Identifying Neurocognitive Deficits in Adolescents Following Concussion

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Abstract

Objectives: This study of concussed adolescents sought to determine if a computer-based neurocognitive assessment (Immediate Postconcussion Assessment and Cognitive Test [ImPACT]) performed on patients who present to the emergency department (ED) immediately following head injury would correlate with assessments performed 3 to 10 days postinjury and if ED neurocognitive testing would detect differences in concussion severity that clinical grading scales could not.

Methods: A prospective cohort sample of patients 11 to 17 years of age presenting to the ED within 12 hours of a head injury were evaluated using two traditional concussion grading scales and neurocognitive testing. ED neurocognitive scores were compared to follow-up scores obtained at least 3 days postinjury. Postconcussive symptoms, outcomes, and complications were assessed via telephone follow-up for all subjects.

Results: Sixty patients completed phone follow-up. Thirty-six patients (60%) completed follow-up testing a median of 6 days postinjury. Traditional concussion grading did not correlate with neurocognitive deficits detected in the ED or at follow-up. For the neurocognitive domains of verbal memory, processing speed, and reaction time, there was a significant correlation between ED and follow-up scores trending toward clinical improvement. By 2 weeks postinjury, 23 patients (41%) had not returned to normal activity. At 6 weeks, six patients (10%) still had not returned to normal activity.

Conclusions: Immediate assessment in the ED can predict neurocognitive deficits seen in follow-up and may be potentially useful to individualize management or test therapeutic interventions. Neurocognitive assessment in the ED detected deficits that clinical grading could not and correlated with deficits at follow-up.

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Of the 615,000 children affected annually by traumatic brain injury (TBI), the majority are discharged from the emergency department (ED) with the diagnosis of concussion.[1] Concussion is defined as the ''complex pathophysiologic process affecting the brain, induced by traumatic biomechanical forces secondary to direct or indirect forces to the head.''[2] Evidence shows that concussion heals more slowly in children, and because the recovering brain is more susceptible to reinjury, these patients are at higher risk for cumulative effects such as postconcussive syndrome or second impact syndrome.[3–9] Unfortunately, adolescent patients often return to mental and physical activities prematurely.[10–12]

Appropriate discharge recommendations and management may improve functional outcomes from concussion in pediatric patients evaluated in the ED.[13] For athletes, expert consensus endorses abandoning traditional grading scales and using individualized, patient-centered neurocognitive assessment, which provides an

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objective measure of concussion severity and recovery through the administration of a series of psychological tests measuring neurocognitive function.[14–16] The computer-based Immediate Postconcussion Assessment and Cognitive Test (ImPACT) has been extensively studied and validated and is widely used by concussion specialists because of its ease of administration, speed, and accuracy of assessment and an ability to detect deficits that linger after symptom resolution.[9,17–23] ImPACT has been used to assess concussion in inpatient pediatric trauma patients and as a diagnostic tool in the adult ED setting.[24,25] However, the efficacy of ImPACT to determine concussion severity immediately following injury in adolescent patients has not been established.

The objectives of this study were to determine 1) if ImPACT performed on adolescents who present to the ED within the first 12 hours following head injury would correlate with ImPACT traditionally performed 3 to 10 days after the injury and 2) if ED ImPACT would demonstrate differences in neurocognitive deficits that traditional clinical grading scales could not. Additionally, we sought to determine the extent of under-recognized morbidity in patients with mild TBI.

METHODS

Study Design

This study was approved by the University of Pittsburgh institutional review board. This was a prospective study of mild TBI in patients aged 11 to 17 years, with a Glasgow Coma Scale (GCS) score of 15, presenting to the ED within 12 hours of a head injury.

Study Setting and Population

This study took place in the ED of the Children's Hospital of Pittsburgh. A convenience sample of patients was recruited for participation in a study on concussion assessment. All patients were managed for their injury by the treating emergency physician based on the standard of care. Patients did not require neuroimaging to participate in the study. Treating physicians notified study staff of patients who were eligible for participation.

