Comparison of PECARN, CATCH, and CHALICE Rules for Children With Minor Head Injury: A Prospective Cohort Study

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Study objective: We evaluate the diagnostic accuracy of clinical decision rules and physician judgment for identifying clinically important traumatic brain injuries in children with minor head injuries presenting to the emergency department.

Methods: We prospectively enrolled children younger than 18 years and with minor head injury (Glasgow Coma Scale score 13 to 15), presenting within 24 hours of their injuries. We assessed the ability of 3 clinical decision rules (Canadian Assessment of Tomography for Childhood Head Injury [CATCH], Children's Head Injury Algorithm for the Prediction of Important Clinical Events [CHALICE], and Pediatric Emergency Care Applied Research Network [PECARN]) and 2 measures of physician judgment (estimated of <1% risk of traumatic brain injury and actual computed tomography ordering practice) to predict clinically important traumatic brain injury, as defined by death from traumatic brain injury, need for neurosurgery, intubation greater than 24 hours for traumatic brain injury, or hospital admission greater than 2 nights for traumatic brain injury.

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

Conclusion: Of the 5 modalities studied, only physician practice and PECARN identified all clinically important traumatic brain injuries, 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. [Ann Emerg Med. 2014;64:145-152.]

Please see page 146 for the Editor's Capsule Summary of this article.

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INTRODUCTION

Background

Computed tomography (CT) is the criterion standard for diagnosing traumatic brain injury. Although it rapidly and accurately identifies traumatic brain injuries, potentially reducing morbidity and mortality, it is costly, may be difficult to obtain for 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 to 15), and injuries requiring neurosurgical intervention occur in less than 1% of children.[3] Decision analyses suggest that for most children who are at low risk of traumatic brain injury, the risks of radiation outweigh the risks of traumatic brain injury, and CT is not warranted.[4] Despite this, more than one third of children with minor head injury undergo CT.[5]

Clinical decision rules may prove useful for guiding clinical decisionmaking for children with minor traumatic brain injury. 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 decisionmaking after minor head injury by potentially increasing recognition of injuries and reducing the frequency of CT acquisition (Table 1).[3,6,7] 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 traumatic brain injury.

Editor's Capsule Summary

What is already known on this topic

Some advocate clinical decision rules to guide head computed tomography (CT) use in injured children.

What question this study addressed

How do 3 clinical decision rules compare with clinical judgment?

What this study adds to our knowledge

In this prospective study of 1,009 injured children, only physician baseline ordering practice and Pediatric Emergency Care Applied Research Network (PECARN) identified all of the 21 clinically important brain injuries, with PECARN being slightly more specific. Physician risk estimation missed 1 injury, and 2 other decision rules were insufficiently sensitive.

How this is relevant to clinical practice

Baseline physician ordering practice and PECARN outperformed 2 other clinical decision rules for head CT use in injured children.

Table 1. Decision rules for CT acquisition in children with minor head injury.*

Variables	PECARN <2 Years	PECARN ≥2 Years	CHALICE	CATCH
History				
LOC	≥5 s	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
Physical examination				
Abnormal mental status	Any	Any	Drowsy	Irritable
Skull fracture	Any	Basilar	Penetrating, depressed, or basilar	Open, depressed, or basilar
GCS score	<15	<15	<14‡	<15 at 2 h
Neurologic deficit			Any	
Scalp hematoma	Nonfrontal		>5 cm if <1 y§	Large, boggy

LOC, Loss of consciousness; *NAT*, nonaccidental trauma.

*Children with none of the variables of the rule are considered low risk and do not require CT.

†Severe mechanism was defined as the following: (1) for PECARN as motor vehicle crash with patient ejection, death of passenger, or rollover; pedestrian or cyclist without helmet struck by vehicle; fall greater than 0.9 m if younger than 2 years and greater than 1.5 m if >2 years; or head struck by high-speed projectile; (2) for CHALICE as motor vehicle crash as occupant, pedestrian, or cyclist greater than 40 miles/hour; fall greater than 3 m; or head struck by high-speed projectile; and (3) for CATCH as motor vehicle crash, fall greater than 0.9 m or 5 stairs, or unhelmeted bicycle fall.

‡GCS score less than 15 if younger than 1 year.

§Includes bruises or lacerations.

