-reported and subsequently physician diagnosed in 52 physician-observed regular season games, yielding an incidence of 21.52 concussions per 1000 athlete exposures. A concussion was diagnosed in 19 (36.5%) of 52 observed games. The data from the study (Table 1) demonstrated a general trend of decreasing severity and normalization of the objective measures (SCAT2 symptom inventory, MBESS, SAC score, and ImPACT evaluation) toward the injured player's baseline levels over time.

Seventeen players suffered a physician observed or self-reported physician-diagnosed concussion during a physician-observed game, and 5 (29%) of these 17 players also suffered a second concussion during the study period. One of the 5 individuals who suffered a repeat concussion sustained his initial concussion in a regular season game that was not observed by a physician, and as a result this single case was not included in the total of 21 total concussions. This initial concussion of the player was identified during baseline testing 2 days after the injury and was subsequently medically diagnosed and treated. The mean time interval between the first and second concussions of these 5 players was 78.6 days (median 82 ± 39.8 days), and the mean time between the return-to-play date of the first and second concussions was 61.8 days (median 60 ± 39.7 days).

Eighteen (53%) of the 34 potential concussions identified by the physician and nonphysician observers were positively diagnosed by the physician at rinkside. Three of the diagnosed concussions were not directly identified in an observed game, and were self-reported to the physician either at rinkside or within the next 48 hours. The remaining 16 (47%) of the concussions that were initially identified by the observers were returned to play after a negative clinical and SCAT2 evaluation by the physician.

A total of 67 players competed in at least 1 game during the 2009–2010 regular season. Forty-six (69%) of these 67 players completed baseline SCAT2 and ImPACT testing at the start of the season. No further baseline testing was completed for players entering the study after initial testing was completed, as a result of team and individual noncompliance with the study protocol agreement.

Fifty-three of the 67 players provided a medical history of previous concussions prior to the start of the study. There was no concussion history provided by the remaining 14 players. Thirty-one (58%) of these 53 players denied sustaining any previous concussions. Thirty-four percent (18 of 53) admitted to sustaining 1 to 2 previous concussions. Four (8%) of these 53 players admitted to sustaining 3 or more previous concussions.

Fifteen (88%) of the 17 players with a diagnosed concussion admitted to having experienced at least 1 concussion in the past. Two of the 17 players who suffered a concussion during the study admitted that they had concealed a concussion sustained during the current season to keep playing. Three of the 17 players who sustained a concussion identified themselves to team officials. All 3 players were medically diagnosed with a concussion, and were treated appropriately. Two of the 17 players with the diagnosis of a concussion suffered associated injuries. One player suffered a separated shoulder and another player suffered a dislocated shoulder.

Fifteen (22%) of all 67 participating players played 5 regular season games or fewer. Three of the 15 players who participated in 5 regular season games or less were diagnosed with a concussion. These 3 players eventually returned to play: 1 player was medically cleared to return

TABLE 1: Objective-measure results for the 17 HCEP players who sustained concussions during a physician-observed game*

