ORIGINAL ARTICLE

Multidisciplinary Management of Pediatric Sports-Related Concussion

Michael J. Ellis, Lesley J. Ritchie, Patrick J. McDonald, Dean Cordingley, Karen Reimer, Satnam Nijjar, Mark Koltek, Shahid Hosain, Janine Johnston, Behzad Mansouri, Scott Sawyer, Norm Silver, Richard Girardin, Shannon Larkins, Sara Vis, Erin Selci, Michael Davidson, Scott Gregoire, Angela Sam, Brian Black, Martin Bunge, Marco Essig, Peter MacDonald, Jeff Leiter, Kelly Russell

ABSTRACT: ***Objectives:*** To summarize the clinical characteristics and outcomes of pediatric sports-related concussion (SRC) patients who were evaluated and managed at a multidisciplinary pediatric concussion program and examine the healthcare resources and personnel required to meet the needs of this patient population. ***Methods:*** We conducted a retrospective review of all pediatric SRC patients referred to the Pan Am Concussion Program from September 1st, 2013 to May 25th, 2015. Initial assessments and diagnoses were carried out by a single neurosurgeon. Return-to-Play decision-making was carried out by the multidisciplinary team. ***Results:*** 604 patients, including 423 pediatric SRC patients were evaluated at the Pan Am Concussion Program during the study period. The mean age of study patients was 14.30 years (SD: 2.32, range 7-19 years); 252 (59.57%) were males. Hockey (182; 43.03%) and soccer (60; 14.18%) were the most commonly played sports at the time of injury. Overall, 294 (69.50%) of SRC patients met the clinical criteria for concussion recovery, while 75 (17.73%) were lost to follow-up, and 53 (12.53%) remained in active treatment at the end of the study period. The median duration of symptoms among the 261 acute SRC patients with complete follow-up was 23 days (IQR: 15, 36). Overall, 25.30% of pediatric SRC patients underwent at least one diagnostic imaging test and 32.62% received referral to another member of our multidisciplinary clinical team. ***Conclusion:*** Comprehensive care of pediatric SRC patients requires access to appropriate diagnostic resources and the multidisciplinary collaboration of experts with national and provincially-recognized training in TBI.

RÉSUMÉ: Prise en charge par une équipe multidisciplinaire de la commotion cérébrale subie au cours d'activités sportives chez des enfants. ***Objectifs:*** Le but de l'étude était de résumer les caractéristiques cliniques et les résultats du traitement chez des enfants qui ont subi une commotion cérébrale au cours d'activités sportives (CCS) et qui ont été évalués et traités dans le cadre d'un programme pédiatrique multidisciplinaire de traitement de la commotion cérébrale. Le but était également d'examiner les ressources sanitaires et le personnel requis pour satisfaire aux besoins de cette population de patients. ***Méthodologie:*** Nous avons effectué une revue rétrospective des dossiers de tous les patients pédiatriques ayant subi une CCS qui ont été référés au Pan Am Concussion Program du 1er septembre 2013 au 25 mai 2015. Le même neurochirurgien a procédé aux évaluations initiales et a posé les diagnostics. Une équipe multidisciplinaire décidait du moment du retour au jeu. ***Résultats:*** Six cent quatre patients, dont 423 patients pédiatriques ont été évalués par le Pan Am Concussion Program au cours de cette période. L'âge moyen des patients de l'étude était de 14,30 ans (écart type : 2,32 ; intervalle 7 à 19 ans) et 252 (59,57%) étaient de sexe masculin. Au moment de la blessure, les sports les plus fréquemment pratiqués étaient le hockey (182 ; 43,03%) et le soccer (60 ; 14,18%). En tout, 294 (69,50%) patients atteints d'une CCS rencontraient les critères cliniques de rétablissement suite à la commotion cérébrale alors que 75 (17,73%) ne se sont pas présenté pour le suivi et 53 (12,53%) étaient encore sous traitement à la fin de la période de l'étude. La durée médiane des symptômes chez les 261 patients ayant subi une CCS et dont le suivi était complet était de 23 jours (écart interquartile : 15 à 36). En tout, 25,30% des patients pédiatriques atteints d'une CCS ont subi au moins un test d'imagerie diagnostique et 32,62% ont été référés à un autre membre de notre équipe clinique multidisciplinaire. ***Conclusion:*** Pour recevoir des soins complets, les patients pédiatriques présentant une CCS doivent avoir accès à des ressources diagnostiques appropriées et à la collaboration multidisciplinaire d'experts ayant une formation reconnue au niveau national et provincial sur le traumatisme crânien.

Keywords: Sports-related concussion, traumatic brain injury, pediatric, healthcare utilization, multidisciplinary, concussion program

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From the Department of Surgery (MJE, PJM, BB, PM, JL); Pediatrics and Child Health (MJE, PJM, SS, NS, ES, BB, MB, KR); Clinical Health Psychology (LJR); Rehabilitation Sciences (KR, SL); Neurology (SN, JJ, BM); Psychiatry (MK, SH); Diagnostic Imaging (MD, SG, AS, MB, ME); Section of Neurosurgery (MJE, PJM) and Orthopedics (BB, PM), University of Manitoba; Pan Am Clinic and Pan Am Concussion Program (MJE, LJR, PJM, DC, KR, SN, MK, SH, JJ, BM, SS, NS, RG, SL, SV, MD, SG, AS, BB, MB, ME, PM, JL); Childrens Hospital Research Institute of Manitoba (MJE, PJM, KR); Canada North Concussion Network (MJE, LJR, PJM, DC, KR, SN, MK, SH, JJ, BM, SS, NS, RG, SL, SV, MD, SG, AS, BB, MB, ME, PM, JL), Winnipeg, Manitoba, Canada.

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Correspondence to: Michael Ellis, Pan Am Clinic, 75 Poseidon Bay, Winnipeg, MB, Canada R3M 3E4. Email: mellis@panamclinic.com.

