Neurocognitive Evaluation of Mild Traumatic Brain Injury in the Hospitalized Pediatric Population

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Objective: To test the feasibility of inpatient neurocognitive testing and measure the degree of disability in children hospitalized with mild traumatic brain injury (MTBI).

Summary Background Data: MTBI is common in the pediatric population. A standardized approach to identify neurocognitive impairment and determine optimal time to return to exertional activities (eg, school, sports) is lacking.

Methods: For a 2-year period, children (age: 11–17 years) hospitalized at a level 1 urban Pediatric Trauma Center with MTBI were prospectively enrolled. Neurocognitive performance was assessed utilizing previously validated computer-based tests (Immediate Postconcussion Assessment and Cognitive Testing) as inpatient and in follow-up clinic after discharge. The feasibility of inpatient testing and the degree neurocognitive impairment and symptomatology were assessed. This study was approved by the IRB and registered with clinicaltrials.gov (NCT00715949).

Results: For the 2 years of study, 116 subjects were prospectively enrolled and tested. The population had a mean age of 14 years and 69.8% were male. On initial in-hospital testing, the overall population demonstrated considerable neurocognitive deficits (mean values for all 4 subtests below 25th percentile, norm 50%) with at least one subtest score below 25% in 95.7% and an abnormal symptom score in 83.4% of patients. In comparing initial testing to follow-up testing (N = 63), significant improvements were noted for all subtests (verbal memory: 28.0% vs. 37.5%, respectively, norm 50%, $P = 0.02$; visual memory: 24.9% vs. 38.1%, respectively, norm 50%, $P < 0.01$; visual motor: 21.8% vs. 31.1%, respectively, norm 50%, $P = 0.01$; reaction time: 21.8% vs. 30.3%, respectively, norm 50%, $P = 0.05$), with a decline in the symptom score (26.9 vs. 9.2, respectively, norm 0-8, $P < 0.01$) as well. Patients not seen in follow-up (N = 53) did not differ demographically from those seen in clinic.

Conclusions: Inpatient neurocognitive testing was feasible in pediatric MTBI patients. Neurocognitive abnormalities were nearly universally present on initial evaluation with significant improvements demonstrated at the time of outpatient follow-up. Return to activity recommendations are thus best deferred for most hospitalized MTBI children until formal assessment can be performed after discharge.

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Head injuries are a frequent source of morbidity and the most common source of mortality in the pediatric trauma population.[1] It is estimated that head injuries result in more than 500,000 emergency department visits, 95,000 hospital admissions, and 7000 deaths in the pediatric age-group annually.[1] The CDC estimates that there may be as many as 1.8 to 3.6 million sports and recreation-related concussions per year.[2] Despite the enormity of these numbers, they still likely underestimate the problem as many injured children (particularly those with mild or even moderate severity) are not brought to medical attention. Fortunately, most head injuries (75%) are classified as mild (ie, "concussion").[3] Although severe head injuries pose a greater threat to life or cause of major morbidity, a National Institutes of Health consensus panel recognized that because of the sheer volume of patients with mild traumatic brain injury (MTBI), as well as the potential for enduring neurologic sequelae, this disease represents a "societal burden."[4] Management of this sizable group of patients can be challenging due to a lack of consensus in the health care community regarding even the definition of MTBI, uncertainty as to the ideal assessment modality for the injured child, and a lack of uniform recommendations for return to activity (including school) after MTBI. The American Academy of Pediatrics recognized the importance of mild head injury in children and issued management guidelines for treatment of this common disease.[5] These guidelines however, failed to address postinjury sequelae and their management, an omission likely related to the scarcity of available data. Most accepted return-to-play algorithms that do exist are designed for sport-related head injuries and their applicability to the more commonly encountered nonsports-related MTBI is not known.

We sought to test the feasibility of administering a computer-based neurocognitive test battery to young hospitalized trauma patients with MTBI. Further, we sought to quantify the potential severity of neurocognitive deficits and their near-term recovery in this patient population.

METHODS

Pediatric blunt trauma patients (age: 11–17 years) admitted for treatment of MTBI were eligible for inclusion in the study. Patients with penetrating injuries, those treated and released from the emergency room, Spanish speaking only, and patients with associated injuries that limited their ability to take the computer-based test (eg, upper extremity injury) were excluded. For the purposes of this study, minor traumatic brain injury included patients with a Glasgow Coma Scale (GCS) of 14 to 15 on arrival in the trauma receiving area. Patients with or without abnormalities on head CT scans and with or without a reported loss of consciousness were included. Eligible subjects underwent neurocognitive testing utilizing the ImPACT assessment tool (as detailed later) during the acute hospitalization and at the time of outpatient follow-up.

