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Development of the CIDSS$_2$ Score for Children with Mild Head Trauma without Intracranial Injury

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Abstract

While most children with mild traumatic brain injury (mTBI) without intracranial injury (ICI) can be safely discharged home from the emergency department, many are admitted to the hospital. To support evidence-based practice, we developed a decision tool to help guide hospital admission decisions. This study was a secondary analysis of a prospective study conducted in 25 emergency departments. We included children under 18 years who had Glasgow Coma Scale score 13–15 head injuries and normal computed tomography scans or skull fractures without significant depression. We developed a multi-variable model that identified risk factors for extended inpatient management (EIM; defined as hospitalization for 2 or more nights) for TBI, and used this model to create a clinical risk score. Among 14,323 children with mTBI without ICI, 20% were admitted to the hospital but only 0.76% required EIM for TBI. Key risk factors for EIM included Glasgow **C**oma Scale score less than 15 (odds ratio [OR] = 8.1; 95% confidence interval [CI] 4.0–16.4 for 13 vs. 15), drug/alcohol **I**ntoxication (OR = 5.1; 95% CI 2.4–10.7), neurological **D**eficit (OR = 3.1; 95% CI 1.4–6.9), **S**eizure (OR = 3.7; 95% CI 1.8–7.8), and **S**kull fracture (odds ratio [OR] 24.5; 95% CI 16.0–37.3). Based on these results, the CIDSS$_2$ risk score was created. The model C-statistic was 0.86 and performed similarly in children less than (C = 0.86) and greater than or equal to 2 years (C = 0.86). The CIDSS$_2$ score is a novel tool to help physicians identify the minority of children with mTBI without ICI at increased risk for EIM, thereby potentially aiding hospital admission decisions.

Keywords: clinical decision tool; emergency medicine; pediatric neurosurgery; traumatic brain injury

Introduction

HEAD TRAUMA is one of the most prevalent diagnoses affecting children, leading to approximately 600,000 emergency department (ED) visits and 6,000 deaths per year in the United States.[1,2] Traumatic brain injury (TBI) is also among the most expensive pediatric diagnoses, with more than $1 billion in annual inpatient charges in the U.S.[3] Over 90% of new head injuries in children are categorized as mild TBI (mTBI)[4]—defined as those with a Glasgow Coma Scale (GCS) score of 13–15[5,6]—and this group comprises approximately one-third of the 50,000 to 60,000 annual pediatric TBI hospital admissions.[3,7,8]

Among children presenting to the ED with suspected mild head injuries, about one-third receive a head computed tomography (CT) scan, and approximately 95% of those scans show no intracranial injury (ICI).[8,9] Recent studies of children with mTBI and normal head computed tomography (CT) scans, including a large-scale analysis of data collected by the Pediatric Emergency Care Applied Research Network (PECARN), have demonstrated that the risk of neurosurgical intervention is exceedingly small, suggesting such patients may not require inpatient observation for sudden neurological worsening.[10,11] Even among children with isolated linear skull fractures—i.e., with no intracranial pathology—neurosurgical intervention or the delayed development of intracranial hemorrhage remains extremely uncommon.[12,13]

While such findings have led several authors and institutional guidelines to recommended against inpatient admission in this population,[10,11,14,15] many patients are still admitted due to concerns regarding the need for extended inpatient management (EIM) for problems such as repeated seizures or persistent inability to tolerate oral intake. Indeed, recent reports suggest that admission rates in this population may be as high as 70%,[11] and closer to 80% among those with isolated skull fracture.[16,17] These findings illustrate the need for more specific guidance regarding which mTBI patients are likely to require inpatient management.

Building on the existing literature, the objective of this study was to define the baseline rate and key risk factors for EIM for TBI management in children with mTBI without ICI. By creating a tool

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that reflects the prognostic importance of both isolated skull fracture and other clinically relevant findings, this study aims to provide an evidence-based foundation to facilitate shared decision making between clinicians and families.

Methods

Study population

This study was a secondary analysis of the publicly available, prospective PECARN cohort study of children with mild head injuries.[18] The details of this study have been described previously, but briefly, this study included children younger than 18 years who were enrolled in one of 25 participating EDs in North America. Enrollment occurred from 2004 to 2006. To maximize the capture of clinically relevant outcomes, research coordinators reviewed inpatient records and conducted follow-up telephone interviews with patients' guardians 7 to 90 days post-ED evaluation. When guardians could not be reached, additional hospital and county records were reviewed.

Within the PECARN cohort, we included children with GCS scores of 13–15 who had a CT scan performed in the ED that did not show ICI. Consistent with the PECARN methods, ICI was defined as intracranial hemorrhage, cerebral edema, skull diastasis, midline shift, pneumocephalus, significantly depressed skull fracture (depressed by at least the width of the skull), traumatic infarction, diffuse axonal injury, herniation, shear injury, or sigmoid sinus thrombosis identified on CT.[18] Mildly depressed skull fractures (i.e. depressed less than the width of the skull) and non-depressed skull fractures were not considered ICI, keeping with the original PECARN terminology.[18] Imaging findings were extracted from radiology reports and approved by site principal investigators. A quality review also was conducted, assessing all positive and any unusual findings. The PECARN cohort excluded patients with trivial injury presentations (e.g. ground-level falls, running into stationary objects), as well as those with penetrating TBI, pre-existing comorbid neurological disease, and bleeding disorders.

Predictor variables

Among the variables collected by PECARN, we focused on those thought to be the most clinically relevant in the post-CT evaluation of mTBI patients. The full list of potential predictors evaluated is shown in the Appendix Table 1. All of these variables—except scalp hematoma—had kappa coefficients of at least 0.5, indicating at least moderate inter-rater reliability.[18,19] For the "skull fracture" variable, we grouped together non-depressed and mildly depressed fractures (combining those depressed less than the width of the skull) since we found that the event rate for the two groups was similar. Patients with fractures depressed by the width of the skull or greater were considered to have ICI and were excluded from the analysis.[8] Presence of a neurological deficit was defined as any abnormality noted in the cranial nerve, motor, sensory, or reflex assessment.[18] The composite variable for any neurological deficit was analyzed for predictive modeling, but the frequency of each subtype of deficit also was reported for descriptive purposes.

