Medical necessity of routine admission of children with mild traumatic brain injury to the intensive care unit

Jared D. Ament, MD, MPH,¹ Krista N. Greenan, MD, MPH,¹ Patrick Tertulien, MPH, MS,¹ Joseph M. Galante, MD,² Daniel K. Nishijima, MD, MAS,³ and Marike Zwienenberg, MD¹

Departments of ¹Neurological Surgery, ²Trauma Surgery, and ³Emergency Medicine, University of California Davis Medical Center, Sacramento, California

OBJECTIVE Approximately 475,000 children are treated for traumatic brain injury (TBI) in the US each year; most are classified as mild TBI (Glasgow Coma Scale [GCS] Score 13–15). Patients with positive findings on head CT, defined as either intracranial hemorrhage or skull fracture, regardless of severity, are often transferred to tertiary care centers for intensive care unit (ICU) monitoring. This practice creates a significant burden on the health care system. The purpose of this investigation was to derive a clinical decision rule (CDR) to determine which children can safely avoid ICU care.

METHODS The authors retrospectively reviewed patients with mild TBI who were ≤ 16 years old and who presented to a Level 1 trauma center between 2008 and 2013. Data were abstracted from institutional TBI and trauma registries. Independent covariates included age, GCS score, pupillary response, CT characteristics, and Injury Severity Score. A composite outcome measure, ICU-level care, was defined as cardiopulmonary instability, transfusion, intubation, placement of intracranial pressure monitor or other invasive monitoring, and/or need for surgical intervention. Stepwise logistic regression defined significant predictors for model inclusion with $p < 0.10$. The authors derived the CDR with binary recursive partitioning (using a misclassification cost of 20:1).

RESULTS A total of 284 patients with mild TBI were included in the analysis; 40 (14.1%) had ICU-level care. The CDR consisted of 5 final predictor variables: midline shift > 5 mm, intraventricular hemorrhage, nonisolated head injury, postresuscitation GCS score of < 15, and cisterns absent. The CDR correctly identified 37 of 40 patients requiring ICU-level care (sensitivity 92.5%; 95% CI 78.5–98.0) and 154 of 244 patients who did not require an ICU-level intervention (specificity 63.1%; 95% CI 56.7–69.1). This results in a negative predictive value of 98.1% (95% CI 94.1–99.5).

CONCLUSIONS The authors derived a clinical tool that defines a subset of pediatric patients with mild TBI at low risk for ICU-level care. Although prospective evaluation is needed, the potential for improved resource allocation is significant.

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KEY WORDS traumatic brain injury; clinical decision rule; ICU monitoring; triage; resource allocation; trauma

APPROXIMATELY 475,000 children are treated for traumatic brain injury (TBI) in the US each year.¹³ Falls appear to be the most frequent mechanism in children < 12 years old, whereas assault, sports activities, and motor vehicle crashes (MVCs) are more common in adolescents.¹⁹ Although the majority of children with TBI sustain mild TBI, defined by a Glasgow Coma Scale (GCS)

score of 13–15, it remains the leading cause of death and disabilities in children > 1 year old. Consequently, children with TBI and positive findings on cranial CT scans (i.e., intracranial hemorrhage [ICH] or skull fracture), regardless of severity, are often monitored in intensive care units (ICUs) for early detection of secondary brain injury.⁸ Secondary insults, most commonly from cerebral edema,

ABBREVIATIONS CDR = clinical decision rule; GCS = Glasgow Coma Scale; ICH = intracranial hemorrhage; ICP = intracranial pressure; ICU = intensive care unit; IQR = interquartile range; ISS = Injury Severity Score; IVH = intraventricular hemorrhage; LOS = length of hospital stay; MLS = midline shift; MVC = motor vehicle crash; NPV = negative predictive value; PECARN = Pediatric Emergency Care Applied Research Network; TBI = traumatic brain injury.

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increased intracranial pressure (ICP), cerebral ischemia, and expanding extraaxial hematoma, are the leading cause of inpatient death after TBI.¹⁴ Despite this discernable societal impact, the need for ICU monitoring specifically in children with mild TBI is not well defined, and this practice pattern, which is augmented by transfers from non-tertiary care hospitals, creates a significant burden on the health care system.