ImPACT Software

The Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) computer program is a Windows-based software application that can be administered at the bedside with a laptop computer. Studies have demonstrated ImPACT to have adequate

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reliability, validity, sensitivity/specificity, and added value in managing sports-related concussion and MTBI.[6–10] The program contains normative data for patients down to the age of 11 years. The program employs a series of neurocognitive tests and requires approximately 25 minutes to complete. Specific abilities measured include: attention span, working memory, sustained and selective attention time, response variability, nonverbal problem solving, and reaction time. The components of the test include:

Demographic information– baseline subject information including gender, age, height, weight, concussion history, preexisting conditions.

Symptom scale–the subject rates the severity of 22 currently accepted concussive symptoms, via a 7-point Likert scale.[11]

Neurocognitive Testing–a battery of neurocognitive tests are the backbone of the program. Areas tested include:

- Word discrimination-evaluates attentional processes/verbal recognition memory via a word discrimination paradigm.
- Design memory-evaluates attentional processes and visual recognition memory through recall of designs.
- X's and O's-measures visual working memory and processing speed through a visual memory paradigm with a distracter task.
- Symbol matching-evaluates visual processing speed, learning, and memory.
- Color matching-measures choice reaction time and impulse control/response inhibition.
- Three letters-measures working memory and visual-motor response speed.

Injury Description

Injury descriptors (eg, duration of loss of consciousness, retrograde amnesia, on-field symptoms) as well as evaluation and treatment modalities employed, if any (eg, CT, MRI, emergency room visit, etc.) are recorded.

The data gathered by the ImPACT software were supplemented with additional demographic and clinical information including: admission GCS, injury severity score, associated injuries, and hospital length of stay.

As part of routine care for these patients, trauma clinic follow-up was recommended for all patients with a minor head injury 2 to 3 weeks after hospital discharge. At the time of this clinic visit, consenting patients underwent repeat ImPACT testing in the office setting.

The initial and postdischarge neurocognitive test results were compared. Descriptive statistics were used to describe the population and statistical comparisons were undertaken utilizing *t* test.

Mean pre- and postdischarge neurocognitive test values were compared using *t* tests. Median values were also compared using nonparametric tests, yielding results that did not differ substantively from the mean tests and are not presented for brevity. Nonparametric tests and *t* tests were also used to test for differences between the subsamples of patients who did versus did not return for follow-up.

Eligible subjects were enrolled prospectively during the weekdays when research personnel were available to recruit participants and administer the test. Informed consent was obtained from the parent or legal guardian, as well as assent from the study subject. Neurocognitive testing was administered at the bedside via a laptop computer and full-sized mouse. The testing was performed as soon as it was clinically reasonable but no later than 72 hours from the time of injury. This study was approved by the Institutional Review Board of The Children's Hospital of Philadelphia and registered with clinicaltrials.gov (NCT00715949). This study was conducted in accord with the ethical standards of the Committee on Human Experimentation of the institution in which the experiments were done or in accord with the ethical standards of the Helsinki Declaration of 1975.

TABLE 1. Injury Mechanisms Observed in Overall Study Population

Injury Mechanism (N = 116)	
Fall	26.7%
Motorized vehicle	18.1%
Bicycle	18.1%
Assault	13.8%
Sports	12.1%
Pedestrian	11.2%

RESULTS

Overall

Over the 2-year period, 143 eligible subjects were identified and approached for enrollment. A total of 23 patients declined to participate in the study. Of the remaining 120 patients initially enrolled and consented, 4 did not finish the initial test and were dropped from the study. Thus, the overall study population consisted of 116 patients pediatric patients with MTBI. The overall population had a mean age of 14 years (range, 11–17 years), and 69.8% was male. The mean GCS on arrival was 14.8 with 15.8% presenting with a GCS of 14. The mean injury severity score was 8.7 (range, 4–32). A prior history of concussion was reported in 12.8%. A loss of consciousness at the time of the injury was reported in 68.4%. The initial test was administered a mean of 2.1 days (range, 1–3) from the time of injury. The mean hospital length of stay was 2.5 days (range, 1–12 days). The most common injury mechanism encountered in this population was a fall (26.7%). Motorized vehicle-related injuries (includes automobile, motorcycle and all-terrain vehicle) were encountered in 18.1% (Table 1).