Study Protocol

To ensure that patients met standard definitions of concussion for study participation, patients were assessed by study staff (principal investigator or research assistant) using the Acute Concussion Evaluation (ACE) screening tool.[2] The ACE was developed and adapted for the Centers for Disease Control and Prevention to provide a standardized diagnostic assessment of concussion. The ACE does not assess concussion severity. The ACE has been validated in the pediatric through adolescent age range.[26–28] To meet the ACE definition of concussion, patients must have had a force to the head and neck and experience at least one postconcussive sign or symptom. Neuroimaging was not needed to make the definition of concussion, nor was it necessary for participation in the study. Subjects who were identified as having a concussion by the ACE were eligible for participation.

Given that study tasks involved an assessment of neurocognitive function, subjects were also asked to complete the Galveston Orientation and Amnesia Test (GOAT) as a preliminary neurocognitive assessment.[29] The GOAT measures orientation to person, place, time, and memory for events preceding and following the injury. It has been validated in the adolescent age range.[29] Patients scoring less than 75 on this test were deemed too disoriented to participate in the study.

Patients were excluded for the following reasons: not awake enough or otherwise unwilling to complete the GOAT, prior mental defect or disease (e.g., mental retardation, developmental delay, attention deficit hyperactivity disorder [ADHD], or learning disability), or known intracranial injury (e.g., intracranial bleeding, cerebral contusion). We also excluded subjects with conditions that would interfere with the ability to complete computer-based neurocognitive assessment: vision impairment (including known color-blindness), restricted use of dominant hand, or inability to sit upright for testing.

Neurocognitive testing was self-administered in the ED and results were reviewed with the families of enrolled patients. The standard discharge instructions given to concussed patients in our ED recommend follow-up evaluation with their primary care physicians and provide information on follow-up with the university's Center for Sports Medicine concussion program. Athletes or other patients who are at risk for significant morbidity postconcussion (e.g., patients with past concussions, history of migraines) are strongly encouraged to follow up with sports medicine. For study purposes, all enrolled subjects were asked to return for a follow-up ImPACT assessment with sports medicine 3 to 10 days after their ED visit. If follow-up testing was not covered by the insurer or the patient could not be scheduled within 10 days, follow-up testing was offered at no cost for study participants in the study (see Figure 1 for study overview).

Measurements

All eligible subjects had their concussions graded by the principal investigator using American Academy of

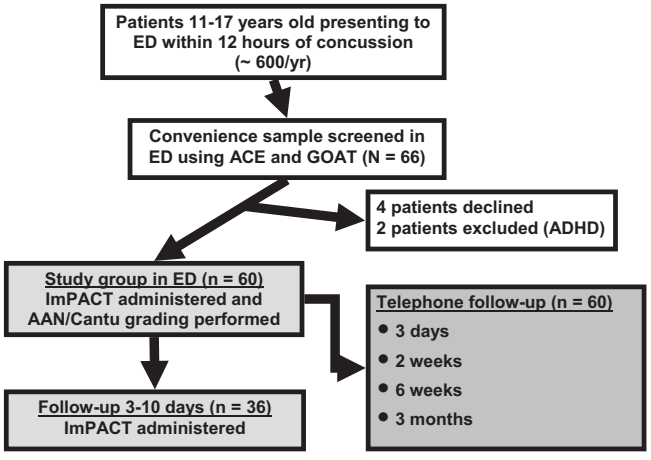

Figure 1. Study overview. AAN = American Academy of Neurology; ACE = Acute Concussion Evaluation; ADHD = attention deficit hyperactivity disorder; GOAT = Galveston Orientation and Amnesia Test; ImPACT = Immediate Postconcussion Assessment and Cognitive Test.

Table 1
Concussion Grading*

Grade	Cantu Guidelines	American Academy of Neurology Guidelines
1	No LOC and PTA < 30 min	No LOC; transient confusion, concussive symptoms, or mental status change lasting < 15 min
2	LOC < 5 min and/or PTA between 31 min-24 hr	No LOC; transient confusion, concussive symptoms, or mental status change lasting > 15 min
3	LOC > 5 min and/or PTA > 24 hr	Any LOC (either brief or prolonged)

*Adapted from Leclerc et al.[30]
LOC = loss of consciousness; PTA = posttraumatic amnesia.