Based on clinical observation, most children with mild TBI who are admitted to the ICU never require critical care measures or surgical intervention. This parallels findings in the adult population with mild TBI.^{11,16,21,23,24} In a retrospective study of 321 adult patients with mild TBI, 3 patients (< 1%) developed neurological decline requiring medical intervention and 4 patients (1%) required neurosurgical intervention.²⁴ The authors of this study also reported specific cranial CT criteria to better select patients for ICU admission. Due to this uncertainty about disposition, Nishijima et al. derived a clinical decision rule (CDR) that successfully identified a subgroup of adults with mild TBI that may not require ICU admission.¹⁶ To our knowledge, a CDR that tests the need for ICU admission in the pediatric population with mild TBI has not been created.^{1,7,21,23}

Although some management guidelines in the pediatric population with TBI are fairly well established, such as the use of serial neurological examinations, indications for obtaining an initial head CT, and the need for repeat imaging when monitoring for significant delayed intracranial injury, the guidelines are based largely on retrospective data.⁶ In addition, there are numerous other factors that may influence clinical decisions in these patients, including mechanism of injury, time from injury, age, ability to perform an accurate neurological examination, and the presence of distracting injuries. The objective of this study was therefore to develop and evaluate a CDR that identifies low-risk pediatric patients with mild TBI that can be safely managed in non-ICU settings.

Methods

Study Design and Setting

We retrospectively reviewed pediatric patients with mild TBI presenting to a single Level 1 trauma center between 2008 and 2015. Data were abstracted from prospectively collected institutional TBI and trauma registries. Each registry uses standardized data collection forms. Variables included the following: age; sex; comorbidities; medication use; vital signs; postresuscitation GCS score; mechanism of injury; cranial CT findings; neurological examination findings; and Injury Severity Score (ISS). Cranial CT findings were determined by the on-call neurosurgery and radiology teams, and often—but not always—occurred in conjunction with a neuroradiologist's interpretation. After inspection for accuracy, the 2 registries were merged using patient medical record numbers and Microsoft Excel for Mac (version 15.23.2). Missing data were obtained from the electronic medical record where available. Data abstractors were not blinded to study objectives. The institutional review board at the study site approved the study.

Patient Selection

To be included in the analysis, patients had to be ≤ 16 years old, have suffered a mild TBI, and have a documented initial nonoperative treatment plan. Specific cranial CT characteristics also had to be available, and included the amount of midline shift (MLS), types of ICH, skull fractures, and cistern patency. Our definition of a nonisolated head injury was modified from the Abbreviated Injury Scale system (injuries associated with a score of ≥ 3) and included patients with spinal fracture and/or injury, significant facial fractures (LeFort II or III), vascular injuries, intrathoracic or intraabdominal injuries, femur or pelvic fracture, and second- or third-degree burns comprising $> 20\%$ body surface area.⁴ Nonisolated head injury (polytrauma) was therefore defined as an ISS of ≥ 16 . Detailed patient characteristics are shown in Table 1.

Outcome Measure

We defined the need for ICU admission as the occurrence of an ICU-level intervention during the initial 48 hours after presentation. The 48-hour interval was chosen because of our institutional practice to routinely observe patients with mild TBI for 1–2 days; this time frame is also consistent with that of previous literature and in published guidelines.^{11,21,23} An ICU-level intervention included any of the following scenarios: cardiopulmonary instability requiring continuous monitoring or supportive care (i.e., arterial line placement or vasopressor and/or inotrope use); a decrease in GCS score of > 1 point; development of focal neurological deficits; seizure; blood or blood product transfusion; intubation; placement of ICP monitor or other invasive monitoring; or unanticipated need for surgical intervention of any kind. The list of ICU-level interventions was derived from the Task Force of the American College of Critical Care Medicine guidelines for ICU admission, in conjunction with expert opinion.²² Details of what was defined as an ICU-level intervention are provided in Table 2.

Sample Size and Power Calculation

Of the adult population from the same database, 20% of patients required an ICU-level intervention.¹⁶ We assumed the same for our pediatric TBI population. Based on this, we estimated requiring a cohort of 243 patients by using the sample size equations below, where n is the population size from which the sample is chosen, r is the proportion of events (0.20), and $Z(c/100)$ is the critical value for the confidence level c (assuming a margin of error of 5% and a confidence level of 95%).^{9,20} The equations are as follows: $x = Z(c/100)2r(100 - r)$, and $n = Nx/((N - 1)E^2 + x)$.