Neurocognitive deficits as measured by the ImPACT tool were common in this population. The mean percentiles were below 25% (norm 50%) for all subtests for the population as a whole (Table 2). Overall, 95.7% of tested subjects scored below the 25th percentile on at least one subtest including 36.2% who scored below the 25th percentile for all subtests administered. The mean symptom score recorded for the population was 27.9 (range, 1–111; normal, 0–8). An abnormal symptom score (score >8) was noted in 83.4% of subjects at the time of inpatient testing.

No follow-Up Testing Group

A total of 53 patients elected not return to clinic for their scheduled follow-up visit. Attempts were made to contact all patients not showing for follow-up care. A minimum of 2 phone calls were made to the family and a letter was sent to the primary care provider before declaring a patient lost to follow-up.

Patients electing not to follow-up had a mean age of 14.1 years and 67.9% were male. This population did not differ statistically demographically or by injury severity from the patients (N = 63) who were seen and tested in the follow-up clinic (Table 3).

Neurocognitive deficits in the cohort without follow-up testing were common. The mean percentiles were below 50% (the normative value) for all subtests for the population as a whole. Overall, 98.1% of tested subjects scored below the 25th percentile on at least one subtest including 47.2% that scored below the 25th percentile for all subtests administered. The mean symptom score recorded for the population was 29.2 (range, 2–111; normal, 0–8). An abnormal symptom score (score >8) was noted in 79.2% of subjects at the time of inpatient testing.

TABLE 2. Neurocognitive Test Results at Initial Assessment for Overall Population (N = 116)

	Verbal Memory (Norm = 50)	Visual Memory (Norm = 50)	Visual Motor (Norm = 50)	Reaction Time (Norm = 50)	Symptom Score (Norm 0–8)
Median	14.0%	9.9%	12.0%	4.5%	23.5
Mean	22.4%	24.2%	17.8%	18.3%	27.9
SD	23.2	26.7	20.4	28.5	21.2

TABLE 3. Demographic Comparison of Patients With and Without Follow-Up Neurocognitive Testing

	Overall (N = 116)	Follow-Up (N = 63)	No Follow-Up (N = 53)	P*
Age, mean (SD)	14.1 (1.8)	14.1 (1.8)	14.1 (1.8)	P = NS
Male, %	69.8	71.4	67.9	P = NS
GCS, mean (SD)	14.9 (0.4)	14.9 (0.4)	14.8 (0.4)	P = NS
ISS, mean (SD)	8.2 (6.5)	9.2 (7.0)	6.9 (5.8)	P = NS
LOS, mean (SD)	2.4 (3.0)	2.7 (3.2)	2.1 (2.7)	P = NS
LOC, %	68.4	73.0	64.2	P = NS
Prior concussion, %	12.8	15.9	9.4	P = NS

*Comparing follow-up to no follow-up groups.
ISS indicates injury severity score; LOC, loss of consciousness; LOS, length of stay; NS, not significant.

Follow-Up Testing Group

A total of 63 patients returned to clinic for routine follow-up evaluation during which time neurocognitive testing was performed. This population had a mean age of 14.1 years and 71.4% was male. This group was similar to that population that chose not to receive follow-up care (Table 3).

Neurocognitive deficits in the cohort with follow-up testing were also common. The mean percentiles were below 50% (the normative value) for all subtests for the population as a whole. Overall, 93.7% of tested subjects scored below the 25th percentile on at least one subtest including 27.0% that scored below the 25th percentile for all subtests administered. The mean symptom score recorded for the population was 26.9 (range, 1–98; normal, 0–8). An abnormal symptom score (score >8) was noted in 87.3% of subjects at the time of inpatient testing.

Patients who elected not to pursue follow-up demonstrated greater neurocognitive impairment (Fig 1), than patients seen in follow-up. This difference was noted in all 4 subtests and achieved statistical significance for the verbal memory and visual motor subtests. Symptoms scores for those with and without follow-up were similar (26.9 vs. 29.2, respectively).

Initial Versus Follow-Up Test Results

Results of initial, inpatient neurocognitive test results were compared with follow-up test results for the cohort of 63 patients who returned to clinic. The follow-up group as a whole demonstrated a significant improvement in neurocognitive performance on all 4 subtests (Fig 2). Additionally, the symptom score at the time of follow-up was markedly improved (66.0% decrease, $P < 0.001$) as compared with the in-hospital results. At the time of follow-up, 55 of 63 (87.3%) of patients still demonstrated at least one subtest result below the 25th percentile but fewer (7.9%) had all subtest values below the 25th percentile. An abnormal symptom score (>8) was noted in 38.1% of patients (down from 83.4% at initial testing).

