Published in final edited form as:

Ann Emerg Med. 2014 August ; 64(2): 145–152.e5. doi:10.1016/j.annemergmed.2014.01.030.

Comparison of PECARN, CATCH, and CHALICE Rules for Children with Minor Head Injury: A prospective cohort study

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Abstract

Objective—To evaluate the diagnostic accuracy of clinical decision rules and physician judgment for identifying clinically important traumatic brain injuries (TBIs) in children with minor head injuries presenting to the emergency department (ED).

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Conflicts of interest:

Contents are the authors' sole responsibility and do not necessarily represent official NIH views. No authors had financial relationships with any organizations that might have an interest in the submitted work in the previous three years.

Reprints: Not available from the authors.

CONTRIBUTORS' STATEMENTS

Joshua Easter: Dr. Easter conceptualized and designed the study, supervised data collection, assisted in data analysis, drafted the initial manuscript, and approved the final manuscript as submitted. He is the guarantor of the study and affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Katherine Bakes: Dr. Bakes assisted in the conceptualization of the study, data collection, and manuscript revision. She approved the final manuscript as submitted.

Jasmeet Dhaliwal: Dr. Dhaliwal assisted in the conceptualization of the study and manuscript revision. He also coordinated data collection. He approved the final manuscript as submitted.

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Jason Haukoos: Dr. Haukoos designed the study, assisted in data collection, carried out the initial analyses, critically reviewed the manuscript, and approved the final manuscript as submitted.

All authors had full access to all of the data (including statistical reports and tables) in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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Methods—We prospectively enrolled children <18 years of age with minor head injury (Glasgow Coma Scale 13 – 15) presenting within 24 hours of their injuries. We assessed the ability of 3 clinical decision rules (CATCH, CHALICE, PECARN) and 2 measures of physician judgment (estimated of <1% risk of TBI, actual CT ordering practice) to predict clinically important TBI, as defined by death from TBI, need for neurosurgery, intubation >24 hours for TBI, or hospital admission >2 nights for TBI.

Results—Among the 1,009 children, 21 (2%; 95% CI: 1% to 3%) had clinically important TBIs. Only physician practice and PECARN identified all clinically important TBIs, with ranked sensitivities as follows (95% CI): Physician practice and PECARN each 100% (84% to 100%), physician estimates 95% (76% to 100%), CATCH 91% (70% to 99%), and CHALICE 84% (60% to 97%). Ranked specificities were as follows: CHALICE 85% (82% to 87%), physician estimates 68% (65% to 71%), PECARN 62% (59% to 66%), physician practice 50% (47% to 53%), and CATCH 44% (41% to 47%).

Conclusions—Of the 5 modalities studied, only physician practice and PECARN identified all clinically important TBIs, with PECARN being slightly more specific. CHALICE was incompletely sensitive but the most specific of all rules. CATCH was incompletely sensitive and had the poorest specificity of all modalities.

Keywords

Sensitivity; specificity; clinical decision rules; clinical prediction rules; minor head injury; pediatric; physician judgment

INTRODUCTION

Background

Computerized tomography (CT) is the criterion standard for diagnosing traumatic brain injury (TBI). While CT rapidly and accurately identifies TBIs, potentially reducing morbidity and mortality, it is costly, may be difficult to obtain in children, and exposes patients to radiation.^{1,2}

Clinically important intracranial injuries are rare, occurring in less than 5% of children presenting to the emergency department (ED) with minor head injury (Glasgow Coma Scale (GCS) scores of 13–15), and injuries requiring neurosurgical intervention occurring in less than 1% of children.³ Decision analyses suggest that for most children, who are at low risk of TBI, the risks of radiation outweigh the risks of TBI, and CT is not warranted.⁴ Despite this, over one third of children with minor head injury undergo CT.⁵

Clinical decision rules may prove useful for guiding clinical decision making for children with minor TBI. Three recently published rules, the Pediatric Emergency Care Applied Research Network (PECARN) rule, Canadian Assessment of Tomography for Childhood Head injury (CATCH), and the Children's Head injury ALgorithm for the prediction of Important Clinical Events (CHALICE), show promise for improving clinical decision making following minor head injury by potentially increasing recognition of injuries and reducing the frequency of CT acquisition (Table 1).^{6,7,8} For each of the rules, the absence of

any features of the rule obviates the need for CT by categorizing a patient as low risk for clinically important TBI.

Importance

Prior to being incorporated into usual practice, clinical decision rules require external validation and comparison to clinical judgment.⁹ Without validation, results may represent unique aspects of the studied patient population, clinicians employing the rule, or over-fitting of the model. Several examples exist in the literature of rules that worked well in derivation but failed when applied to new cohorts.^{10,11,12} Appropriate validation requires both an assessment of rule performance in settings apart from the derivation study, as well as a comparison of performance to physician estimates of injury. To date, external validation and comparison have not yet occurred for the minor head injury rules.^{13,13,14}

Goals of This Investigation

In this study we aimed to evaluate the diagnostic accuracy of PECARN, CATCH, CHALICE, and physician estimates for identifying clinically important TBIs in children with minor head injury.