Outcome variable

The study dataset did not include variables to reflect the potential benefit of a brief overnight admission (e.g., intravenous hydration). Further, given evidence demonstrating that this population is at exceedingly low risk of needing neurosurgical intervention,[10,11] many potential indications for hospital admission relate to brief, symptomatic management (e.g., nausea or pain). While no decision tool will absolutely distinguish which patients may derive any potential benefit from hospital admission, our goal was to focus on those patients with more persistent and prolonged TBI-related difficulties that would be challenging to manage at home. Therefore, for the primary study outcome we used EIM, defined as hospitalization for 2 or more nights due to the TBI, with the goal of providing physicians and families with an outlook of the child's near-term clinical course. While patients with extracranial injuries were included in the study, this outcome of EIM excluded patients with prolonged admissions due to social reasons, workup of non-accidental trauma, or other extracranial injuries. However, specific indications for inpatient TBI management (e.g., seizure treatment or intravenous hydration) were not recorded. To the extent possible, we included in this outcome patients initially discharged home but later readmitted for EIM. As secondary outcomes, we evaluated the rate of intubation, neurosurgical intervention, and death due to TBI.

Statistical analysis

We found that some variables in the risk prediction analysis had missing data. These missing data were treated as previously reported.[8] For dichotomous variables with less than 5% missing data, we assumed that missing indicated not present (i.e., "0" values). We verified that this assumption did not significantly alter the results by conducting a sensitivity analysis where such missing data were instead treated as missing in a complete case analysis (see Appendix). For other variables with missing data, we used multiple imputation with 10 imputed datasets, using previously published approaches for missing data exploration and imputation.[20–22] The details of our imputation techniques have been reported previously.[8]

After imputation, multi-variable logistic regression was used to develop a model to predict the risk of EIM. Univariate analyses were first conducted with potential predictors, and variables with $p < 0.20$ were entered into the multi-variable analysis. Forward selection was used to select variables for the final multi-variable model that had $p < 0.10$ in 50% of more of the imputed datasets. Rubin's rules were used to combine p values and regression coefficients across the imputed datasets.[23]

Using this approach, we developed an initial model that included all variables identified by the automatic selection procedure. This "large" model was further refined to maximize the simplicity and clinical utility of the final decision tool. For example, although length of loss of consciousness was initially selected for the multi-variable model, using history of loss of consciousness (yes/no) instead improved the ease of clinical use with a negligible impact on the model's overall predictive ability—as evaluated by the C-statistic. In addition, we recognized that the size of the initial 10-variable model made it impractical for routine use. Consequently, we derived an abridged model by evaluating the model beta coefficients, first-differences of each variable, variable prevalence, and the clinical significance of each variable in the larger model. In this context, first-difference refers to the difference in predicted risk between two levels of a variable, holding all other factors constant (e.g., the difference in risk between yes vs. no headache when all other variables are constant).

We evaluated the discrimination of both models using the C-statistic, which represented the area under the receiver operating characteristic curve. Bootstrapping was used to obtain the bias-corrected confidence interval of the C-statistic. We evaluated calibration using the Hosmer-Lemeshow test, which compares observed versus predicted values.[24] To evaluate whether model performance varied between very young and older children, we tested the discrimination of the final model in children younger than 2 years versus children age 2 years or older.

Based on the final multi-variable model, we created a clinical risk score using previously described approaches, assigning integer point values to each factor in the model.[25] The details of this process are described in the Appendix. After the $CIDSS_2$ score was finalized, its performance was evaluated by examining the sensitivity, specificity,

positive and negative predictive value, and negative likelihood ratio for different point score cutoffs. Ninety-five percent confidence intervals were calculated using exact methods as previously described.[8] Statistical analyses were done using R statistical software and related packages (R Foundation for Statistical Computing, Vienna, Austria),[21,22,26] along with SAS version 9.4 (SAS Institute Inc, Cary, NC). Statistically significant outcomes were defined based on two-tailed p values less than 0.05.

Results

Among the 15,162 children enrolled in the PECARN study who received a CT scan in the ED, 14,323 (94.5%) had no ICI and constituted the study cohort. Most children were white (58.6%), male (63.2%), and older than 2 years of age (78.5%). The vast majority of patients presented to the ED with a GCS score of 15 (91.5%) and with a moderate severity mechanism of injury (65.6%).

Of the 14,323 children without ICI, 11,288 (78.8%) were sent home, while 2506 (17.5%) were admitted to a general ward or short-stay unit. A small number of children were sent straight to the operating room (0.71%) for extracranial injuries or to the intensive care unit (1.9%). Only 109 children (0.76%) required EIM for 2 or more nights due to problems associated with their TBI, including two children initially discharged home from the ED. No children with mTBI without ICI required neurosurgical intervention, but two (0.01%) required intubation for more than 24 hours related to their head trauma. No patients died due to TBI.

In univariate analyses (Table 1), EIM was associated with multiple different presenting signs and symptoms, including headache, post-traumatic vomiting, GCS score, injury mechanism severity, history of loss of consciousness, skull fracture, presence of a neurological deficit, and suspected drug or alcohol intoxication. Given the similar rate of prolonged hospitalization among patients with non-depressed (10.1%) and mildly depressed (8.3%) skull fractures, these variables were grouped together for this analysis and the subsequent multi-variable analysis.