Over the past 10-15 years sports-related concussion (SRC) has evolved into a significant public health issue in Canada. With increasing recognition of the acute and long-term consequences of concussion and repetitive head injuries, government, medical, and community stakeholders have begun to raise concerns about the safety of children participating in contact and collision sports. Although most adult SRC patients will return to their neurological baseline within 1-2 weeks following injury,[1] children and adolescents with concussion appear to take longer, with 21-73% of patients developing prolonged symptoms or post-concussion syndrome (PCS).[2-7] Emerging evidence suggests that PCS patients represent a heterogeneous population with multi-disciplinary needs that can often take the form of vestibulo-ocular dysfunction, chronic headaches, aerobic deconditioning, post-injury psychiatric disorders, convulsive disorders, and cervical spine injuries.[8,5,9-18]

To address these concerns, national and international working groups representing a wide range of healthcare disciplines have convened to summarize the existing literature and put forth expert consensus guidelines to help guide the diagnosis, management, and prevention of SRC.[19,20-22,1] Despite these efforts no studies have examined the unique healthcare needs of Canadian pediatric acute SRC and PCS patients or identified the healthcare professionals who are best qualified to meet these needs. In addition, there are no guidelines addressing how comprehensive multi-disciplinary care of this patient population can be regionalized within sustainable specialized healthcare programs in Canada.

To meet these objectives in the province of Manitoba, provincial government, regional health authority, university, and community stakeholders have partnered to establish the Pan Am Concussion Program. This provincial government-funded clinical program is devoted to the comprehensive multidisciplinary medical care of children and adolescents with sports and non-sports related concussion and mild traumatic brain injury (mTBI). Here we examine the clinical characteristics and outcomes of pediatric SRC patients presenting to this clinic and the diagnostic and healthcare professional resources utilized by these patients during the first 21 months of this program. Using this data we compare and contrast the personnel and practices of our program against other concussion healthcare providers and clinics in Canada.

Methods

The Pan Am Concussion Program

The primary objectives of the Pan Am Concussion Program were to establish a multidisciplinary clinical program that 1) provided comprehensive evaluation and management of children and adolescents with sports and non-sports related concussion and TBI; and 2) ensured every aspect of patient care was carried out by the healthcare professional(s) with the highest level of nationally- or provincially-licensed clinical training and experience in that TBI-related subdiscipline.

To achieve these objectives, we initiated a three-stage project to evaluate the volume and needs of pediatric concussion patients in Manitoba. Stages 1 and 2 included a pilot project in partnership with the emergency department at Health Sciences Centre Children's Hospital (HSC-CH), the only pediatric hospital in the province of Manitoba, serving a catchment area of approximately 1.5 million residents, including regions of Northwestern Ontario and Eastern Saskatchewan. Stage 3 included a by-referral-only multidisciplinary pediatric concussion program housed within a provincial government-funded facility. Stage 1 ran from September 1 to December 31, 2013, during which time emergency medicine physicians at HSC-CH were permitted to refer sports and non-sports related concussion patients with at least 4 concussion-related symptoms for follow-up with a neurosurgeon at the Pan Am Clinic, an off-site orthopedic surgery and sports medicine clinic in Winnipeg, Manitoba. Stage 2 ran from January 1 to October 14, 2014, during which time emergency medicine physicians were permitted to refer any pediatric concussion patient who they felt would benefit from additional evaluation and follow-up to the Pan Am Clinic. During Stages 1 and 2 of this pilot project no other referral sources were solicited; however, additional patient referrals received from outside emergency medicine physicians, pediatricians, primary care, and sports medicine physicians were also accepted. During Stage 1 and 2 the Pan Am Clinic initiated a city-wide concussion protocol for all Bantam and Midget-aged Winnipeg Minor Hockey (WMH) AAA players that permitted patients with a suspected concussion to be evaluated without physician referral.

During Stage 2 of the project the Manitoba Provincial Government, Winnipeg Regional Health Authority, University of Manitoba, HSC-Children's Hospital, Pan Am Clinic Foundation, Winnipeg Jets True North Sports and Entertainment Ltd., and Pan Am Clinic partnered to build a dedicated 2,500 square foot clinic located within the MTS Iceplex, the practice facility of the Winnipeg Jets National Hockey League (NHL) team. Government funding covered capital expenses for construction and furnishing of the new clinical space as well as establishing a website that provided concussion educational materials tailored for all Manitoban patients, parents, coaches, and teachers. In addition, operating funding covered the cost of clinical clerks, a part-time clinical neuropsychologist, a part-time vestibular physiotherapist, and selected neuropsychological testing instruments.

Stage 3 of the project began on October 15, 2014, when the Pan Am Concussion Program was opened at the MTS Iceplex. Access to the clinic was made available to all pediatric acute and PCS patients with sports and non-sports related concussions upon physician referral from pediatricians, as well as emergency room, primary care, and sports medicine physicians. During Stage 3 of the project a city-wide concussion protocol was established for all WMH players whereby patients were directed to receive follow-up care and medical clearance from the Pan Am Concussion Program following physician referral.

Clinical Assessments, Diagnostic Imaging, and Healthcare Personnel

During all stages of the project, all patients referred to the multidisciplinary pediatric concussion program underwent initial consultation by a single neurosurgeon who is a fellow of the Royal College of Physician and Surgeons of Canada. The neurosurgeon completed his neurosurgery residency at the University of Toronto, which included 8 months of pediatric neurosurgery as well as an in-folded fellowship in concussion spectrum disorders. During the study period the neurosurgeon held clinical appointments in the University of Manitoba Department of Surgery and Pediatrics and Child Health and section of Neurosurgery. At the time of initial consultation all patients completed a standardized data collection form that included demographic data,

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past medical and concussion history, family history and information regarding the mechanism and setting or injury, initial concussion symptoms and the presence of a loss of consciousness or post-traumatic amnesia at the time of injury. At initial consultation and during follow-up appointments all patients completed the post-concussion symptom scale (PCSS), a self-reported symptom inventory that includes 22 symptoms rated on a 7-point (0–6) Likert scale with a maximum score of 132.