Case No. (Test)†	CRTP Interval (days)	Baseline	Day of Injury	Office Visit No. 1	2	3	4	5	6	7	8
1	refused FU, out of study			refused FU							
SCAT2		NP	0/0								
SAC			25/30								
MBESS			24/30								
2	refused FU, out of study			refused FU							
SCAT2		NP	10/17								
SAC			30/30								
MBESS			21/30								
3	10			PID 4							
SCAT2		0/0	7/8	0/0							
SAC		25/30	28/30	29/30							
MBESS		27/30	NP	21/30							
IC/IR		IC		IC							
4	16			PID 3	PID 10						
SCAT2		NP	0/0	1/1	0/0						
SAC			28/30	25/30	28/30						
MBESS			NP	27/30	30/30						
IC/IR				IC	IC						
5a	10			PID 1	PID 4						
SCAT2		0/0	1/4	0/0	0/0						
SAC		24/30	24/30	25/30	25/30						
MBESS		26/30	NP	NP	25/30						
IC/IR		IC		IC	IC						
5b	no CRTP clearance for remainder of season		0	PID 1	PID 5	PID 18	declined further testing				
SCAT2		0/0	12/26	6/10	3/4	3/4					
SAC		24/30	21/30	25/30	26/30	27/30					
MBESS		26/30	23/30	26/30	21/30	22/30					
IC/IR		IC		IR	IR	IC					
6 (SRP)	28			PID 2	PID 4	PID 8	PID 18				
SCAT2		14/35	NP	17/38	17/27	5/5	0/0				
SAC		30/30	SRP	27/30	28/30	28/30	29/30				
MBESS		27/30		28/30	27/30	24/30	30/30				
IC/IR		IR		IR	IC	IC	IC				
7a (SRP)	29			PID 2	PID 6	PID 11	PID 18	PID 23			
SCAT2		3/4	NP	10/14	1/1	0/0	0/0	0/0			
SAC		27/30	SRP	25/30	27/30	27/30	28/30	27/30			
MBESS		27/30		NP	24/30	28/30	28/30	28/30			
IC/IR		IC		IR	IR	IR	IC	IC			

(continued)

TABLE 1: Objective-measure results for the 17 HCEP players who sustained concussions during a physician-observed game* *(continued)*

Case No. (Test)†	CRTP Interval (days)	Baseline	Day of Injury	Office Visit No. 1	2	3	4	5	6	7	8
7b	9			PID 3							
SCAT2		3/4	0/0	0/0							
SAC		27/30	29/30	29/30							
MBESS		27/30	NP	28/30							
IC/IR		IC		IC							
8a	15			PID 2	PID 4	PID 9					
SCAT2		6/30	5/7	2/2	0/0	0/0					
SAC		28/30	27/30	27/30	24/30	29/30					
MBESS		25/30	NP	18/30	23/30	30/30					
IC/IR		IC		IR	IR	IC					
8b	8 (delayed due to shoulder injury)			PID 2							
SCAT2		6/30	0/0	1/2							
SAC		28/30	28/30	29/30							
MBESS		25/30	26/30	25/30							
IC/IR		IC		IC							
9a	12			PID 3	PID 6						
SCAT2		13/14	4/5	2/2	0/0						
SAC		24/30	20/30	23/30	24/30						
MBESS		30/30	NP	28/30	27/30						
IC/IR		IC		IC	IC						
9b	refused FU, out of study			refused FU							
SCAT2		13/14	0/0								
SAC		24/30	29/30								
MBESS		30/30	24/30								
IC/IR		IC									
10	10			PID 1	PID 5						
SCAT2		8/10	9/13	3/3	1/1						
SAC		24/30	25/30	29/30	30/30						
MBESS		19/30	12/30	30/30	27/30						
IC/IR		IC		IR	IC						
11	9			PID 3							
SCAT2		NP	3/4	1/1							
SAC			26/30	26/30							
MBESS			26/30	23/30							
IC/IR				IC							

(continued)

TABLE 1: Objective-measure results for the 17 HCEP players who sustained concussions during a physician-observed game* *(continued)*