In the multi-variable analysis, there were 10 variables retained in the initial selection procedure, all of which had p values less than 0.05. The final 10-variable model is shown in Appendix Table 2. In an attempt to create a risk tool more practical for clinical use, this initial model was further refined by examining the statistical strength and prevalence, as well the clinical appropriateness of each predictor. This abridged model (Table 2) included skull fracture (odds ratio [OR] = 24.5; 95% confidence interval [CI] 16.0–37.3), GCS score (OR = 8.1; 95% CI 4.0–16.4 for 13 vs. 15), post-traumatic seizure (OR = 3.7; 95% CI 1.8–7.8), presence of a neurological deficit (OR = 3.1; 95% CI 1.4–6.9), and suspected alcohol/drug intoxication (OR = 5.1; 95% CI 2.4–10.7). The model C-statistic was 0.86 (95% CI 0.81–0.90) and the Hosmer-Lemeshow chi-squared test was not significant (p = 0.42). Among children younger than 2 years, the C-statistic was 0.86 (95% CI 0.78–0.97) and was nearly the same (0.86; 95% CI 0.81–0.91) among children 2 years or older.

Based on this final multi-variable model, we created a simple decision tool, the CIDSS2 score, that assigned 1 point to four variables (Glasgow **C**oma Scale, **I**ntoxication, neurological **D**eficit, **S**eizure), and 2 points for a **S**kull fracture (Fig. 1A). For practical utility, the score was divided into low- (0–1 points), medium- (2 points), and high-risk (≥ 3 points) groups (Fig. 1B). In the low-risk group, 0.39% (95% CI 0.30–0.51) had EIM, compared with 6.5% (95% 4.5–8.9) in the medium-risk group and 19.6% (95% CI 12.6–28.4) in the high-risk group.

Using a cutoff of ≥2 points to admit to the hospital had a sensitivity of 50.5% and a negative predictive value of 99.6% for capturing prolonged hospitalizations. Alternatively, using a cutoff of ≥3 points to admit to the hospital had a sensitivity of 19.3% and a negative predictive value of 99.4% (Fig. 1C). Using the first cutoff would have reduced the admission rate from 20% (2,873 admissions) to 4.4% (633 admissions), while using the higher cutoff of ≥3 points to admit would have further reduced the admission rate to 0.75% (107 admissions; Fig. 2).

Discussion

In this analysis of over 14,000 children with mTBI without ICI on head CT, we found that the rate of EIM for TBI was extremely low, indicating this population is at low risk for persistent TBI-related problems requiring inpatient management. To aid physicians and families uncertain of these patients' near-term course, we developed the CIDSS2 score to help identify the minority of children at risk of experiencing EIM due to TBI.

Mild TBI is among the most common reasons children are admitted for inpatient observation,[27] and reducing unnecessary admissions has the potential to yield substantial savings in healthcare spending. Admission for observation at pediatric hospitals typically costs over $2000—about $1500 more than the cost for patients discharged from the ED.[16,27,28] Likewise, hospital transfer costs for patients with mTBI average over $4000 per patient.[29] These estimates also do not account for the time parents spend away from work and other family when their children are admitted. Given these substantial economic and social pressures, safely reducing mTBI admissions has the potential to yield substantial health care savings while reducing the burden on patients and families.

Focusing on this goal, prospectively gathered, multi-center evidence has shown that among children with mTBI that warranted head CT, those without ICI—including those with linear skull fractures—are at extremely low risk of neurological deterioration or needing neurosurgical intervention.[10,12] These findings have led to recommendations against hospital admission in this population. However, multiple studies indicate that such blanket recommendations based only on the risk of severe deterioration have not sufficiently addressed clinician concerns regarding which patients require inpatient management.

For example, despite recommendations from the American Academy of Pediatrics and the Eastern Association for the Surgery of Trauma to the contrary,[14,15] a recent study found that approximately 70% of children with predominantly mTBI without ICI were admitted for observation.[11] Likewise, among children with mTBI and isolated skull fractures, approximately 80% of patients are admitted to the hospital.[16,17] Even after the implementation of programs recommending against this practice, admission rates remained at or above 50%.[17,30]

While several factors—including social and medicolegal concerns—may influence these practices, these admission patterns indicate that despite assurances against severe neurological deterioration, clinicians remain concerned about the need for inpatient management for TBI-related symptoms. Although certain local protocols and societal guidelines have highlighted risk factors for a complicated course—such as post-traumatic seizure or vomiting[30,31]—the evidence supporting those recommendations is weak. This shortcoming emphasizes the need for further guidance regarding the near-term course of mTBI patients without ICI.

Seeking to identify those patients most likely to encounter problems if discharged home, we used a large, prospective, multi-center dataset to create a simple model identifying key risk factors for EIM for TBI management. Based on the results of this accurate

TABLE 1. POPULATION DEMOGRAPHIC CHARACTERISTICS, CLINICAL CHARACTERISTICS, AND EMERGENCY DEPARTMENT
DISPOSITION OF CHILDREN WITH mTBI AND NO ICI ON CT