The diagnosis of concussion was made by the neurosurgeon according to the definition set forth by the International Consensus on Concussion in Sport as an injury caused by transmission of biomechanical forces to the brain leading to clinical symptoms affecting multiple domains of physical, cognitive, sleep, and neurobehavioral functioning.[1] In general, patients were classified as fully recovered when they were asymptomatic at rest according to clinical interview and PCSS, were participating in full-time school activities without symptoms, successfully completed the International Consensus on Concussion in Sport graduated Return-to-Play protocol,[1] had a normal neurological examination, and did not meet the clinical criteria for vestibulo-ocular dysfunction as previously defined.[5] Confirmation of concussion recovery was supplemented on a selective basis by the use of a hybrid neuropsychological testing approach (computerized and pencil-and-paper testing instruments) that was administered and interpreted by a certified clinical neuropsychologist. Neuropsychological testing instruments used to assess neurocognitive functioning were selected on an individualized basis at the discretion of the clinical neuropsychologist depending on the patient's age, clinical findings, and duration of symptoms. All subsequent diagnostic tests and referrals to other multidisciplinary team members were initiated based on the clinical discretion of the treating neurosurgeon and not according to pre-determined research criteria. The clinical treatment team was assembled over the course of the project as novel patient needs and resources were

Table 1: Multi-disciplinary pediatric concussion program clinical team members, qualified roles, and responsibilities

Team member (number)	Qualified roles and responsibilities
Neurosurgeon	• Neurological assessment of acute SRC, PCS, and mTBI patients • Rule out associated intracranial and spinal injuries and other neurological disorders • Consideration of neuroimaging studies • Return-to-Play decision-making
Neuropsychologist	• Administration and interpretation of neurocognitive and formal neuropsychological tests • Coordination of Return-to-learn program • Return-to-Play decision-making
Neurologist	• Evaluation and management of patients with post-traumatic and migraine headaches, and occipital neuralgia • Evaluation of patients with co-existing neurological disorders (e.g. seizures, vascular injuries)
Vestibular physiotherapist	• Evaluation and rehabilitation of patients with central vestibulo-ocular dysfunction, cranial nerve palsies, postural imbalance, peripheral vestibulopathies (e.g. BPPV)
Cervical spine physiotherapist	• Evaluation and rehabilitation of patients with cervicogenic headaches and cervical spine soft tissue injury (e.g. whiplash)
Adolescent psychiatrist (2)	• Evaluation and management of patients with novel psychiatric disorders, suicidal ideation, and patients with worsening symptoms of a pre-injury psychiatric disorder
Neuro-ophthalmologist (2)	• Evaluation and management of patients with visual and oculomotor disorders
Exercise scientist/exercise physiologist (2)	• Administration and interpretation of graded aerobic treadmill testing • Prescription of tailored sub-maximal exercise programs
Neuroradiologist (3)	• Coordination and interpretation of neuroimaging studies (e.g. CT, MRI)
Musculoskeletal radiologist (2)	• Coordination and interpretation of musculoskeletal imaging studies (e.g. x-ray, CT)
Pediatric neurosurgeon	• Evaluation and management of structural intracranial and spinal injuries and other structural neurological conditions (e.g. arachnoid cysts, Chiari Malformation)
ENT surgeon	• Evaluation and management of patients with traumatic temporal bone and cranial nerve pathology
Orthopedic surgeon	• Evaluation and management of co-existing orthopedic injuries
Sports medicine physician	• Initial evaluation of acute SRC and mTBI patients and coordination of patients who require acute assessment outside concussion program office hours • Evaluation and management of co-existing sports injuries
Pediatric emergency medicine physician (2)	• Initial evaluation of SRC and mTBI patients and coordination of patients who require acute assessment or imaging studies outside concussion program office hours
Athletic therapist/research coordinator	• Assist in neurocognitive and graded aerobic treadmill test administration • Coordination of research studies

SRC = sports-related concussion; PCS = post-concussion syndrome; mTBI = mild traumatic brain injury; BPPV = benign paroxysmal positional vertigo; CT = computerized tomography; MRI = magnetic resonance imaging; ENT = ear, nose, and throat.

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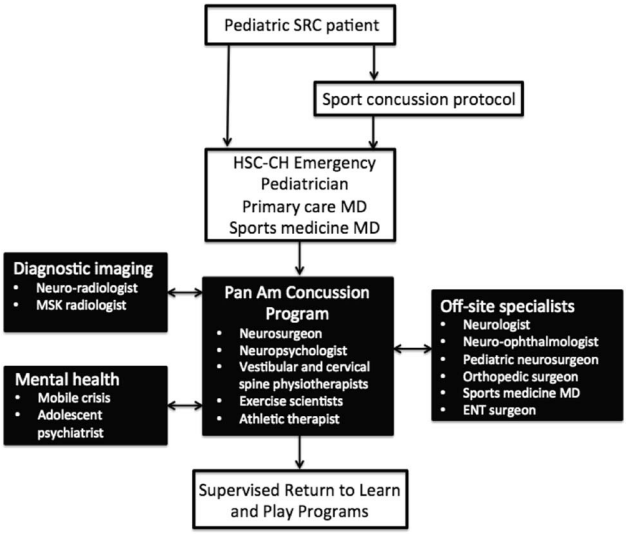

Figure 1: *Structure and organization of the clinical referral pathway for pediatric SRC patients and multidisciplinary pediatric concussion program. SRC = sports-related concussion; MSK = musculo-skeletal; ENT = ear, nose, and throat; MD = medical doctor.*

identified. By the end of the 21-month project, the multidisciplinary pediatric concussion program included 23 clinical team members (Table 1). Because there were no diagnostic imaging services available at the new concussion program facility, these studies were carried out at Pan Am Clinic, HSC-CH, and other outside hospitals. To facilitate management of acute psychiatric patients, dedicated referral pathways were established with adolescent mobile crisis and adolescent psychiatry.

The overall philosophy of the pediatric concussion program was to manage pediatric acute SRC patients conservatively, with proper Return-to-Play and Return-to-Learn guidance for the first 3-4 weeks. Acute concussion patients who reported persistent symptoms that were not improving 3-4 weeks post-injury and those referred with PCS were considered for targeted rehabilitation strategies such as vestibular and cervical physiotherapy, submaximal aerobic exercise therapy, pharmacological management of post-traumatic and migraine headaches, and multidisciplinary management of post-injury psychiatric outcomes.[9] Overall structure and organization of the clinical referral pathway for pediatric SRC patients and multidisciplinary pediatric concussion program is illustrated in Figure 1.