METHODS

Study design and setting

We performed a prospective cohort study of children <18 years of age presenting to the ED at Denver Health Medical Center with minor head injury from January 15, 2012 through June 15, 2013. Denver Health Medical Center is a 477-bed urban, Level 2 pediatric trauma center for Denver, Colorado. The ED has approximately 30,000 annual pediatric visits managed by general pediatric, emergency, and pediatric emergency physicians. The ED did not participate in the original derivation of PECARN, CATCH, or CHALICE. Patients receive follow-up at 26 affiliated community and school-based clinics. The STAndards for the Reporting of Diagnostic accuracy studies (STARD) were followed in study development. Our institutional review board approved the study with a waiver of informed consent.

Selection of participants

We included children <18 years of age with: (1) a history or signs of blunt injury to the head; (2) GCS scores $\geq$ 13; (3) injury within the previous 24 hours prior to presentation to the ED; and (4) physician concern for potential TBI. We excluded children known to be at heightened risk of TBI, including those with GCS scores <13, brain tumors, ventricular shunts, anticoagulant therapy, or bleeding disorders. Children presenting >24 hours after injury were also excluded as the risk of clinically important TBI decreases with time.¹⁵ We identified eligible patients, who were not enrolled, through systematic review of ED patient logs.

Measurements

Prior to enrollment, physicians underwent a 30 minute training session regarding completion of the data collection instrument. After assessing a patient but prior to obtaining the results of any diagnostic tests, physicians recorded the presence of the predictor variables associated with each decision rule on a standardized closed-response data collection instrument. The particular definitions of each of the predictor variables were provided during data collection. Attending physicians also recorded demographic information, including the patient's age and gender. When feasible, a second attending physician, blinded to the first attending physician's assessment, examined the patient and also recorded the presence of predictor variables.

In addition to assessing the performance of the rules, we also measured the performance of physician judgment. After recording the presence of predictor variables attending physicians treating the patient recorded their estimate of the likelihood of their patient having a clinically important TBI through free text entry of a percentage between 0% and 100%. Attending physicians were not given any explicit instructions on determining their estimates of the likelihood of clinically important TBI.

Outcomes

The primary outcome was clinically important TBI, as defined by death from TBI, need for neurosurgery, intubation >24 hours for TBI, or hospital admission >2 nights for TBI. While there is no consensus on the definition of clinically important TBI in children, this definition was used because it focuses on clinically meaningful outcomes and is the same as the PECARN outcome.

Secondary outcomes were similar to the derivation studies and included TBI requiring neurosurgery (CATCH, PECARN) and any TBI visible on CT (CATCH, PECARN, CHALICE). Need for neurosurgery included craniotomy, elevation of skull fracture, monitoring of intracranial pressure, or intubation for elevated intracranial pressure.

While blinded to the presence of predictor variables from the decision rules, we verified outcomes through review of the medical record. Board certified attending radiologists interpreted all CTs. For patients who did not undergo CT, we determined if they had been evaluated for follow-up at the ED or outpatient clinic. If they had been evaluated, we reviewed the medical record to determine if they had any of the outcomes. If they had not been evaluated, we employed a proxy outcome assessment tool that was adapted from a validated follow-up tool used for minor head injury.^{16,17} This entailed a standardized telephone interview with patients' guardians to determine if patients exhibited any signs or symptoms of clinically important TBI. Patients with concerning symptoms were instructed to return for re-evaluation, and their subsequent medical records and imaging were reviewed. We also reviewed trauma registries and quality improvement reports to determine if any patients had died.

Data Management and Statistical Analyses

We reviewed the data collection instrument for the presence of any of the predictor variables explicit to the existing rules. The decision rule was considered positive when 1 of the predictor criteria was present. We applied the unique criteria PECARN provides for children <2 and 2 years of age. PECARN and CATCH also distinguish between high and “intermediate” (PECARN) or “medium” (CATCH) risk criteria. As the rules were designed to identify patients at low risk of TBI, we focused on the performance of these “low risk” criteria. We assessed the performance of the “intermediate” and “medium” risk criteria separately.

All data were manually entered into Microsoft Excel (Microsoft Corporation, Redmond, WA) and transferred into native SAS format using translational software (dfPower DBMS Copy, Dataflux Corporation, Cary, NC). All statistical analyses were performed using SAS 9.2 (SAS Institute, Cary, NC) or Stata 12 (StataCorp, College Station, TX). Descriptive statistics for all variables and the prevalence of TBI were determined and reported with 95% confidence intervals (CIs). Continuous data are presented as medians with interquartile ranges (IQRs) and categorical data as percentages with 95% CIs. We used 95% confidence intervals to determine statistical separation between measures of diagnostic accuracy, including sensitivity, specificity, and predictive values. We calculated kappa to estimate agreement on blinded assessment of study variables and considered kappa >0.5 acceptable.

For our analysis of rule performance, only data for complete observations, including assessment of all variables from the rule, are presented. Sensitivity analyses were used to determine the impact of missing data on rule performance. The most optimistic estimate of rule sensitivity was determined by assuming all missing predictor variables were positive, and the most pessimistic estimate by assuming all missing predictor variables were negative. Receiver operating characteristic curves and the areas under the curve with 95% confidence intervals compared the discriminatory performance of the three rules and physician estimation.