Statistical Analysis

Data were analyzed using both univariate and multivariate strategies. Candidates for variables were selected based on clinical experience, historical precedent, and evidence-based practice. Independent variables were tested in a multivariate analysis through a stepwise regression. At each step the best remaining variable is added, provided it passes the 5% significance criterion, and then all variables currently in the regression are checked to see if

TABLE 1. Characteristics in 284 patients with mild TBI

Characteristic	No. (%)
Demographics	
Mean age in yrs, $\pm$ SD	7 $\pm$ 5
Male	184 (64.8)
Mechanism of injury	
Fall	159 (56.0)
MVC	35 (12.3)
Bicycle accident	33 (11.6)
Sports related	17 (6.0)
Assault	12 (4.2)
Pedestrian vs car	10 (3.5)
GSW	4 (1.4)
Animal bite	2 (0.7)
Other	12 (4.2)
Injury severity	
Initial ED GCS Score 13	12 (4.2)
Initial ED GCS Score 14	105 (37.0)
Initial ED GCS Score 15	167 (58.8)
Isolated head injury*	221 (77.8)
Median ISS; IQR	10; 9–16
CT characteristics	
ICH	
Intraparenchymal hemorrhage	141 (49.6)
Subdural hematoma	86 (30.3)
Epidural hematoma	62 (21.8)
Subarachnoid hemorrhage	59 (20.8)
IVH	16 (5.6)
Diffuse axonal injury	0 (0)
Skull fracture	
Linear	51 (18.0)
Depressed	5 (1.8)
Presence of MLS >5 mm	32 (11.3)
Compressed cisterns	12 (4.2)
Effaced cisterns	11 (3.9)
Disposition & LOS	
Admit to ward from ED	53 (18.7)
Admit to ICU from ED	231 (81.3)
Need for ICU upgrade	0 (0)
Median LOS; IQR	2; 1–3

ED = emergency department; GSW = gunshot wound.

* See Patient Selection in text for definition.

any can be removed using the > 10% significance criterion. Predictors identified with a p value of < 0.10 were analyzed by binary recursive partitioning using Classification and Regression Trees (CART) (Salford Systems) to create the final CDR. In recursive partitioning, sequences of binary splits are made to better elucidate the relationship between a series of independent predictor covariates and the dependent outcome covariate. We used the Ginni splitting function in the software and set a misclassification cost for missing a patient with an ICU-level interven-

TABLE 2. Critical care interventions in 284 patients with mild TBI

Intervention	No. (%)
Required ICU intervention	40 (14.1)
Cardiopulmonary instability required continuous monitoring or vasopressor &/or inotrope therapy	20 (7.0)
Intubation	13 (4.6)
Surgery*	12 (4.2)
Transfusion	3 (1.1)
Decrease in GCS score	0
Developed focal neurological deficit(s)	0
Seizure	0

* No patients received an ICP monitor.

tion at 20:1. This represents the cost of misclassifying 20 patients who did not receive an ICU-level intervention for 1 patient who did receive one. In statistical theory, this is analogous to the Type 2 (false negative) error rate and is, ideally, mitigated as much as possible. The final CDR is composed of multiple variables that, by definition, must all be satisfied for patients to be classified as having a low risk of requiring an ICU-level intervention.

Results

Initially, a total of 563 and 385 patients were identified in the TBI and trauma registries, respectively. After reviewing for accuracy and completeness and merging the 2 databases, a total of 290 patients met our inclusion criteria for pediatric patients (age $\leq$ 16 years), with mild TBI and positive cranial CT findings. On further review, however, it was determined that 6 patients requiring neurosurgical intervention were inappropriately included for having an initial nonoperative treatment plan. In these instances (i.e., children with depressed skull fractures) the definitive decision for neurosurgical treatment was deferred to obtain subspecialty consultation and treatment by a pediatric neurosurgeon. Because these patients technically had initial operative plans, they were excluded. (None of these patients suffered from neurological decline or needed surgical intervention for a change in neurological status.) As a result, a total of 284 patients were analyzed.

