Vestibulo-ocular dysfunction in pediatric sports-related concussion

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OBJECT The objective of this study was 2-fold: 1) to examine the prevalence of vestibulo-ocular dysfunction (VOD) among children and adolescents with acute sports-related concussion (SRC) and postconcussion syndrome (PCS) who were referred to a multidisciplinary pediatric concussion program; and 2) to determine if VOD is associated with the development of PCS in this cohort.

METHODS The authors conducted a retrospective review of all patients with acute SRC (presenting 30 days or less postinjury) and PCS (3 or more symptoms for at least 1 month) referred to a multidisciplinary pediatric concussion program between September 2013 and July 2014. Initial assessment included clinical history, physical examination, and Post-Concussion Symptom Scale assessment. Patients were also assessed for VOD, which was defined as more than one subjective vestibular and oculomotor complaint (dizziness, blurred vision, and so on) and more than one objective physical examination finding (abnormal smooth pursuits, saccades, vestibulo-ocular reflex, and so on). This study was approved by the local institutional ethics review board.

RESULTS A total of 101 patients (mean age 14.2 years, SD 2.3 years; 63 male and 38 female patients) participated, including 77 (76.2%) with acute SRC and 24 (23.8%) with PCS. Twenty-two of the 77 patients (28.6%) with acute SRC and 15 of the 24 (62.5%) with PCS met the clinical criteria for VOD. The median duration of symptoms was 40 days (interquartile range [IQR] 28.5–54 days) for patients with acute SRC who had VOD compared with 21 days (IQR 13–32 days) for those without VOD ($p = 0.0001$). There was a statistically significant increase in the adjusted odds of developing PCS among patients with acute SRC who had VOD compared with those without VOD (adjusted OR 4.10; 95% CI 1.04–16.16).

CONCLUSIONS Evidence of VOD was detected in a significant proportion of children and adolescents with acute SRC and PCS who were referred to a multidisciplinary pediatric concussion program. This clinical feature was a significant risk factor for the subsequent development of PCS in this pediatric acute SRC cohort.

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KEY WORDS vestibulo-ocular dysfunction; sports-related concussion; postconcussion syndrome; pediatric; vestibular therapy; trauma

SPORTS-RELATED concussion (SRC) is a public health concern that affects thousands of children and adolescents in the United States and Canada annually.^{34,43,47} Although the vast majority of collegiate and professional athletes return to their neurological baseline within 7–10 days,^{9,20,21,33} it remains uncertain whether pediatric patients with SRC take longer to recover. Studies

suggest that 21%–59% of all pediatric patients who suffer concussion develop persistent symptoms lasting longer than 1 month,^{4,5,19,35,46} a condition defined by the WHO *International Classification of Diseases, 10th Revision* (ICD-10) as postconcussion syndrome (PCS). Children and adolescents with PCS are at increased risk of additional chronic health conditions, including anxiety, de-

ABBREVIATIONS ICD-10 = *International Classification of Diseases, 10th Revision*; IQR = interquartile range; LOC = loss of consciousness; mTBI = mild traumatic brain injury; NPC = near-point convergence; PCS = postconcussion syndrome; PCSS = Post-Concussion Symptom Scale; SRC = sports-related concussion; VOD = vestibulo-ocular dysfunction; VOR = vestibulo-ocular reflex.

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pression, migraine headaches, and impaired school performance.^{29,40,45} Consequently, there is an urgent need to identify pediatric patients at risk for developing PCS and to direct these patients toward rehabilitation strategies that target the pathophysiological mechanisms underlying persistent symptom complexes.¹³

Among the most common and debilitating symptoms that occur following mild traumatic brain injury (mTBI) in adults are those caused by dysfunction of the vestibular and oculomotor systems. Because of the rich reciprocal connections shared between these 2 neurological subsystems, symptoms of vestibulo-ocular dysfunction (VOD) often overlap and may include dizziness, vertigo, fogginess, motion sensitivity, disequilibrium, postural or gait imbalance, gaze instability, blurred vision, or diplopia.^{1,11,18,24} Approximately 50%–90% of adults with mTBI exhibit signs and symptoms of vestibular or oculomotor dysfunction;^{3,10,16,44} however, only limited studies have examined the prevalence of VOD among children and adolescents with acute SRC or PCS.^{1,37} Furthermore, no study has examined the impact of VOD on the development of PCS.