Neurology (AAN) and Cantu guidelines.[30] These are both conventional concussion grading systems that use immediate signs and symptoms to grade concussion severity on a three-point ordinal scale (Table 1). All eligible subjects underwent screening in the ED by the principal investigator or research assistant using the ACE and GOAT. After screening, subjects were introduced to the ImPACT test. ImPACT Version 2.0 (ImPACT Applications, Inc., Pittsburgh, PA) is a commercially available computer program that: 1) collects demographic information, 2) assesses 22 postconcussive symptoms using a 7-point (0–6) Likert postconcussive symptom scale (ImPACT PCSS), and 3) administers a neuropsychological test battery.[20,31] Six neuropsychological test modules measuring cognitive functioning in attention, memory, reaction time, and processing speed are self-administered in less than 25 minutes. Scores from these modules are reported in four composite domains: verbal memory, visual memory, processing speed, and reaction time. In addition to these four domains, ImPACT also generates an ''impulse control'' composite that screens for invalidity by measuring the number of errors committed during testing (see Table 2 for full test details). Patient's scores are reported as raw scores as well as age- and sex-matched percentiles for 11- to 13-year-olds and 14- to 17-year-olds using existing ImPACT normative data.[32]

Postconcussive symptoms, complications, and activity levels were assessed in enrolled subjects via telephone 3 days and 2 weeks after the ED encounter to determine the morbidity of concussion. Subjects who remained symptomatic or had not returned to normal activity by 2 weeks were contacted again at 6 weeks and 3 months. The follow-up phone survey assessed symptoms using the 19 item 7-point (0–6) Likert scale of post-concussive symptoms published in the summary statement of the 2001 International Conference on Concussion in Sport.[16] Activity and exertion levels were assessed by asking subjects to rate their activity level as a percentage of full activity (e.g., 0% = no activity, 100% = full activity including sports) and to report the mean number of hours per day spent sleeping, playing video games, watching TV, or involved in physical activity. Subjects were also asked to report when their

Table 2
ImPACT Neuropsychological Test Features

Module	Methods	Domain(s) Evaluated
1. Word Discrimination	A series of 12 target words are presented and then must be identified from a series of 24 words Delay Paradigm After other modules are completed, subject tested for recall of 12 target words	Verbal Memory
2. Design Memory	A series of 12 target designs are presented and then must be identified from a series of 24 designs Delay Paradigm After other modules are completed, subject tested for recall of 12 target designs	Visual Memory Verbal Memory
3. Xs and Os	Random assortment of Xs and Os with three of the Xs or Os illuminated in yellow Must remember the location of the illuminated letters following a distracter task	Visual Memory Processing Speed Reaction Time Impulse Control
4. Symbol Matching	Grid presented with nine common symbols; under each symbol is a number button from 1 to 9 Symbol presented below grid; subject must quickly click the matching number Recall Paradigm Symbols disappear from grid, numbers remain Symbol presented below grid; subject must quickly click the matching number	Verbal Memory Reaction Time
5. Color Match	The word ''red,'' ''blue,'' or ''green'' is displayed on the screen in the same colored ink as the word or in a different colored ink Subject must click in the box if the word is in the matching ink	Reaction Time Impulse Control
6. Three Letters	Subject presented with three consonant letters. Must recall the three letters following a distracter task	Verbal Memory Visual Processing Speed

ImPACT = Immediate Postconcussion Assessment and Cognitive Test.

symptoms had resolved, when they had returned to normal activity including sports, and if any school days were missed.