Case No. (Test)†	CRTP Interval (days)	Baseline	Day of Injury	Office Visit No. 1	2	3	4	5	6	7	8
12	7			PID 1							
SCAT2		4/6	0/0	0/0							
SAC		28/30	25/30	26/30							
MBESS		28/30	NP	NP							
IC/IR		IC		IC							
13	sent to ER for evaluation on Day 1, refused FU, out of study			PID 1	PID 3	refused further FU					
SCAT2		NP	8/23	22/60	13/30						
SAC			23/30	21/30	28/30						
MBESS			23/30	NP	24/30						
IC/IR				NP	IR						
14	7			PID 1							
SCAT2		2/2	2/4	0/0							
SAC		22/30	28/30	23/30							
MBESS		27/30	NP	28/30							
IC/IR		IC		IC							
15	15			PID 2	PID 6	PID 9					
SCAT2		9/19	18/49	8/8	3/3	0/0					
SAC		27/30	20/30	26/30	26/30	27/30					
MBESS		29/30	18/30	21/30	27/30	26/30					
IC/IR		IC		IR	IC	IC					
16	no CRTP clearance for regular season or playoffs, neurosurgical consult			PID 2	PID 5	PID 8	PID 16	PID 20	PID 33	PID 55	PID 75
SCAT2		4/9	NP	3/3	1/1	14/25	19/47	7/8	9/10	3/3	5/7
SAC		24/30		29/30	30/30	28/30	29/30	28/30	NP	28/30	NP
MBESS		28/30		30/30	27/30	23/30	29/30	25/30	NP	27/30	NP
IC/IR		IC		IR	IR	IR	IR	IR	IR	IR	IR
17	7			PID 1							
SCAT2		0/0	0/0	0/0							
SAC		28/30	26/30	29/30							
MBESS		22/30	NP	28/30							
IC/IR		IC		IC							

* CRTP = clinical return to play; ER = emergency room; FU = follow-up; IC = ImPACT neuropsychological-based clearance given by neuropsychologist; IR = ImPACT neuropsychological-based restriction given by neuropsychologist; NP = not performed; PID = postinjury day; SRP = self-reported concussion.

† MBESS score (max 30); SAC score (max 30); SCAT2 symptoms (max 22)/symptom severity score (range 0–6, max 6 × 22 = 132).

to play in 11 days, the second player was medically cleared to return to play in 15 days, and the third player returned to play high school ice hockey in 7 days against medical advice.

The forward position suffered the most diagnosed concussions (12 of 17 patients, 71%), while defensemen were diagnosed with 29% of the concussions. No goalies suffered a concussion. Fifty-seven percent (12 of 21 patients) of diagnosed concussions occurred in the third period, while 29% (6 of 21) occurred in the second period, and 14% (3 of 21) occurred in the first period. Seven (30%) of the 21 diagnosed concussions were not associated with immediate self-declared symptoms (0–6 Likert scale) on the SCAT2 inventory by the athlete. Inclusive of those athletes who did not declare immediate symptoms, the mean number of symptoms reported was 5.5 ± 5.8 (range 0–18 symptoms). The most common self-disclosed symptom was headache (mean score 1.9 ± 0.74, range 1–3/6, 10 patients). The second most common symptoms were "don't feel right" (mean score 2.7 ± 1.6, range 1–4, 9 patients) and fatigue/low energy (mean score 1.8 ± 1.1, range 1–4, 9 players). The third most common symptom reported by the players was sensitivity to light (mean score 1 ± 0, range 0).

There were 2 players who demonstrated an observable period of loss of consciousness (10–15 seconds). One individual required the physician to come onto the ice surface and initiate emergency assessment and cervical stabilization. This player did not require an activation of the 911 system. Both of these individuals were taken out of the game, diagnosed with a concussion, and followed up with the physician for appropriate evaluation and sequential care. A careful review of the files demonstrated that 7 other players recalled a possible momentary loss of consciousness (on secondary or tertiary historical questioning) associated with their diagnosed concussion.

One of the 17 players who was diagnosed with a concussion was sent to the hospital for emergency evaluation secondary to severe and increasing concussion symptoms. This player was released the same day. Two of the players were disqualified from return to play for their teams for the remainder of the regular season and playoffs due to persistent concussion symptoms. One of these 2 players continues to remain clinically symptomatic, while the other declined further follow-up.