Accordingly, the aim of this study is 2-fold: 1) to examine the prevalence of VOD among children and adolescents who were referred to a multidisciplinary pediatric concussion program with acute SRC and PCS; and 2) to determine if VOD is associated with developing PCS among pediatric patients with acute SRC.

Methods

Research Design and Inclusion Criteria

A retrospective chart review was performed for all consecutive pediatric patients referred to the Pan Am Concussion Program at Pan Am Clinic, Winnipeg, Manitoba, Canada, with suspected SRC between September 1, 2013, and July 30, 2014. The Pan Am Concussion Program is a multidisciplinary clinical program that accepts referrals for suspected concussions in patients age 19 years or younger from emergency room physicians, pediatricians, neurologists, and primary care physicians. Study inclusion criteria included the following: 1) patient age 19 years or younger; and 2) diagnosis of acute SRC (defined as a clinical consultation on a patient meeting the criteria set forth by the Zurich Consensus Statement and evaluated less than 30 days from the time of injury) or diagnosis of sports-related PCS (defined as a clinical consultation on a patient meeting the ICD-10 criteria of 3 or more concussion symptoms present for at least 1 month following an SRC [symptoms 30 days or more in duration]).⁶ Exclusion criteria were as follows: 1) patients with intracranial hemorrhage or traumatic structural cervical spine injury; 2) patients who suffered a second concussion during follow-up for a previous symptomatic concussion; 3) patients with coexistent neuroophthalmological conditions (i.e., strabismus); and 4) patients in whom other coexistent medical conditions that prevented return to play (i.e., orthopedic injuries) were diagnosed during follow-up. Patients with SRC were also excluded if they were lost to follow-up prior to documented medical clearance. This study was approved by the institutional ethics review board at the University of Manitoba.

Clinical Assessments

At the time of initial medical consultation all patients completed a standardized data collection form that included demographic data, medical history, concussion history, and family history. Also at initial consultation, all patients completed the Post-Concussion Symptom Scale (PCSS), a symptom inventory consisting of 22 symptoms that are rated on a 7-point (0–6) Likert scale with a maximum score of $(6 \times 22) = 132$.²⁶ Patients were asked to rate their symptoms according to how they felt at the time they completed the PCSS inventory.

All patients underwent a clinical history and physical examination by a single neurosurgeon. The physical examination included evaluation of cranial nerve, motor, sensory, cerebellar, gait, balance, and cervical spine functioning. A standardized, focused vestibulo-ocular clinical examination was also performed using standard techniques, including evaluation of gross extraocular movements and smooth pursuits, near-point convergence (NPC), and horizontal and vertical saccades.³⁹ Specifically, extraocular movements and smooth pursuits were tested by asking the patient to fixate on an object that was moved through all 4 quadrants of the visual field within 30° of midline while the head was kept stationary. An abnormal test was indicated by the inability to follow the object without saccadic eye movements or evidence of a cranial nerve deficit.

Horizontal saccades were tested by asking the patient to look quickly back and forth between 2 stationary targets placed 30° off the midline for 10 seconds while the head was kept stationary. An abnormal test was indicated by overshooting, need for more than 2 saccadic corrections, or gross dysconjugate eye movements. The NPC was tested by having the patient fixate with both eyes on an object while it was slowly moved toward the patient's nose. An abnormal test was indicated by the inability of the eyes to converge, patient's report of double vision, or an NPC of greater than 6 cm.