	No extended inpatient management (%)	Extended inpatient management (%)	p value
Age in years (median)	8	8	0.82
Age ≥2 years	11,159 (78.5)	89 (81.7)	0.43
Gender			0.23
Male	8980 (63.2)	75 (68.8)	
Female	5234 (36.8)	34 (31.2)	
Race			
White	8333 (58.6)	62 (56.9)	Ref
Black	4059 (28.6)	38 (34.9)	0.27
Asian	281 (2.0)	1 (0.92)	0.47
Other	1541 (10.8)	8 (7.3)	0.34
GCS score			
15	13,000 (91.5)	62 (56.9)	Ref
14	1001 (7.0)	35 (32.1)	0.16
13	213 (1.5)	12 (11.0)	<0.01
Injury severity			
Low	1898 (13.4)	6 (5.5)	Ref
Moderate	9320 (65.6)	69 (63.3)	0.04
High	2996 (21.1)	34 (31.2)	<0.01
Loss of consciousness	5111 (36.0)	54 (49.5)	<0.01
Neurological deficit*	433 (3.1)	8 (7.3)	0.01
Motor deficit	97 (0.68)	2 (1.8)	NA
Sensory deficit	85 (0.60)	0 (0)	NA
Cranial nerve deficit	62 (0.44)	2 (1.8)	NA
Reflex abnormality	9 (0.06)	0 (0)	NA
Other deficit (e.g., cerebellar, gait)	244 (1.7)	5 (4.6)	NA
Non-cranial significant injury	2365 (16.6)	31 (28.4)	<0.01
Suspected drug intoxication	283 (2.0)	9 (8.3)	<0.01
Altered mental status	4347 (30.6)	76 (69.7)	<0.01
Acting normally	9199 (64.7)	36 (33.0)	<0.01
Amnesia			
No amnesia	6102 (42.9)	31 (28.4)	Ref
Yes amnesia	3734 (26.3)	41 (37.6)	<0.01
Pre-verbal	4378 (30.8)	37 (33.9)	0.03
Headache			
No headache	3682 (25.9)	8 (7.3)	Ref
Headache	6564 (46.2)	64 (58.7)	<0.01
Pre-verbal	3968 (27.9)	37 (33.9)	<0.01
Post-head trauma vomiting	3456 (24.3)	42 (38.5)	<0.01
Post-traumatic seizure	391 (2.8)	10 (9.2)	<0.01
Skull fracture	428 (3.0)	47 (43.1)	<0.01
Scalp hematoma	5566 (39.2)	58 (53.2)	<0.01
Bulging fontanelle	14 (0.10)	1 (0.92)	0.03
ED disposition			
Home	11,286 (79.5)	2 (1.8)	NA
Operating room	100 (0.70)	2 (1.8)	NA
General ward	1,815 (12.8)	68 (62.4)	NA
Intensive care unit	240 (1.7)	25 (22.9)	NA
Observation unit	612 (4.3)	11 (10.1)	NA
Other	161 (1.1)	1 (0.92)	NA

*Some patients had more than one type of neurological deficit noted, explaining the disparity between the number of patients with any deficit and the sum of all subtypes of neurological deficits.

The p values refer to the comparison between patients that did and did not experienced extended inpatient management for TBI (simple logistic regression).

mTBI, mild traumatic brain injury; ICI, intracranial injury; CT, computed tomography; Ref, reference category; GCS, Glasgow Coma Scale; ED, emergency department; NA, not applicable.

model, the CIDSS$_2$ score quantifies this risk based on GCS score less than 15, suspected drug/alcohol intoxication, presence of a focal neurological deficit, post-traumatic seizure, and skull fracture. While the score's sensitivity was relatively low (19–50%), the

negative predictive value remained high (> 99%), reflecting the low prevalence of prolonged hospitalization in this population.

Recognizing that the CIDSS$_2$ score was not intended to identify any possible symptomatic benefit from brief overnight admission,

TABLE 2. THE ABRIDGED MULTI-VARIATE RISK MODEL
PREDICTING EXTENDED INPATIENT MANAGEMENT
IN CHILDREN WITH MTBI WITHOUT INTRACRANIAL INJURY

	Beta	Odds ratio (95% CI)
Skull fracture	3.2	24.5 (16.0–37.3)
Suspected drug/alcohol use	1.6	5.1 (2.4–10.7)
Seizure	1.3	3.7 (1.8–7.8)
Neurological deficit	1.1	3.1 (1.4–6.9)
GCS score		
15	Ref	Ref
14	1.6	5.1 (3.3–8.0)
13	2.1	8.1 (4.0–16.4)

The model intercept was −6.0.

mTBI, mild traumatic brain injury; GCS, Glasgow Coma Scale; Ref, reference category.

we recommend considering routine discharge home for children in the low-risk group (0–1 points), given the extremely low rate of EIM. Likewise, for children in the medium-risk group (2 points)—which includes those with isolated skull fractures—only 6% have a prolonged course, indicating discharge home is likely appropriate in most circumstances. This recommendation is consistent with other recent studies recommending discharge home for most patients with isolated skull fractures.[12,13] However, clinicians also should discuss with families the risk of persistent symptoms that could require return to the hospital. Finally, clinicians should consider the need to admit the small minority of children in the high-risk (>3 points) category, based in part on shared decision making using valid patient decision aids,[32] family preferences, patient proximity to the hospital, and other individual considerations. Implementing this

evidence-based framework may help reassure providers and families, thereby helping lower admission rates.

This study has several limitations. Most importantly, we retrospectively evaluated a prospectively collected database, which limited our ability to verify findings and methodological questions and evaluate certain novel end-points. Most notably, the dataset lacked information on specific indications for EIM, such as intravenous hydration or seizure management. Lacking such end-points could have led us to include children who experienced EIM only due to an overabundance of caution. Likewise, the $CIDSS_2$ score was not intended to exclude any possible symptomatic benefit from brief overnight admission (e.g., intravenous antiemetics). In addition, we were unable to evaluate the overall readmission rate or the impact of the timing of patients' initial CT scans relative to their injuries in predicting their subsequent clinical course. Finally, we could not assess how many patients underwent a brain magnetic resonance imaging scan—an increasingly important modality for evaluating pediatric TBI[33,34]—or evaluate the impact of repeat neuroimaging data on patients' clinical course. However, previous studies by PECARN have shown that among children in this cohort with GCS 14–15 head injuries without ICI, only 26 of 396 (6.6%) with repeat neuroimaging had abnormal findings on follow-up exam. Moreover, less than half of those with abnormal repeat neuroimaging findings and reported lengths of hospital stay underwent EIM, suggesting the impact of such findings was limited.[10,12]

