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ORIGINAL CONTRIBUTION

PECARN algorithms for minor head trauma: Risk stratification estimates from a prospective PREDICT cohort study

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Abstract

Background: The Pediatric Emergency Care Applied Research Network (PECARN) head trauma clinical decision rules informed the development of algorithms that risk stratify the management of children based on their risk of clinically important traumatic brain injury (ciTBI). We aimed to determine the rate of ciTBI for each PECARN algorithm risk group in an external cohort of patients and that of ciTBI associated with different combinations of high- or intermediate-risk predictors.

Methods: This study was a secondary analysis of a large multicenter prospective data set, including patients with Glasgow Coma Scale scores of 14 or 15 conducted in Australia and New Zealand. We calculated ciTBI rates with 95% confidence intervals (CIs) for each PECARN risk category and combinations of related predictor variables.

Results: Of the 15,163 included children, 4,011 (25.5%) were aged <2 years. The frequency of ciTBI was 8.5% (95% CI = 6.0%–11.6%), 0.2% (95% CI = 0.0%–0.6%), and 0.0% (95% CI = 0.0%–0.2%) in the high-, intermediate-, and very-low-risk groups, respectively, for children <2 years and 5.7% (95% CI = 4.4%–7.2%), 0.7% (95% CI = 0.5%–1.0%), and 0.0% (95% CI = 0.0%–0.1%) in older children. The isolated high-risk predictor with the highest risk of ciTBI was "signs of palpable skull fracture" for younger children (11.4%, 95% CI = 5.3%–20.5%) and "signs of basilar skull fracture" in children ≥2 years (11.1%, 95% CI = 3.7%–24.1%). For older children in the intermediate-risk category, the presence of all four predictors had the highest risk of ciTBI (25.0%, 95% CI = 0.6%–80.6%) followed by the combination of "severe mechanism of injury" and "severe headache" (7.7%, 95% CI = 0.2%–36.0%). The very few children <2 years at intermediate risk with ciTBI precluded further analysis.

Conclusions: The risk estimates of ciTBI for each of the PECARN algorithms risk group were consistent with the original PECARN study. The risk estimates of ciTBI within

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the high- and intermediate-risk predictors will help further refine clinical judgment and decision making on neuroimaging.

KEYWORDS
child, clinical decision rule, PECARN, traumatic brain injury

INTRODUCTION

Head injuries in children are common and represent a leading cause of morbidity and mortality among pediatric patients. In the United States, over 800,000 children are evaluated in emergency departments (EDs) for blunt head trauma every year.[1] While most children present with minor head trauma defined as a Glasgow Coma Scale (GCS) score of 14–15, a small proportion will have clinically significant intracranial injuries that require rapid diagnosis by a computed tomography (CT) scan. However, the majority of children who undergo a CT scan for minor head trauma will have no clinically relevant findings.[2–4] Despite this, some multicenter studies in the United States have found that head trauma is the most frequent condition leading to a CT.[5–7] While the use of head CT varies widely between institutions and across different countries,[2,8–10] reducing unnecessary CT use in children is important to minimize exposure to the

harmful effects of ionizing radiation and potential risks of sedation in younger patients.[7,11,12]

Many clinical decision rules have been created to assist clinicians to identify head-injured children in need of CT scans based on their risk of significant intracranial injury. A large validation study by Babl et al.[2] evaluated three different high-quality clinical decision rules that have been prospectively derived. While all three rules had good accuracy in identifying clinically significant head injuries, the Pediatric Emergency Care Applied Research Network (PECARN) had the highest sensitivity and therefore the lowest risk of missing a clinically important traumatic brain injury (ciTBI).[3]