Twenty-four percent (5 of 21) of the HCEP concussions occurred in players who were directly involved in a fight immediately prior to their diagnosis. Three of the 4 players who sustained a concussion as a result of involvement in a fight refused follow-up with the primary investigator and were taken out of the study. Sixty-nine percent of the HCEP observers' reports (29 of 42) documented that the point of contact of the majority of hits documented as causing a concussion was the head. Eighty percent of these observer reports (33 of 41) also documented that the hit causing the concussion was purposeful versus incidental. The difference in the number of observer reports is accounted for by the varied (1–3) number of nonphysician observers who attended each game.

Discussion

This is the first study of its kind to document an incidence of concussion in fourth-tier junior ice hockey players based on the 2009 Zurich consensus statement on concussions from the 3rd International Conference on Concussion in Sport.[19] The literature reports the incidence of concussion in terms of level of play, age, and sex of participants. The most common denominators for incidence calculation are player hours, athlete exposures, and games played.[1–3,8–10,16,17,24,25,29] Flick[10] reported an incidence rate of 3.1 per 1000 athlete exposures for Division 1 university ice-hockey players in 1 season. Wennberg and Tator[29] reported an incidence of concussion in the National Hockey League that ranged from 1.81 per 1000 athlete exposures in 1998–1999 to a low of 1.04 per 1000 athlete exposures in 2005–2006. Our rate per athlete exposure (21.52 per 1000) was 7 times higher than the highest rate reported by these authors, and our rate of concussions observed per game (36.5%) was also far higher than the National Hockey League game rate (3.1%) reported by Keating.[17]

The reasons for the differences in incidence may be multifactorial. There are several possible reasons for these differences. First, prior studies have not incorporated prospective, direct, physician-based diagnosis and follow-up. The majority of prior studies depended on either the retrospective self-reporting of the athlete, or the judgment of a certified team trainer or first responder.[6,7,11,14,15,18,22,31] Second, the elevated and multisite points of observation used in our study provided improved ability to view the events occurring on the ice surface. Because our observers were specifically looking for concussions prospectively, as opposed to collecting these retrospectively or using historical injury data previously collected, we likely observed and recorded more events than otherwise might have been detected by team staff who have a multitude of other duties. Our observers often reported that team trainers, despite not being engaged with other duties at the time of the event, did not either see or react to an observed concussion event. The team therapist/first responder then had to be prompted to evaluate a player with a suspected concussion. Third, it is possible that the threshold for diagnosis using our observers and the Zurich statement was more sensitive than prior diagnostic systems. Fourth, player recognition of concussions may be improving, despite obvious barriers and resistance. Three of our players who were diagnosed with a concussion initially self-reported their injury. And finally, there could be a true increase in the rate of concussion based on increased speed and aggression of players. Some of these players were motivated to play as physically as possible in hopes of attaining upper level junior or collegiate status, and may have taken more risk than players in previous studies.

Five (24%) of 21 individuals who sustained a concussion were directly involved in a fight immediately prior to their concussion diagnosis. The majority of hits causing a concussion were to the head (29 of 42 observer reports, 69%). Eighty percent of the observer reports (33 of 41) described the hit that was perceived to cause the concussion as purposeful. These observations demonstrate the need for a closer examination of preventable hits to the head in ice hockey and other sports. Although the intention of an aggressor in ice hockey is difficult to determine, it is im-

portant to objectively and directly document these events in this manner. Future studies may use video surveillance as well as human surveillance to provide an improved historical record and analysis of each event.

We did not specifically monitor practices, and no concussions that occurred in practices were reported by either team during the study. Previous sport concussion studies demonstrated that concussion predominantly occurs in game situations.[1–3,10,30]

Gerberich et al.,[11] a commonly cited retrospective study on recurrent concussions, states that the relative risk of concussions is 4 times higher than for individuals without this history. A prospective survey study of US high school and college football athletic trainers by Guskiewicz et al.[15] found that players who had sustained 1 concussion were 3 times more likely to sustain a second concussion than those players who had not sustained a previous injury. A large prospective study by Zemper[31] indicates that the risk of sustaining a cerebral concussion is 6 times greater for individuals with a history of concussion than for individuals with no such history.