Another limitation is that the $CIDSS_2$ score only reflects the need for hospitalization for TBI; other concerns, such as need for a non-accidental trauma evaluation, may still prompt admission among some patients with low scores. In addition, this study included a relatively broad age group and some elements of the $CIDSS_2$ score, such as suspected drug or alcohol intoxication, may not be appropriate in very young populations. Nevertheless, the score showed high discrimination in both younger and older populations,
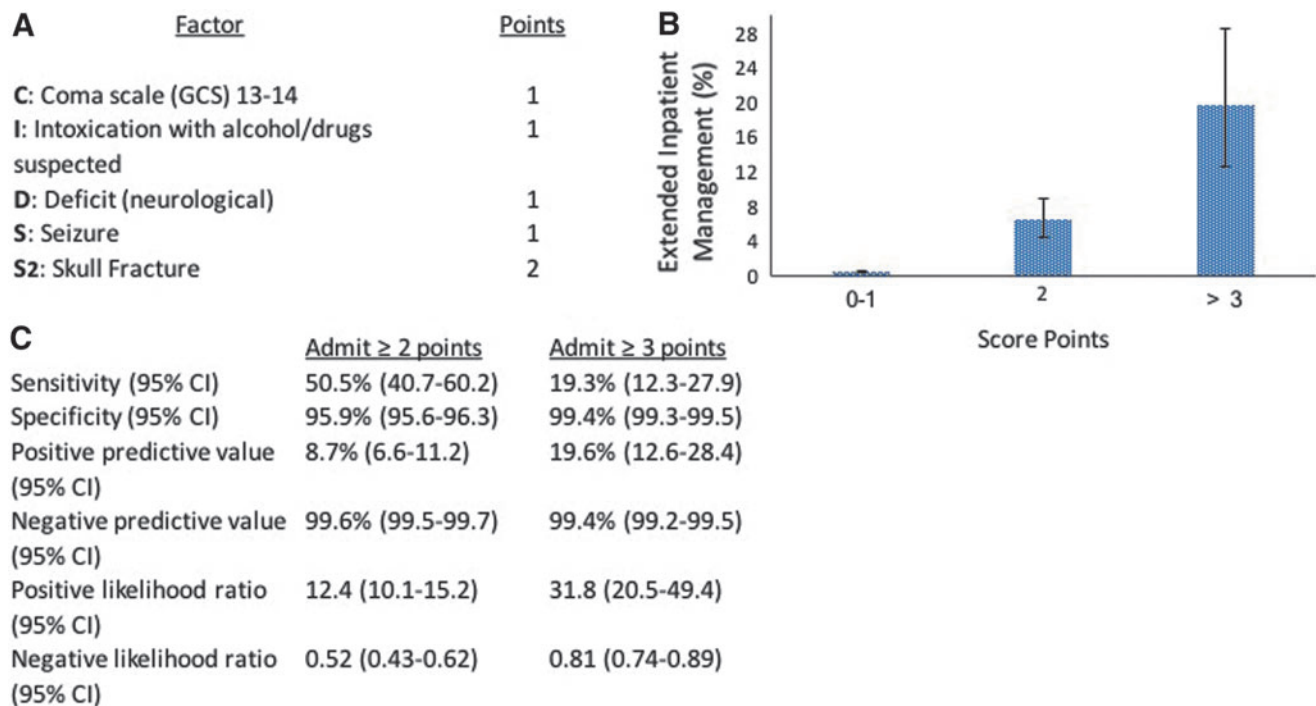

A

Factor	Points
C: Coma scale (GCS) 13-14	1
I: Intoxication with alcohol/drugs suspected	1
D: Deficit (neurological)	1
S: Seizure	1
S2: Skull Fracture	2

C

	Admit ≥ 2 points	Admit ≥ 3 points
Sensitivity (95% CI)	50.5% (40.7-60.2)	19.3% (12.3-27.9)
Specificity (95% CI)	95.9% (95.6-96.3)	99.4% (99.3-99.5)
Positive predictive value (95% CI)	8.7% (6.6-11.2)	19.6% (12.6-28.4)
Negative predictive value (95% CI)	99.6% (99.5-99.7)	99.4% (99.2-99.5)
Positive likelihood ratio (95% CI)	12.4 (10.1-15.2)	31.8 (20.5-49.4)
Negative likelihood ratio (95% CI)	0.52 (0.43-0.62)	0.81 (0.74-0.89)

FIG. 1. The $CIDSS_2$ score. (A) The point values assigned to different risk factors. (B) The risk (with 95% confidence interval) of extended inpatient management (EIM) at different point levels. (C) The performance characteristics of different risk cutoffs in predicting EIM. Color image is available online at www.liebertpub.com/neu.
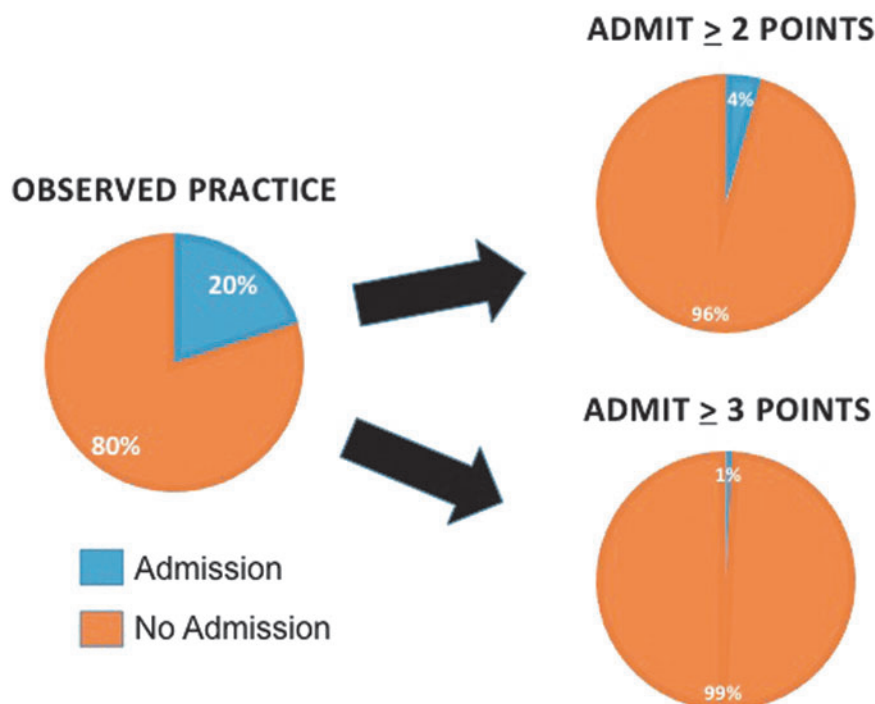
FIG. 2. Admission practices observed in the Pediatric Emergency Care Applied Research Network (PECARN) head injury study and proposed reductions in hospital admissions by implementing the CIDSS$_2$ score. Color image is available online at www.liebertpub.com/neu