Importance

Before being incorporated into usual practice, clinical decision rules require external validation and comparison to clinical judgment.[8] Without validation, results may represent unique aspects of the studied patient population, clinicians using the rule, or overfitting of the model. Several examples exist in the literature of rules that worked well in derivation but failed when applied to new cohorts.[9-11] Appropriate validation requires both an assessment of rule performance in settings apart from the derivation study and a comparison of performance to physician estimates of injury.[12] To date, external validation and comparison have not yet occurred for the minor head injury rules.[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 traumatic brain injuries in children with minor head injury.

MATERIALS AND METHODS

Study Design and Setting

We performed a prospective cohort study of children younger than 18 years and 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 II pediatric trauma center for Denver, CO. The ED has approximately 30,000 annual pediatric visits managed by general pediatric, pediatric emergency, and emergency physicians. The ED did not participate in the original derivation of PECARN, CATCH, or CHALICE. Patients received follow-up at 26 affiliated community and school-based clinics. The Standards for the Reporting of Diagnostic Accuracy studies were followed in study development. Our institutional review board approved the study, with a waiver of informed consent.

Selection of Participants

We included children younger than 18 years with (1) a history or signs of blunt injury to the head; (2) GCS scores greater than or equal to 13; (3) injury within the 24 hours before presentation to the ED; and (4) physician concern for potential traumatic brain injury. We excluded children known to be at heightened risk of traumatic brain injury, including those with GCS scores less than 13, brain tumors, ventricular shunts, anticoagulant therapy, or bleeding disorders. Children presenting greater than 24 hours after injury were also excluded because the risk of clinically important traumatic brain injury decreases with time.[15] We identified eligible patients who were not enrolled through systematic review of ED patient logs.

Methods of Measurement

Before enrollment, physicians underwent a 30-minute training session in regard to completion of the data collection instrument. After assessing a patient but before 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 sex. 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 traumatic brain injury 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 traumatic brain injury.

Outcome Measures

The primary outcome was clinically important traumatic brain injury, as defined by death from traumatic brain injury, need for neurosurgery, intubation greater than 24 hours for traumatic brain injury, or hospital admission greater than 2 nights for traumatic brain injury. Although there is no consensus on the definition of clinically important traumatic brain injury 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 those of the derivation studies and included traumatic brain injury requiring neurosurgery (CATCH and PECARN) and any traumatic brain injury visible on CT (CATCH, PECARN, and 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 whether 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 whether they had any of the outcomes. If they had not been evaluated, we used a proxy outcome assessment tool that was adapted from a validated follow-up tool used for minor head injury.[6] This entailed a standardized telephone interview with patients' guardians to determine whether patients exhibited any signs or symptoms of clinically important traumatic brain injury. Patients with concerning symptoms were instructed to return for reevaluation, and their subsequent medical records and imaging were reviewed. We also reviewed trauma registries and quality improvement reports to determine whether any patients had died.

Primary Data Analysis

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 at least 1 of the predictor criteria was present. We applied the unique criteria PECARN provides for children younger than 2 and aged 2 years or older. PECARN and CATCH also distinguish between high-risk and "intermediate"-risk (PECARN) or "medium"-risk (CATCH) criteria. Because the rules were designed to identify patients at low risk of traumatic brain injury, 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 version 14.0 (Microsoft, Redmond, WA) and transferred into native SAS format with translational software (dfPower DBMS Copy; Dataflux, Cary, NC). All statistical analyses were performed with SAS (version 9.2; SAS Institute, Inc., Cary, NC) or Stata (version 12; StataCorp, College Station, TX). Descriptive statistics for all variables and the prevalence of traumatic brain injury were determined and reported with 95% confidence intervals (CIs). Continuous data are presented as medians with interquartile ranges and categorical data as percentages with 95% CIs. We used 95% CIs to determine statistical separation between measures of diagnostic accuracy, including sensitivity, specificity, and predictive values. We calculated κ 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 effect of missing data on rule performance. The most optimistic estimate of rule sensitivity was determined by assuming all missing predictor variables were positive; the most pessimistic estimate, by assuming all missing predictor variables were negative. Receiver operating characteristic curves and the areas under the curve with 95% CIs compared the discriminatory performance of the 3 rules and physician estimation.