The PECARN rule, which differentiates between children aged <2 years and ≥2 years, informed the development of algorithms that can be used by treating clinicians as a bedside decision aid. The PECARN rule was statistically derived to identify children at very low risk of ciTBI for whom a CT scan could safely be avoided based on the absence of predictor variables. The PECARN stratification algorithm was developed based on risk estimates from the PECARN data set, as part of the discussion points of the original study, to assist physician decision making. The PECARN algorithm has been widely implemented in clinical practice worldwide. In the presence of predictor variables, the algorithm stratifies the management of children into an intermediate-risk or high-risk group based on the risk of ciTBI. Children at high risk are recommended to have a CT scan as the risk of ciTBI outweighs the risks associated with radiation exposure.[3] For children at intermediate risk, the rule becomes assistive rather than directive and encourages physicians to evaluate the appropriateness of observation over immediate CT on the basis of physician experience, multiple versus isolated findings, worsening condition over time, age of the child, and parental preference.[3] Despite many validation studies on the PECARN rule, the risk of ciTBI within each stratification group has not been assessed in an external cohort of patients. In addition, although many secondary analyses of the PECARN database evaluated the risk of ciTBI when isolated predictors were present, very limited data are available on the risk associated with a combination of predictors compared with isolated predictors.[4]

The primary aim of this study was to determine the rate of ciTBI for each PECARN algorithms risk group in an external cohort of patients. The secondary objective was to assess the risk of ciTBI associated with different combinations of high- or intermediate-risk predictors.

METHODS

Study design, setting, and patients

We performed a planned secondary analysis of a prospective multicenter observational study, the Australasian Paediatric Head Injury Rules Study (APHIRST) that enrolled children presenting with head trauma of any severity to 10 pediatric EDs in Australia and New Zealand between April 2011 and November 2014.[2,13] All EDs are members of the Paediatric Research in Emergency Departments International Collaborative (PREDICT) research network.[14]

We collected all rule-specific predictor and outcome variables for the PECARN rule for all head-injured children aged <18 years presenting with head trauma.[2,3,13] Based on the original PECARN rule, we included patients presenting within 24 h with a GCS of 14 or 15 and excluded patients meeting any of the following criteria: trivial mechanism of injury, GCS ≤13, penetrating trauma, known brain tumors, preexisting neurological disorder complicating assessment, patient with ventricular shunts or bleeding disorders, patient/family refusal to participate, referral from ED triage to an external provider (i.e., not seen in the ED), did not wait to be seen, or neuroimaging done prior to the transfer to a study site.

The outcome of ciTBI was defined as death from traumatic brain injury (TBI), neurosurgical intervention for TBI, intubation of more than 24 h for TBI, or hospital admission of two nights or more for TBI-related symptoms, associated with TBI on CT, defined as per the original PECARN study (admission for persistent neurological symptoms or signs such as persistent alteration in mental status, recurrent emesis due to head injury, persistent severe headache, or ongoing seizure management). TBI on CT was defined by any of the following descriptions: intracranial hemorrhage or contusion, cerebral edema, traumatic infarction, diffuse axonal injury, shearing injury, sigmoid sinus thrombosis, midline shift of intracranial contents or signs of brain herniation, diastasis of the skull, pneumocephalus, or skull fracture depressed by at least the width of the table of the skull.

The study was approved by the institutional ethics committees at each participating site. We obtained informed verbal consent from parents/guardians apart from instances of significant life-threatening or fatal injuries where participating ethics committees granted a waiver of consent.

The trial protocol (described in detail elsewhere[2,13]) was developed by the study investigators. The study was registered with the Australian New Zealand Clinical Trials Registry (ANZCTR) ACTRN12614000463673 and followed the Standards for Reporting of Diagnostic Accuracy studies guidelines.

Study procedures

Patients were enrolled by the treating ED clinician who collected clinical data. Data were collected on the PECARN rule inclusion and exclusion criteria, predictor variables, and outcome measures (Table 1), as well as demographic and epidemiological information. Patients were enrolled by the treating clinician who collected predictive clinical data in the clinical report form prior to any neuroimaging done. The clinical report form was completed directly by consultant-level clinicians and senior trainees or under their supervision for patients initially seen by junior trainees. We used the GCS scores as assigned by the ED clinician or, if not available, GCS scores at triage. Hospital admission was defined as admitted to inpatient ward, ED short-stay unit, or intensive care unit. A research assistant recorded ED and hospital management data after the visit and conducted up to six telephone follow-up attempts, between 14 and 90 days after injury, for patients who had not undergone neuroimaging. As per the

TABLE 1 Inclusion and exclusion criteria, predictor variables, and outcome measures of PECARN clinical decision rule