demonstrating the tool's relevance in both groups. Finally, future efforts will be needed to externally validate the predictive accuracy and clinical effectiveness of the CIDSS$_2$ score using additional endpoints that reflect the need for inpatient care.

Conclusions

The vast majority of children with mTBI without ICI do not undergo neurosurgical intervention or require EIM for TBI management. The CIDSS$_2$ score risk stratifies this group, helping identify the minority of patients at increased risk of experiencing EIM, potentially aiding admission decisions. The effectiveness and impact of this score should be externally validated in a prospective multi-center study.

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Author Disclosure Statement

No competing financial interests exist.

References

1. Mannix, R., O'Brien, M.J., and Meehan, W.P. 3rd (2013). The epidemiology of outpatient visits for minor head injury: 2005 to 2009. Neurosurgery. 73, 129–134.
2. Faul, M., Xu L., Wald, M.M., and Coronado, V.G. (2010). *Traumatic Brain Injury in the United States: Emergency Department Visits, Hospitalizations and Deaths 2002–2006.* National Center for Injury Prevention and Control: Atlanta, GA.
3. Schneier, A.J., Shields, B.J., Hostetler, S.G., Xiang, H., and Smith, G.A. (2006). Incidence of pediatric traumatic brain injury and associated hospital resource utilization in the United States. Pediatrics 118, 483–492.
4. Koepsell, T.D., Rivara, F.P., Vavilala, M.S., Wang, J., Temkin, N., Jaffe, K.M., and Durbin, D.R. (2011). Incidence and descriptive epidemiologic features of traumatic brain injury in King County, Washington. Pediatrics 128, 946–954.
5. National Center for Injury Prevention and Control (2003). *Report to Congress on Mild Traumatic Brain Injury in the United States: Steps to Prevent a Serious Public Health Problem.* Atlanta, GA: Centers for Disease Control and Prevention: Atlanta, GA.

6. Centers for Disease Control and Prevention (2016). Injury prevention and control: Traumatic brain injury and concussion. Available at: www.cdc.gov/traumaticbraininjury/severe.html. Accessed April 5, 2016.

7. Bowman, S.M., Bird, T.M., Aitken, M.E., and Tilford, J.M. (2008). Trends in hospitalizations associated with pediatric traumatic brain injuries. Pediatrics. 122, 988–993.

8. Greenberg, J.K., Yan, Y., Carpenter, C.R., Lumba-Brown, A., Keller, M.S., Pineda, J.A., Brownson, R.C., and Limbrick, D.D. (2017). Development and internal validation of a clinical risk score for treating children with mild head trauma and intracranial injury. JAMA Pediatr. 171, 342–349.

9. Quayle, K.S., Powell, E.C., Mahajan, P., Hoyle, J.D. Jr., Nadel, F.M., Badawy, M.K., Schunk, J.E., Stanley, R.M., Miskin, M., Atabaki, S.M., Dayan, P.S., Holmes, J.F., and Kuppermann, N. (2014). Epidemiology of blunt head trauma in children in U.S. emergency departments. N. Engl. J. Med. 371, 1945–1947.

10. Holmes, J.F., Borgialli, D.A., Nadel, F.M., Quayle, K.S., Schambam, N., Cooper, A., Schunk, J.E., Miskin, M.L., Atabaki, S.M., Hoyle, J.D., Dayan, P.S., and Kuppermann, N. (2011). Do children with blunt head trauma and normal cranial computed tomography scan results require hospitalization for neurologic observation? Ann. Emerg. Med. 58, 315–322.

11. Plackett, T.P., Asturias, S., Tadlock, M., Wright, F., Ton-That, H., Demetriades, D., Esposito, T., and Inaba, K. (2015). Re-evaluating the need for hospital admission and observation of pediatric traumatic brain injury after a normal head CT. J. Pediatr. Surg. 50, 1758–1761.

12. Powell, E.C., Atabaki, S.M., Wootton-Gorges, S., Wisner, D., Mahajan, P., Glass, T., Miskin, M., Stanley, R.M., Jacobs, E., Dayan, P.S., Holmes, J.F., and Kuppermann, N. (2015). Isolated linear skull fractures in children with blunt head trauma. Pediatrics. 135, e851–e857.

13. Rollins, M.D., Barnhart, D.C., Greenberg, R.A., Scaife, E.R., Holsti, M., Meyers, R.L., Mundorff, M.B., and Metzger, R.R. (2011). Neurologically intact children with an isolated skull fracture may be safely discharged after brief observation. J. Pediatr. Surg. 46, 1342–1346.

14. Barbosa, R.R., Jawa, R., Watters, J.M., Knight, J.C., Kerwin, A.J., Winston, E.S., Barraco, R.D., Tucker, B., Bardes, J.M., and Rowell, S.E. (2012). Evaluation and management of mild traumatic brain injury: an eastern association for the surgery of trauma practice management guideline. J Trauma Acute Care Surg. 73, S307–S314.