Sample size was calculated to estimate the precision for the sensitivity of the rules for clinically important traumatic brain injury. We estimated a prevalence of clinically important traumatic brain injury 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 nonenrolled patients: respectively, median age 6.1 and 5.0 years; sex 64% and 58% male; and GCS score 15

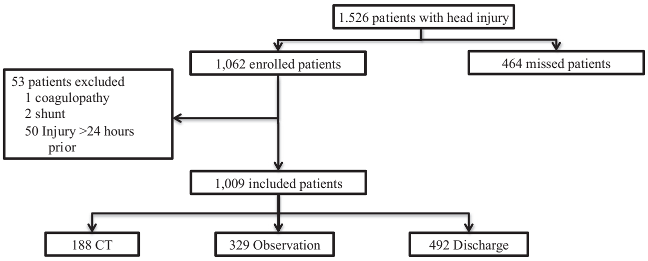

Figure 1. Study flow diagram.

for 95% and 99%. We excluded 53 enrolled patients; nearly all were excluded because they presented greater than 24 hours after the injury. Nearly half of patients were discharged after initial evaluation in the ED, whereas a third of patients were observed in the ED for a median duration of 3 hours (interquartile range 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 for 717 of 821 (87%) patients who did not undergo CT, with 412 of 717 (57%) being evaluated by a physician in the ED or outpatient clinic and 305 of 717 (43%) through telephone follow-up. Complete data were obtained for 981 of 1,009 (97%) patients with PECARN, 1,002 of 1,009 (99%) with CATCH, and 858 of 1,009 (85%) with CHALICE.

Characteristics of the study patients compared with 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 those of 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 traumatic brain injuries (Table 2). The most common clinically important traumatic brain injuries were 13 skull fractures (1%; 95% CI 0.7% to 2.2%), 11 subarachnoid hemorrhages (1%; 95% CI 0.6% to 2%), and 9 subdural hemorrhages (1%; 95% CI 0.4% to 2%). Neurosurgical intervention was required in 4 of 1,009 patients (0.4%; 95% CI 0.1% to 1.0%), including 2 craniotomies, elevation of a skull fracture, and placement of an external ventricular drain for

Table 2. Patient characteristics in the study cohort compared with 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 (IQR), y	6.1 (2.6–13.7)	7.1* (SD 5.5)	10 (5–14)	5.7*
Male	650 (64)	NR	2,505 (65)	147,676 (65)
GCS score				
13	4 (0.4)	0	95 (3)	73 (0.3)
14	40 (4)	1,341 (3)	282 (7)	229 (1)
15	961 (95)	41,071 (97)	3,489 (90)	21,996 (97)
Mechanism of injury				
Fall from standing	250 (25)	7,106 (17)	1,029† (27)	NR
Struck from bicycle, unhelmeted	13 (1)	524 (1)	40 (1)	NR
Sports related	90 (9)	2,934 (7)	870 (23)	NR
Motor vehicle accident	91 (9)	3,717 (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)	11,665 (27)	687‡ (18)	129 (0.6)
Fall from stairs	6 (0.6)	2,858 (7)	‡	NR
Fall from bicycle, unhelmeted	27 (3)	1,668§ (4)	294§ (8)	NR
Automobile vs pedestrian	18 (2)	1,303 (3)	133 (4)	NR
Hit with high-speed projectile	1 (0.1)	NR	NR	456 (2)
LOC	201 (20)	6,286 (16)	1,267 (33)	1,185 (5)
Amnesia	101 (10)	NR	1,730 (59)	720 (3)
CT	188 (19)	14,969 (35)	2,043 (53)	766 (3)
Observation	329 (33)	5,433 (14)	NR	NR
Any injury on CT	52 (5)	780 (5)	159 (4)	281 (1)
Clinically important TBI	21 (2)	376 (1)	NR	NR
Neurosurgical intervention	4 (0.4)	60 (0.1)	24 (0.6)	137 (0.6)

IQR, Interquartile range; *NR*, not reported; *TBI*, traumatic brain injury.
*Mean age.
†Not differentiated between fall from standing and fall from less than 3 feet or fewer than 5 stairs.
‡Fall from greater than 3 feet or from 5 stairs or more.
§Not specified whether the patient who fell was unhelmeted.

elevated intracranial pressure. Excluding these patients requiring neurosurgical intervention, no patients (0%; 0% to 0.4%) required intubation for more than 24 hours or died from their injuries. Injuries were present on CT for 52 patients (5%; 95% CI 4% to 7%).