	PECARN	
	<2 years	**≥2 years**
Inclusion	Age <18 years; presenting with GCS 14 or 15 within 24 h of head injury	Age <18 years; presenting with GCS 14 or 15 within 24 h of head injury
Exclusion	Trivial mechanism of injury, defined by ground-level fall or walking or running into stationary objects and no signs or symptoms of head trauma other than scalp abrasions and lacerations Penetrating trauma Known brain tumors Preexisting neurological disorder Complicating assessment Patient with ventricular shunt Patient with bleeding disorder Neuroimaging at an outside hospital	Trivial mechanism of injury, defined by ground-level fall or walking or running into stationary objects and no signs or symptoms of head trauma other than scalp abrasions and lacerations Penetrating trauma Known brain tumors Preexisting neurological disorder Complicating assessment Patient with ventricular shunt Patient with bleeding disorder Neuroimaging at an outside hospital
Predictor variables[a]		
Mechanism of injury	Severe mechanism of injury (MVC with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by motorized vehicle; falls >0.9 m; or head struck by high-impact object)	Severe mechanism of injury (MVC with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by motorized vehicle; falls >1.5 m; or head struck by high-impact object)
History	LOC for ≥5 s Not acting normally per parent report	Any or suspected LOC History of vomiting Severe headache
Examination	GCS score <15 Other signs of altered mental status (agitation, somnolence, repetitive questioning, slow response to verbal communication) Palpable or unclear skull fracture Occipital, parietal, or temporal scalp hematoma	GCS score <15 Other signs of altered mental status (agitation, somnolence, repetitive questioning, slow response to verbal communication) Signs of basilar skull fracture (retroauricular bruising [Battle's sign], periorbital bruising [raccoon eyes], hemotympanum, cerebral spinal fluid otorrhea, or cerebral spinal fluid rhinorrhea)
Primary outcome	Clinically important TBI, defined as death from TBI, neurosurgical intervention for TBI (intracranial pressure monitoring, elevation of depressed skull fracture, ventriculostomy, hematoma evacuation, lobectomy, tissue debridement, dura repair, or other), intubation of more than 24 h for TBI or hospital admission of 2 nights or more for TBI[b], associated with TBI on CT[c]	Clinically important TBI, defined as death from TBI, neurosurgical intervention for TBI (intracranial pressure monitoring, elevation of depressed skull fracture, ventriculostomy, hematoma evacuation, lobectomy, tissue debridement, dura repair, or other), intubation of more than 24 h for TBI, or hospital admission of 2 nights or more for TBI[b], associated with TBI on CT[c]

Abbreviations: GCS, Glasgow Coma Scale; LOC, loss of consciousness; MVC, motor vehicle collision; PECARN, Pediatric Emergency Care Applied Research Network; TBI, traumatic brain injury.

[a]The absence of predictor variables indicates that cranial CT scan is unnecessary.

[b]Hospital admission for TBI defined by admission for persistent neurological symptoms or signs such as persistent alteration in mental status, recurrent emesis due to head injury, persistent severe headache, or ongoing seizure management.

[c]TBI on CT defined by any of the following descriptions: intracranial hemorrhage or contusion, cerebral edema, traumatic infarction, diffuse axonal injury, shearing injury, sigmoid sinus thrombosis, midline shift of intracranial contents or signs of brain herniation, diastasis of the skull, pneumocephalus, or skull fracture depressed by at least the width of the table of the skull.

original APHIRST study, this secondary analysis only included patients with complete follow-up data.

We used senior radiologist reports to determine the results of CT scans and operative reports for patients who underwent neurosurgery. Neurosurgical intervention was defined as intracranial pressure monitoring, elevation of depressed skull fracture, ventriculostomy, hematoma evacuation, lobectomy, tissue debridement, or dura repair. Site investigators, research assistants, and participating ED clinicians received formal training and were not blinded to the purpose of the study.

Data analysis

The PECARN algorithms provide the risk of ciTBI for children aged under 2 years and those 2 years and above separately; as such,

we analyzed our data in two groups. We stratified our cohort into the three categories of high, intermediate, and very low risk based on the PECARN predictor variables.[2] Children were considered to be at very low risk if none of the predictor variables were present. Children were classified as high or intermediate risk based on age-specific high- or intermediate-risk predictors, as reported in Figure 1.