Recurrent concussions may be related to the fact that players are often prematurely returned to play.[23,30] Guskiewicz et al.[14] found that of the 12 incidents of repeat concussions that occurred within the same season, 11 (97%) occurred within 10 days of the first injury, and 9 (75%) occurred within 7 days of the first injury.[14] The time interval between the first and second concussions found in the HCEP differed significantly from the findings of Guskiewicz et al. The HCEP findings demonstrated a mean time interval between the first and second concussions of these 5 players of 78.6 days (median 82 ± 39.8 days), and the mean time between the return-to-play date of the first and second concussions was 61.8 days (median 60 ± 39.7 days). The difference in these findings may be attributable to the direct surveillance and strict adherence to the Zurich return-to-play protocol used in the HCEP.

In our opinion, the singular results of standardized tools such as SCAT2 and ImPACT should not be considered independent decision-making instruments. Rather, these tools can supplement clinical information, but not override physician judgment. In 3 of the 17 cases (18%) of diagnosed concussions in which medical follow-up was obtained, the athletes scored either in the normal range or were within their baseline ImPACT score, but still declared significant symptoms. In 2 of the 17 (12%) diagnosed concussions which underwent medical follow-up, the athletes declared no symptoms, yet demonstrated cognitive deficits when compared to their their baseline ImPACT score, or age-/gender-matched normative scores.

Baseline standardized testing served to identify 1 athlete who had been concussed in a game 2 days earlier and did not report his injury or resulting symptoms. This athlete was withheld from play until he recovered from his injury. A second player was less fortunate. He had a positive symptom inventory on his baseline SCAT2 testing from a nondisclosed prior concussion, and was permitted to play on the basis of a normal ImPACT result when compared with age-group means. This player suffered 2 subsequent concussions (a second nondeclared and 1 physician identified) during the 2009–2010 season, and was forced to retire permanently secondary to persistent postconcussion syndrome.

In retrospective analysis, 12 of the 17 athletes who were diagnosed with a concussion demonstrated a positive symptom inventory or abnormal SAC score (< 25/30) at baseline, despite the fact that their baseline ImPACT scores were reviewed and found not to be outside their expected age-related normative range. These athletes were not clinically examined, retested, or withheld from competition. Improved vigilance concerning interpretation of abnormal baseline test results is suggested for future studies, to identify individuals who may be suffering from a nondisclosed concussion at baseline testing.

A limitation of this study was the lack of compliance of athletes with requested neuropsychological evaluations. Five of the players who were diagnosed with a concussion did not complete their baseline SCAT2 and ImPACT testing prior to entering the study. A second example of noncompliance was the resistance to the recommended physician evaluation for medical release to game play. The lack of compliance made it difficult to document a complete data set of the measurements for comparison purposes.

Complaints by coaches, players, and parents concerning the inconvenience of multiple physician visits for serial testing and evaluation were common. The reluctance to report concussion symptoms and to follow such protocols likely results from certain cultural factors such as athletes asserting their masculinity by playing through the discomfort of an injury, and the belief that winning is more important than the athlete's long-term health.

Future studies should focus on improved education and compliance of the athlete, coaching staff, medical/training staff, club executives, and parents concerning adherence to a direct surveillance protocol. The complete SCAT2 data should be collected and compared across the population to assist in validating and improving this screening tool. Studies should also be performed on larger populations, in other contact sports, across sexes, across different levels of play, and across different countries to assess the generalizability of these findings.

Conclusions

Physician observation and diagnosis using current internationally agreed-upon diagnostic criteria and standardized assessment tools showed that the incidence of concussion in fourth-tier junior ice hockey players was significantly greater than has previously been reported in the literature for this age group. The results of this study demonstrate the need for follow-up studies involving larger and more diverse sample groups to reflect generalizability of the findings. These follow-up studies should involve other contact sports (for example football and rugby) and also include the full spectrum of gender, age, and skill levels.