Sample size was calculated to estimate the precision for the sensitivity of the rules for clinically important TBI. We estimated a prevalence of clinically important TBI of 1.6% and sensitivity of the rules of 100%. We powered the study to have a lower 95% confidence limit of 80%. As such, we estimated requiring 1,000 patients.

RESULTS

During the study period, 1,526 children with head injury presented to the ED, and physicians completed data forms for 1,062 (70%) patients (Figure 1). Characteristics were similar between enrolled and non-enrolled patients: median age: 6.1 and 5.0 years; gender: 64% and 58% male; and GCS=15: 95% and 99%. We excluded 53 enrolled patients; nearly all were excluded because they presented >24 hours after the injury. Nearly half of patients were discharged after initial evaluation in the ED, while a third of patients were observed in the ED for a median duration of 3 hours (IQR: 2 to 4 hours) (Table 2). The remaining patients underwent CT.

The outcome measure was determined for 90% of patients through follow-up or CT. Follow-up was obtained on 717/821 (87%) patients who did not undergo CT, with 412/717 (57%) being evaluated by a physician in the ED or outpatient clinic and 305/717 (43%) through telephone follow-up. Complete data were obtained for 981/1,009 (97%) patients with PECARN, 1,002/1,009 (99%) with CATCH, and 858/1,009 (85%) with CHALICE.

Characteristics of the study patients compared to the rules' original derivation studies are presented in Table 2. Nearly all study patients had GCS scores of 15, and approximately one third had loss of consciousness or amnesia. Patient characteristics were similar to the derivation cohorts of PECARN and CHALICE. The CATCH derivation cohort had a larger proportion of patients with depressed GCS scores, loss of consciousness, and amnesia.

Of the 1,009 patients, 21 (2%; 95% CI: 1% to 3%) had clinically important TBIs (Table 2). The most common clinically important TBIs were 13 (1%; 95% CI: 0.7 – 2.2%) skull fractures, 11 (1%; 95% CI: 0.6–2%) subarachnoid hemorrhages, and 9 (1%; 95% CI: 0.4 – 2%) subdural hemorrhages. Neurosurgical intervention was required in 4/1,009 (0.4%; 95% CI: 0.1% to 1.0%) patients, including 2 craniotomies, elevation of a skull fracture, and placement of an external ventricular drain for elevated intracranial pressure. Excluding these patients requiring neurosurgical intervention, no (0%; 0% to 0.4%) patients required intubation for more than 24 hours or died from their injuries. Injuries were present on CT for 52 (5%; 95% CI: 4% to 7%) patients.

Frequencies of predictor variables differed between patients with clinically important TBI and without clinically important TBI (Appendix 1). The presence of depressed GCS score and severe mechanism consistently were more common in children with clinically important TBIs. All predictor variables had κ values >0.5 except for worsening headache ($\kappa=0.49$) and intoxication ($\kappa=0.43$) (Appendix 2).

Performance of the Rules

The diagnostic accuracy of the 3 rules varied for detection of clinically important TBI (Table 3). PECARN accurately classified all patients with clinically important TBI. CATCH and CHALICE misclassified a small proportion of patients with clinically important TBIs as low risk (Table 4). In terms of identification of injuries requiring neurosurgical intervention, PECARN was the only rule to identify all of the injuries (Table 3). CATCH and CHALICE both missed one injury. PECARN missed one injury, when non-clinically important injuries on CT were included. CATCH missed 5 of these injuries, and CHALICE missed 14 of these injuries. The specificity for clinically important TBI was greatest for CHALICE followed by PECARN and then CATCH (Table 3). CHALICE also had the greatest specificity for identifying injuries requiring neurosurgical intervention and any injuries on CT.

Sensitivity analyses revealed similar diagnostic accuracies for the rules when accounting for missing data (Appendix 3). The rules also performed similarly when they were applied to restricted cohorts with the inclusion criteria of their derivation cohorts (Appendix 4).

PECARN and CATCH differentiated between high, intermediate, and low risk criteria in their rules; the performances of these different criteria are presented in Appendix 5.

Physician Practice and Estimates

Table 5 describes the distribution of physician estimates of clinically important TBI. Physicians estimated 67% of patients to have <1% probability of clinically important TBI. Among this group, only 1 patient (0.2%) had a clinically important TBI, yielding a sensitivity of 95% (95% CI: 76 – 100%) and specificity of 68% (95% CI: 65–71%) for physician estimation at a 1% likelihood of clinically important TBI. Physician estimation had an area under the curve of 0.94 (95% CI: 0.89 to 0.98), exceeding the area under the curve for PECARN (0.81; 95% CI: 0.80 – 0.83), CATCH (0.67; 95% CI: 0.61 – 0.74), and CHALICE (0.84; 95% CI: 0.76 – 0.93) (Figure 2).

LIMITATIONS

The prevalence of clinically important TBI is inherently low in children, and we only identified 21 clinically important TBIs. As a result, our estimates are less precise than the original derivation studies. This prevents absolute conclusions about the exact sensitivities of the rules.

