Vestibular Deficits following Youth Concussion

Daniel J. Corwin, MD[1], Douglas J. Wiebe, PhD[2,3], Mark R. Zonfrillo, MD, MSCE[1,3,4], Matthew F. Grady, MD[3,5,6], Roni L. Robinson, MSN, CRNP[5], Arlene M. Goodman, MD[7], and Christina L. Master, MD[3,5,6]

Objective To characterize the prevalence and recovery of pediatric patients with concussion who manifest clinical vestibular deficits and to describe the correlation of these deficits with neurocognitive function, based on computerized neurocognitive testing, in a sample of pediatric patients with concussion.

Methods This was a retrospective cohort study of patients ages 5-18 years with concussion referred to a tertiary pediatric hospital-affiliated sports medicine clinic from July 1, 2010 to December 31, 2011. A random sample of all eligible patient visits was obtained, and all related visits for those patients were reviewed.

Results A total of 247 patients were chosen from 3740 eligible visits for detailed review and abstraction; 81% showed a vestibular abnormality on initial clinical examination. Those patients with vestibular signs on the initial examination took a significantly longer time to return to school (median 59 days vs 6 days, $P = .001$) or to be fully cleared (median 106 days vs 29 days, $P = .001$). They additionally scored more poorly on initial computerized neurocognitive testing, and it took longer for them to recover from neurocognitive deficits. Those patients with 3 or more previous concussions had a greater prevalence of vestibular deficits, and it took longer for those deficits to resolve.

Conclusion Vestibular deficits in children and adolescents with a history of concussion are highly prevalent. These deficits appear to be associated with extended recovery times and poorer performance on neurocognitive testing. Further studies evaluating the effectiveness of vestibular therapy on improving such deficits are warranted. *(J Pediatr 2015;166:1221-5).*

Sports- and recreation-related concussions are common injuries in children and adolescents. Studies have estimated that 144 000 children and adolescents are seen in emergency departments for concussion annually,[1] with the full incidence of concussion in both youth and adult populations estimated to be as high as 3.8 million per year.[2,3]

Balance and vestibular ocular reflex (VOR) deficits, secondary to dysfunction of the vestibular system, have been recognized as a key component of the morbidity from concussions.[4,5] The vestibular system is composed of central (including the vestibular nuclei, cerebellum, autonomic nervous system, thalamus, and cerebral cortex) and peripheral (semicircular canals, otoliths, vestibular ganglia, and the vestibular nerve) components,[6] and given its widely distributed locations, is vulnerable to translated forces occurring during a traumatic brain injury.[7] Even though the authors of previous studies have examined vestibular symptoms of concussion, including dizziness, balance problems, and visual deficits,[8-10] physical findings indicative of vestibular injury during recovery from youth concussion and their correlation with recovery outcomes have not been described.

By examining a sample of patients referred to a specialty pediatric sports medicine clinic for concussion, we aimed to: (1) describe the prevalence of vestibular deficits in youth concussion; (2) identify any association of vestibular deficits with prolonged recovery from youth concussion; (3) correlate vestibular deficits in youth concussion with results of computerized neurocognitive testing; and (4) determine whether previous history of concussion influenced the prevalence and severity of vestibular and neurocognitive deficits.

Methods

We conducted a retrospective cohort study approved by our institutional review board of patients seen in the subspecialty sports medicine clinics of The Children's Hospital of Philadelphia, of a large pediatric tertiary care network, with the goal of identifying risk factors for prolonged recovery from youth concussion. The dataset used in this study also was used in a previous study by Corwin et al[11] in which they described per-injury characteristics associated with prolonged recovery from concussion. The data were collected via an electronic medical record query. A total of 3740 unique visits for patients ages 5-18 years with a diagnosis of concussion occurred in the sports medicine clinics between July 1,

ImPACT	Immediate Postconcussion Assessment and Cognitive Testing
VOR	Vestibular ocular reflex

From the [1]Division of Emergency Medicine, The Children's Hospital of Philadelphia; [2]Department of Biostatistics and Epidemiology, and [3]Perelman School of Medicine, University of Pennsylvania; [4]Center for Injury Research and Prevention, [5]Sports Medicine and Performance Center, and [6]Department of Pediatrics, The Children's Hospital of Philadelphia, Philadelphia, PA; and [7]Pediatric Sports Medicine, Saint Peter's Sports Medicine Institute, Somerset, NJ

