Risk of Traumatic Brain Injuries in Infants Younger than 3 Months With Minor Blunt Head Trauma

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Study objective: Infants with head trauma often have subtle findings suggestive of traumatic brain injury. Prediction rules for traumatic brain injury among children with minor head trauma have not been specifically evaluated in infants younger than 3 months old. We aimed to determine the risk of clinically important traumatic brain injuries, traumatic brain injuries on computed tomography (CT) images, and skull fractures in infants younger than 3 months of age who did and did not meet the age-specific Pediatric Emergency Care Applied Research Network (PECARN) low-risk criteria for children with minor blunt head trauma.

Methods: We conducted a secondary analysis of infants <3 months old in the public use data set from PECARN's prospective observational study of children with minor blunt head trauma. Main outcomes included (1) clinically important traumatic brain injury, (2) traumatic brain injury on CT, and (3) skull fracture on CT.

Results: Of 10,904 patients <2 years old, 1,081 (9.9%) with complete data were <3 months old; most (750/1081, 69.6%) sustained falls, and 633/1081 (58.6%) underwent CT scans. Of the 514/1081 (47.5%) infants who met the PECARN low-risk criteria, 1/514 (0.2%, 95% confidence interval [CI] 0.005% to 1.1%), 10/197 (5.1%, 2.5% to 9.1%), and 9/197 (4.6%, 2.1% to 8.5%) had clinically important traumatic brain injuries, traumatic brain injuries on CT, and skull fractures, respectively. Of 567 infants who did not meet the low-risk PECARN criteria, 24/567 (4.2%, 95% CI 2.7% to 6.2%), 94/436 (21.3%, 95% CI 17.6% to 25.5%), and 122/436 (28.0%, 95% CI 23.8% to 32.5%) had clinically important traumatic brain injuries, traumatic brain injuries, and skull fractures, respectively.

Conclusion: The PECARN traumatic brain injury low-risk criteria accurately identified infants <3 months old at low risk of clinically important traumatic brain injuries. However, infants at low risk for clinically important traumatic brain injuries remained at risk for traumatic brain injuries on CT, suggesting the need for a cautious approach in these infants. [Ann Emerg Med. 2021;78:321-330.]

Please see page 322 for the Editor's Capsule Summary of this article.

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INTRODUCTION

Background and Importance

Blunt head trauma is common in children younger than 1 year, accounting for approximately 81,000 emergency department (ED) visits annually in the United States.[1] Prediction rules have helped determine whether cranial computed tomography (CT) scans can be avoided after minor head trauma in this young age group, although the decision remains particularly challenging in those younger than 3 months old.[2] These younger infants can have subtle signs and symptoms yet have clinically important traumatic brain injuries.[3] Traumatic brain injuries without any clearly concerning signs and symptoms are more prevalent in young infants than in older children, prompting recommendations for a low threshold to obtain CTs.[4,5] As a consequence, clinicians obtain CTs more frequently for these youngest infants.[6] Clinicians must balance the risk of missing clinically important traumatic brain injuries, however, with the risk of radiation-induced malignancies from CTs, understanding that the radiation risk increases as age decreases.[7]

Prior studies of minor head trauma have typically combined the youngest infants with the group of children younger than 1 to 2 years, with little data specifically addressing those younger than 3 months old. In retrospective and prospective observational studies, it was not infrequent for infants younger than 3 months old with traumatic brain injuries after minor head trauma to have had seemingly minor mechanisms of injury (eg, falls from low heights) and minimal physical findings (eg, only small scalp hematomas).[2,6,8-13] In the Pediatric Emergency Care Applied Research Network (PECARN)'s cohort of 2,998 children younger than 24 months with minor blunt head trauma whose only clinical findings were scalp hematomas, those

Editor's Capsule Summary

What is already known on this topic

Prediction rules for traumatic brain injury have not been specifically evaluated in infants younger than 3 months who present with minor blunt head trauma.

What question this study addressed

How accurate is the PECARN prediction rule in identifying children younger than 3 months at low risk of clinically important traumatic brain injuries.

What this study adds to our knowledge

This retrospective database study reported that only one of the 514 infants who met the PECARN low-risk criteria had a clinically important traumatic brain injury, but 9 others who had no other concerning findings had intracranial bleeding on CT.

How this is relevant to clinical practice

Physicians may use the PECARN head trauma rule among young infants but should be aware that it does not rule out traumatic brain injuries.

younger than 3 months were at higher risk of traumatic brain injuries on CT compared to older infants and children.[6] Details of those younger than 3 months in the PECARN cohort, however, have not been analyzed in detail.