We also did not enroll all patients, potentially leading to selection bias. We did not identify any demographic differences between enrolled and non-enrolled patients. In reviewing the medical records of non-enrolled patients, it appeared most of these patients were not enrolled, because their injuries were trivial, without any risk of TBI.

In addition, our study was performed at a single center potentially limiting generalizability of the results. Our ED is similar to the sites where most children receive care (i.e., a pediatric ED within a general ED, staffed by a variety of physicians, with only a small number of pediatric emergency subspecialists).

Our cohort was somewhat different from the cohorts of the derivation studies, and this may have affected the rules' performances. We planned to overcome the varied inclusion criteria of the derivation studies and compare the rules in a broad, inclusive cohort of patients that resembles those children physicians manage regularly with minor head injury. We aimed to include patients where physicians entertained the possibility of clinically important TBI. This entailed including patients without loss of consciousness or amnesia, who were not included in the CATCH cohort, as well as inclusion of patients with GCS scores of 13, who were not included in PECARN. It appears our prevalence of clinically important TBI was higher than PECARN and CHALICE in part due to a greater proportion of higher acuity patients with GCS scores <15 and loss of consciousness. This may have arisen from enrollment bias. Notably, when the rules were applied to restricted cohorts matching their derivation studies, the performance of the rules was similar to the performance in our cohort.

Another potential limitation arose because treating physicians recoded the presence of predictor variables from the rules, but we do not know if physicians incorporated the rules into their decisions to obtain CTs or their judgments of the likelihood of TBI. Moreover, the actual diagnostic accuracy associated with implementation of a rule might be limited by many factors not assessed in this observational study, such as interpretation of the rule, acceptability, or bias. We intentionally did not mandate use of a particular rule in our ED,

because the diagnostic accuracy of the rules outside of their derivation sites is unknown. A key question for the future is the effect of implementation of a rule on its' performance and the frequency of CT acquisition.

DISCUSSION

This study conducted in an urban medical center with a designated pediatric ED is the first study to prospectively evaluate PECARN, CATCH, and CHALICE in a head-to-head fashion. Our study is also the first to compare the 3 rules against physician estimation in order to understand how judgment compares to empirically developed tools. In our cohort, the PECARN and physician practice were the only approaches to demonstrate 100% sensitivity for identifying patients with clinically important TBI. CATCH and CHALICE missed several clinically important TBIs; although, the 95% confidence intervals of their estimates overlapped with PECARN and physician practice. CHALICE demonstrated the greatest specificity followed by physician estimation.

PECARN performed similarly to its derivation study, while CATCH and CHALICE showed a trend towards decreased diagnostic accuracy compared to their derivation cohorts. The high performance of PECARN for detecting clinically important TBIs is notable given that decision rules often demonstrate reduced performance when assessed in external cohorts. For CHALICE and CATCH, our estimates of their sensitivities were within the 95% confidence intervals for the estimates of sensitivities from the derivation studies. Notably, physicians obtained CTs on all of the patients with clinically important TBI missed by CATCH and CHALICE, and estimated high likelihoods of clinically important TBI (median= 4% likelihood of clinically important TBI; IQR: 3 to 5%) for these patients missed by the rules.

While the approaches demonstrated overlapping estimates of their sensitivities, they had quite different specificities. CHALICE had the greatest specificity of the rules and performed similarly to its derivation study. PECARN had the next high specificity and demonstrated slightly greater specificity than its' derivation study, which is remarkable given our utilization of a more inclusive cohort than the derivation study. CATCH had the lowest specificity of any of the rules. This likely stems from CATCH's inclusion of all motor vehicle collisions and large, boggy scalp hematomas as criteria in the rule; these features were present in nearly one third of all patients. The specificity of physician estimation was similar to PECARN but less than CHALICE. Physician practice had lower specificity than physician estimation, suggesting other factors contributed to physicians' decision to obtain CTs, perhaps including patient preference, concerns for litigation, or attempts to avoid prolonged observation in the ED.

While our sample size limits absolute conclusions about the ideal strategy for identifying pediatric minor head injury, it suggests that PECARN and physician practice provide an acceptable combination of sensitivity and specificity. The superior strategy between these two approaches may depend on the experience of the physicians working in the ED and their ability to assess the likelihood of TBI. CATCH had lower specificity than any other approach, and it did not improve upon the sensitivity of PECARN or physician estimation.

The upper bound of the 95% CI for CHALICE's sensitivity was only 97%, a sensitivity which many providers would consider unacceptable for clinically important TBIs in children.^{18,19,20}

In summary, for identifying clinically significant TBI in children presenting to an urban pediatric ED for minor closed head injury, PECARN and physician practice were the only approaches to identify all clinically important TBIs, with PECARN being slightly more specific. CHALICE was incompletely sensitive but the most specific of all rules. CATCH was incompletely sensitive and had the poorest specificity of all modalities.

Acknowledgments

Sources of funding:

JSE (K12HS019464) and JSH (K02HS017526) had financial support from the Agency for Healthcare Research and Quality (AHRQ) for the submitted work. JSE was also supported by NIH/NCATS Colorado CTSI Grant Number UL1 TR001082.