Data Analysis

For patients who completed ImPACT follow-up, scores recorded in the ED were compared with scores recorded at follow-up 3 to 10 days later to assess the correlation with ED testing. Differences in means of composite ImPACT scores between those obtained during the ED visit and those obtained at follow-up were assessed with a paired t-test. Phone follow-up data were recorded as demographic/outcome data. ED ImPACT was compared to two concussion grading scales (AAN and Cantu) for all study patients. A one-way analysis of variance (ANOVA) was used to assess the difference in means of percentile scores on ImPACT with concussion grading (1–3) using the referenced grading scales. Additionally, we used a one-way ANOVA to assess differences in follow-up percentile scores on ImPACT; school days missed; time to return to activity; and 3-day, 2-week, and 6-week postconcussive symptoms with concussion grading in the ED. Statistics were performed using SPSS (SPSS Inc., Chicago, IL) and Stata/IC 10 for Windows (StataCorp, College Station, TX).

Sample size was based on the ability to detect clinically significant differences in the four domains of ImPACT and was determined a priori using PASS 2000 Power Analysis and Sample Size for Windows (NCSS, LLC, Kasville, UT). Estimates of standard deviation for the components of ImPACT were based on published data.[20] Previous studies with ImPACT have shown that, in normal teenagers tested at before injury and retested 7–10 days postconcussion, a 10% difference in scores was clinically significant.[20] All calculations were done assuming a paired t-test analysis with a two-sided $\alpha = 0.05$ and 80% power. The estimated sample size needed for analysis of this hypothesis was 73 patients. With this sample size, we would be able to detect clinically significant differences in the four domains of ImPACT. The initial recruitment goal was 120 patients, with an estimated 40% loss to follow-up. A planned interim analysis to assess the primary outcome of the correlation between ED and outpatient ImPACT scores was conducted when we reached the midpoint of our recruitment goal (60 patients recruited with 36 patients completing follow-up). Interim analysis found a correlation between ED and follow-up ImPACT scores that was statistically significant; thus, the study was closed to further enrollment.

RESULTS

Demographics

Sixty-six patients were identified for participation; two patients were excluded because of preexisting conditions (ADHD), and four patients declined participation. No patients were excluded based on the ACE screening tool or GOAT scores (median GOAT score = 99; interquartile range [IQR] = 95–100). Sixty patients were recruited over a 7-month period from June 2007 through December 2007. The group was predominantly male (47 males, 78.3%) and median age was 15 years (IQR = 13–16 years). Sports injuries were the most common cause of concussion in our study (80%). All mechanisms are listed in Table 3. Thirteen (21.7%) patients were admitted to the hospital from the ED. Of those 13, five were admitted for other injuries. Eight patients (13%) were admitted for observation following head injury, and their length of stay was 1 day. This admission rate is only slightly higher than the national ED concussion admissions rate of 9.9%.[33] There were no statistically significant differences between patients who were admitted to the hospital versus those discharged from the ED. Cranial computed tomography (CT) scans were obtained in 61.7% (37 out of 60) patients; all CT scans were negative for intracranial injury. The decision to obtain a CT scan was made at the discretion of the ED clinician. There were no differences between the patients who received imaging and those who did not with regard to demographics, ED scores, or follow-up scores.

Table 3
Mechanisms of Injury

Mechanism	*n* (%)
Sports	48 (80.0)
Football	25 (41.7)
Soccer	5 (8.3)
Baseball	4 (6.7)
Biking	3 (5.0)
Cheerleading	3 (5.0)
Basketball	2 (3.3)
Hockey	2 (3.3)
Other sports/recreation	4 (6.7)
Nonsports	12 (20.0)
Motor vehicle collision	7 (11.7)
Falls	4 (6.7)
Assault	1 (1.7)

Presenting Symptoms in the ED

Loss of consciousness was reported by 27% of patients and amnesia by 42% of patients (44% anterograde amnesia only, 8% retrograde amnesia only, and 48% both). The median amnesia duration was 5 to 10 minutes. The majority (95%) of patients reported postconcussive symptoms (e.g., headache, nausea) persisting in the ED. The median number of the 22 ACE postconcussive symptoms reported was 8 (IQR = 5–10). The median ImPACT PCSS score reported by patients in the ED was 26.5 (IQR = 17–34.5), which is consistent with previous reported postinjury ImPACT PCSS scores (reference: baseline score 5.14, postinjury scores 26.18).[20] Neither of these symptom measures (ACE and ImPACT PCSS) in the ED correlated with follow-up outcome measures, including time to return to normal activity and follow-up ImPACT scores.