Testing of the vestibulo-ocular reflex (VOR) was also carried out using a modified head-shaking test in which the patient was asked to focus on a stationary object 1 m from the bridge of the nose while rapidly shaking the head back and forth at least 30° from neutral for 10 seconds.¹² An abnormal test was indicated by the detection of nystagmus or dysconjugate eye movements. Results of testing for horizontal saccades, vertical saccades, and VOR were classified as normal or abnormal based on examination findings, and symptomatic (defined as eliciting or worsening symptoms such as diplopia, nausea, light-headedness, headache, or disorientation) or asymptomatic (defined as eliciting no symptoms). The neurosurgeon in this study was not blinded to symptom checklist results or details from the clinical history prior to documenting physical examination findings. Although the clinical tests that comprise the focused vestibulo-ocular clinical examination used in this study have been previously described in the vestibular and optometry literature, subtle variations in testing techniques exist among sources.^{23,37,39,42} At present, we are not aware of any intrarater or interrater reliability testing that has been conducted using the clinical tests as they are described in this study.

All patients were seen in follow-up at 1- to 4-week intervals depending on the severity of symptoms, trajectory of recovery, and patient availability, and not according to a predesigned controlled research protocol. At each follow-up appointment, patients completed the PCSS inventory and underwent clinical interview and physical examination follow-up as medically indicated by the neurosurgeon. Neuroimaging studies were not performed on all patients but only as indicated by the neurosurgeon, and not according to any predetermined criteria.

Definition of VOD

At present there is no standardized definition of VOD. For the purposes of this study, VOD was defined as occurring in those patients with more than one subjective complaint of intermittent blurred or double vision, visual disturbance, gaze instability or difficulty focusing, dizziness, difficulty reading, or motion sensitivity, as well as the presence of more than one of the following objective physical examination findings: NPC greater than 6 cm, abnormal extraocular movements or smooth pursuits, abnormal or symptomatic horizontal or vertical saccades, or VOR. The presence of VOD was assessed at initial consultation for all patients with acute SRC and for those with PCS. Due to the retrospective nature of the study, the presence of VOD was assessed at follow-up at the discretion of the neurosurgeon and not according to a predesigned controlled research protocol.

Definitions of Recovery and PCS, and Concussion Management

Patients were classified as fully recovered when they were asymptomatic at rest as assessed by clinical interview and PCSS, were able to tolerate full-time school without self-reported concussion symptoms, successfully completed the graduated return-to-play protocol set forth by the Zurich Consensus Statement without self-reported concussion symptoms, and no longer met the clinical criteria for VOD. At the time of the study, a certified clinical neuropsychologist was not available to administer and interpret neurocognitive testing in this patient population. As such, computerized neurocognitive tools were not used as a supplemental tool to aid in the diagnosis and confirmed recovery of patients in this study.

Patients within the SRC cohort received a diagnosis of PCS (i.e., prolonged recovery) if they met the ICD-10 criteria. Patients who recovered within less than 30 days from their injury date were deemed to have a short recovery and did not receive a diagnosis of PCS. Therapeutic interventions such as formal vestibular physiotherapy consultation, home vestibular therapy, and pharmacological treatment of migraine or posttraumatic headache were prescribed for patients with acute SRC and PCS as indicated by the neurosurgeon.

Statistical Analysis

The distributions of baseline characteristics for patients who presented with acute SRC or PCS were summarized

using proportions for dichotomous/polytomous characteristics and means with standard deviations for continuous characteristics. If a continuous variable was not normally distributed, it was summarized as a median with interquartile range (IQR). The days to recovery data were summarized using medians with IQR, and the Wilcoxon rank-sum test was used to compare median days to recovery among patients who had SRC with and without VOD. Therapeutic interventions were tabulated.

A crude odds ratio with 95% confidence intervals was calculated in which the exposure was presence or absence of VOD and the outcome was the development of PCS versus short recovery. To control for potential confounders, forward selection logistic regression modeling was used. Plausible potential confounders were age (continuous), sex (male/female), previous concussion injury (yes/no), previous history of migraines (yes/no), initial PCSS score (continuous), amnesia at time of concussion (yes/no), and loss of consciousness (LOC) at time of injury (yes/no). Because PCSS was skewed to the left, the scores were transformed into their square root, and this variable was included in the logistic regression models.