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2010, and December 31, 2011. A convenience sample of 250 patients was selected randomly via a computerized program based on the estimated workload for data abstraction. All visits for each patient were identified, and charts were abstracted electronically. Eligible patients were those with a diagnosis of concussion (*International Classification of Diseases, 9th Revision* codes 850.0, 850.1, 850.11, 850.12, 850.2, 850.3, 850.4, 850.5, or 850.9) made by the referring provider. This diagnosis was confirmed by the sports medicine physician at the initial visit using the definition of concussion specified in the Consensus Statement on Concussion in Sport 4th International Conference on Concussion in Sport (mechanism of injury that results in direct or indirect forces to head resulting in symptoms including somatic, cognitive, and emotional disturbances).[5]

For most of the patients seen, the mechanism of injury was sports-related, although some injuries were trauma-related, including motor vehicle crashes, falls, and playground injuries. Those patients seen in the office with nonsports, trauma-related injuries experienced whiplash-type injuries, which were considered to be a low-impact injury mechanism and therefore comparable with sports-related concussion. Patients with high-impact, traumatic injury mechanisms (including motor vehicle crashes with patient ejection, death of another passenger, or rollover; and pedestrian/bicyclist without a helmet struck by a motorized vehicle) are not seen typically in this practice.

Patients with intracranial hemorrhage or previous neurologic surgery were excluded from the study; however, those with a pre-existing vestibular disorder, substance abuse, or psychiatric disorder were not excluded. Three of the 250 charts were duplicate patients and thus were excluded. Most of the patients seen in the sports medicine practice often are referred for more severe or prolonged symptoms of concussion from a sports-related injury, but there are also patients who are referred to the clinic immediately after injury regardless of severity or mechanism. Study data were collected and managed using Research Electronic Data Capture tools hosted at The Children's Hospital of Philadelphia.[12]

Demographics, injury details (date, mechanism), physical examination findings during the initial patient visit, and computerized neurocognitive testing scores were all collected from the record. The physical examination, a modified version of the Vestibular/Ocular Motor Screening Assessment validated by the University of Pittsburgh,[13] is a standardized concussion evaluation performed by physicians at The Sports Medicine and Performance Center at The Children's Hospital of Philadelphia. It includes assessment for dysmetria, nystagmus, smooth pursuits, fast saccades,[14] and gaze stability testing (both the horizontal and vertical VOR), near-point convergence testing,[15] and gait/balance testing. The physical examination, previously published,[16,17] is conducted in a standardized fashion by 3 sports-medicine-trained pediatricians. The examination was administered only by these 3 physicians and was documented in a standardized template in the electronic health record. Patients were defined as having vestibular deficits if they showed either abnormal VOR testing, defined as symptom provocation or inability to complete multiple successive repetitions, or abnormal tandem gait, defined as symptom provocation or loss of balance during tandem gait examination.

Outcomes

Patients were classified as suffering from vestibular deficits if they showed abnormalities either on VOR testing or tandem gait as described previously.[8,9] Recovery outcomes were measured by the use of both clinical and computerized neurocognitive data. Clinical factors included time until a patient returned to school full-time without academic accommodations (including homebound education, half-days, full days with breaks, elimination of examinations, examinations with extra time and/or note cards, and elimination of honors classes) and time until a patient was fully cleared to participate in sports by the sports medicine physician. For clearance for sports participation, patients underwent a standard exertional return-to-play protocol, as described in the most recent Zurich guidelines,[5] and had to be carrying a full cognitive workload at school, be asymptomatic with cognitive and physical exertion, and have normal vestibular and oculomotor physical examinations.[17]

Neurocognitive testing was performed using Immediate Postconcussion Assessment and Cognitive Testing (ImPACT), a computerized neurocognitive battery that has been designed and validated for the evaluation of concussion.[18-20] Four outcome measures are obtained from testing: verbal memory (a composite score for a word recognition paradigm, a symbol number match test, and a letter memory task), visual memory (average percent score for a recognition memory task and an identification memory task), processing speed (the weighted average of three tasks done as interference tasks for the memory paradigms), and reaction time (average response time on 3 tasks). Both age- and sex-adjusted percentiles from the initial patient visit to the sports medicine clinic, as well as recovery of initial ImPACT score deficits, were used as outcome measures. Because the majority of patients seen in the clinic do not have baseline testing scores available, recovery of score deficits was determined to be the date of follow-up visit where a patient's score in each category plateaued and was therefore considered to have reached their new baseline moving forward. ImPACT testing was performed at the initial patient visit and each subsequent follow-up visit, except in cases in which patients were too symptomatic to complete the testing. Finally, data were examined for patients with self-reported history of previous concussion by use of the aforementioned outcome measures.

Statistical Analyses

Descriptive statistics included means, ranges, medians, and IQRs. Statistical comparisons to assess the prevalence or timing of outcomes between subsets of patients were conducted with several methods. Dichotomous outcomes were analyzed by the use of logistic regression. Outcomes classified as times were analyzed by the use of quantile regression, given the highly skewed nature of these data and the fact that