Study Design and Analysis

We performed a retrospective chart review for all consecutive pediatric patients referred to the Pan Am Concussion Program at Pan Am Clinic, Winnipeg, Manitoba, Canada with a concussion from September 1, 2013 to May 25, 2015. Included patients were those who were age 19 or younger and diagnosed with an acute SRC or PCS secondary to a SRC. Patients who were 20 years of age or older and who were diagnosed with a non-sports related concussion or moderate and severe TBI were excluded. Acute SRC was defined as a clinical consultation on a SRC patient evaluated less than 30 days from the time of injury. PCS was defined as the presence of 3 or more concussion symptoms identified by the International Classification of Diseases-10[64] and persistent symptoms for greater than one month in duration (30 days). The primary outcomes were the clinical characteristics of this patient population, the diagnostic and healthcare professional resources utilized by these patients and concussion recovery outcomes. This study was approved by the Institutional Research Ethics Board at the University of Manitoba.

Dichotomous data were tabulated as proportions and the chi-square test was used to determine statistical significance comparing those who presented with acute SRC versus PCS. Continuous variables that were normally distributed were summarized as means with standard deviations and means were compared using a t-test. Non-normally distributed data were summarized as medians with interquartile ranges and the rank sum test was used to determine statistical significance. P-values less than 0.05 were interpreted as statistically significant.

Results

During the study period 604 pediatric concussion patients were evaluated at the Pan Am Concussion program including 423 pediatric SRC patients. Of these SRC patients, 320 (75.65%) were classified as acute SRC patients, 102 (24.11%) were classified as PCS patients, and one (0.24%) was asymptomatic at the time of initial consultation. The distribution of patient referrals according to the study stages is summarized in Table 2 and included 45 (10.64%) patients in Stage 1, 142 (33.57%) patients in Stage 2, and 236 (55.79%) patients in Stage 3. The mean age of study patients was 14.30 years (SD: 2.32; range 7-19 years) and 252 (59.57%) were males. Past medical history was notable for previous concussion (197; 46.57%), migraine or non-specific headaches (48; 11.35%), attention-deficit hyperactivity disorder (27; 6.38%), pre-injury depression (16; 3.78%), and non-specific learning disorder (13; 3.07%). Hockey (182; 43.03%) and soccer (60; 14.18%) were the most commonly played sports at the time of injury for males and females.

The median time from injury to initial consultation was 7 days (IQR: 5, 12) for acute SRC patients and 86.5 days (IQR: 41.75, 163.5) for those who presented with PCS. The median PCSS score

Table 2: Summary of sports-related concussion patients referred to the Pan Am Concussion Program during the 21 month study period

Project Stage	Referral Criteria	No. of Patients Evaluated (Total patients = 423)
1 (September 1st, 2013-December 31st, 2013)	Patients referred from HSC-CH ED with 4 or more concussion symptoms	45
2 (January 1st, 2014-October 14th, 2014)	Patients referred from HSC-CH ED who the emergency medicine physician deemed appropriate for additional evaluation and follow-up	142
3 (October 15th, 2014-May 25th, 2015)	Patients referred from HSC-CH ED, pediatricians, primary care physicians, and sports medicine physicians	236

HSC-CH ED = Health Sciences Centre-Children's Hospital Emergency Department.

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was 10.5 (IQR 2, 30) for acute SRC patients and 23 (IQR 8, 39) for PCS patients ($p < 0.001$). The most common symptoms reported at initial consultation were headache (294; 69.50%), fatigue (231; 54.61%), difficulties concentrating (219; 51.77%), sensitivity to light (208; 49.17%), and dizziness (194; 45.86%). Fourteen patients (3.31%) presented with focal neurological deficits secondary to co-existing spinal cord injury (4), optic neuropathy (3), brachial plexus traction injury (3), convulsive disorder (2), orbital trauma (1), or unknown etiology (1). Four (0.95%) patients presented with seizure-like activity at the time of injury. Additional characteristics are summarized in Table 3.

Overall, 25.30% of pediatric SRC patients underwent at least one diagnostic imaging test. Diagnostic tests that were utilized in this cohort included cervical spine x-ray (34; 8.04%), computerized tomography (CT) of the spine (1; 0.24%), magnetic resonance imaging (MRI) of the spine (10; 2.36%), and MRI of the brain (58; 13.71%). CT imaging of the head was obtained in (47; 11.11%) patients with all studies completed in the emergency room setting and all but one completed prior to referral to the pediatric concussion program.

Overall, 138 (32.62%) of SRC patients received referral to at least one other member of our multidisciplinary clinical team (total of 240 referrals). Clinical referrals that were utilized in this study included those to a vestibular physiotherapist (60; 14.18%), neurologist (43; 10.17%), cervical spine physiotherapist (32; 7.57%), clinical neuropsychologist (21; 4.96%), and neuro-ophthalmologist (6; 1.42%). There were 49 (11.58%) patients who were referred to an exercise physiologist for physician-supervised