Each potential confounder was entered into the model containing VOD. The confounder that produced the largest change in the VOD odds ratio was retained, providing the change was at least 15%.³⁶ This process was repeated with the remaining potential confounders until the independent addition of another variable failed to change the VOD odds ratio by more than 15% or there was more than one variable for every 10 cases.²² All statistical analyses were performed using STATA version 12.1 (STATA Corp.).

Results

Study Participants

During the study period, 212 pediatric patients were referred to the multidisciplinary concussion program. Of those patients, 61 were excluded due to concussions occurring outside of a sports setting. Other patients were excluded for the following reasons: intracranial hemorrhage on neuroimaging (1 patient); repeat concussion sustained prior to recovery from a previous concussion (7 patients); coexisting neuroophthalmological conditions (2 patients); and coexisting medical conditions that prevented return to play, including nonhemorrhagic TBI on neuroimaging (1 patient), spinal cord injury (1 patient), orthopedic injury (2 patients), and occult CSF leak (1 patient). Thirty-five patients were lost to follow-up prior to documented medical clearance. Of the 101 remaining patients, 77 (76%) were classified as suffering acute SRC and 24 (24%) were classified as having PCS at their initial clinical assessment.

Among the 77 patients with acute SRC (23 female, 52 male; mean age 13.7 years, SD 2.2 years), 22 (29%) met the criteria for VOD and 36 (47%) had a history of previous concussion. The median time from injury to initial consultation for patients with acute SRC was 7 days (IQR 5–12 days). The median PCSS score for patients with acute SRC was 10 (IQR 3–25). For the 24 patients with PCS (15 female, 9 male; mean age 16.0 years, SD 1.6 years), 15

(63%) met the criteria for VOD and 13 (54%) had a history of concussion. The median PCSS score for patients with PCS was 33 (IQR 14.5–47.5). The median time from injury to initial consultation for patients with PCS was 69.5 days (IQR 40.25–101.75 days). For both patients with acute SRC and those with PCS, hockey and soccer were the most commonly played sports at the time of injury. Additional characteristics are described in Table 1.

Short Recovery Versus the Development of PCS Among Patients With SRC

Table 2 compares patients with SRC who had a short recovery time with those who developed PCS. Patients who reported amnesia at the time of concussion also had statistically significantly higher odds of developing PCS than patients who suffered no amnesia (OR 4.78; 95% CI 1.71–13.34). The odds of developing PCS significantly increased as PCSS scores increased (OR 1.97; 95% CI 1.43–2.73). There was a statistically significant increase in the odds of developing PCS among those in whom VOD was diagnosed compared with those in whom VOD was not diagnosed (OR 8.29; 95% CI 2.61–26.29). After adjustment for each potential confounder, controlling for PCSS score (indicator of concussion severity) resulted in the greatest change in the OR (3.22; 95% CI 0.84–12.22; Table 3).

After the remaining potential confounders were added independently to the model containing the PCSS, the addition of previous migraine status produced the greatest change in the VOD effect estimate, and this changed by more than 15% and was retained in the model. Thus, after adjustment for the confounding effects of PCSS score and previous migraine, the patients with VOD had statistically significantly increased odds of developing PCS compared with those who did not have VOD (OR 4.10; 95% CI 1.04–16.16).