Data were entered into Epidata (The Epidata Association), and later REDCap,[15] and analyzed using Stata 15 (StataCorp). Frequencies and percentages of demographic and injury characteristics, and clinical symptoms and outcomes, as well as mean child age (and standard deviation [SD]), were described for each age group and risk category. High- and intermediate-risk count frequencies were also explored between those with and without ciTBI. Finally, percentage of ciTBI within each combination of high and intermediate risk factors were calculated with 95% confidence intervals (CIs).

RESULTS

Of 20,137 children from the original cohort, 15,163 were eligible for analysis after applying PECARN inclusion and exclusion criteria in children with GCS 14 or 15; 4,011 (25.5%) were aged <2 years, and 11,152 (74.5%), aged ≥2 years. The majority of GCS scores were assigned by the ED clinician and only 148 of 15,163 (0.98%) of cases used GCS scores at triage for the analysis. Overall 1,528 (10.1%) were classified as high risk, 6,448 (42.5%) as intermediate risk, and 7,187 (47.4%) as low risk for ciTBI (Figure 1).

Clinical characteristics and outcomes of the analytic cohort by age group and PECARN risk category are reported in Table S1 (available as supporting information in the online version of this paper, which is available at http://onlinelibrary.wiley.com/doi/10.1111/acem.14308/full). The majority of children presented with GCS scores of 15 (96.6%). Most injuries were fall related (71.5%). Overall, 1,471 (9.7%) underwent cranial CT, 3,718 (24.5%) were admitted, a