Disclosure

This work was funded by the Ontario Trillium Foundation, the Dr. Tom Pashby Safety Fund, and the Dave Irwin Foundation for Brain Injury. The Ontario Neurotrauma Foundation made administrative and facilitative contributions. Dr. Cusimano is funded by the Canadian Institutes of Health Strategic Teams in Applied Injury Research.

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: Echlin, Tator. Analysis and interpretation of data: Echlin, Tator, Cusimano, Cantu, Taunton, Upshur, Hall, Johnson, Forwell. Drafting the article: Echlin, Tator, Cusimano, Cantu, Taunton, Upshur, Johnson. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: Echlin, Tator, Cusimano, Cantu, Upshur, Hall, Johnson, Forwell, Skopelja. Administrative/technical/material support: Echlin, Hall, Johnson, Forwell, Skopelja. Study supervision: Echlin, Hall, Forwell.

Acknowledgments

The authors acknowledge the contributions of the members of the Hockey Concussion Education Project Team (Michael A. Czarnota, Ph.D., Wayne State University, Detroit, Michigan, and Suzanne Riverin, Ph.D., Nipissing University, North Bay Ontario, Canada); the Hockey Neurotrauma and Concussion Initiative Research Committee; the editorial work of Kim Echlin, Ph.D., University of Toronto, Ontario, Canada; and Ann Echlin, B.A., Toronto, Canada. The authors acknowledge the players and staffs of Team A and Team B for their participation in the HCEP, and would also like to acknowledge the participating physicians, observers, and volunteers for their contributions to the HCEP.