Abbreviations

CATCH	Canadian Assessment of Tomography for Childhood Head Injury rule
CHALICE	Children's Head Injury Algorithm for the Prediction of Important Clinical Events
CT	computerized tomography
ED	emergency department
PECARN	Pediatric Emergency Care Applied Research Network rule
TBI	traumatic brain injury
GCS	Glasgow Coma Scale
LOC	loss of consciousness

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Figure 1.
Study flow diagram.

Figure 2. Discrimination of Physician judgment (AUC: 0.94; 95% CI: 0.89 to 0.98), PECARN (AUC: 0.81; 95% CI: 0.80 – 0.83), CATCH (AUC: 0.67; 95% CI: 0.61 – 0.74), and CHALICE (AUC: 0.84; 95% CI: 0.76 – 0.93) for clinically important TBI. Physician practice is depicted as a point estimate of CT or observation versus discharge.

Table 1

Decision rules for CT acquisition in children with minor head injury. Children with none of the variables of the rule are considered low risk and do not require CT.

	PECARN <2 years	PECARN 2 years	CHALICE	CATCH
<u>Historical Variables</u>				
Loss of consciousness	5 sec	Any	>5 min	
Vomiting		Any	3 episodes	
Headache		Severe		Worsening
Acting abnormally to parents	Any			
Amnesia			>5 min	
Seizure			Any	
Concern for NAT			Any	
Severe mechanism *	Any	Any	Any	Any
<u>Physical Exam Variables</u>				
Abnormal mental status	Any	Any	Drowsy Penetrating, Depressed, or Basilar	Irritable Open, Depressed, or Basilar
Skull fracture	Any	Basilar		
GCS Score	<15	<15	<14 [†]	<15 at 2 hours
Neurologic deficit			Any	
Scalp hematoma	Non-frontal		>5cm if <1 year [‡]	Large, Boggy

Abbreviations: NAT= non-accidental trauma; GCS= Glasgow Coma Scale; sec= seconds; min= minutes

* Severe mechanism defined: (1) for PECARN as motor vehicle collision with patient ejection, death of passenger, or rollover, pedestrian or cyclist without helmet struck by vehicle, fall >0.9 meters if <2 years and >1.5 meters if >2 years, or head struck by high speed projectile; (2) for CHALICE as motor vehicle collision as occupant, pedestrian or cyclist >40 miles/hour, fall >3 meters, or head struck by high speed projectile; and (3) for CATCH as motor vehicle collision, fall >0.9 meters or 5 stairs, or unhelmeted bicycle fall.

[†] GCS<15 if <1 year

[‡] Includes bruises or lacerations

Table 2

Patient characteristics in the study cohort compared to the derivation cohorts of PECARN, CATCH, and CHALICE (number and percentage given for study cohorts).

Characteristics	Study Cohort n=1,009	PECARN n=42,412	CATCH n=3,866	CHALICE N=22,772
Median age (years), (IQR)	6.1 (2.6 – 13.7)	7.1* (± 5.5)	10 (5–14)	5.7*
Male	650 (64)	NR	2505 (65)	147676 (65)
GCS				
13	4 (0.4)	0 (0)	95 (3)	73 (0.3)
14	40 (4)	1341 (3)	282 (7)	229 (1)
15	961 (95)	41071 (97)	3489 (90)	21996 (97)
Mechanism of injury				
Fall from standing	250 (25)	7106 (17)	1029 [†] (27)	NR
Struck from bicycle, unhelmeted	13 (1)	524 (1)	40 (1)	NR
Sports related	90 (9)	2934 (7)	870 (23)	NR
Motor vehicle accident	91 (9)	3717 (9)	115 (3)	NR
Unrestrained	23 (2)	NR	115 (3)	NR
Ejected	2 (0.2)	NR	11 (0.3)	NR
Rollover	2 (0.2)	NR	38 (1)	NR
Death of other passenger in vehicle	1 (0.1)	NR	7 (0.2)	NR
High speed	8 (0.8)	NR	14 (0.4)	204 (1)
Fall from height	237 (24)	11665 (27)	687 [‡] (18)	129 (0.6)
Fall from stairs	6 (0.6)	2858 (7)	[‡]	NR
Fall from bicycle, unhelmeted	27 (3)	1668 [§] (4)	294 [§] (8)	NR
Automobile vs. pedestrian	18 (2)	1303 (3)	133 (4)	NR
Hit with high speed projectile	1 (0.1)	NR	NR	456 (2)
Loss of consciousness	201 (20)	6286 (16)	1267 (33)	1185 (5)
Amnesia	101 (10)	NR	1730 (59)	720 (3)
CT	188 (19)	14969 (35)	2043 (53)	766 (3)
Observation	329 (33)	5433 (14)	NR	NR
Any injury on CT	52 (5)	780 (5)	159 (4)	281 (1)
Clinically important TBI	21 (2)	376 (1)	NR	NR

Characteristics	Study Cohort n=1,009	PECARN n=42,412	CATCH n=3,866	CHALICE N=22,772
Neurosurgical intervention	4 (0.4)	60 (0.1)	24 (0.6)	137 (0.6)

Abbreviations: IQR= interquartile range; GCS= Glasgow Coma Scale; NR= not reported

* Mean age

[†] Not differentiate between fall from standing and fall from <3 feet or <5 stairs