Goals of This Investigation

To help inform decisionmaking, we aimed to determine the risk of clinically important traumatic brain injuries, traumatic brain injuries on CT, and skull fractures on CT in infants younger than 3 months with blunt head trauma who did and did not meet the age-specific PECARN low-risk criteria.

METHODS

Study Design and Setting

We performed a secondary analysis of the public use data set from the PECARN prospective observational study conducted in 25 EDs in the United States.[2] Data were collected between June 2004 and September 2006. The parent study was approved by each site's institutional review board. This secondary analysis was deemed exempt from Columbia University's full institutional review board approval. We followed the Strengthening the Reporting of Observational Studies in Epidemiology guidelines to report the present study.[14]

Selection of Participants

Participants enrolled in the main cohort study included patients younger than 18 years presenting to the ED within 24 hours of head trauma with Glasgow Coma Scale scores of 14 to 15. Excluded were patients with penetrating head trauma, preexisting neurologic disease precluding clinical assessment, or syncope or seizure preceding the head trauma and patients transferred to the ED with neuroimaging already obtained. The parent study also excluded patients with trivial trauma (defined as ground-level falls or running into stationary objects), those without evidence of traumatic brain injury other than scalp abrasions or lacerations and patients with bleeding disorders or ventricular shunts. In the current study, we only included infants younger than 3 months.

Outcomes

Our outcomes were (1) clinically important traumatic brain injury, (2) traumatic brain injury on CT, and (3) skull fracture on CT. As in the original study, clinically important traumatic brain injury was defined as death from the traumatic brain injury, traumatic brain injuries requiring neurosurgical procedures, intubation for at least 24 hours for the traumatic brain injury, or hospitalization for 2 or more nights because of head trauma and ongoing signs/symptoms in association with traumatic brain injury on CT. The criterion of at least 2 nights of hospitalization was determined by consensus and defined to exclude brief intubations for imaging or overnight admission for minor or questionable CT findings. In the parent study, research coordinators or site investigators reviewed the medical records of hospitalized patients to determine the presence of clinically important traumatic brain injuries and performed standardized telephone surveys and reviews of medical records for those patients discharged from the ED to identify any infants with missed traumatic brain injuries.[2] Traumatic brain injuries on CT were defined as any acute traumatic intracranial findings or skull fractures depressed by at least the width of the table of the skull. Skull fractures were defined as any skull fracture seen on CT, including basilar skull fractures, depressed skull fractures, and other fractures meeting the definition of traumatic brain injury on CT, or those requiring neurosurgical intervention (eg, depressed fractures requiring elevation). Basilar skull fractures were not differentiated from other skull fractures in the available data set.

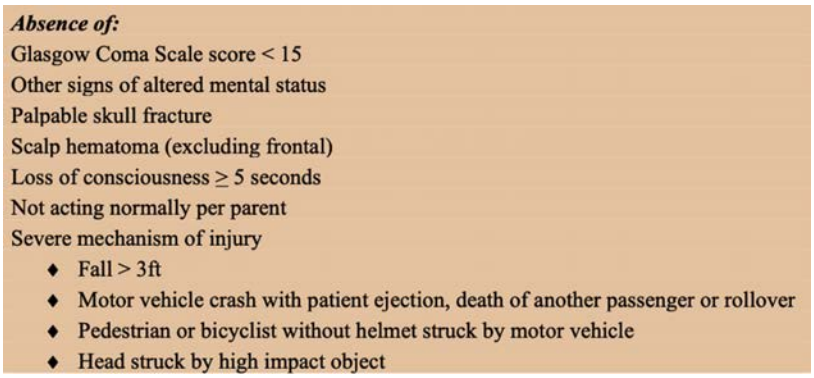

Figure 1. PECARN traumatic brain injury low-risk criteria for children <2 years old.

CT scans were obtained at the treating clinicians' discretion and were interpreted by site faculty radiologists without knowledge of the clinical findings documented on the case report forms. For inconclusive scans, a central study pediatric radiologist made definitive interpretations without knowledge of clinical data.[2] Patients could meet the definition for more than one outcome.

Analysis

We conducted descriptive analyses in 2 main groups: (1) those who met the PECARN low-risk criteria that were developed for children younger than 2 years; and (2) those who did not meet those PECARN low-risk criteria. Of those who met the PECARN low-risk criteria, we also analyzed 2 subgroups: (1) those who had no other clinical signs or symptoms suggestive of head trauma beyond those of the PECARN criteria; and (2) those who met the PECARN low-risk criteria but had other clinical findings of head trauma (not in the PECARN criteria). The low-risk PECARN criteria for children younger than 2 years are listed in Figure 1.