Frequencies of predictor variables differed between patients with and without clinically important traumatic brain injury (Appendix E1, available online at http://www.annemergmed.com). The presence of depressed GCS score and severe mechanism consistently were more common in children with clinically important traumatic brain injuries. All predictor variables had κ values greater than 0.5 except for worsening headache (κ=0.49) and intoxication (κ=0.43) (Appendix E2, available online at http://www.annemergmed.com).

The diagnostic accuracy of the 3 rules varied for detection of clinically important traumatic brain injury (Table 3). PECARN accurately classified all patients with clinically important traumatic brain injury. CATCH and CHALICE misclassified a small proportion of patients with clinically important traumatic brain injuries 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 1 injury. PECARN missed 1 injury when non–clinically important injuries on CT were included.

Table 3. Performance of the PECARN, CHALICE, and CATCH rules for the prediction of injury.*

			Sensitivity		Specificity					
Clinically Important TBI	**Yes**	**No**	**%**	**(95% CI)**	**%**	**(95% CI)**	**LR+**	**(95% CI)**	**LR−**	**(95% CI)**
PECARN										
Met criteria	21	361	100	(84–100)	62	(59–66)	2.7	(2.5–2.9)	0	(0–†)
Did not meet criteria	0	599								
CATCH										
Met criteria	19	550	91	(70–99)	44	(41–47)	1.6	(1.4–1.9)	0.2	(0.1–0.8)
Did not meet criteria	2	431								
CHALICE										
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								
Physician practice										
CT or observation	21	496	100	(84–100)	50	(47–53)	2.0	(1.9–2.1)	0	(0–†)
Discharge	0	492								
Physician estimation of risk, %										
≥1	20	317	95	(76–100)	68	(65–71)	3.0	(2.6–3.4)	0.1	(0–0.5)
<1	1	671								
Injury requiring neurosurgical intervention										
PECARN										
Met criteria	4	378	100	(40–100)	61	(58–64)	2.6	(2.4–2.8)	0	(0–†)
Did not meet criteria	0	599								
CATCH										
Met criteria	3	566	75	(19–99)	43	(40–46)	1.3	(0.7–2.3)	0.6	(0.1–3.2)
Did not meet criteria	1	432								
CHALICE										
Met criteria	3	141	75	(19–99)	84	(81–86)	4.5	(2.5–8.2)	0.3	(0.1–1.6)
Did not meet criteria	1	713								
Physician practice										
CT or observation	4	513	100	(40–100)	49	(46–52)	2.0	(1.8–2.1)	0	(0–†)
Discharge	0	492								
Any injury on CT										
PECARN										
Met criteria	51	399	98	(89–100)	64	(61–67)	2.4	(2.2–5.7)	0	(0–0.2)
Did not meet criteria	1	598								
CATCH										
Met criteria	47	522	90	(79–97)	45	(42–48)	1.6	(1.5–1.8)	0.2	(0.1–0.5)
Did not meet criteria	5	428								
CHALICE										
Met criteria	25	119	64	(47–79)	86	(83–88)	4.4	(3.3–5.9)	0.4	(0.3–0.6)
Did not meet criteria	14	700								
Physician practice										
CT or observation	50	467	96	(86–99)	51	(48–54)	2.0	(1.8–2.2)	0.1	(0–0.3)
Discharge	2	490								

LR+, Positive likelihood ratio; *LR−*, negative likelihood ratio.

*Observations with missing data are not reported. 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.

†The upper bound of the 95% CI 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
Patients missed by CATCH								
1	0.8	M	Fall 0.6 m	Subdural hemorrhage	External ventricular drain	Acting abnormal to parent	None	Seizure
2	12	M	Snowboarding fall	Thalamic hemorrhage	Admission for 3 days	LOC	None	Amnesia >5 min
Patients missed by CHALICE								
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 h	None
5	14	M	Fall 2.5 m	Subdural hemorrhage	Admission for 2 days	LOC; severe headache; severe mechanism	Severe mechanism	None
Patient missed by physician estimation								
6	17	M	Motor vehicle crash	Bilateral frontal intraparenchymal hemorrhages; intraventricular hemorrhage	Admission for 3 days	LOC	Severe mechanism	Amnesia >5 min

M, Male.