[‡] Fall from >3 feet or from 5 stairs

[§] Not specify if fall was unhelmeted

Table 3

Performance of the PECARN, CHALICE, and CATCH rules for the prediction of injury.*

<u>Clinically important TBI</u>	<u>Sensitivity</u>		<u>Specificity</u>		<u>LR₊</u>	<u>(95% CI)</u>	<u>LR₋</u>	<u>(95% CI)</u>
	<u>Yes</u>	<u>No</u>	<u>(%)</u>	<u>(95% CI)</u>	<u>(%)</u>	<u>(95% CI)</u>	<u>(%)</u>	<u>(95% CI)</u>
<u>PECARN</u>								
Met criteria	21	361	100	(84 – 100)	62	(59 – 66)	2.7	(2.5 – 2.9)
Did not meet criteria	0	599					0.0	(0.0 – .7)
<u>CATCH</u>								
Met criteria	19	550	91	(70 – 99)	44	(41 – 47)	1.6	(1.4 – 1.9)
Did not meet criteria	2	431					0.2	(0.1 – 0.8)
<u>CHALICE</u>								
Met criteria	16	128	84	(60 – 97)	85	(82 – 87)	5.5	(4.3 – 7.1)
Did not meet criteria	3	711					0.2	(0.1 – 0.5)
<u>Physician Practice</u>								
CT or Observation	21	496	100	(84 – 100)	50	(47 – 53)	2.0	(1.9 – 2.1)
Discharge	0	492					0.0	(0.0 – .7)
<u>Physician Estimation</u>								
1% risk	20	317	95	(76 – 100)	68	(65 – 71)	3.0	(2.6 – 3.4)
<1 risk	1	671					0.1	(0.0 – 0.5)
<u>Injury requiring neurosurgical intervention</u>								
<u>PECARN</u>								
Met criteria	4	378	100	(40 – 100)	61	(58 – 64)	2.6	(2.4 – 2.8)
Did not meet criteria	0	599					0.0	(0.0 – .7)
<u>CATCH</u>								
Met criteria	3	566	75	(19 – 99)	43	(40 – 46)	1.3	(0.7 – 2.3)
Did not meet criteria	1	432					0.6	(0.1 – 3.2)
<u>CHALICE</u>								
Met criteria	3	141	75	(19 – 99)	84	(81 – 86)	4.5	(2.5 – 8.2)
Did not meet criteria	1	713					0.3	(0.1 – 1.6)
<u>Physician Practice</u>								
CT or Observation	4	513	100	(40 – 100)	49	(46 – 52)	2.0	(1.8 – 2.1)
							0.0	(0.0 – .7)

<u>Clinically important TBI</u>		Sensitivity		Specificity			
Yes	No	(%)	(95% CI)	(%)	(95% CI)	<u>LR</u> +	<u>LR</u> -
0	492						
<u>Any injury on CT</u>							
<u>PECARN</u>							
Met criteria	51	399					
Did not meet criteria	1	598	98 (89 – 100)	64 (61 – 67)	2.4 (2.2 – 5.7)	0.0 (0.0 – 0.2)	
<u>CATCH</u>							
Met criteria	47	522					
Did not meet criteria	5	428	90 (79 – 97)	45 (42 – 48)	1.6 (1.5 – 1.8)	0.2 (0.1 – 0.5)	
<u>CHALICE</u>							
Met criteria	25	119					
Did not meet criteria	14	700	64 (47–79)	86 (83–88)	4.4 (3.3 – 5.9)	0.4 (0.3 – 0.6)	
<u>Physician Practice</u>							
CT or Observation	50	467					
Discharge	2	490	96 (86 – 99)	51 (48 – 54)	2.0 (1.8 – 2.2)	0.1 (0.0 – 0.3)	

Abbreviations: CI = confidence interval; LR $\pm$ = positive likelihood ratio; LR $-$ = negative likelihood ratio.

Note: PECARN and CHALICE rules described include both high and intermediate risk criteria. Physicians did not report estimates of the likelihood of injury requiring neurosurgical intervention or any injury on CT.

* Observations with missing data are not reported.

[†]The upper bound of the 95% confidence interval is undefined because all injuries were identified by the criteria.

Table 4

Characteristics of patients with clinically important TBI not identified by the rules.

Patient	Age (years)	Sex	Mechanism of injury	Injury	Treatment	PECARN Positive Criteria	CATCH Positive Criteria	CHALICE Positive Criteria
<u>Patients Missed by CATCH</u>								
1	0.8	M	Fall 0.6 meters	Subdural hemorrhage	External ventricular drain	Acting abnormal to parent	None	Seizure
2	12	M	Snowboarding fall	Thalamic hemorrhage	Admission for 3 days	Loss of consciousness	None	Annesia >5 minutes
<u>Patients Missed by CHALICE</u>								
3	17	M	Struck by rock	Epidural hemorrhage; fracture sphenoid and frontal sinus	Cranialization	Severe headache	Worsening headache	None
4	16	M	Pedestrian struck	Subarachnoid hemorrhage	Admission for 2 days	Severe mechanism; GCS score <15	GCS score <15 at 2 hours	None
5	14	M	Fall 2.5 meters	Subdural hemorrhage	Admission for 2 days	Loss of consciousness; severe headache; severe mechanism	Severe mechanism	None
<u>Patient Missed by Physician Estimation</u>								
6	17	M	Motor vehicle collision	Bilateral frontal intraparenchymal hemorrhages; intraventricular hemorrhage	Admission for 3 days	Loss of consciousness	Severe mechanism	Annesia >5 minutes

Abbreviation: GCS= Glasgow Coma Scale

Table 5
Distribution of physicians' estimation of clinically important TBI and actual clinically important TBI.