Clinical Concussion Grading

Concussion grading using the AAN and Cantu scales was not associated with variation seen in ED ImPACT scores in each of the four testing domains. Additionally, these scales were not associated with follow-up

Table 4
Association Between Mean ED and Follow-up (F/U) Raw Impact Scores (n = 36)

Raw ImPACT Composite Test Score	Correlation* Between ED and F/U Scores (p-value)	ED Mean Score	F/U Mean Score	Mean Difference† Between ED and F/U Scores	Clinically Significant Change‡	95% CI for Mean Difference	Significance for Mean Difference (p-value)
Verbal memory	0.37 (0.03)	0.79	0.85	–0.06	±0.09	–0.1 to –0.02	<0.010
Visual memory	0.08 (0.662)	0.65	0.77	–0.12	±0.14	–0.18 to –0.06	<0.010
Processing speed	0.60 (<0.01)	33.05	36.11	–3.06	+3 or –7	–5.47 to –0.65	0.014
Reaction time (sec)	0.57 (<0.01)	0.66	0.56	0.09	±0.06	0.05 to 0.14	<0.010

ImPACT = Immediate Postconcussion Assessment and Cognitive Test.
*Paired samples correlations reported as Pearson correlation coefficient; small = ±0.1–0.3; medium = ±0.3–0.5; large = ±0.5–1.0
†Difference between ED and F/U scores in negative in all fields except reaction time, which shortens with improvement
‡Reference values for clinically significant changes are taken from Iverson et al.[31]

outcome measures, specifically time to return to normal activity; 2-day, 2-week, or 6-week postconcussive symptoms; and follow-up ImPACT scores.

ED and Follow-up ImPACT

Emergency department ImPACT was performed a median of 5 hours postinjury (IQR = 4–6). Follow-up ImPACT assessment was completed by 36 patients a median of 6 days postinjury (IQR = 5–8). ED and follow-up ImPACT scores correlated significantly in three out of four domains. In all four domains, there was improvement in mean ImPACT scores at follow-up ($p \leq 0.014$); however, with the exception of reaction time, the mean improvement in follow-up scores did not represent a clinically significant change based on previous validation studies (Table 4 and Figure 2).[20] Furthermore, the majority of patients continued to have significant dysfunction at follow-up, with follow-up ImPACT scores well below the 50th percentile based on normative data for nonconcussed adolescents (Figure 2). Given the transient nature of postconcussive symptoms and the expected improvement with time, we divided subjects into early (2 to 5 days; n = 25) and late (6 to 11 days; n = 11) follow-up groups and assessed the mean difference between ED ImPACT and follow-up ImPACT scores using a t-test. While we found numeric differences with the late group showing a clinically significant improvement in ImPACT scores across four test fields, this was not statistically significant. This is consistent with previous research using ImPACT, which demonstrated improvement in scores over time with clinical recovery occurring for the majority of adolescents between 8 and 14 days.[34–36]

Morbidity of Concussion

Telephone follow-up was completed for all 60 patients. Phone follow-up survey data demonstrated the morbidity of concussion, with the majority of patients experiencing greater than 7 days of postconcussive symptoms (Figure 3). Over the 3-month phone follow-up, 85% of patients reported at least one postconcussive symptom in four main categories: physical, cognitive, emotional, and sleep disturbances (Table 5).