15. Committee on Quality Improvement, American Academy of Pediatrics. Commission on Clinical Policies and Research, American Academy of Family Physicians. (1999). The management of minor closed head injury in children. Pediatrics 104, 1407–1415.

16. Mannix, R., Monuteaux, M.C., Schutzman, S.A., Meehan, W.P. 3rd, Nigrovic, L.E., and Neuman, M.I. (2013). Isolated skull fractures: trends in management in us pediatric emergency departments. Ann. Emerg. Med. 62, 327–331.

17. Lyons, T.W., Stack, A.M., Monuteaux, M.C., Parver, S.L., Gordon, C.R., Gordon, C.D., Proctor, M.R., and Nigrovic, L.E. (2016). A qi initiative to reduce hospitalization for children with isolated skull fractures. Pediatrics 137.

18. Kuppermann, N., Holmes, J.F., Dayan, P.S., Hoyle, J.D. Jr., Atabaki, S.M., Holubkov, R., Nadel, F.M., Monroe, D., Stanley, R.M., Borgialli, D.A., Badawy, M.K., Schunk, J.E., Quayle, K.S., Mahajan, P., Lichenstein, R., Lillis, K.A., Tunik, M.G., Jacobs, E.S., Callahan, J.M., Gorelick, M.H., Glass, T.F., Lee, L.K., Bachman, M.C., Cooper, A., Powell, E.C., Gerardi, M.J., Melville, K.A., Muizelaar, J.P., Wisner, D.H., Zuspan, S.J., Dean, J.M., and Wootton-Gorges, S.L. (2009). Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. Lancet. 374, 1160–1170.

19. Landis, J.R. and Koch, G.G. (1977). The measurement of observer agreement for categorical data. Biometrics 33, 159–174.

20. van Buuren, S., Boshuizen, H.C., and Knook, D.L. (1999). Multiple imputation of missing blood pressure covariates in survival analysis. Stat. Med. 18, 681–694.

21. van Buuren, S. and Groothuis-Oudshoorn, K. (2011). Mice: Multivariate imputation by chained equations in R. J. Stat. Software Healthcare. 45, 1–67.

22. R Core Team. (2013). R: A language and environment for statistical computing. Available at: www.R-project.org. Accessed July 30, 2018.

23. Rubin, D.B. and Schenker, N. (1991). Multiple imputation in healthcare databases: an overview and some applications. Stat Med. 10, 585–598.

24. Steyerberg, E.W., Vickers, A.J., Cook, N.R., Gerds, T., Gonen, M., Obuchowski, N., Pencina, M.J., and Kattan, M.W. (2010). Assessing the performance of prediction models: a framework for traditional and novel measures. Epidemiology 21, 128–138.

25. Sullivan, L.M., Massaro, J.M., and D'Agostino, R.B. Sr. (2004). Presentation of multivariate data for clinical use: The Framingham study risk score functions. Stat. Med. 23, 1631–1660.

26. Harrell, F.E. (2015). Rms: Regression modeling strategies. R package version 4.4-1.

27. Fieldston, E.S., Shah, S.S., Hall, M., Hain, P.D., Alpern, E.R., Del Beccaro, M.A., Harding, J., and Macy, M.L. (2013). Resource utilization for observation-status stays at children's hospitals. Pediatrics 131, 1050–1058.

28. Blackwood, B.P., Bean, J.F., Sadecki-Lund, C., Helenowski, I.B., Kabre, R., and Hunter, C.J. (2016). Observation for isolated traumatic skull fractures in the pediatric population: unnecessary and costly. J. Pediatr. Surg. 51, 654–658.

29. White, I.K., Pestereva, E., Shaikh, K.A., and Fulkerson, D.H. (2016). Transfer of children with isolated linear skull fractures: Is it worth the cost? J. Neurosurg. Pediatr. 17, 602–606.

30. Metzger, R.R., Smith, J., Wells, M., Eldridge, L., Holsti, M., Scaife, E.R., Barnhart, D.C., and Rollins, M.D. (2014). Impact of newly adopted guidelines for management of children with isolated skull fracture. J. Pediatr. Surg. 49, 1856–1860.

31. Astrand, R., Rosenlund, C., and Unden, J. (2016). Scandinavian guidelines for initial management of minor and moderate head trauma in children. BMC Med. 14, 33.

32. Sepucha, K.R., Breslin, M., Graffeo, C., Carpenter, C.R., and Hess, E.P. (2016). State of the science: tools and measurement for shared decision making. Acad. Emerg. Med. 23, 1325–1331.

33. Young, J.Y., Duhaime, A.C., Caruso, P.A., and Rincon, S.P. (2016). Comparison of non-sedated brain MRI and CT for the detection of acute traumatic injury in children 6 years of age or less. Emerg. Radiol. 23, 325–331.

34. Sheridan, D.C., Newgard, C.D., Selden, N.R., Jafri, M.A., and Hansen, M.L. (2017). Quickbrain MRI for the detection of acute pediatric traumatic brain injury. J. Neurosurg. Pediatr. 19, 259–264.