For the subgroups of patients who were at low risk based on the PECARN low-risk criteria, we defined the presence or absence of other clinical signs and symptoms based on those factors collected in the cohort study but not included in the PECARN low-risk criteria for children younger than 2 years old, as had been done for previous secondary analyses.[6,9,12] These factors included any loss of consciousness (ie, not just ≥5 seconds as defined in the PECARN rule), any vomiting, abrasions/lacerations/hematomas above the clavicle other than on the scalp, frontal scalp hematomas, neurologic deficits on examination, and signs of basilar skull fracture.

We calculated the frequencies and proportions of outcomes in each group and exact binomial confidence intervals (CIs) for the proportions. All analyses were performed using SAS University Edition (SAS Institute, Cary, NC).

RESULTS

Characteristics of Study Participants

Figure 2 shows the derivation of our study population. The data set consisted of 10,904 children <2 years old with minor blunt head trauma, of whom 1,147 (10.5%) were <3 months old. There were 65 infants <3 months old in the database whom we excluded due to missing data regarding the presence or absence of clinical variables in the PECARN rule. We excluded one infant for missing outcome data. Therefore, 1,081 infants (94%) had complete data and were analyzed. The rate of CT use in the 65 excluded patients (53.9%) was similar to that in the 1,081 included infants (58.6%). Among the 65 excluded infants, the rates of clinically important traumatic brain injury (0%) and traumatic brain injury on CT (5.6%) were lower than those in the analyzed group (2.3% and 16.3%, respectively). Of the 1,081 infants, 282 (26.1%) were <1 month old, 445 (41.2%) were between 1 and 2 months old, and 354 (32.8%) were between 2 and 3 months old. Overall, 750 (69.6%) of the infants sustained falls.

Table 1 displays the characteristics of patients who did and did not meet the PECARN low-risk criteria as well as the 2 subgroups of patients who met the PECARN low-risk criteria and either did or did not have other clinical findings. Of the 514 infants who met the PECARN low-risk criteria, abrasions/lacerations/nonscalp hematomas (156, 33.1%) and/or frontal scalp hematomas (69, 13.4%) were relatively common. One half of the infants who met the PECARN low-risk criteria had no other documented findings (261, 50.1%).

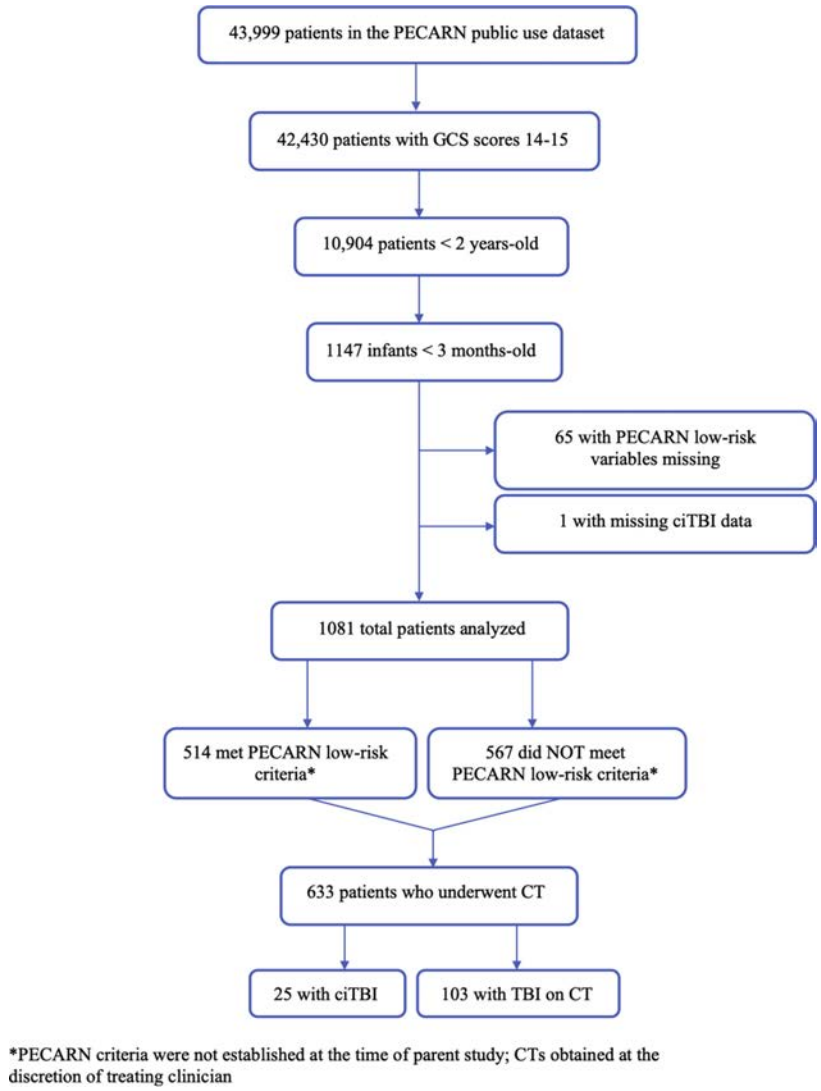

Figure 2. Study population.