DISCUSSION

The same decisions facing clinicians treating children with sports-related head injuries also exist for other nonsports-related but everyday injury mechanisms (eg, motor vehicle collisions, falls). In fact, motor vehicle-related causes and falls are the most common sources of traumatic brain injury in children.[12] Sports and recreation typically account for less than 10% of hospitalized MTBI.[13] Nonsports-related traumatic brain injuries are often more severe but can be equally challenging to characterize. For the hospitalized pediatric patient with MTBI, standardized assessment tools and recommendations for timing of return-to-play are lacking. As such, postdischarge recommendations for medical follow-up and a determination of timing for return to exertional activities are highly variable if not absent altogether. Premature exertion (both cognitive and physical) can increase the metabolic demands on the injured brain at a particularly vulnerable time.[14] The detrimental affects of premature return to exertional activities are related to the underlying pathophysiology of MTBI. Although incompletely understood, MTBI likely results in axonal injury (commonly through accelerative/decelerative forces). This axonal injury sets in motion a cascade of neurometabolic changes the result of which is an increase in metabolism (glucose utilization) along with a local decrease in cerebral blood flow.[15] These metabolic changes can promote additional neuronal injury or delay in recovery. Just as recovery from head injury is variable, so to is the attenuation of these metabolic changes. A reliable assessment tool to judge the adequacy of recovery is thus vital. In this study, we demonstrated the feasibility of administering a previously validated, computer-based neurocognitive test battery (ImPACT) in the inpatient setting. Thus, a common barrier to determining optimal postdischarge care recommendations, an objective measure of neurocognitive deficits, has been addressed. It is hoped that this (or similar testing) can be more routinely used in the management algorithm for treatment of this common pediatric injury.

A strikingly high rate of neurocognitive deficits was observed in this hospitalized population with MTBI. The mean percentiles in all 4 subtests of the ImPACT tool fell well below the 50th percentile for the population as a whole with nearly all patients (95.7%) demonstrating at least one value below the 25th percentile. Although not compared with self-baselines, the findings do suggest an alarmingly high frequency of neurocognitive deficits. Thus, for the overwhelming majority of these patients, any recommendations regarding return to exertional activities should be deferred until a formal follow-up assessment to ensure appropriate recovery and minimize the risk of long-term sequelae. Although the reasons for poor test performance may be more than simply the brain injury (eg, associated injury, medications), the fact remains that for most of these children, recommendations cannot be rooted to the clinical status of the patient at the time of inpatient hospitalization. Even by the time of clinic follow-up, the overall scores were still below age and gender-matched normative values indicating possible ongoing deficits.

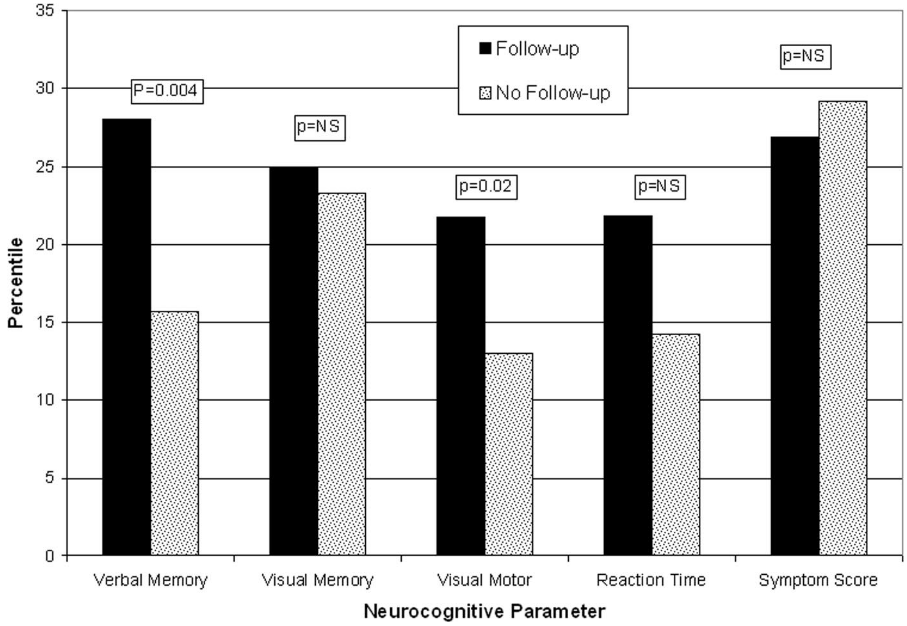

FIGURE 1. Comparison of initial neurocognitive testing for patients with and without follow-up testing.