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APPENDIX

CIDSS₂ Score Development

Based on our final multi-variable model, we created the CIDSS₂ score using the methods outline by Sullivan and colleagues[1] This was implemented as follows:

1) We first determined the reference values for each category. For our model, all variables were dichotomous except for Glasgow Coma Scale (GCS) score, where a value of 15 was set as the reference category.
2) The referent risk factor profile was thus assigned as a patient having a GCS score of 15 and the absence of the four other risk factors (suspected drug/alcohol intoxication; presence of a neurological deficit; post-traumatic seizure; or skull fracture).
3) The value of the constant, B, was defined as the number of regression units that would correspond to 1 point in the score. Defining this constant involved trial and error to achieve a point score with a reasonable range.
4) The number points associated with each category of each risk factor was defined as:
   a. $Point_{sij} = B_i(W_{ij} - W_i REF)/B$
      i. B_i = regression coefficient
      ii. $W_i REF$ = reference value for a given category
      iii. W_{ij} = specific value of interest for a given category
5) The number of points for all risk factors was summed
6) The risk for each point total was calculated as follows:
   a. $\hat{p} = \frac{1}{1 + \exp(-\sum_{i=0}^{p} \beta_i X_i)}$
   b. Where $\sum_{i=0}^{p} B_i X_i$ is approximated as: model intercept + B(Point total)

Imputation sensitivity analysis

To simplify the multiple imputation with a negligible impact on the results, we treated dichotomous variables with 5% or less missing data as ''not present'' or ''0'' values. To test whether this assumption had any significant impact on the results, we repeated the multi-variable model selection with a complete case analysis, treating such missing data as ''missing.'' Multiply-imputed variables were used for other missing data (i.e. categorical variables or those with more than 5% missing data). The results of this multi-variable analysis yielded a nearly identical result to our initial multi-variable selection, with the only difference being that the variable for timing of headache onset was selected rather than ''headache (yes/no).'' However, as described in the methods, to obtain the final 10-variable model, we substituted similar variables for clinical simplicity (e.g. loss of consciousness [yes/no] for

APPENDIX TABLE 1. VARIABLES EVALUATED AS POTENTIAL PREDICTORS OF EXTENDED INPATIENT MANAGEMENT

- Injury mechanism severity: divided into severe (motor vehicle collision with ejection, death of a passenger, or rollover; pedestrian or cyclist struck by a car without a helmet; falls greater than 5 [≥ 2 years] or 3 feet [< 2 years]; or struck by a high impact object), mild (ground-level fall or running into a stationary object), or moderate (all other mechanisms)[1]
- Loss of consciousness: evaluated as yes/no and less than vs. greater than 5 sec,
- Post-traumatic seizure: evaluated as yes/no and also by seizure length
- Acting normally according to the caregiver
- Headache: evaluated as yes/no and also by headache severity and timing
- Post-traumatic vomiting: evaluated as yes/no and according to vomit timing and number of times vomited
- Amnesia to the trauma
- GCS score: recorded when the patient was initially evaluated by the ED team as part of routine care, and thus reflected any impairment from pharmacologic sedation or drug or alcohol intoxication; the score was not updated if the patient's neurological condition subsequently changed while in the ED. The pediatric GCS score was used for children 2 years or younger[1]
- Altered mental status
- Bulging anterior fontanelle
- Signs of basal skull fracture
- Scalp hematoma
- Neurological deficit: any deficit noted in the cranial nerve, motor or sensory, or reflex assessment[1]
- Suspicion for alcohol or drug intoxication
- Other (non-cranial) significant injuries
- Skull fracture
- Age: classified by year and also as younger than vs. older than 2 years
- Race
- Ethnicity
- Gender

GCS, Glasgow Coma Scale; ED, emergency department.

1. Kuppermann, N., Holmes, J.F., Dayan, P.S., Hoyle, J.D. Jr., Atabaki, S.M., Holubkov, R., Nadel, F.M., Monroe, D., Stanley, R.M., Borgialli, D.A., Badawy, M.K., Schunk, J.E., Quayle, K.S., Mahajan, P., Lichenstein, R., Lillis, K.A., Tunik, M.G., Jacobs, E.S., Callahan, J.M., Gorelick, M.H., Glass, T.F., Lee, L.K., Bachman, M.C., Cooper, A., Powell, E.C., Gerardi, M.J., Melville, K.A., Muizelaar, J.P., Wisner, D.H., Zuspan, S.J., Dean, J.M., and Wootton-Gorges, S.L. (2009). Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. Lancet. 374, 1160–1170.

APPENDIX TABLE 1. THE FULL 10-VARIABLE MULTI-VARIATE RISK MODEL PREDICTING EXTENDED INPATIENT MANAGEMENT AMONG CHILDREN WITH MILD TRAUMATIC BRAIN INJURY WITHOUT INTRACRANIAL INJURY

	Beta	Odds ratio (95% CI)
Skull fracture	3.3	28.3 (17.9–44.7)
Suspected drug/alcohol use	1.5	4.6 (2.2–9.9)
Seizure	1.4	4.2 (2.0–9.1)
Headache		
No	Ref	Ref
Yes	1.4	4.2 (2.0–9.1)
Pre-verbal	0.98	2.7 (1.2–6.1)
Neurological deficit	1.1	2.9 (1.3–6.5)
GCS score		
15	Ref	Ref
14	1.2	3.2 (1.9–5.5)
13	1.3	3.6 (1.6–8.1)
Post-injury vomiting	0.88	2.4 (1.6–3.7)
Non-cranial significant injury	0.81	2.2 (1.4–3.6)
Altered mental status	0.76	2.1 (1.3–3.6)
Loss of consciousness	0.57	1.8 (1.1–2.7)

CI, confidence interval; Ref, reference category; Glasgow Coma Scale, GCS.

length of consciousness) with minimal impact on model performance.

Finally, we tested the discrimination (i.e., C-statistic) of the final 10-variable model reported in Appendix Table 2 using the complete case analysis where dichotomous variables with 5% or less missing data were treated as missing. We found that across 10 imputed datasets, the mean C-statistic was 0.90 (range 0.900–0.909), essentially the same as the C-statistic found in the 10-variable model shown in Appendix Table 2 (C = 0.90) based on the original imputation approach.

Reference

1. Sullivan L. M., Massaro J. M., and D'Agostino R. B. Sr. (2004). Presentation of multivariate data for clinical use: the Framingham Study risk score functions. Stat. Med. 23, 1631–1660.