Table 3: Baseline characteristics and symptoms at initial consultation*

	All Concussions (N = 423; %)	Acute SRC (N = 320; %)	PCS (N = 102; %)	p-value
Age (year, SD)	14.30 (2.31)	13.95 (2.31)	15.38 (2.01)	<0.0001
Males	252 (59.57)	209 (65.31)	42 (41.81)	<0.0001
Past Concussion	197 (46.57)	133 (41.56)	63 (61.76)	<0.0001
Past Migraines and non-specific headaches	48 (11.35)	29 (9.06)	19 (18.63)	0.008
Past Depression	16 (3.78)	7 (2.19)	8 (7.84)	0.007
Delayed Symptoms	129 (30.50)	90 (28.13)	39 (38.24)	0.054
Post-traumatic amnesia	133 (31.44)	96 (30.00)	37 (36.27)	0.235
LOC	68 (16.08)	44 (13.75)	24 (23.53)	0.021
Missing	7 (1.65)	6 (1.88)	1 (0.97)	
Initial PCSS at Consultation (median, IQR)	14 (3,32)	10.5 (2,30)	23 (8,39)	<0.0001
Headache at Consultation	294 (69.50)	217 (67.81)	77 (75.49)	0.147
Missing	6 (1.42)	4 (1.25)	1 (0.98)	
Dizziness at Consultation	194 (45.86)	144 (45.00)	50 (49.02)	0.490
Missing	6 (1.42)	4 (1.25)	1 (0.98)	
Light Sensitivity at Consultation	208 (49.17)	151 (47.19)	57 (55.88)	0.130
Missing	6 (1.42)	4 (1.25)	1 (0.98)	
Sound Sensitivity at Consultation	192 (45.39)	134 (41.88)	58 (56.86)	0.009
Missing	7 (1.65)	5 (1.57)	1 (0.98)	
Fatigue at Consultation	231 (54.61)	167 (52.19)	64 (62.75)	0.064
Missing	6 (1.42)	4 (1.25)	1 (0.98)	
Difficulty Concentration at Consultation	219 (51.77)	153 (47.81)	66 (64.71)	0.003
Missing	6 (1.42)	4 (1.25)	1 (0.98)	
Unable to Fall Asleep at Consultation	192 (45.39)	128 (40.00)	64 (62.75)	<0.0001
Missing	6 (1.42)	4 (1.25)	1 (0.98)	
Sport**				
Hockey	182 (43.03)	143 (44.69)	38 (37.25)	
Soccer	60 (14.18)	44 (13.74)	16 (15.69)	
Football	43 (10.17)	38 (11.88)	5 (4.90)	
Basketball	26 (6.15)	16 (5.00)	10 (9.80)	
Volleyball	12 (2.84)	7 (2.19)	5 (4.90)	

SRC = sports-related concussion; PCS = post-concussion syndrome; SD = standard deviation; IQR = intra-quartile range; LOC = loss of consciousness.
*Only reported symptoms manifested by at least 40% of patients at initial consultation.
**Includes only the top 5 sports played by patients at the time of injury.

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graded aerobic treadmill testing. For mental health services the cohort used adolescent psychiatry (21; 4.96%) and mobile crisis (2; 0.47%). Four patients (0.95%) were referred to a pediatric neurosurgeon, two patients (0.74%) were referred to an orthopedic surgeon, and one (0.24%) to a sports medicine physician.

Overall, 294 (69.50%) of SRC patients met the clinical criteria for concussion recovery, 75 (17.73%) were lost to follow-up, and 53 (12.53%) remained in active treatment at the end of the study period. One asymptomatic patient who was referred with a history of SRC and a newly diagnosed post-injury psychiatric outcome committed suicide. Overall, 261 (81.81%) of acute SRC and 33 (32.04%) of PCS patients met the clinical criteria for recovery. The median duration of symptoms among the 261 acute SRC patients with complete follow-up was 23 days (IQR: 15, 36).

Discussion

To our knowledge, the present study represents the largest single-center cohort of Canadian pediatric SRC patients reported in the academic literature and provides important insight into the clinical features of this unique population and the healthcare resources and personnel required to deliver multidisciplinary care to these patients.

Clinical Population

These findings suggest that pediatric SRC is a heterogeneous condition that can affect children of all ages, occur in the setting of various sporting activities, presents with a wide spectrum of clinical symptoms, and has a highly variable clinical outcome. As a consequence of increased recognition and awareness, rates of emergency room visits for pediatric concussion continue to rise in North America, with sports accounting for 23-48% of injuries.[23-27] In a retrospective study utilizing Canadian Hospital Injury Reporting and Prevention Program (CHIRPP) data from 1990-2009, 81% of children aged 5-19 years of age sustaining a head injury during team sports were male, had a mean age of 13 years, and sustained injury most commonly during ice hockey, soccer, American football, and basketball.[28] Although tertiary concussion programs such as ours may select for more severely injured patients, clinical characteristics of our study population appear similar to this generalized sample and included a 59.6% male cohort with a mean age of 14.3 years who sustained a SRC most commonly in hockey, soccer, and football.

The initial assessment of pediatric SRC patients must meet three main objectives: 1) a clinical decision of whether the patient has suffered a SRC; 2) a clinical decision about whether signs and symptoms indicate more severe forms of TBI; and 3) a clinical decision about whether signs and symptoms indicate coexisting spine trauma or point to other neurological conditions that can coexist or mimic symptoms of concussion. Accomplishing these objectives requires a careful clinical history and physical examination ideally performed by a physician (M.D.) with clinical training in TBI and neurological disorders in the pediatric population. Depending on the referral structure of specialized concussion clinics, many patients will not have received any previous medical attention or care prior to initial assessment. Failure to properly evaluate children and adolescents with neurological symptoms following TBI can lead to inappropriate return of patients to environments with an elevated risk of more severe traumatic brain and spine injuries as well as a delay in diagnosis of other serious neurological conditions.

The clinical presentation of pediatric SRC is highly variable, but typically manifests as a combination of physical, cognitive, sleep, and emotional symptoms. As illustrated here and by other researchers, the most common symptoms reported by pediatric SRC patients at initial consultation are headache, dizziness, sensitivity to light and sound, fatigue, and difficulty concentrating.[4,22] Although most pediatric patients experience symptoms immediately following the inciting event, in 30% of patients symptoms can manifest more than an hour after injury. Loss of consciousness and/or post-traumatic amnesia at the time of injury are often signs of more severe injury and were reported in 16.0% and 31.4% of patients, respectively. Although most symptoms of concussion are representative of a global metabolic brain injury, pediatric SRC patients can also present with focal neurological deficits that can arise from coexisting injury to central and peripheral nervous system structures, seizures, or other undiagnosed neurological conditions.