Concussion Management Resources and Recovery

Of the 37 patients who met the clinical criteria for VOD, 15 (40%) were referred to a trained vestibular physiotherapist (3 patients with acute SRC and 12 with PCS). Three patients were prescribed initial home-based vestibular therapy programs (2 with SRC and 1 with PCS), with 1 patient eventually referred to the vestibular physiotherapist for formal assessment and treatment. All home and formal vestibular therapy programs were prescribed to patients with acute SRC after a diagnosis of PCS was confirmed. Among the patients with PCS, 4 (all with evidence of VOD) were referred to a neurologist for pharmacological management of headaches. Among patients with acute SRC, all 77 were deemed recovered, with a median time to recovery of 25.5 days (IQR 16.25–40 days). However, the median time to recovery among those with VOD was 40 days (IQR 28.5–54 days) compared with 21 days (IQR 13–32 days) for those without VOD ($p < 0.001$). Of the patients with PCS, only 6 received medical clearance to return to sporting activities within the study period (median 130 days; IQR 104.25–223.5 days), with 18 patients remaining under the medical care of the treating neurosurgeon. Four of the 6 patients with PCS who recovered had VOD, and 3 were referred to vestibular physiotherapy.

TABLE 1. Baseline characteristics of 101 patients with acute SRC and PCS*

Characteristic	Acute SRC (%)	PCS (%)
No. of patients	77 (76)	24 (24)
VOD	22 (29)	15 (63)
Mean age in yrs (SD)	13.7 (2.2)	16.0 (1.6)
Female	23 (30)	15 (63)
Previous concussion	36 (47)	13 (54)
Missing†	1 (1)	0
Previous migraine	3 (4)	4 (17)
Missing	1 (1)	0
Median PCSS score (IQR)	10 (3–25)	33 (14.5–47.5)
Missing	2 (3)	0
Amnesia	25 (33)	15 (63)
LOC	12 (16)	4 (17)
Sport		
Baseball	5 (7)	0
Basketball	4 (5)	5 (21)
Skating	1 (1)	1 (4)
Football	7 (9)	1 (4)
Hockey	33 (43)	6 (25)
Ringette	2 (3)	2 (8)
Skiing/snowboarding	4 (5)	1 (4)
Soccer	15 (20)	6 (25)
Volleyball	2 (3)	0
Other	4 (5)	2 (8)

* Unless otherwise indicated, values in parentheses represent percentages.

† Data not recorded.

Discussion

In this study, VOD was detected in a significant proportion of children and adolescents with acute SRC and PCS who were referred to a multidisciplinary concussion program. Furthermore, the detection of VOD at initial consultation was a significant risk factor for the development of PCS in this patient population.

Previous studies have aimed to determine the proportion of children and adolescents with concussion who develop PCS and which clinical variables predict PCS development. Unfortunately, heterogeneity in study populations, definitions, follow-up, and clinical end points make it difficult to facilitate direct comparisons between studies.⁴⁸ Together, these studies suggest that 21%–59% of pediatric patients presenting with acute concussion or mTBI develop symptoms lasting longer than 1 month.^{4,5,19,35,46} Clinical variables associated with development of PCS and prolonged recovery in these studies include adolescent age (11–18 years), presence of headache, hospital admission,⁴ and initial symptom severity score.³⁵ Additional factors that have been suggested to act as modifiers or potential predictors of prolonged recovery in broader populations of patients with concussion include the following: younger age; female sex; LOC; amnesia; and medical history of previous concussions, headaches, attention deficit hyperactivity disorder, and learning disorders.^{27,30} Although

TABLE 2. Comparison of 77 patients with acute SRC who had either short recovery or PCS*

Variable	PCS (%)	Short Recovery (%)	OR (95% CI)
No. of patients	33 (43)	44 (57)	
VOD	17 (52)	5 (11)	8.29 (2.61–26.29)
Mean age in yrs (SD)	13.9 (2.0)	13.5 (2.4)	1.08 (0.88–1.33)
Female	9 (27)	14 (32)	0.80 (0.30–2.17)
Previous concussion	18 (55)	18 (41)	1.86 (0.74–4.67)
Missing	1 (3)	0	
Previous migraine	2 (6)	1 (2)	2.87 (0.25–33.06)
Missing	1 (3)	0	
Median PCSS score (IQR)	22 (11–34)	5 (0.25–10.75)	1.97 (1.43–2.73)†
Missing	2 (6)	0	
Amnesia	17 (52)	8 (18)	4.78 (1.71–13.34)
LOC	4 (12)	8 (18)	0.62 (0.17–2.27)

* Unless otherwise indicated, values in parentheses represent percentages.