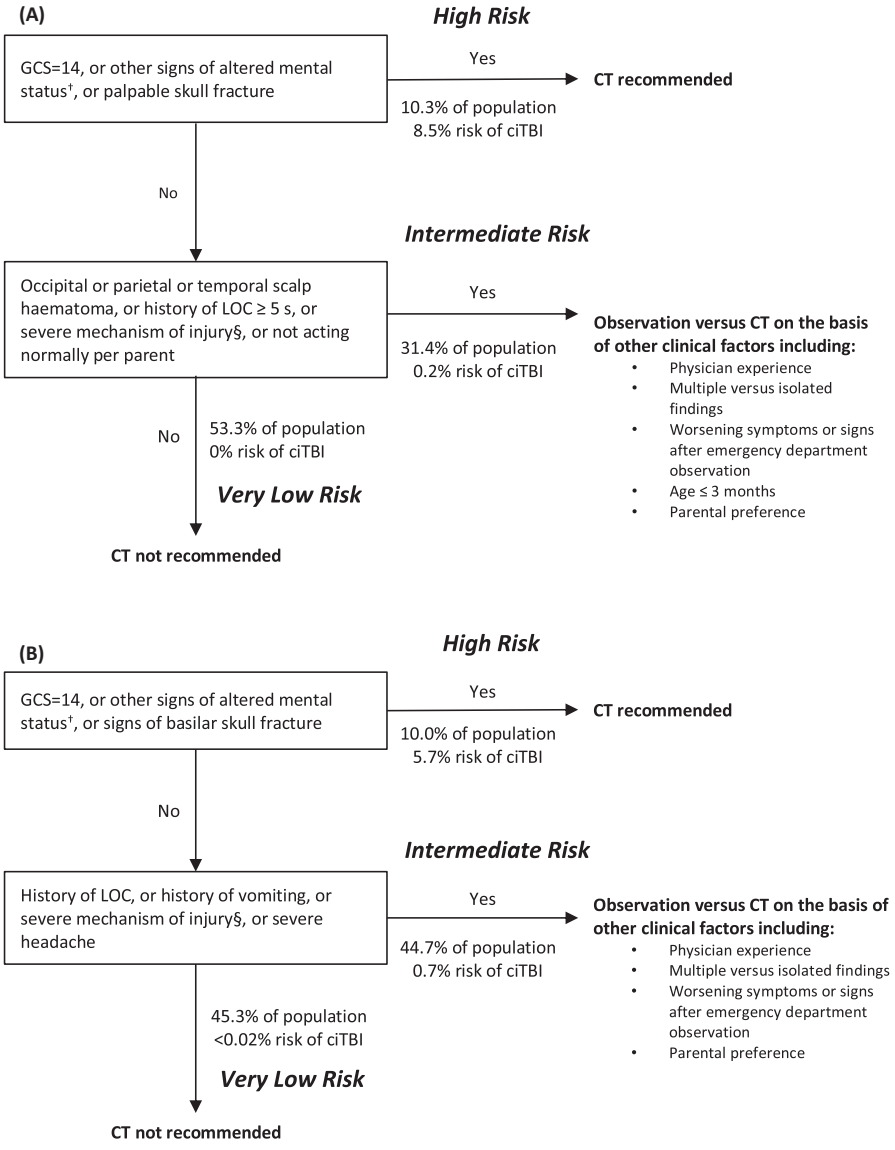

FIGURE 1 Children with GCS 14 and 15 from the APHIRST study stratified according to the PECARN CT algorithm for children younger than 2 years (A) and those aged 2 years and above (B).†Signs of altered mental status: agitation, somnolence, repetitive questioning or slow response to verbal communication. §Severe mechanism of injury: motor vehicle collision with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by motorized vehicle; falls of more than 0.9 m (or more than 1.5 m for B); or head struck by high-impact object. ciTBI, clinically important traumatic brain injury; GCS, Glasgow Coma Scale; LOC, loss of consciousness

ciTBI occurred in 0.9% (136 of 15,163), and 19 (0.1%) required neurosurgery. There was only one child in the very-low-risk category with ciTBI, who was missed; this child had no predictors, had a parenchymal hemorrhage revealed on CT, was admitted for ≥2 days, and did not require neurosurgery.

The high-risk group had higher rates of cranial CT, abnormal CT, admission, and ciTBI (45.2%, 17.0%, 56.6%, and 6.4%, respectively), compared to the intermediate-risk group (10.1%, 1.9%, 30.0%, and 0.6%, respectively) and very-low-risk group (1.8%, 0.2%, 12.7%, and 0.01%, respectively). The most common findings on CT in the high-risk group were skull fracture (13.3%), 17.8% were depressed; and 15.8% were basilar, intracranial hemorrhage/contusion (7.7%), and extraaxial (subdural or extradural) hemorrhage (4.9%). In the intermediate-risk group, cranial CT rates were higher in children aged ≥2 years (11.6%) compared to children aged <2 years (4.9%). Six children aged ≥2 years at intermediate risk required neurosurgery, four underwent craniotomy and elevation of depressed skull fracture, and two required hematoma evacuation. None of children aged <2 years at intermediate-risk required neurosurgery.

The most frequent high-risk predictor was altered mental status in both age groups (<2 years, 131/413, 31.7%; ≥2 years, 921/1,115, 82.6%). Severe mechanism of injury was the most common predictor variable in the intermediate-risk group for both ages (<2 years, 836/1,461, 57.2%; ≥2 years, 3,352/4,987, 67.2%).

The risk of ciTBI according to age-specific PECARN risk group stratification is reported in Figure 1. The frequency of ciTBI per age group based on the number of predictors present is described in Table 2. In the younger age group, 38 of 4,011 (0.9%) had a ciTBI. Of these 35 of 38 (92.1%) had one or more high-risk predictors, while three (7.9%) had only intermediate-risk predictors. A ciTBI was identified in 98 of 11,152 (0.9%) older children, of which 63 of 98 (64.3%) had one or more high-risk predictors, 34 of 98 (34.7%) had only intermediate-risk predictors, and one (1%) had no PECARN predictors.

Overall, most children classified at high risk (*n* = 1528) presented with only one high risk predictor (77.1%) while 21.5% presented with two predictors. Similarly, of the 6448 children in the intermediate risk group, the majority presented with only one intermediate risk predictor (77.2%) while 20.6% presented with two predictors. In both age groups, the risk of ciTBI increased as the number of predictors increased.

The most frequent high-risk predictors in children <2 years who had ciTBI were a palpable skull fracture (26/35, 74.3%) and altered mental status (24/35, 68.6%). In older children with a ciTBI the most frequent high-risk predictors were altered mental status (48/63, 76.2%) and GCS score of 14 (37/63, 58.7%). The frequency of ciTBI according to the type and number of high-risk predictors for both age groups is reported in Tables 3 and 4.