Physician estimate of likelihood (%)	Clinically important TBI (N = 21)		No clinically important TBI (N = 988)	
	n	(%)	n	(%)
< 1	1	4.8	673	68.1
1 – 1.9	2	9.5	237	24.0
2 – 2.9	3	14.3	33	3.3
3 – 3.9	1	4.8	3	0.3
4 – 4.9	1	4.8	1	0.1
5 – 9.9	6	28.6	27	2.7
10 – 19.9	3	14.3	9	0.9
20 – 50	4	19.1	2	0.2
> 50	0	0.0	3	0.3

Appendix 1

Presence of predictor variables for each of the rules among patients with and without clinically important traumatic brain injury.

	cTBI		No cTBI		Absolute Difference, (95% CI)	
	N	%, (95 % CI)	N	%, (95 % CI)		
PECARN (n = 981)*	21		960			
Age < 2 (n = 174)	6	29 (11 – 52)	168	18 (15 – 20)		11 (–8 – 31)
GCS < 15	4	19 (5 – 42)	5	0.5 (0.2 – 1)		19 (2 – 35)
Other signs of altered mental status	3	14 (3 – 36)	4	0.4 (0.1 – 1)		14 (–1 – 29)
Palpable skull fracture	1	5 (0.1 – 24)	2	0.2 (0 – 0.8)		5 (–5 – 14)
Skull hematoma	3	14 (3 – 36)	13	1 (0.7 – 2)		13 (–2 – 28)
History of LOC 5 seconds	1	5 (0.1 – 24)	15	2 (0.9 – 3)		3 (–6 – 12)
Severe mechanism of injury	3	14 (3 – 36)	43	4 (3 – 6)		10 (–5 – 25)
Acting abnormal per parent	2	10 (1 – 30)	23	2 (2 – 4)		7 (–6 – 20)
Head stuck by high-impact object	0	0.0 (0 – 16)	0	0.0 (0 – 0.4)		0 (0 – 0)
Age 2 (n = 807)	15	71 (48 – 89)	792	83 (80 – 85)		–11 (–31 – 8)
GCS < 15	4	19 (5 – 42)	29	3 (2 – 4)		16 (–0.8 – 33)
Other signs of altered mental status	2	10 (1 – 30)	40	4 (3 – 6)		5 (–7 – 18)
Signs of basilar skull fracture	1	5 (0.1 – 24)	1	0.1 (0 – 0.6)		5 (–4 – 14)
History of LOC	9	43 (22 – 66)	170	18 (15 – 20)		25 (39 – 47)
History of vomiting	3	14 (3 – 36)	86	9 (7 – 11)		5 (–10 – 20)
Severe mechanism of injury	8	38 (18 – 62)	60	6 (5 – 8)		32 (11 – 53)
Severe headache	5	24 (8 – 47)	51	5 (4 – 7)		19 (0.2 – 37)
CATCH (n = 1,002)*	21		981			
GCS < 15	8	38 (18 – 62)	35	4 (3 – 5)		34 (14 – 55)
Suspected open or depressed skull fracture	1	5 (0.1 – 24)	2	0.2 (0 – 1)		5 (–5 – 14)
History of worsening headache	1	5 (0.1 – 24)	16	2 (1 – 3)		3 (–6 – 12)
Irritability on examination	5	24 (8 – 47)	57	6 (4 – 7)		18 (–0.3 – 36)
Any sign of basal skull fracture	1	5 (0.1 – 24)	1	0.1 (0 – 1)		5 (–4 – 14)
Large, boggy hematoma of the scalp	13	62 (38 – 82)	329	34 (31 – 37)		28 (7 – 49)
Dangerous mechanism of injury	14	67 (43 – 85)	275	28 (25 – 31)		39 (18 – 59)
CHALICE (n = 858)*	19		839			