† Transformed to square root of PCSS score.

these studies have identified several important clinical predictors of PCS among pediatric patients, limited attention has been paid to features of the physical examination that are associated with specific concussion symptoms and which together may provide important insight into the pathophysiological mechanisms mediating persistent symptoms.¹³

The present study meets an urgent unmet need by introducing a novel clinical definition that uses a combination of subjective and objective clinical findings that can potentially identify patients at an elevated risk of developing PCS. In this study, 29% of patients with acute SRC and 63% of those with PCS met the clinical criteria for VOD at initial clinical consultation. The median duration of symptoms was 40 days for patients with SRC who had VOD compared with 21 days for those without VOD. Most importantly, pediatric patients with acute SRC who met the clinical criteria for VOD at initial clinical consultation had 4 times the odds of developing PCS, even after we simultaneously controlled for the confounding effects of initial PCSS score and history of migraine.

The pathophysiological mechanisms governing the vestibular and oculomotor symptoms following concussion remain unclear. The neuroanatomical circuitry mediating vestibulo-ocular function consists of a rich network of complex special sense organs and primary processing units that share rich direct, indirect, and reciprocal projections to the spinal cord, autonomic nervous system, brainstem nuclei, cerebellum, thalamus, basal ganglia, and cerebral cortex.²⁵ Although physical examination can offer insight into the level at which dysfunction occurs within this neurological subsystem,³⁹ it remains unclear whether VOD is mediated by concussive damage to peripheral structures¹⁴ or is a result of ongoing impairments in cellular metabolism and cerebral blood flow regulation affecting the CNS.^{15,31,38}

Without a clear understanding of the pathophysiological mechanisms mediating vestibular and oculomotor symptoms, it is difficult to evaluate the benefit of rehabilitation strategies such as vestibular physiotherapy that were

used in this study. Although vestibular and vision physiotherapy has emerged as an effective treatment option for patients with concussion and TBI,^{1,2,17,24,41} further studies are needed to help evaluate the effect of vestibular therapy on patients with concussion who experience isolated vestibular and oculomotor dysfunction. Failure to accurately identify the pretreatment physiological mechanisms governing persistent concussion symptoms (i.e., physiological, vestibular, or cervicogenic) will have an important impact on evaluating the effect of therapeutic interventions in future studies, especially given potential differences in natural history and responses to physiotherapy observed among these unique populations.^{13,28}

Although the focused vestibulo-ocular examination used in the present study may help physicians identify those pediatric patients with acute SRC who are at risk for PCS and who may benefit from physiotherapy interventions, the widespread incorporation of these tests into standardized sideline or office assessment tools to be used by health care providers without clinical training in neurological, neuroophthalmological, and vestibular examination must be approached with caution. Clinicians using these assessment techniques should not only appreciate

TABLE 3. Association between VOD and length of recovery after independently adjusting for potential confounders

Variable	OR (95% CI)
Crude; VOD only	8.89 (2.61–26.29)
Age in yrs	8.92 (2.73–29.11)
Female	8.41 (2.62–27.07)
Previous concussion	9.45 (2.97–30.06)
Previous migraine	9.94 (3.06–32.32)
PCSS*	3.22 (0.84–12.22)
Amnesia	7.17 (2.15–23.83)
LOC	8.29 (2.60–26.44)

* Transformed to square root of PCSS score.

the neuroanatomy and physiology that govern each test but should also be aware of the myriad neurological conditions that can present with abnormalities of vestibular and oculomotor function.⁷ Such clinical subtleties are exemplified by an adolescent patient excluded from the present study who met the criteria for VOD following acute SRC, but in whom optic neuritis and multifocal demyelinating disease were diagnosed following the appropriate use of other physical examination tools and neuroimaging.