Return to Normal Activity

Return to normal activity (including return to sports for athletes) was reported by 58 of 60 subjects during the 3-month phone follow-up period. The median time to return to activity was 13.5 days (IQR = 7–31 days). The median number of school days missed was 2 (IQR = 1–4

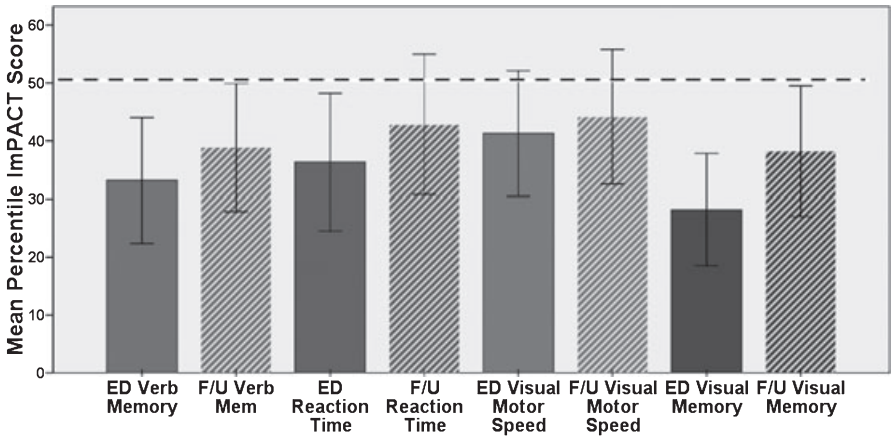

Figure 2. Mean percentile scores. These demonstrate that while most subjects improved in follow-up, the majority were still scoring below the 50th percentile for normal nonconcussed adolescents. F/U = follow-up; ImPACT = Immediate Postconcussion Assessment and Cognitive Test.

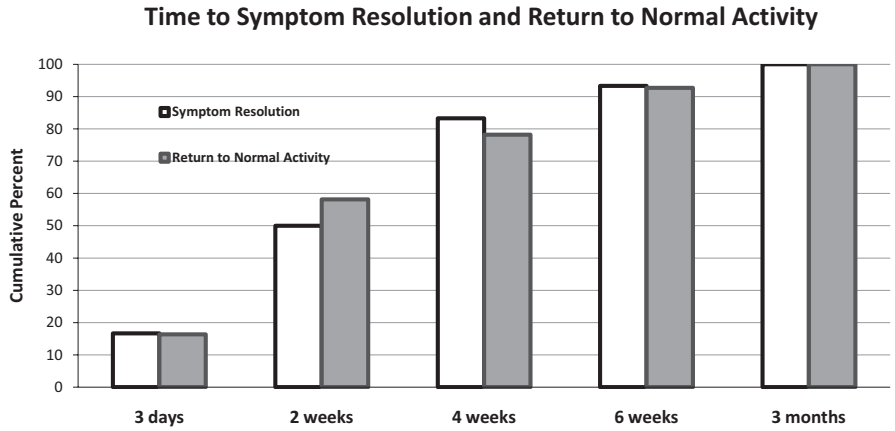

Figure 3. Cumulative percentage of patients reporting symptom resolution and return to normal activity over course of phone follow-up.

Table 5
Cumulative Postconcussive Symptoms Reported During the 3-Month Phone Follow-up Period (n = 60)

Symptom	Percent*
Physical	76.7
Headache	68.3
Nausea	20.0
Vomiting	16.7
Numbness/tingling	18.3
Dizziness	46.7
Balance problems	31.7
Sensitivity to light	38.3
Sensitivity to sound	36.7
Sleep	73.3
Sleeping more than usual	61.7
Sleeping less than usual	55.0
Drowsiness	35.0
Cognitive	71.7
Feeling slowed down	55.0
Feeling mentally foggy	33.3
Difficulty concentrating	51.7
Difficulty remembering	61.7
Emotional	51.7
More emotional	26.7
Irritability	41.7
Sadness	15.0
Nervousness	23.3

85% of patients reported at least one postconcussive symptom during the 3-month follow-up period.
*Data reported as the percentage of subjects reporting this complaint or category at least once during the 3-month follow-up period.

days). Time to symptom resolution was an outcome measure that was added during the study, and data were available for 31 patients. Median time to symptom resolution was 21 days (IQR = 6–28). At 2 weeks, while only 48% of patients reported a resolution of symptoms, 59% had returned to normal activity (Figure 3). At 4 weeks, over 20% of patients had still not returned to normal activity. No significant association between overall ED ImPACT scores and time to return to normal activity was observed in the overall patient group (n = 60). At 2 weeks postconcussion, those who completed follow-up ImPACT also reported significantly less activity than those patients who did not (79.7% vs. 93.3% of full activity; p = 0.01). However, patients who completed ImPACT follow-up did not report greater symptom severity from ED recruitment through 3-month phone follow-up.