The mean age was 7 years (SD 5 years), and 184 patients were male (64.8%). Patients were either admitted to the ICU (231; 81.3%) or to the wards (53; 18.7%). The most common mechanisms of injury were falls (159; 56.0%), MVC (35; 12.3%), and bicycle accidents (33; 11.6%). The majority of patients had an initial GCS score of 15 (167; 58.8%); only 12 patients (4.2%) had a GCS score of 13. Most patients (221; 77.8%) had isolated head injuries. The most common cranial CT findings were intraparenchymal hemorrhage and/or contusion (141; 49.6%), subdural hematoma (86; 30.3%), and epidural hematoma (62; 21.8%). The median length of hospital stay (LOS) was 2 days, with an interquartile range (IQR) of 1–3 days. Table 1 presents an overview of patient characteristics.

A total of 40 (14.1%) patients required an ICU-level intervention. These cases were most commonly cardiopulmonary instability (20; 7.0%), intubation unrelated to

TABLE 3. Multivariate analysis of test characteristics in patients with mild TBI

Step	Parameter	Chi-Square	p Value
1	IVH	13.723	0.0002
2	GCS score <15	11.275	0.0008
3	Cisterns absent	4.055	0.044
4	ISS >16	3.889	0.048
5	MLS >5 mm	3.552	0.053
6	Depressed skull fracture	2.628	0.097
7	Cisterns compressed	2.625	0.099
8	Age <2 yrs	2.618	0.100
9	Pupil(s) not brisk	2.415	0.120

surgery (13; 4.6%), and unanticipated surgery (12; 4.2%) (Table 2).

Derivation of Our CDR

From the 8 independent predictor covariates identified by multivariate regression analysis (Table 3), binary recursive partitioning derived a CDR with 5 predictor variables for requiring an ICU-level intervention: MLS > 5

TABLE 4. Test performance of the CDR

Measure	Values	% (95% CI)
Sensitivity	37/40	92.5 (78.5–98.0)
Specificity	154/244	63.1 (56.7–69.1)
PPV	37/127	29.1 (21.6–38.0)
NPV*	154/157	98.1 (94.1–99.5)

PPV = positive predictive value.

* Z-test findings for NPV occurring by chance: Z = 12.0511, p < 0.0001.

mm, intraventricular hemorrhage (IVH), nonisolated head injury (polytrauma and ISS > 16), postresuscitation GCS score of < 15, and cisterns absent (Fig. 1). According to the CDR, low-risk patients cannot have any of the aforementioned predictor variables; any “yes” causes an immediate departure from the low-risk cohort. The CDR correctly identified 37 of 40 patients who required an ICU-level intervention (sensitivity 92.5%; 95% CI 78.5–98.0) and 154 of 244 patients who did not require an ICU-level intervention (specificity 63.1%; 95% CI 56.7–69.1). This results in a negative predictive value (NPV) of 98.1% (95% CI 94.1–99.5) (Table 4). The likelihood of this NPV occurring by chance is extremely low (Z-test, p < 0.0001). Once

FIG. 1. Flow chart showing CDR derived from binary recursive partitioning.

TABLE 5. Application of CDR in 284 patients with mild TBI

Disposition	Standard of Care, No. (%)	CDR Applied, No. (%)	Difference	p Value†
Admit to ICU*	231 (81.3)	162 (57)		
Admit to wards	53 (18.7)	122 (43)	69	<0.0001

* Includes patients sent to operating room from the ED.

† According to the chi-square test.

the CDR was applied, 69 patients (30%) who were initially admitted to the ICU would have instead been admitted to the wards (Table 5). This change in disposition was statistically significant according to the chi-square test ($p < 0.0001$).

Three patients (1.1%) were misclassified by the CDR. This means that 3 patients initially categorized as low risk and admitted to the ward would have ended up requiring an ICU-level intervention by our definition (Table 6). One patient required operative intervention for orbital muscle entrapment; one required multiple transfontanelle taps (and eventual shunt placement) for symptomatic subdural hygromas; and the remaining patient required repair of a skull fracture, after a dog bite, to retrieve an intraparenchymal bone fragment. All patients misclassified by the CDR survived to hospital discharge.