References

1. 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 42:** 249–254, 2007
2. 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 42:**241–248, 2007
3. Benson BW, Rose MS, Meeuwisse WH: The impact of face shield use on concussions in ice hockey: a multivariate analysis. **Br J Sports Med 36:**27–32, 2002
4. De Beaumont L, Lassonde M, Leclerc S, Théoret H: Long-term and cumulative effects of sports concussion on motor cortex inhibition. **Neurosurgery 61:**329–337, 2007
5. De Beaumont L, Théoret H, Mongeon D, Messier J, Leclerc S, Tremblay S, et al: Brain function decline in healthy retired athletes who sustained their last sports concussion in early adulthood. **Brain 132:**695–708, 2009
6. Delaney JS, Lacroix VJ, Gagne C, Antoniou J: Concussions among university football and soccer players: a pilot study. **Clin J Sport Med 11:**234–240, 2001
7. Delaney JS, Lacroix VJ, Leclerc S, Johnston KM: Concussions during the 1997 Canadian Football League season. **Clin J Sport Med 10:**9–14, 2000
8. Emery CA, Kang J, Shrier I, Goulet C, Hagel BE, Benson BW, et al: Risk of injury associated with body checking among youth ice hockey players. **JAMA 303:**2265–2272, 2010
9. Emery CA, Meeuwisse WH: Injury rates, risk factors, and mechanisms of injury in minor hockey. **Am J Sports Med 34:**1960–1969, 2006
10. Flik K, Lyman S, Marx RG: American collegiate men's ice hockey: an analysis of injuries. **Am J Sports Med 33:**183–187, 2005
11. Gerberich SG, Priest JD, Boen JR, Straub CP, Maxwell RE: Concussion incidences and severity in secondary school varsity football players. **Am J Public Health 73:**1370–1375, 1983
12. Guskiewicz KM, Marshall SW, Bailes J, McCrea M, Cantu RC, Randolph C, et al: Association between recurrent concussion and late-life cognitive impairment in retired professional football players. **Neurosurgery 57:**719–726, 2005
13. Guskiewicz KM, Marshall SW, Bailes J, McCrea M, Harding HP Jr, Matthews A, et al: Recurrent concussion and risk of depression in retired professional football players. **Med Sci Sports Exerc 39:**903–909, 2007
14. Guskiewicz KM, McCrea M, Marshall SW, Cantu RC, Randolph C, Barr W, et al: Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. **JAMA 290:**2549–2555, 2003
15. Guskiewicz KM, Weaver NL, Padua DA, Garrett WE Jr: Epidemiology of concussion in collegiate and high school football players. **Am J Sports Med 28:**643–650, 2000
16. Honey CR: Brain injury in ice hockey. **Clin J Sport Med 8:** 43–46, 1998
17. Keating P: Reporting from the National Academy of Neuropsychology's Sports Concussion Symposium: The NHL releases the first data from its concussion program. But what do the numbers mean? **ESPN Magazine** (http://sports.espn.go.com/espnmag/story?id=3656016) [Accessed October 6, 2010]
18. Langburt W, Cohen B, Akhthar N, O'Neill K, Lee JC: Incidence of concussion in high school football players of Ohio and Pennsylvania. **J Child Neurol 16:**83–85, 2001
19. McCrory P, Meeuwisse W, Johnston K, Dvorak J, Aubry M, Molloy M, et al: Consensus statement on concussion in sport: 3rd International Conference on Concussion in Sport held in Zurich, November 2008. **Clin J Sport Med 19:**185–200, 2009
20. McKee AC, Cantu RC, Nowinski CJ, Hedley-Whyte ET, Gavett BE, Budson AE, et al: Chronic traumatic encephalopathy in athletes: progressive tauopathy after repetitive head injury. **J Neuropathol Exp Neurol 68:**709–735, 2009
21. Moser RS, Schatz P, Jordan BD: Prolonged effects of concussion in high school athletes. **Neurosurgery 57:**300–306, 2005
22. Pinto M, Kuhn JE, Greenfield ML, Hawkins RJ: Prospective analysis of ice hockey injuries at the Junior A level over the course of one season. **Clin J Sport Med 9:**70–74, 1999
23. Randolph C, Millis S, Barr WB, McCrea M, Guskiewicz KM, Hammeke TA, et al: Concussion symptom inventory: an empirically derived scale for monitoring resolution of symptoms following sport-related concussion. **Arch Clin Neuropsychol 24:**219–229, 2009
24. Roberts WO, Brust JD, Leonard B: Youth ice hockey tournament injuries: rates and patterns compared to season play. **Med Sci Sports Exerc 31:**46–51, 1999
25. Schick DM, Meeuwisse WH: Injury rates and profiles in female ice hockey players. **Am J Sports Med 31:**47–52, 2003
26. Schwarz A: Former Bengal Henry found to have had brain damage. **New York Times.** June 28, 2010 (http://www.nytimes.com/2010/06/29/sports/football/29henry.html) [Accessed October 6, 2010]
27. Schwarz A, Klein JZ: Brain damage found in hockey player. **New York Times.** December 17, 2009 (http://www.nytimes.com/2009/12/18/sports/hockey/18concussion.html?_r=1) [Accessed October 6, 2010]
28. Shuttleworth-Edwards AB: Central or peripheral? A positional stance in reaction to the Prague statement on the role of neuropsychological assessment in sports concussion management. **Arch Clin Neuropsychol 23:**479–485, 2008
29. Wennberg RA, Tator CH: National Hockey League reported concussions, 1986-87 to 2001-02. **Can J Neurol Sci 30:**206–209, 2003
30. Williamson IJS, Goodman D: Converging evidence for the under-reporting of concussions in youth ice hockey. **Br J Sports Med 40:**128–132, 2006
31. Zemper ED: Two-year prospective study of relative risk of a second cerebral concussion. **Am J Phys Med Rehabil 82:** 653–659, 2003

Manuscript submitted July 15, 2010.
Accepted September 16, 2010.

Address correspondence to: Paul Sean Echlin, M.D., 320 Adelaide Street, South London, Ontario, Canada N5Z 3L2. email: p_echlinfp@hotmail.com.