Of the 3 children <2 years with intermediate-risk predictors and ciTBI, two had an isolated nonfrontal scalp hematoma and one had both a scalp hematoma and did not act normally according to the parents. In older children with intermediate-risk predictors and ciTBI the most frequent were severe mechanism of injury (27/34, 79.4%) and vomiting (19/34, 55.9%). The highest frequency of ciTBI in older children occurred when all the intermediate risk predictors were present (25%, 95% CI = 0.6%–80.6%). Other combinations associated with a high frequency of ciTBI included severe mechanism of injury with severe headache (7.7%, 95% CI = 0.2%–36.0%) and loss of consciousness, vomiting, and severe mechanism of injury (3.3%, 95% CI = 0.7%–9.4%; Tables 5 and 6).

TABLE 2 Rates of ciTBI by combinations of intermediate risk predictors and high risk predictors

	Age <2 years (*n* = 4,011)			Age ≥2 years (*n* = 11,152)		
	n/N	%	(95% CI)	*n/N*	%	(95% CI)
Any predictors present	38/1,874	2.0	(1.4–2.8)	97/6,102	1.6	(1.3–1.9)
High-risk predictors only	35/413	8.5	(6.0–11.6)	63/1,115	5.7	(4.4–7.2)
• One predictor	14/342	4.1	(2.3–6.8)	35/836	4.2	(2.9–5.8)
• Two predictors	15/60	25.0	(14.7–37.9)	24/269	8.9	(5.8–13.0)
• Three predictors	6/11	54.5	(23.4–83.3)	4/10	40.0	(12.2–73.8)
Intermediate-risk predictors only	3/1,461	0.2	(0.0–0.6)	34/4,987	0.7	(0.5–1.0)
• One predictor	2/1,184	0.2	(0.0–0.6)	15/3,796	0.4	(0.2–0.7)
• Two predictors	1/245	0.4	(0.0–2.3)	15/1,086	1.4	(0.8–2.3)
• Three predictors	0/32	0.0	(0.0–10.9)	3/101	3.0	(0.6–8.4)
• Four predictors	0/0	0.0	—	1/4	25.0	(0.6–80.6)
No predictors present	0/2,137	0.0	(0.0–0.2)	1/5,049	0.0	(0.0–0.1)

Abbreviations: ciTBI, clinically important traumatic brain injury; *n*, number of ciTBI; *N*, number of patients for each group described in the first column of the table.

DISCUSSION

In this multicenter prospective cohort study, we have analyzed the PECARN algorithm risk stratification in detail in a large external cohort of children with minor head trauma. We have assessed the risk of ciTBI for each PECARN algorithms risk group and shown the risk of ciTBI associated with different combinations of high- or intermediate-risk predictors. There was only one child with ciTBI who was missed; this child in the very-low-risk category had no predictors, was admitted for ≥2 days, and did not require neurosurgery.

The majority of patients who were not at very low risk of ciTBI had a single predictor within the intermediate-risk category. Although PECARN secondary analyses on the risk of ciTBI associated with isolated intermediate-risk factors have been previously published, our study provides further clinically useful information on the risk of ciTBI (i) associated with isolated intermediate-risk predictors in an external population, (ii) in children with isolated high-risk predictors, and (iii) according to the type and combination of predictors within the high- and intermediate-risk groups.

Our study expands upon previous research by Nigrovic et al.,[16] which found that the risk of ciTBI increased in children with severe mechanism of injury plus one other PECARN predictors (altered mental status, any loss of consciousness, history of vomiting, clinical signs of basilar skull fracture, and severe headache). Our data have shown that as the number of predictor variables increases, there is an associated increased risk of ciTBI both overall and within the high- and intermediate-risk groups for children of both age groups.