DISCUSSION

To the best of our knowledge, this study is the first to demonstrate that ImPACT testing in the ED is correlated with testing at follow-up. We also found that neurocognitive testing in the ED provides an objective measure of neurocognitive deficits and detects differences in concussion severity that cannot be identified with clinical concussion grading. The accurate assessment of injury severity and consequent outpatient management may decrease recovery time, reduce risk of secondary complications, and improve outcomes.[13,23,37,38]

The importance of early concussion management is underscored by the considerable morbidity following concussion that we found in this population. Expert consensus recommends that patients refrain from returning to full activity until their symptoms have resolved.[16] Unfortunately, we found that at 2 weeks postconcussion, a number of patients had returned to normal activity *before* symptom resolution and therefore placed themselves at increased risk for further injury. Conversely, we found that patients who completed follow-up testing were more likely to report a gradual return to normal activity and wait to return to full activity until symptoms had resolved.

While ED ImPACT was valid in three out of four composite test domains, memory domains seemed to have the least correlation with follow-up scores. Memory domains may be more affected by the immediate symptoms of concussion, such as amnesia. While the ED verbal memory domain displayed moderate correlation with follow-up scores, the visual memory domain displayed no correlation at all. In general, ED scores for the visual memory domain were lower than scores for the three other test domains. This was only noted in our study and may be unique to testing in this setting or within hours of concussive injury.

Majerske and colleagues[39] recently published a retrospective study of patients treated at a concussion center that demonstrated a complex association between postconcussive activity level and outcome using ImPACT scores. Using a five-point activity scale coded on chart review, the study found that patients with both the lowest *and* highest levels of activity postinjury did poorly on follow-up neurocognitive testing using ImPACT.[39] Our study did not find any association between reported postconcussion activities (e.g., sleep, physical activity, school attendance) and recovery times. However, we did find a correlation between completing follow-up and reporting a delay in return to full activity that was not associated with differences in symptom severity. One explanation for this finding may be improved compliance with discharge recommendations in patients who completed follow-up. This improved compliance may represent a beneficial effect follow-up had on reinforcing a safe and slow return to activity. An alternative explanation is that patients who follow up may inherently be more compliant. It is possible that those patients who did follow up were more invested in their treatment and recovery, and therefore more adherent to advice given regarding returning to normal activity.

We did not find a correlation between ImPACT scores and symptom duration or return to normal activity. While these are subjective measures, they are currently the outcomes of primary importance. Defining recovery following concussion remains a challenge for clinicians and researchers. Past studies of concussion recovery have found that in concussed patients, cognitive recovery often lags behind symptom recovery.[40] Additionally, adolescents are known to underreport symptoms.[41] ImPACT has been able to detect neurocognitive deficits that persist after resolution of self-reported symptoms.[22,23] These findings have prompted sports concussion specialists to recommend that adolescent athletes achieve both symptom resolution *and* normalization of neuropsychological measures before returning to play.[14] Given the increased importance of neuropsychological measures, assessment early in the course of injury may help guide management. We did establish that the ED ImPACT can be used as an objective measure of acute concussion severity. Patients and clinicians may not be invested in cases of concussion where the patient does not display overt symptoms. Nonetheless, neurocognitive testing has demonstrated that in many asymptomatic patients, persistent dysfunction following concussion still exists.[23,42] In the outpatient setting, this ability to detect subtle dysfunction has been used to motivate patients to comply with rest recommendations. Neurocognitive testing in the ED may prove to be equally motivating. The addition of neurocognitive testing to the tools available in the ED shifts the paradigm from passive evaluation of acute concussion to comprehensive evaluation and active management. Future studies should be directed at the ability of ED neurocognitive testing to increase compliance with discharge recommendations and improve outcomes. The ability of ED ImPACT to gauge severity may also allow it to serve as a research tool in future efforts to evaluate the effect of individualized concussion management recommendations or novel treatment strategies (e.g., mandatory athletic or academic rest, symptom-based pharmacology) on outcomes.