Discussion

We derived a CDR that defines a subset of pediatric patients with mild TBI who are at low risk for an ICU-level intervention. We contend that these low-risk patients can be safely managed on the ward. According to the Pediatric Emergency Care Applied Research Network (PECARN) study results, these low-risk patients with TBI are the majority (98%) of those presenting to emergency departments across the US.¹⁹ Our registry data seem congruent with this large prospective epidemiological study that suggests that falls, assault, MVCs, and sports-related activities are the most frequent mechanisms of injury in this population.

One of many important outcomes from PECARN and subsequent studies has been the validation of their CDR to identify patients who do not need cranial CT scans.¹⁶ From the perspective of radiation exposure and resource overuse, this has important implications. However, most of the other large predictive TBI studies have been in the adult population.^{3,5,10,12,17,18} These have helped with our understanding of the pathophysiology and management of this condition; however, it is unmistakable that pediatric patients suffering from TBI are unique.² For example, in children, presentation to the hospital is often delayed, and

their first point of contact in falls is more likely to be their heads.² The cranium is more compliant, and hypotension and hemodynamic instability is often a late finding in pediatric shock. It is also clear that GCS scores for young children and infants can be difficult to assess accurately, and that the clinical history obtained is often vague, especially in the setting of nonaccidental trauma. Management also differs, from securing the airway to weight-based medication dosing. Consequently, despite the well-developed CDR in adults, which successfully identified a subgroup with mild TBI who did not require ICU admission, it is clear that this does not necessarily apply to pediatric patients.¹⁶

The CDR developed here is unique in its focus and may offer a novel adjunct in the triage of pediatric TBI. It does not supplant the PECARN CDR and is only pertinent once a patient meets criteria for a cranial CT. It also appears to make sound clinical sense. Patients without polytrauma, with normal findings on neurological examination, patent cisterns, and insignificant MLS on cranial CT would reduce the level of concern for any clinician. Even the absence of IVH after TBI is reassuring because its presence (without the immediate need for external ventricular drainage) is a known indicator of a more severe injury.¹⁵ There are, however, a multitude of factors that can influence clinical decision making, and we do not recommend that this CDR be used in isolation.

This study should also be interpreted in the context of several limitations. Most notably, the data, although prospectively collected, were retrospectively analyzed and are representative of a single center's experience. External validity is therefore not achievable. Furthermore, only 284 patients were identified who satisfied our inclusion criteria, due in part to difficulty with merging the trauma and neurosurgery TBI registries. From the onset, the initial database queries returned with different sized cohorts that could not be reconciled. As a result, it is plausible that patients were missed who should have been included during the merging process. It is unclear how this would have affected our results or the derived CDR; however, a larger sample would have allowed for a more robust and statistically stable multivariate analysis that does inform the binary recursive partitioning algorithm. Inaccuracies may have also occurred because the initial cranial CT findings were not consistently corroborated by an attending neuro-radiologist.

It seems unlikely, however, that major findings would be missed—consultation at our institution inevitably involves the chief resident and/or faculty neurosurgeon. Furthermore, if a neuroradiology addendum occurs, the initial consultation notes from which the data were abstracted

TABLE 6. Patients misclassified as low risk by CDR, of 284 total

Age (yrs), Sex	Mechanism	Initial GCS Score	ICU-Level Intervention	LOS in Days
0.42, M	MVC	15	Transfontanelle tap on hospital Days 2 & 3; eventual subdural-peritoneal shunt on hospital Day 4	8
7, F	MVC	15	Orbital muscle entrapment requiring surgery	3
2, M	Dog bite	15	Surgery planned for next day due to depressed skull fracture, washout, & dural evaluation	10

are updated accordingly. Changes seen on serial imaging were also not addressed by this CDR unless they resulted in the need for closer monitoring or surgical intervention. Neither scenario occurred in this cohort. Although we did not specifically look at overall outcomes in this analysis, our outcomes measure, ICU-level intervention, may have been confounded by the fact that the majority of patients were routinely monitored in the ICU. Because neurological assessments are performed every 1–2 hours in the ICU, compared with every 4 hours on the ward, continuous ICU monitoring may have either averted an intervention from occurring or have been overly sensitive at detection of events (i.e., cardiopulmonary instability) that would have otherwise been missed. Whereas continuous pulse oximetry can be measured on the ward at our institution, pediatric telemetry can only be done in an ICU setting. Whether this made our estimation of an event more or less conservative (with pulse oximetry on the ward or with telemetry in the ICU, respectively), and how that would have affected the final CDR, is unclear.