CATCH missed 5 of these injuries, and CHALICE missed 14 of these injuries. The specificity for clinically important traumatic brain injury 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 E3, available online at http://www.annemergmed.com). The rules also performed similarly when they were applied to restricted cohorts with the inclusion criteria of their derivation cohorts (Appendix E4, available online at http://www.annemergmed.com).

PECARN and CATCH differentiated between high-, intermediate-, and low-risk criteria in their rules. The performance of these different criteria is presented in Appendix E5, available online at http://www.annemergmed.com.

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

Physician Estimate of Likelihood, %	Clinically Important TBI (N=21) n	Clinically Important TBI (N=21) (%)	No Clinically Important TBI (N=988) n	No Clinically Important TBI (N=988) (%)
<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	3	0.3

Table 5 describes the distribution of physician estimates of clinically important traumatic brain injury. Physicians estimated 67% of patients to have less than 1% probability of clinically important traumatic brain injury. Among this group, only 1 patient (0.2%) had a clinically important traumatic brain injury, yielding a sensitivity of 95% (95% CI 76% to 100%) and specificity of 68% (95% CI 65% to 71%) for physician estimation at a 1% likelihood of clinically important traumatic brain injury. 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 to 0.83), CATCH (0.67; 95% CI 0.61 to 0.74), and CHALICE (0.84; 95% CI 0.76 to 0.93) (Figure 2).

LIMITATIONS

The prevalence of clinically important traumatic brain injury is inherently low in children, and we identified only 21 instances of it. As a result, our estimates are less precise than those of the original derivation studies, preventing 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 nonenrolled patients. In review of the medical records of nonenrolled patients, it appeared most were not enrolled because their injuries were trivial, without any risk of traumatic brain injury.

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 (ie, a pediatric ED within a general ED, staffed by a variety of physicians, with only a small number of pediatric emergency subspecialists).

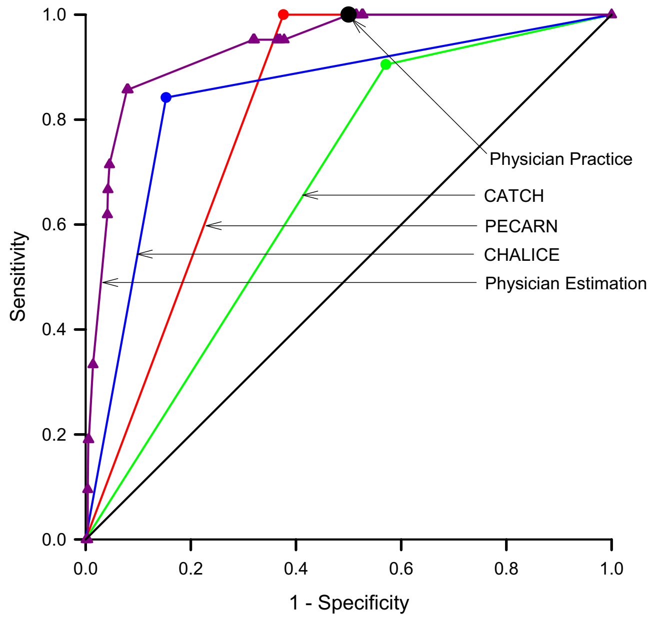

Figure 2. Discrimination of physician judgment (AUC 0.94; 95% CI 0.89 to 0.98), PECARN (area under curve 0.81; 95% CI 0.80 to 0.83), CATCH (AUC 0.67; 95% CI 0.61 to 0.74), and CHALICE (AUC 0.84; 95% CI 0.76 to 0.93) for clinically important TBI. Physician practice is depicted as a point estimate of CT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

Our cohort was somewhat different from the cohorts of the derivation studies, which may have affected the rules' performance. 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 when physicians entertained the possibility of clinically important traumatic brain injury. This entailed including patients without loss of consciousness or amnesia who were not included in the CATCH cohort, as well as patients with GCS scores of 13 who were not included in PECARN. It appears our prevalence of clinically important traumatic brain injury was higher than that of PECARN and CHALICE in part because of a greater proportion of higher-acuity patients with GCS scores less than 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 recorded the presence of predictor variables from the rules, but we do not know whether physicians incorporated the rules into their decisions to obtain CTs or their judgments of the likelihood of traumatic brain injury. 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