Patient outcomes following SRC are highly variable and may be influenced by a number of clinical factors. Although most adult SRC patients achieve complete neurological recovery within 1-2 weeks of injury,[1] some studies suggest that children and adolescents take longer to recover. Among studies of pediatric concussion patients, 21-73% take longer than four weeks or one month to recover[2-7] and 2.3% reported persistent symptoms over one year post-injury.[29] Clinical variables suggested to modify the risk of concussion and the development of prolonged recovery or PCS include female sex, younger age, the presence of a loss of consciousness or post-traumatic amnesia at the time of injury, a past medical history of previous concussion, ADHD, learning disorder, and mood disorders, initial dizziness, delayed symptom onset, and higher PCSS scores and clinical evidence of vestibulo-ocular dysfunction at initial consultation.[3,5,30,31,17,32-36] In the present study, 69.5% of all SRC patients met the clinical criteria for concussion recovery, including 81.8% of acute SRC and 32.0% of PCS patients. The median duration of symptoms among acute SRC patients with complete follow-up was 23 days, which is comparable to findings observed among other specialized pediatric concussion clinics in the United States.[37,3] Overall, 17.7% of patients were lost to follow-up and 12.5% remained in active treatment at the end of the study period. Taken together, most pediatric SRC patients will achieve complete recovery allowing successful return to school and sports related activities. However, a smaller but important proportion will present with more severe, worrisome, or prolonged symptoms requiring a more extensive diagnostic work-up and multidisciplinary approach to patient management.

Diagnostic Resources

These findings suggest that comprehensive management of pediatric SRC patients requires access to diagnostic imaging tools including x-ray, CT, and MRI. Overall, 25.3% of pediatric SRC patients in this study underwent at least one diagnostic imaging test. In recent years physicians have benefited from evidence-based clinical decision making rules that help guide the judicious use of these resources in adults and children presenting with head and neck trauma. Because of the potential long-term risk of radiation exposure, CT imaging in the pediatric SRC population should only be used to rule out structural brain or skull injury during initial assessment in the emergency department.

In Canada CT imaging of the head in children and adolescents is often guided by the CATCH and PECARN rules that

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recommend considering CT imaging in patients with a Glasgow coma scale score less than 15, loss of consciousness, suspected open, depressed, or basal skull fracture, worsening headache, persistent irritability or vomiting, large or boggy scalp hematoma, and dangerous mechanism of injury defined as motor vehicle related, fall from greater than 3 feet, or fall from a bicycle without a helmet.[38,39] Among the 47 (11%) study patients who underwent CT imaging, all were performed in the emergency room setting; there were abnormal findings in 5 cases, including calvarial skull fracture, orbital skull fracture, arachnoid cyst, suspected intra-parenchymal hemorrhage, and suspected hemorrhage into an arachnoid cyst. In contrast to the use of CT imaging in minor head injury, there are no evidence-based guidelines to direct the use of MRI in pediatric SRC and PCS. Although expert consensus statements suggest that neuroimaging is typically normal in SRC patients and therefore adds little to the evaluation of these patients, there are few studies that have examined clinical MRI findings in pediatric and adult SRC patients. At our institution we consider clinical MRI imaging in pediatric SRC patients who present with focal neurological deficits; severe, worsening or persistent headaches; post-traumatic seizures; objective deficits on formal neuropsychological testing; abnormalities on prior CT imaging; and PCS patients who are not improving with multidisciplinary management. Even in these cases, clinical neuroimaging is often normal but in selective patients the detection of congenital brain malformations, traumatic abnormalities, and other neurological disorders can influence clinical and return-to-sport decisions.[40] In the present study, 58 (13.7%) patients underwent MR-imaging, of which 45 studies were normal, but helpful in ruling out structural brain injury and other conditions that can present with persistent neurological symptoms. Abnormal results among the remaining 13 studies included intraparenchymal hemorrhage and sylvian fissure arachnoid cyst (1); isolated intraparenchymal hemorrhage (1); non-hemorrhagic contusion (1); optic neuritis and multi-focal demyelinating disease (1); isolated and small arachnoid cyst (2); posterior fossa arachnoid cyst, cerebellar volume loss, and non-specific white matter change (1); non-specific subcortical white matter changes (1); septum pellucidum (2); non-specific frontal FLAIR abnormality (1); complex pineal gland cyst (1); and Chiari I malformation (1).

For SRC patients presenting with co-existing neck trauma, x-ray imaging of the cervical spine is often guided by the Canadian Cervical Spine rule in adults[41] and by various pediatric c-spine clearance protocols in children.[42-45] Children and adolescents with acute SRC commonly present with whiplash-like symptoms that are associated with paraspinal and sub-occipital muscle spasm, such as mild neck pain and tightness, fogginess, imbalance, and dizziness. Patients who present with a dangerous mechanism of injury (fall from greater than 3 feet or ejection from a vehicle), parasthesias of the extremities, delayed onset of neck pain, or midline neck tenderness should undergo antero-posterior, lateral and odontoid radiographs to rule out structural spine injury. Because of the increased lifetime risk of malignancy associated with ionizing radiation,[46] CT imaging of the c-spine should only be reserved for patients for whom there is a high suspicion of bony injury or inconclusive x-ray findings.[43] Patients with normal x-rays, a normal neurological examination, and painless and full range of motion can be safely cleared by physicians; however those with neurological deficits at the time of injury and those with abnormalities on physical examination should undergo further investigations to rule out spinal cord injury and spinal instability. Cervical spine MRI including T2 short tau inversion recovery (STIR) sequences is the modality of choice to rule out spinal cord injury and ligamentous injury.[42,47,48] In the setting of normal findings, flexion-extension x-rays can be valuable to rule out dynamic spinal instability. Even in the setting of normal x-ray and MRI findings, children and adolescents with SRC can present with clinical signs attributable to spinal cord injury without radiographic abnormality (SCIWORA), central cord neuropraxia, or focal injuries to the exiting nerve roots or brachial plexus (i.e. burners, stingers); these patients require proper evaluation and management by a physician with clinical training in traumatic brain, spine, and peripheral nerve injuries.[10] Clinically indicated diagnostic imaging studies used to evaluate co-existing spine trauma in our patients included cervical spine x-rays (34; 8.0%), CT spine (1; 0.2%), and MRI spine (10; 2.4%). Coexisting conditions diagnosed in patients who underwent spinal imaging included SCIWORA (4), brachial plexus traction injuries (3), demyelinating disease (1) and symptomatic lumbar disc herniation (1).

Healthcare Personnel

These findings suggest that comprehensive management of pediatric SRC patients requires the contributions of several important team members each with their own expertise in TBI-related sub-disciplines. At the outset of this project the highest value was placed not only on identifying the needs of pediatric concussion patients but also in identifying those healthcare professionals with the highest standard of national or provincially-licensed training in these practice areas. Although previous authors have supported a multidisciplinary approach to concussion and made suggestions about how to establish concussion specialty clinics,[16,49] there are no guidelines that address which professional qualifications are needed to safely participate in the care of pediatric concussion and mTBI patients.