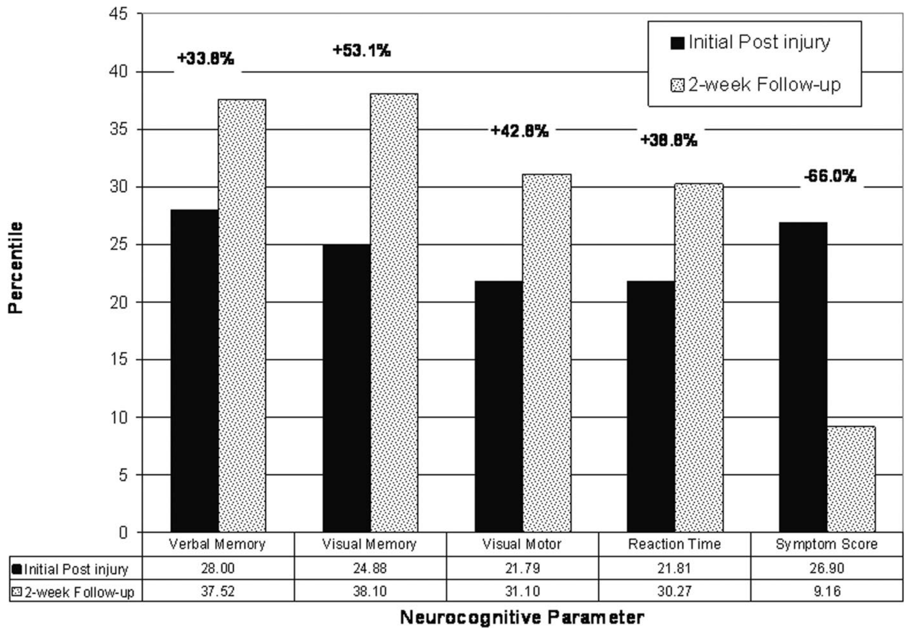

FIGURE 2. Comparison of initial and 2-week post injury neurocognitive testing (N = 63 patients). Normative values for subtests = 50th percentile. Symptom score is ordinal and normal values range between 0 and 8.

Determining when it is safe to return to exertional activities is of paramount importance in this population. The perils of premature return to activities (most notably contact sports) for children with traumatic brain injury are well documented.[16–18] Dangers include prolongation of postconcussive symptoms, lower threshold for repeat concussion, and death.[16–18] Further, these dangers may be more common in younger athletes.[19] However, there is evidence that even noncontact, exertional activities may be detrimental if initiated too quickly. It was the observation of the First International Conference on Concussion in Sport that no previously published guideline for management of concussion was adequate for assessment of all concussions. In addition, they recognized the utility of neuropsychological testing in understanding the injury and determining management for the concussed patient.[20] Unfortunately, the majority of treating clinicians have few tools available to help determine when it is appropriate for the individual to return to activities. One such tool that has been used extensively and effectively in the head injured athlete is the ImPACT program. This is an interactive software program originally designed to assess subjective and objective cognitive abilities of the head injured athlete. The program has been validated and used extensively for assessment of sports-related concussions in amateur and professional athletes.[6–10] Studies of concussed athletes have demonstrated a much slower return to baseline than previously had been appreciated.[21] Further, the younger athletes (high school vs. college or professional) were the slowest to return to baseline.[19] This program has proven quite useful in determining the optimal time to return to activities in the population of head injured athletes by providing objective data upon which to base recommendations. In this study, we have demonstrated the utility of neurocognitive testing in a broader pediatric population with MTBI. As it has been suggested that trauma-related MTBI recovery is slower even than sports-related MTBI, the information obtained from this neurocognitive testing may be invaluable in crafting an optimal care plan.[22]

Despite the best efforts of the health care team, just over half of patients returned for their scheduled clinic follow-up visit. However, minimal differences were observed between those returning for follow-up and those electing not to follow-up. Thus, we do not feel as if the follow-up population analyzed was more severely injured and would therefore be expected to have a slower recovery. On the contrary, we suspect that the cohort of patients electing not to follow-up were at risk as well and would have benefited from formal assessment before returning to school-based or physically exertive activity. It is this misconception of not feeling injured that places the patient at additional risk. Determination of the need for structured follow-up evaluation should be made at the time of hospital discharge. Clearance to return to exertional activities should be withheld in most patients until such follow-up and compliance with this care needs to be strongly encouraged.