To our knowledge, this study, conducted in an urban medical center with a designated pediatric ED, is the first study to prospectively evaluate PECARN, CATCH, and CHALICE head-to-head. Our study is also the first, to our knowledge, to compare the 3 rules against physician estimation to understand how judgment compares with empirically developed tools. In our cohort, the PECARN rule and physician practice were the only approaches to demonstrate 100% sensitivity for identifying patients with clinically important traumatic brain injury. CATCH and CHALICE missed several clinically important traumatic brain injuries, although the 95% CIs of their estimates overlapped with those of PECARN and physician practice. CHALICE demonstrated the greatest specificity, followed by physician estimation.

PECARN performed similarly to its derivation study, whereas CATCH and CHALICE showed a trend toward decreased diagnostic accuracy compared with their derivation cohorts. The high performance of PECARN for detecting clinically important traumatic brain injuries 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% CIs for the estimates of sensitivities from the derivation studies. Physicians obtained CTs for all of the patients with clinically important traumatic brain injury missed by CATCH and CHALICE and estimated high likelihoods of clinically important traumatic brain injury (median=4% likelihood of clinically important traumatic brain injury; interquartile range 3% to 5%) for these patients missed by the rules.

Although 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-highest specificity and demonstrated slightly greater specificity than its derivation study, which is remarkable, given our use 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 crashes 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 that of PECARN but lower than that of CHALICE. Physician practice had lower specificity than physician estimation, suggesting that 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.

Although 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 2 approaches may depend on the experience of the physicians working in the ED and their ability to assess the likelihood of traumatic brain injury. CATCH had lower specificity than any other approach, and it did not improve on the sensitivity of PECARN or physician estimation. The upper bound of the 95% CI for CHALICE's sensitivity was only 97%, a sensitivity that many providers would consider unacceptable for clinically important traumatic brain injuries in children.[16-18]

In summary, for identifying clinically significant traumatic brain injury 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 traumatic brain injuries, 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.

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Appendix E1. Presence of predictor variables for each of the rules among patients with and without clinically important traumatic brain injury.