In the present study 32.6% of pediatric SRC patients who were evaluated at our concussion program underwent referral to another member of the multidisciplinary team. Headaches and seizures are the two conditions that can occur in pediatric SRC patients for which neurologists have the highest level of licensed training. Chronic headaches account for a significant proportion of morbidity among pediatric PCS patients and can manifest as post-traumatic headaches, post-traumatic migraine headaches, physiologic or exertional headaches, and those arising from cervicogenic causes.[9] Preliminary studies suggest that properly diagnosed headaches in pediatric concussion patients can benefit from a multidisciplinary approach guided by experienced neurologists.[50,18] On the other hand, seizure-like activity following pediatric SRC is rare and requires a careful history and physical examination performed by an expert, as well as the judicious use of neuroimaging and electroencephalography to diagnose and manage concussive convulsions and post-traumatic seizures.[12,17] In this study 43 (10.2%) patients were referred to a neurologist: 40 for management of post-traumatic headaches that did not respond to conservative management and sub-maximal exercise prescription, and 3 who presented with concussive convulsions or post-traumatic seizures.

The role of neuropsychological testing in the multidisciplinary management of pediatric concussion remains controversial.

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Although clinical neuropsychologists are the only healthcare professionals with optimal training in the administration and interpretation of neuropsychological and neurocognitive tests, a significant proportion of testing in this patient population continues to be offered by various healthcare professionals without this training.[51,57,58] At present, experts agree that neuropsychological testing performed by a clinical neuropsychologist may be used as a supplemental tool to help detect neurocognitive deficits and manage patients with concussion.[1,52,59,60] At our institution hybrid formal neuropsychological testing is used on a selective basis to confirm recovery in pediatric patients with multiple concussions; a pre-injury history of ADHD, learning disorders, and headache disorders; and to evaluate neurocognitive functioning in those with persistent cognitive and mood-related symptoms. The clinical neuropsychologist also coordinates the Return-to-Learn program for patients requiring advanced academic accommodations. Overall, 21 (4.7%) patients were referred to a clinical neuropsychologist for formal neuropsychological testing, the majority of whom were referred during Stage 3 of the study once funding for a part-time, on-site clinical neuropsychologist was secured.

A significant proportion of pediatric TBI and SRC patients can present with visual disturbances that can arise from functional impairments in the oculomotor and vestibular neurological subsystems or structural injury to brain and cranial nerves. Although numerous abbreviated concussion tools have been developed to assess certain aspects of vestibular and oculomotor function,[53,54,61,62] comprehensive assessment of patients presenting with blurred vision, diplopia, and dizziness requires evaluation by physicians with clinical training in TBI and neuro-ophthalmology. The vast majority of patients with clinical evidence of vestibulo-ocular dysfunction–including objective abnormalities in convergence, saccades, pursuits, and the vestibulo-ocular reflex will experience complete neurological recovery with conservative management,[5] while those with persistent symptoms and PCS often benefit from targeted vestibular physiotherapy.[10,55,63] However, subtle cranial neuropathies and other neurological disorders can also account for persistent visual symptoms in pediatric SRC patients that require more comprehensive assessment and management by an experienced neuro-ophthalmologist.[9,56,64] In this study 6 (1.4%) patients were referred to our neuro-opthalmologists, resulting in the diagnosis of traumatic optic neuropathy (2), optic neuritis and multi-focal demyelinating disease (1), and migraine headaches (3). Overall, 60 (14.2%) patients were referred to the vestibular physiotherapist for targeted vestibular physiotherapy. Patients with isolated soft tissue injuries of the cervical spine and persistent cervicogenic symptoms can often benefit from cervical spine physiotherapy, carried out in 32 (7.6%) pediatric SRC patients in this study.

Another emerging diagnostic tool that can aid in the diagnosis and rehabilitation of SRC patients is graded aerobic treadmill testing. Performed by an experienced exercise physiologist, graded aerobic treadmill testing can be used as a supplemental tool to confirm physiological recovery in SRC patients and distinguish between PCS patients with a persistent global metabolic brain injury (Physiologic Post-Concussion Disorder) and those with isolated dysfunction of the vestibulo-ocular and cervicogenic subsystems.[10,15,16] Studies in adolescents and adults have demonstrated a high rate of symptomatic improvement and successful return to sports in patients treated with tailored sub-maximal exercise programs,[65,66,16] with future studies needed to evaluate the safety, tolerability, and clinical utility of this approach in younger patients. Importantly, patients with concussion, seizures, and other neurological conditions may incur a risk in exercise testing so it is imperative for all patients to be evaluated by a physician prior to testing. In the present study 49 (11.6%) patients underwent referral to an exercise specialist for physician-supervised graded aerobic treadmill testing.

Studies in pediatric patients suggest that those with mild, moderate, and severe TBI are at an elevated risk of psychiatric and mental health related disorders.[63-65] In pediatric SRC patients, post-injury psychiatric outcomes can manifest as novel psychiatric conditions whether or not there is a lifetime history of psychiatric illness, isolated suicidal ideation, or worsening symptoms of a pre-injury psychiatric disorder. In a previous study we found that female sex, higher presenting PCSS and emotional PCSS scores, presence of a pre-injury psychiatric disorder, and previous family history of psychiatric illness were significantly associated with the development of a post-injury psychiatric outcome.[12] Comprehensive management of this unique patient population requires close collaboration between healthcare professionals with clinical training in TBI and psychiatry, often utilizing pharmacological and behavioral interventions.[12,67] Mobile crisis networks are especially valuable for providing timely care of patients with acute deterioration or suicidal ideation. In the present study, 21 (5.0%) patients were referred to an adolescent psychiatrist for formal assessment leading to the diagnosis of at least one post-injury psychiatric outcome in 17 patients. One of these patients referred to the concussion program with a significant concussion history and a recent diagnosis of adjustment disorder with depressed mood committed suicide. Six additional patients developed post-injury psychiatric outcomes but were managed without adolescent psychiatry referral.