Within the high-risk group, we found that most younger children presented with either a palpable skull fracture or altered mental status, while older children most often presented with altered mental status or GCS scores of 14. At the same time, we found that the isolated high-risk predictors associated with the lowest ciTBI risk was GCS 14 or altered mental status in the younger age group and altered mental status in the older children. A clinical decision analysis published by Hennelly et al.[17] determined the optimal imaging strategy for young children with minor head trauma considering health-related quality of life and radiation risk. They determined that the threshold above which CT for all patients became the preferred strategy according to the decision analysis model was when the probability of ciTBI was 4.8% or higher, with the threshold decreasing with lower radiation exposure, such as in in centers where rapid magnetic resonance imaging is available.[18] Based on this analysis our findings may help refine clinical decision making for CT in

TABLE 3 Rates of ciTBI by combinations of high-risk predictors in children aged <2 years

	GCS 14	Altered mental status[a]	Palpable skull fracture	ciTBI	*N*	%	(95% CI)
One risk	●			1	65	1.5	(0.0–8.3)
		●		4	197	2.0	(0.6–5.1)
			●	9	79	11.4	(5.3–20.5)
Two risks	●	●		4	19	21.1	(6.1–45.6)
	●		●	1	1	100.0	(2.5–100.0)
		●	●	10	40	25.0	(12.7–41.2)
Three risks	●	●	●	6	11	54.6	(23.4–83.3)

Abbreviation: ciTBI, clinically important traumatic brain injury; GCS, Glasgow Coma Scale.

[a]Signs of altered mental status: agitation, somnolence, repetitive questioning or slow response to verbal communication.

TABLE 4 Rates of ciTBI by combinations of high-risk predictors in children aged ≥2 years

	GCS 14	Altered mental status[a]	Basilar skull fracture[b]	ciTBI	*N*	%	(95% CI)
One risk	●			10	146	6.9	(3.3–12.2)
		●		20	644	3.1	(1.9–4.8)
			●	5	45	11.1	(3.7–24.1)
Two risks	●	●		23	260	8.9	(5.7–13.0)
	●		●	0	2	0.0	(0.0–84.2)
		●	●	1	7	14.3	(0.4–57.9)
Three risks	●	●	●	4	10	40.0	(12.2–73.8)

Abbreviation: ciTBI, clinically important traumatic brain injury; GCS, Glasgow Coma Scale.

[a]Signs of altered mental status: agitation, somnolence, repetitive questioning or slow response to verbal communication.

[b]Signs of basilar skull fracture: as retroauricular bruising (Battle's sign), periorbital bruising (raccoon eyes), hemotympanum, cerebral spinal fluid otorrhea, or cerebral spinal fluid rhinorrhea.

TABLE 5 Rates of ciTBI by combinations of intermediate-risk predictors in children aged <2 years

	Hematoma[a]	LOC[b]	Severe MOI[c]	Not acting normal	ciTBI	*N*	%	(95% CI)
One risk	●				2	259	0.8	(0.1–2.8)
		●			0	70	0.0	(0.0–5.1)
			●		0	610	0.0	(0.0–0.6)
				●	0	244	0.0	(0.0–1.5)
Two risks	●	●			0	5	0.0	(0.0–52.2)
	●		●		0	101	0.0	(0.0–3.6)
	●			●	1	34	2.9	(0.1–15.3)
		●	●		0	24	0.0	(0.0–14.3)
		●		●	0	8	0.0	(0.0–36.9)
			●	●	0	73	0.0	(0.0–4.9)
Three risks	●	●	●		0	5	0.0	(0.0–52.2)
	●	●		●	0	5	0.0	(0.0–52.2)
	●		●	●	0	15	0.0	(0.0–21.8)
		●	●	●	0	7	0.0	(0.0–41.0)
Four risks	●	●	●	●	0	0		

Abbreviation: ciTBI, clinically important traumatic brain injury; LOC, loss of consciousness; MOI, mechanism of injury.

[a]Hematoma: either occipital, parietal or temporal hematoma.

[b]LOC ≥5 s in children aged <2 years.

[c]Severe MOI defined as motor vehicle crash with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by motorized vehicle; falls >0.9 m; or head struck by high-impact object.