The results of our study must be considered in light of several important limitations. First, there is no standardized definition of VOD that has been previously presented in the literature. Although the definition of VOD used in this study has not been previously validated, it does include validated physical tests that have been previously used by trained professionals to confirm vestibular and oculomotor impairment in other populations, including patients with TBI and SRC. Indeed, most of the physical tests comprising the focused vestibulo-ocular examination used in the present study were rated as demonstrating strong clinical utility for confirming CNS vestibular and oculomotor dysfunction in patients with concussion by an international working group of concussion experts and vestibular physiotherapists.³⁹

Second, although the presence of VOD was associated with a significant risk of developing PCS, it is possible that this feature interacted with other factors that were not directly measured in this study. Previous research has suggested that insufficient amounts of cognitive rest following concussion are associated with prolonged recovery in children;⁸ however, further study is needed to confirm this finding.³² Although not objectively collected in this study, cognitive activities that place increased demands on the vestibulo-ocular system (such as reading, computer use, and texting) could worsen symptoms in patients with VOD, and this may have contributed to the development of PCS in selected patients without adequate cognitive rest.

Third, a significant number of patients were excluded or lost to follow-up prior to medical clearance, potentially impacting the results of this study. This limitation has been observed in similar studies performed at tertiary concussion clinics.³⁵ However, we believe that this limitation is ultimately unavoidable and is significantly offset by medically supervised end points (i.e., physician-confirmed recovery) that cannot be accomplished by previous and ongoing studies using emergency department populations.^{4,5,19,47}

Fourth, patients referred to a multidisciplinary pediatric concussion program may include those with more severe injuries and those who may be more likely to develop PCS. Therefore, the results of this study cannot be used to estimate the prevalence of VOD in a general pediatric SRC or PCS population.

Fifth, several patients in the present study were treated with home and formal vestibular therapy programs, which may have also impacted the results of the study. Because all vestibular therapy programs were initiated after the diagnosis of PCS in patients with acute SRC, it would not have impacted statistical analysis aimed at examining the risk of developing PCS among patients with acute SRC who had VOD. However, vestibular therapy may have led

to enhanced recovery in the patients treated, thereby decreasing the median recovery time of patients with acute SRC who experienced VOD, which was significantly longer than those without VOD.

Last, whereas the median time from injury to initial consultation was 7 days for patients with acute SRC, this group does comprise athletes evaluated at different levels of acuity within a 30-day period. Patients were also seen in follow-up depending on the severity of symptoms, trajectory of recovery, and patient availability, and not according to a predesigned controlled research protocol. Such variability in patient referrals and follow-up is commonly experienced in tertiary concussion clinics and must be controlled for in future studies.

Despite the methodological limitations inherent in a retrospective study performed at a tertiary multidisciplinary concussion program, the results of this study provide preliminary evidence that VOD can occur in children and adolescents with SRC and is a potential risk factor for the development of PCS. Future studies performed using standardized clinical assessment tools that incorporate subjective and objective measures of VOD and that are administered by experts trained in neurological, neuroophthalmological, and vestibular examination are needed to confirm the prevalence of VOD among pediatric patients with SRC and PCS, as well as the impact of VOD on the development of PCS. Additional prospective studies are also needed to examine the effects of targeted vestibular therapy on subjective and objective measures of VOD in pediatric patients with SRC and PCS.

Conclusions

Evidence of VOD was detected in a significant proportion of children and adolescents with acute SRC and PCS who were referred to a multidisciplinary concussion program. Furthermore, VOD was a significant risk factor for the development of PCS in this acute SRC cohort, even after we controlled for other predictors of PCS identified in the literature. Future studies are needed to confirm the prevalence of VOD among broader pediatric SRC populations and to evaluate the efficacy of vestibular therapy in patients with concussion who present with subjective and objective evidence of VOD.

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