	cTBI		No cTBI		Absolute Difference, (95% CI)	
	N	%, (95% CI)	N	%, (95% CI)		
Witnessed LOC > 5 minutes in duration	0	0 (0 – 18)	2	0.2 (0 – 1)		–0.2 (–0.6 – 0)
History of amnesia of >5 minutes in duration	1	5 (0.1 – 26)	16	2 (1 – 3)		3 (–7 – 13)
Abnormal drowsiness	7	37 (16 – 62)	51	6 (5 – 8)		31 (9 – 52)
3 vomits after head injury	1	5 (0.1 – 26)	24	3 (2 – 4)		2 (–8 – 12)
Seizure after head injury [†]	3	16 (3 – 40)	12	1 (1 – 2)		14 (–2 – 31)
GCS < 14, or GCS < 15 if < 1 year old	4	21 (6 – 46)	2	0.2 (0 – 1)		21 (2 – 39)
Suspicion of penetrating or depressed skull fracture or tense fontanelle	2	10 (1 – 33)	0	0 (0 – 4)		10 (–3 – 24)
Signs of basal skull fracture	0	0 (0 – 18)	0	0 (0 – 4)		0 (0 – 0)
Positive focal neurology	0	0 (0 – 18)	8	1 (0.4 – 2)		–1.0 (–2 – –0.3)
Presence of bruise, swelling, or laceration if < 1 year old	2	10 (1 – 33)	1	0.1 (0 – 1)		10 (–3 – 24)
High-speed traffic accident either as pedestrian, cyclist or occupant	3	16 (3 – 40)	29	3 (2 – 5)		12 (–4 – 29)
Fall of > 3 meters in height	3	16 (3 – 40)	5	1 (0.2 – 1)		15 (–1 – 31)
High-speed injury from a projectile or an object	0	0 (0 – 18)	1	0.1 (0 – 1)		–0.1 (–0.3 – 0.1)

Abbreviations: CI = confidence interval, LOC = loss of consciousness; GCS= Glasgow Coma Scale; n= meters

* Observations with missing data are not reported.

Appendix 2

Interobserver agreement between providers based on 180 total observations.

Variable	Kappa
Head Struck	0.90
Bike Struck	1.0
Unhelmeted	1.0
Sports Related	1.0
Motor Vehicle Collision	1.0
Unrestrained	0.88
Ejected	1.0
Rollover	1.0
Death	1.0
High Speed	1.0
Fall	1.0
Standing	1.0
Fall Stairs	1.0
Bike Fall	1.0
Unhelmeted	1.0
Auto-pedestrian	1.0
High Speed Projectile	1.0
Loss of Consciousness	0.79
Duration (sec)	0.79
Vomiting	1.0
# episodes	1.0
Amnesia	0.65
Duration (minutes)	0.77
Seizure	1.0
Headache	0.95
Severe	0.67
Worsening	0.49
Acting Abnormal Guardian	0.79

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Variable	Kappa
Drowsy	0.79
Intoxication	0.43
Scalp hematoma	0.95
Frontal	0.88
Temporal	0.71
Parietal	0.65
Occipital	1.0
Large	1.0
Skull Fracture	1.0
Basilar	1.0
Depressed	1.0
Open	1.0
Irritable	1.0
GCS	0.65
Abnormal Mental Status	0.86
Neurologic Deficit	0.79

Appendix 3

Sensitivity analyses showing the impact of missing data on rule performance for identifying clinically important TBI.

Sensitivity		Specificity	
%	(95% CI)	%	(95% CI)
<u>Missing variables coded as negative</u>			
PECARN	95 (76 – 100)	63	(59 – 66)
CATCH	91 (70 – 99)	44	(41 – 47)
CHALICE	86 (64 – 97)	78	(75 – 80)
<u>Missing variables coded as positive</u>			
PECARN	95 (76 – 100)	61	(58 – 64)
CATCH	91 (70 – 99)	44	(41 – 47)
CHALICE	86 (64 – 97)	77	(74 – 79)

Abbreviations: CI = confidence interval

Appendix 4

Performance of the PECARN, CATCH, and CHALICE rules for the prediction of clinically important TBI in cohorts with the inclusion criteria of their derivation cohorts.

	ctTBI		Sensitivity		Specificity		LR +	(95% CI)	LR -	(95% CI)
	Yes	No	(%)	(95% CI)	(%)	(95% CI)				
<u>PECARN</u>										
Met criteria	21	357	100	(84 – 100)	63	(60 – 66)	2.7	(2.5 – 2.9)	0.0	(0.0 – 0.5)
Did not meet criteria	0	599								
<u>CATCH</u>										
Met criteria	15	164	94	(72 – 99)	39	(31 – 43)	1.5	(1.3 – 1.7)	0.2	(0.0 – 0.1)
Did not meet criteria	1	95								
<u>CHALICE</u>										
Met criteria	16	128	84	(60 – 97)	85	(82 – 87)	5.5	(4.3 – 7.1)	0.2	(0.1 – 0.5)
Did not meet criteria	3	711								

Abbreviations: CI = confidence interval; LR + = positive likelihood ratio; LR - = negative likelihood ratio.

Appendix 5

Performance of the high, intermediate, and low risk criteria from the PECARN and CATCH rules for the prediction of clinically important traumatic brain injury. *

	cTBI		Sensitivity		Specificity		LR +	(95% CI)	LR -	(95% CI)
	Yes	No	(%)	(95% CI)	(%)	(95% CI)				
<u>PECARN</u>										
High risk	9	38								
Intermediate or low risk	12	922	43	(22 – 66)	96	(95 – 97)	1.5	(0.9 – 2.5)	0.8	(0.4 – 1.2)
<u>CATCH high risk</u>										
High risk	12	97								
Intermediate or Low risk	9	884	57	(34 – 78)	90	(88 – 92)	5.8	(3.8 – 8.8)	0.5	(0.3 – 0.8)

Abbreviations: CI = confidence interval; LR += positive likelihood ratio; LR - = negative likelihood ratio.

* Observations with missing data are not reported.