The CDR also has inherent misclassification. Simply put, it is not 100% sensitive, and false negatives do occur. In this instance, our instrument failed to identify 3 patients who underwent an ICU-level intervention. On review of the charts, the infant requiring repeated transfontanelle taps, although initially stable, had been acting irritable for several hours prior to the intervention. In both of the surgical patients (1 with orbital muscle entrapment and 1 with a depressed skull fracture) surgical planning decisions were made after some deliberation among treating physicians. Thus, on closer examination, the failure of the CDR to identify these patients would probably have had a minimal effect on their outcomes. Our false-negative rate in the context of all patients admitted to the ward by the CDR (3/154, 1.9%) is consistent with the literature on adult patients.²⁴ Of note, the infant's irritability did not correspond with a documented change in GCS score. This could represent a reporting error that affected the CDR's ability to detect an ICU event.

Conclusions

Ultimately, the goal is to determine the generalizability of the CDR and to limit the selection bias inherent in retrospective analyses. If this CDR was generalizable, its impact on policy, health care utilization, and overall quality of care delivered to pediatric patients with TBI would ostensibly be substantial. In our institution, this patient population represents approximately 40% of all pediatric ICU admissions, illustrating the considerable potential for the CDR to improve resource allocation. Although this analysis has produced promising results, we wish to reiterate that it is a single institution's experience. It will require further confirmation with prospectively collected multicenter data, examined against a control group, prior to meaningful implementation. Furthermore, this effort is insufficient because it lacks a formal cost-effectiveness analysis. This is in part due to inconsistent Extended Glasgow Outcome Scale data in our pediatric registries. The goal of a future prospective analysis would be to include such data to assess utilities, changes in quality-adjusted life years, and cost.

It is important to note that general "cost savings" is not our perspective; rather, our perspective is the appropriate allocation of limited resources. By identifying a subgroup of pediatric patients with TBI who can be safely monitored and managed on the ward, the ICU can be reserved for the most critically ill patients.

References

1. Bullock MR, Chesnut R, Ghajar J, Gordon D, Hartl R, Newell DW, et al: Surgical management of traumatic parenchymal lesions. **Neurosurgery** **58** (3 Suppl):S25–S46, Si–Siv, 2006
2. Bullock RM, Chesnut RM, Clifton G, Ghajar J, Marion DW, Narayan RK, et al: Guidelines for the management of severe traumatic brain injury. **J Neurotrauma** **17**:451–553, 2000
3. Brown AW, Malec JF, McClelland RL, Diehl NN, Englander J, Cifu DX: Clinical elements that predict outcome after traumatic brain injury: a prospective multicenter recursive partitioning (decision-tree) analysis. **J Neurotrauma** **22**:1040–1051, 2005
4. Copes WS, Champion HR, Sacco WJ, Lawnick MM, Keast SL, Bain LW: The Injury Severity Score revisited. **J Trauma** **28**:69–77, 1988
5. Demetriades D, Kuncir E, Murray J, Velmahos GC, Rhee P, Chan L: Mortality prediction of head Abbreviated Injury Score and Glasgow Coma Scale: analysis of 7,764 head injuries. **J Am Coll Surg** **199**:216–222, 2004
6. Durham SR, Liu KC, Selden NR: Utility of serial computed tomography imaging in pediatric patients with head trauma. **J Neurosurg** **105** (5 Suppl):365–369, 2006
7. Ferrara P, Basile MC, Dell'Aquila L, Vena F, Coppo E, Chiaretti A, et al: Traumatic brain injury in children: Role of CDRs-PECARN as a clinical predictive resource for evaluation of intracranial lesions and neuropsychiatric outcomes. **Pediatr Neurosurg** **51**:249–252, 2016
8. Graham DI, Ford I, Adams JH, Doyle D, Teasdale GM, Lawrence AE, et al: Ischaemic brain damage is still common in fatal non-missile head injury. **J Neurol Neurosurg Psychiatry** **52**:346–350, 1989
9. Harrell FE Jr, Lee KL, Califf RM, Pryor DB, Rosati RA: Regression modelling strategies for improved prognostic prediction. **Stat Med** **3**:143–152, 1984
10. Hukkelhoven CW, Steyerberg EW, Habbema JD, Farace E, Marmarou A, Murray GD, et al: Predicting outcome after traumatic brain injury: development and validation of a prognostic score based on admission characteristics. **J Neurotrauma** **22**:1025–1039, 2005
11. Huynh T, Jacobs DG, Dix S, Sing RF, Miles WS, Thomason MH: Utility of neurosurgical consultation for mild traumatic brain injury. **Am Surg** **72**:1162–1165, n1166–n1167, 2006
12. Jagoda AS, Bazarian JJ, Bruns JJ Jr, Cantrill SV, Gean AD, Howard PK, et al: Clinical policy: neuroimaging and decisionmaking in adult mild traumatic brain injury in the acute setting. **Ann Emerg Med** **52**:714–748, 2008
13. Langlois JA, Rutland-Brown W, Thomas KE: The incidence of traumatic brain injury among children in the United States: differences by race. **J Head Trauma Rehabil** **20**:229–238, 2005
14. Marshall LF, Gattille T, Klauber MR, Eisenberg HM, Jane JA, Luerssen TG, et al: The outcome of severe closed head injury. **J Neurosurg** **75** Suppl:S28–S36, 1991
15. Mata-Mbamba D, Mugikura S, Nakagawa A, Murata T, Kato Y, Tatewaki Y, et al: Intraventricular hemorrhage on initial computed tomography as marker of diffuse axonal injury after traumatic brain injury. **J Neurotrauma** **32**:359–365, 2015
16. Nishijima DK, Shahlaie K, Echeverri A, Holmes JF: A clinical decision rule to predict adult patients with traumatic