Variable	ciTBI			No ciTBI			Absolute Difference (95% CI)	
	N	% (95 % CI)		N	% (95 % CI)			
PECARN (n=981)*	21			960				
Age <2 y (n=174)	6	29	(11 to 52)	168	18	(15 to 20)	11	(−8 to 31)
GCS score <15	4	19	(5 to 42)	5	0.5	(0.2 to 1)	19	(2 to 35)
Other signs of altered mental status	3	14	(3 to 36)	4	0.4	(0.1 to 1)	14	(−1 to 29)
Palpable skull fracture	1	5	(0.1 to 24)	2	0.2	(0 to 0.8)	5	(−5 to 14)
Skull hematoma	3	14	(3 to 36)	13	1	(0.7 to 2)	13	(−2 to 28)
History of LOC ≥5 s	1	5	(0.1 to 24)	15	2	(0.9 to 3)	3	(−6 to 12)
Severe mechanism of injury	3	14	(3 to 36)	43	4	(3 to 6)	10	(−5 to 25)
Acting abnormal per parent	2	10	(1 to 30)	23	2	(2 to 4)	7	(−6 to 20)
Head struck by high-impact object	0	0	(0 to 16)	0	0	(0 to 0.4)	0	(0 to 0)
Age ≥2 y (n=807)	15	71	(48 to 89)	792	83	(80 to 85)	−11	(−31 to 8)
GCS score <15	4	19	(5 to 42)	29	3	(2 to 4)	16	(−0.8 to 33)
Other signs of altered mental status	2	10	(1 to 30)	40	4	(3 to 6)	5	(−7 to 18)
Signs of basilar skull fracture	1	5	(0.1 to 24)	1	0.1	(0 to 0.6)	5	(−4 to 14)
History of LOC	9	43	(22 to 66)	170	18	(15 to 20)	25	(39 to 47)
History of vomiting	3	14	(3 to 36)	86	9	(7 to 11)	5	(−10 to 20)
Severe mechanism of injury	8	38	(18 to 62)	60	6	(5 to 8)	32	(11 to 53)
Severe headache	5	24	(8 to 47)	51	5	(4 to 7)	19	(0.2 to 37)
CATCH (n=1,002)*	21			981				
GCS score <15	8	38	(18 to 62)	35	4	(3 to 5)	34	(14 to 55)
Suspected open or depressed skull fracture	1	5	(0.1 to 24)	2	0.2	(0 to 1)	5	(−5 to 14)
History of worsening headache	1	5	(0.1 to 24)	16	2	(1 to 3)	3	(−6 to 12)
Irritability on examination	5	24	(8 to 47)	57	6	(4 to 7)	18	(−0.3 to 36)
Any sign of basal skull facture	1	5	(0.1 to 24)	1	0.1	(0 to 1)	5	(−4 to 14)
Large, boggy hematoma of the scalp	13	62	(38 to 82)	329	34	(31 to 37)	28	(7 to 49)
Dangerous mechanism of injury	14	67	(43 to 85)	275	28	(25 to 31)	39	(18 to 59)
CHALICE (n=858)*	19			839				
Witnessed LOC >5 min in duration	0	0	(0 to 18)	2	0.2	(0 to 1)	−0.2	(−0.6 to 0)
History of amnesia of >5 min in duration	1	5	(0.1 to 26)	16	2	(1 to 3)	3	(−7 to 13)
Abnormal drowsiness	7	37	(16 to 62)	51	6	(5 to 8)	31	(9 to 52)
≥3 vomiting episodes after head injury	1	5	(0.1 to 26)	24	3	(2 to 4)	2	(−8 to 12)
Seizure after head injury	3	16	(3 to 40)	12	1	(1 to 2)	14	(−2 to 31)
GCS score <14, or <15 if aged <1 y	4	21	(6 to 46)	2	0.2	(0 to 1)	21	(2 to 39)
Suspicion of penetrating or depressed skull fracture or tense fontanelle	2	10	(1 to 33)	0	0	(0 to 4)	10	(−3 to 24)
Signs of basal skull fracture	0	0	(0 to 18)	0	0	(0 to 4)	0	(0 to 0)
Positive focal neurology	0	0	(0 to 18)	8	1	(0.4 to 2)	−1.0	(−2 to −0.3)
Presence of bruise, swelling, or laceration if aged <1 y	2	10	(1 to 33)	1	0.1	(0 to 1)	10	(−3 to 24)
High-speed traffic accident as pedestrian, cyclist, or occupant	3	16	(3 to 40)	29	3	(2 to 5)	12	(−4 to 29)
Fall of >3 m	3	16	(3 to 40)	5	1	(0.2 to 1)	15	(−1 to 31)
High-speed injury from a projectile or an object	0	0	(0 to 18)	1	0.1	(0 to 1)	−0.1	(−0.3 to 0.1)

y, year; *s*, seconds; *m*, meters.
*Observations with missing data are not reported.

Appendix E2. Interobserver agreement between providers, based on 180 total observations.

Variable	κ
Head struck	0.90
Bike struck	1.0
Unhelmeted	1.0
Sports related	1.0
Motor vehicle crash	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
LOC	0.79
Duration, s	0.79
Vomiting	1.0
No. episodes	1.0
Amnesia	0.65
Duration, min	0.77
Seizure	1.0
Headache	0.95
Severe	0.67
Worsening	0.49
Acting abnormal guardian	0.79
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 score	0.65
Abnormal mental status	0.86
Neurologic deficit	0.79

Appendix E3. Sensitivity analyses showing the effect of missing data on rule performance for identifying clinically important TBI.

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

Appendix E4. 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.

	ciTBI		Sensitivity		Specificity					
Rule	**Yes**	**No**	**%**	**(95% CI)**	**%**	**(95% CI)**	**LR+**	**(95% CI)**	**LR−**	**(95% CI)**
PECARN										
Met criteria	21	357	100	(84–100)	63	(60–66)	2.7	(2.5–2.9)	0	(0–0.5)
Did not meet criteria	0	599								
CATCH										
Met criteria	15	164	94	(72–99)	39	(31–43)	1.5	(1.3–1.7)	0.2	(0–0.1)
Did not meet criteria	1	95								
CHALICE										
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								

Appendix E5. Performance of the high-, intermediate-, and low-risk criteria from the PECARN and CATCH rules for the prediction of clinically important traumatic brain injury.*

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

*Observations with missing data are not reported.