CONCLUSIONS

In this study, we demonstrated the feasibility of inpatient neurocognitive testing in pediatric patients with MTBI. This testing revealed that abnormalities were nearly universally present on initial neurocognitive evaluation with significant improvements demonstrated by the time of outpatient follow-up. This or other structured neurocognitive testing is strongly encouraged. Because of the prevalence of these neurocognitive deficits and concussive symptoms, recommendations regarding the return to exertional activities are best deferred for most hospitalized MTBI children until formal assessment can be performed after discharge.

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REFERENCES

1. Schutzman SA, Greenes DS. Pediatric minor head trauma. *Ann Emerg Med*. 2001;37:65–74.
2. Langlois JA, Rutland-Brown W, Wald M. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehab*. 2006;21:375–378.
3. Sosin DM, Sniezek JE, Thurman DJ. Incidence of mild and moderate brain injury in the United States, 1991. *Brain Inj*. 1996;10:47–54.
4. Consensus conference. Rehabilitation of persons with traumatic brain injury. NIH Consensus Development Panel on Rehabilitation of Persons with Traumatic Brain Injury. *JAMA*. 1999;282:974–983.
5. The American Academy of Pediatrics Committee on Quality Improvement and the American Academy of Family Practice Commission on Clinical Policies and Research. The management of minor closed head injury in children. *Pediatr*. 1999;104:1407–1415.
6. Iverson GL, Lovell MR, Collins MW. Interpreting change on ImPACT following sport concussion. *Clin Neuropsychol*. 2003;17:460–467.
7. Iverson GL, Lovell MR, Collins MW. Validity of impact for measuring processing speed following sports-related concussion. *J Clin Exper Neuropsychol*. 2005;27:1–7.
8. Broglio SP, Macchiocchi SN, Ferrara MS. Sensitivity of the concussion assessment battery. *Neurosurg*. 2007;60:1050–1058.
9. Schatz P, Pardini JE, Lovell MR, et al. Sensitivity and specificity of the impact test battery for concussion in athletes. *Arch Clin Neuropsychol*. 2006;21:91–99.
10. Van Kampen DA, Lovell MR, Pardini JE, et al. The “value added” of neurocognitive testing after sports-related concussion. *Am J Sports Med*. 2006;34:1630–1635.
11. Lovell MR, Iverson GL, Collins MW, et al. Measurement of symptoms following sports-related concussion: reliability and normative data for the post-concussion scale. *Appl Neuropsychol*. 2006;13:166–174.
12. Keenan HT, Bratton SL. Epidemiology and outcomes of pediatric traumatic brain injury. *Dev Neurosci*. 2006;28:256–263.
13. Simon B, Letourneau P, Vitorino E, et al. Pediatric minor head trauma: indications for computed tomographic scanning revisited. *J Trauma*. 2001;51:231–237.
14. Majerske CW, Mihalik JP, Ren D, et al. Concussion in sports: postconcussive activity levels, symptoms, and neurocognitive performance. *J Athl Train*. 2008;43:265–274.
15. Giza CC, Hovda DA. The neurometabolic cascade of concussion. *J Athl Train*. 2001;36:228–235.
16. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *JAMA*. 2003;290:2549–2555.
17. Zemper ED. Two-year prospective study of relative risk of a second cerebral concussion. *Am J Phys Med Rehabil.* 2003;82:653-659.
18. McCrory PR, Berkovic SF. Second impact syndrome. *Neurol*. 1998;50:677–683.
19. Field M, Collins MW, Lovell MR, et al. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *J Pediatr*. 2003;13:222–229.
20. Aubry M, Cantu R, Dvorak J, et al. Concussion in Sport Group. Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. Recommendations for the improvement of safety and health of athletes who may suffer concussive injuries. *Br J Sports Med*. 2002;36:6–10.
21. Lovell MR, Collins MW, Iverson GL, et al. Recovery from mild concussion in high school athletes. *J Neurosurg*. 2003;98:295–301.
22. Iverson GL. Outcome from mild traumatic brain injury. *Curr Opin Psychiatry*. 2005;18:301–317.