TABLE 6 Rates of ciTBI by combinations of intermediate risk predictors in children aged ≥2 years

	LOC[a]	Vomiting	Severe MOI[b]	Severe headache	ciTBI	*N*	%	(95% CI)
1 Risk	●				1	627	0.2	(0.0–0.9)
		●			4	854	0.5	(0.1–1.2)
			●		10	2279	0.4	(0.2–0.8)
				●	0	19	0.0	(0.0–17.7)
2 Risks	●	●			2	120	1.7	(0.2–5.9)
	●		●		3	486	0.6	(0.1–1.8)
	●			●	0	8	0.0	(0.0–36.9)
		●	●		9	453	2.0	(0.9–3.7)
		●		●	0	6	0.0	(0.0–45.9)
			●	●	1	13	7.7	(0.2–36.0)
3 Risks	●	●	●		3	90	3.3	(0.7–9.4)
	●	●		●	0	1	0.0	(0.0–97.5)
	●		●	●	0	3	0.0	(0.0–70.8)
		●	●	●	0	7	0.0	(0.0–41.0)
4 Risks	●	●	●	●	1	4	25.0	(0.6–80.6)

Abbreviation: ciTBI, clinically important traumatic brain injury; LOC, loss of consciousness; MOI, mechanism of injury.

[a]Any or suspected LOC in children aged ≥2 years.

[b]Severe MOI defined as motor vehicle crash with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by motorized vehicle; falls >1.5 m in children aged ≥2 years; or head struck by high-impact object.

the younger children with PECARN high risk of ciTBI variables of isolated GCS of 14 or altered mental status. However, the wide 95% CI boundaries of our results must be taken into account.

Within the intermediate-risk group, most older children presented with either severe mechanism of injury or vomiting. While the highest frequency of ciTBI was observed when all intermediate-risk

predictors were present, CIs were wide due to the small number of patients in each category. Of the three children <2 years with ciTBI in the intermediate-risk category, two had an isolated non–frontal scalp hematoma and one had both a scalp hematoma and did not act normally according to parents. Previous secondary analyses of the PECARN and APHIRST original data set have provided detailed risk estimates of ciTBI for each intermediate-risk predictor in isolation (meaning no other signs or symptoms of ciTBI), namely, vomiting, loss of consciousness, scalp hematoma, severe mechanism of injury, severe headache, and child not acting normally as per guardian; in isolation they were associated with a very low risk of ciTBI of less than 1%.[16,19–25] Our study adds to this literature by providing ciTBI risk estimates for different combinations of predictors within the PECARN high- and intermediate-risk groups. The PECARN risk stratification and the detailed risk estimates of ciTBI according to the presence of isolated predictors or their combination are helpful to further refine clinical decision making by contributing to the overall clinician judgment.

LIMITATIONS

The results of our study should be interpreted in light of its limitations. Although this is the second largest cohort of patients with minor head trauma and prospectively collected PECARN predictor variables, the limited sample size of patients with ciTBI resulted in large CIs of risk estimates for some predictor variables. In addition, there were only three children in the younger age group with ciTBI in the intermediate category, which prevented further analysis on risk refinement based on number or types of predictors present.

CT scans were obtained on a minority of patients; however, the definition of the study outcome, namely, the frequency of ciTBI, which is the PECARN primary outcome variable, is not influenced by the CT scan rate. In the original APHIRST study 10% of patients were lost to follow up and were excluded from the analysis (if they did not have neuroimaging during the follow-up period), as in these patients we could not determine whether a ciTBI was present or absent.

CONCLUSIONS

The rates of clinically important traumatic brain injury for each of the PECARN algorithms risk group in our study were consistent with the original PECARN study. The risk estimates of clinically important traumatic brain injury for different combinations of high- and intermediate-risk predictors provided by this study will help further support and refine clinical judgment and decision making on neuroimaging.

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CONFLICT OF INTEREST

The authors have no potential conflicts to disclose.

AUTHOR CONTRIBUTIONS

Franz E. Babl conceived the main study, and Silvia Bressan and Franz E. Babl conceived this study. Franz E. Babl obtained grant funding and provided overall supervision. Silvia Bressan and Nitaa Eapen provided the initial draft of the paper. All authors designed the study, obtained the data, and provided supervision. Stephen Hearps analyzed the data. Amanda Williams supervised acquisition of the data. All authors contributed to the interpretation of the data, drafted or revised the paper critically, gave final approval to be published, and agreed to be accountable for all aspects of the work.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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