Lastly, there are other trained healthcare professionals who contributed value to the multidisciplinary care of pediatric concussion patients at our institution. A pediatric neurosurgeon was helpful in providing expertise regarding patients with structural brain and spine injuries. Sports medicine physicians were helpful in providing initial assessments of concussion patients, coordinating initial concussion referrals and, along with orthopedic surgeons, providing care for coexisting orthopedic injuries. An ENT surgeon was helpful with patients presenting with temporal bone pathology and hearing loss that can (but did not in this SRC cohort) occur in pediatric non-SRC and mTBI patients. Pediatric emergency medicine physicians also helped with initial patient assessments and coordination of referrals from outside emergency rooms as well as facilitating urgent evaluation and diagnostic imaging for patients requiring care outside outpatient office hours.

Comparison to Other Concussion Clinics in Canada

We are not aware of any other studies that have examined clinical populations or healthcare utilization among any other multidisciplinary pediatric concussion clinics or programs in Canada. However, our own research on concussion healthcare providers and clinics in Canada suggest that there is an urgent unmet need for multidisciplinary programs formed by healthcare providers with nationally- and provincially-licensed training in TBI. In a previous study we performed Google Internet searches using the terms “concussion” and “concussion clinic” to compile a list of the top 10-15 concussion healthcare providers identified

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among all Canadian provinces and territories.[23] Among identified providers only 40% listed an on-site medical doctor as a member of their treatment team and 43% offered access to a concussion clinic, center, or program. Strikingly, the proportion of concussion healthcare providers who advertised access to a neurosurgeon (5%) and neurologist (7%) were low compared with those with access to a massage therapist (33%), athletic therapist (26%), chiropractor (22%), or osteopath (9%). Overall, only 21% of providers who advertised neurocognitive testing as a clinical service on their website identified a clinical neuropsychologist as a member of the clinical team. Taken together, these findings suggest that a significant proportion of specialized concussion care in Canada is undertaken by healthcare professionals with little to no training in TBI and that many providers do not have access to healthcare personnel with this specialized training. Without access to these healthcare professionals it is unclear how the primary objectives of an initial assessment in pediatric SRC patients can be safely met by many of these centers, let alone how specialized rehabilitation for patients with PCS can be provided. Given the heterogeneity among the personnel and practices of concussion healthcare in Canada and the results of the present study, there appears to be an urgent need for leaders in this field to establish guidelines or standards that address which designated healthcare professionals should be permitted to evaluate patients with concussion and TBI and identify the roles and responsibilities of professionals who can safely participate in the care of these patients. Despite a multitude of published expert consensus statements representing national and international groups of neurologists,[19] neuropsychologists,[52] athletic therapists,[20] sports medicine physicians,[22] chiropractors,[63] and multidisciplinary clinicians,[1] there are few guidelines that address these important issues. Importantly, deciding which healthcare professionals have sufficient training to safely evaluate concussion patients will also be important should Canada adopt youth concussion legislation requiring athletes or students with a suspected concussion to undergo medical evaluation and clearance prior to returning to sports or school.

Study Limitations

These findings must be interpreted in light of several important limitations. First and foremost, the present study examined the clinical features, healthcare utilization, and outcomes of patients referred to a tertiary specialized concussion program. Patients evaluated at a tertiary center may include those with more severe injuries and who were therefore more likely to develop some of the long-term complications of TBI and require greater use of diagnostic testing and specialized referral services. Tertiary concussion clinics have also been found to experience high proportions of patients who are lost to follow-up that can present an obstacle to comprehensive assessment of clinical outcomes. Second, the use of healthcare services such as diagnostic tools and multidisciplinary clinical referrals were not dictated by predetermined research criteria but were instead initiated based solely on the clinical judgment of one neurosurgeon. In some cases the use of diagnostic testing studies was dictated by evidence-based guidelines, but in other cases there is a paucity of evidence to guide clinical-decision making among this unique population. Third, because the present study was observational in nature, it was not possible to draw conclusions regarding the effect of specific interventions and treatments on patient outcomes. Although preliminary evidence supports the use of certain rehabilitative interventions in adolescents and adults with SRC, future prospective controlled studies are needed to evaluate the impact of these interventions in younger children. Lastly, although there is inherent value in consolidating concussion and TBI services within a single site, overall healthcare costs associated with the multidisciplinary concussion program were not assessed in this study. Future studies are needed to evaluate the economic value of multidisciplinary pediatric concussion programs and should consider the potential lifetime costs of more severe and fatal injuries associated with suboptimal concussion management and premature return to play.

Conclusions

The present study provides a real-world view of the wide spectrum of clinical presentations and outcomes observed among pediatric SRC patients evaluated and managed at a multidisciplinary pediatric concussion program in Canada. Although the majority of pediatric SRC patients in this study presented with typical concussion-related symptoms, some presented with symptoms attributed to more serious injury to central and peripheral nervous system structures and other neurological conditions. While most pediatric SRC patients will achieve neurological recovery and a successful return to school and sporting activities with proper management, a significant proportion will develop persistent symptoms of PCS, requiring consideration of additional diagnostic tests and targeted rehabilitation approaches. Given the results of this study and the current landscape of concussion healthcare in Canada, it appears that the vast majority of concussion healthcare providers are underqualified and underresourced to meet the specialized needs of this patient population. Based on our early experience, optimizing the care of Canada's pediatric concussion patients can be accomplished through the establishment of government-funded regional concussion programs that have access to appropriate diagnostic resources and are powered by experts with national and provincially recognized training in TBI.

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Statement of Authorship

Co-authors Ellis and Russell conceptualized and designed the study, carried out the data collection, statistical analysis, drafted the initial manuscript, critically reviewed and revised the manuscript, and approved the final manuscript as submitted.

Co-authors Ritchie, McDonald, Cordingley, Reimer, Nijjar, Koltek, Hosain, Johnston, Mansouri, Sawyer, Silver, Girardin, Larkins, Davidson, Gregoire, Sam, Black, Bunge, Essig, MacDonald and Leiter contributed to data analysis, critically reviewed and revised the manuscript, and approved the final manuscript as submitted.

Miss Vis and Miss Selci carried out the data collection, critically reviewed and revised the manuscript, and approved the final manuscript as submitted.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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