- intracranial haemorrhage who do not require intensive care unit admission. **Injury** **43**:1827–1832, 2012
17. Perel P, Arango M, Clayton T, Edwards P, Komolafe E, Pocock S, et al: Predicting outcome after traumatic brain injury: practical prognostic models based on large cohort of international patients. **BMJ** **336**:425–429, 2008
 18. Perel P, Edwards P, Wentz R, Roberts I: Systematic review of prognostic models in traumatic brain injury. **BMC Med Inform Decis Mak** **6**:38, 2006
 19. Quayle KS, Powell EC, Mahajan P, Hoyle JD Jr, Nadel FM, Badawy MK, et al: Epidemiology of blunt head trauma in children in U.S. emergency departments. **N Engl J Med** **371**:1945–1947, 2014
 20. Rosner B: **Fundamentals of Biostatistics**, ed 7. Boston: Brooks/Cole, Cengage Learning, 2011
 21. Sifri ZC, Livingston DH, Lavery RF, Homnick AT, Mosenthal AC, Mohr AM, et al: Value of repeat cranial computed axial tomography scanning in patients with minimal head injury. **Am J Surg** **187**:338–342, 2004
 22. Task Force of the American College of Critical Care Medicine, Society of Critical Care Medicine: Guidelines for intensive care unit admission, discharge, and triage. **Crit Care Med** **27**:633–638, 1999
 23. Vos PE, Alekseenko Y, Battistin L, Ehler E, Gerstenbrand F, Muresanu DF, et al: Mild traumatic brain injury. **Eur J Neurol** **19**:191–198, 2012

24. Washington CW, Grubb RL Jr: Are routine repeat imaging and intensive care unit admission necessary in mild traumatic brain injury? **J Neurosurg** **116**:549–557, 2012

Disclosures

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Author Contributions

Conception and design: Ament, Nishijima. Acquisition of data: Ament, Greenan, Tertulien, Galante, Nishijima. Analysis and interpretation of data: Ament, Greenan, Nishijima. Drafting the article: Ament, Greenan, Tertulien, Galante. Critically revising the article: Ament, Greenan, Galante, Nishijima, Zwienenberg. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Ament. Statistical analysis: Ament, Greenan, Nishijima. Administrative/technical/material support: Galante, Zwienenberg. Study supervision: Zwienenberg.

Correspondence

Jared D. Ament, UC-Davis Medical Center, Neurosurgery, 4860 Y St., Ste. 3740, Sacramento, CA 95817. email: jared.ament@ucdmc.ucdavis.edu.