LIMITATIONS

We studied 11- to 17-year-olds, the ages most likely to sustain concussion; thus, our results are not generalizable to all children. We had a small sample size of patients who were not reimbursed for their participation. This limited our ability to detect more subtle correlations between ImPACT scores and follow-up outcomes and behaviors. We were not powered to detect statistically significant differences between patients who followed up at 3 days and those who followed up at 10 days. The small sample size also did not allow for subgroup analysis and the potential identification of at-risk populations based on presenting symptoms or mechanism of injury. Additionally, although a prospective cohort sample was taken, patients were recruited primarily from Thursday through Sunday in the afternoon to evening, due to the high volume of concussions seen in the ED during that time period. Because most high school sports games occur at this time, our sample may have been biased toward sports-related injuries. These patients may also be overrepresented in our follow-up sample as, regionally, many patients are required to have follow-up ImPACT testing to return to sports. As this was a convenience sample, we do not have data on missed eligible patients.

Our study was not a representation of all adolescent patients with concussion. However, we feel that our study was a reflection of the mild to moderate range of concussion severity in patients presenting to the ED. In support of this, we would note that patients needed to have a GCS score of 15 to participate, and the majority of patients were well enough to be discharged from the ED. Additionally, as neuroimaging was not a requirement for participation, approximately 40% of patients did not receive imaging. It is possible that these patients had undiagnosed intracranial injuries that would have made them ineligible for this study. Similarly, telephone follow-up procedures assumed a steady and permanent resolution of symptoms over time and, therefore, only patients who were symptomatic at 2 weeks were contacted at 6 weeks. It is possible that a number of patients who were asymptomatic at the 2-week call were symptomatic at 6 weeks and 2 months.

We did not address the feasibility of use of ImPACT in the ED. However, a recent case–control study found that the introduction of ImPACT to assess concussion in the ED setting did not significantly increase ED throughput time.[43] In our study, the research team attempted to integrate test procedures with ED flow. If patients had received CT scans, we administered testing while awaiting final radiology readings. Patients' ImPACT results were provided and reviewed in conjunction with their discharge education.

The ImPACT was not compared against a criterion standard of neurocognitive assessment. However, ImPACT has demonstrated construct validity when compared to traditional neuropsychological measures (Trail Making Test, Symbol Digit Modalities Test, and the Brief

Visulospatial Memory Test).[44,45] Unfortunately, a comprehensive neuropsychological evaluation would not have been feasible given the resources and scope of this study. While we chose to use ImPACT, similar results may have been seen with other computer neurocognitive test platforms (Headminders, Cogsport, and others).

CONCLUSIONS

The assessment of concussion severity as measured by the neurocognitive test Immediate Postconcussion Assessment and Cognitive Test administered in the ED provides data regarding specific neurocognitive deficits that traditional grading scales do not and correlates well with follow-up testing in three out of four composite domains. Of note, our study demonstrated that concussion symptoms lasted greater than 2 weeks in more than half of those diagnosed with concussion in the ED. Furthermore, we found that a number of patients had returned to normal activity before symptom resolution, placing them at increased risk for further injury. This study demonstrates that Immediate Postconcussion Assessment and Cognitive Test may be used in the ED setting to determine the severity of concussion in adolescents. The objective information from the tool may also prove useful in the acute setting to provide a benchmark against which to base the pace of recovery. In addition, ED neurocognitive testing may provide an objective measure to test potential interventions immediately postinjury and allow patient stratification based on injury severity.

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