Main Results

Table 2 shows the risk of clinically important traumatic brain injury, traumatic brain injury on CT, and skull fracture on CT among the 2 main analytic groups and 2 subgroups. Among patients who did not meet the PECARN low-risk criteria, the rate of clinically important traumatic brain injury was 4.2% (95% CI 2.7% to 6.2%); 4 (16.7%, 95% CI 4.7% to 37.4%) of these 24 infants with clinically important traumatic brain injury underwent neurosurgery. Traumatic brain injury on CT was relatively common among those who did not meet the PECARN low-risk criteria (21.3%, 95% CI 17.6% to 25.5%), as were skull fractures (28.0%, 95% CI 23.8% to 32.5%). The risk of each of these 3 outcomes did not differ substantially across the 3 age groups studied. There were 5 infants who did not meet the PECARN low-risk criteria who met the definition of traumatic brain injury on CT based solely on having fractures depressed by the width of the skull. One of these infants also met the definition of clinically important traumatic brain injury due to undergoing neurosurgery for the depressed skull fracture. Table E1 (available at http://www.annemergmed.com) notes concurrent traumatic brain injuries in those infants with skull fractures who did not meet the PECARN low-risk criteria.

Among the 514 infants who met the PECARN low-risk criteria, only one had a clinically important traumatic brain injury (0.2%, 95% CI 0.005% to 1.1%), 10 had traumatic

Table 1. Characteristics of infants <3 months old with minor blunt head trauma.*

Characteristic	Total (n=1081)	Did Not Meet PECARN Low-Risk Criteria§ (n=567)	Met PECARN Low-Risk Criteria§ (n=514)	Met PECARN Low-Risk Criteria and Had No Other Clinical Findings‖,¶ (n=261)	Met PECARN Low-Risk Criteria But Had Other Clinical Findings‖,¶ (n=246)
Age					
<1 mo	282 (26.1)	141 (24.9)	141 (27.4)	88 (33.7)	51 (20.7)
1–2 mo	445 (41.2)	239 (42.2)	206 (40.1)	100 (38.3)	103 (41.9)
2–3 mo	354 (32.8)	187 (33.0)	167 (32.5)	73 (28.0)	92 (37.4)
Female	513 (47.5)	276 (48.7)	237 (46.1)	124 (47.5)	108 (43.9)
Race					
White	532 (49.2)	321 (56.6)	211 (41.1)	84 (32.2)	127 (51.6)
Black	405 (37.5)	177 (31.2)	228 (44.4)	138 (52.9)	84 (34.2)
Asian	14 (1.3)	6 (1.1)	8 (1.6)	3 (1.2)	5 (2.0)
American Indian/Alaskan Native	1 (0.1)	1 (0.2)	0 (0)	0 (0)	0 (0)
Pacific Islander	2 (0.2)	2 (0.4)	0 (0)	0 (0)	0 (0)
Other	39 (0.2)	19 (3.4)	20 (3.9)	9 (3.5)	11 (4.5)
Missing	88 (8.1)	41 (7.2)	47 (9.1)	27 (10.3)	19 (7.7)
Ethnicity					
Hispanic	134 (12.4)	73 (12.9)	61 (11.9)	32 (12.3)	29 (11.8)
Non-Hispanic	544 (50.3)	260 (45.9)	284 (55.3)	142 (54.4)	137 (55.7)
Missing	403 (37.3)	234 (41.3)	169 (32.9)	87 (33.3)	80 (32.5)
Mechanism of injury					
Occupant in a motor vehicle crash	31 (2.9)	19 (3.4)	12 (2.3)	5 (1.9)	7 (2.9)
Pedestrian struck by moving vehicle	2 (0.2)	2 (0.4)	0 (0)	0 (0)	0 (0)
Bike rider struck by automobile	1 (0.1)	0 (0)	1 (0.2)	1 (0)	0 (0)
Other wheeled transport crash	6 (0.6)	2 (0.4)	4 (0.8)	0 (0)	4 (1.6)
Fall to ground from standing/walking/running	32 (3.0)	13 (2.3)	19 (3.7)	9 (3.5)	10 (4.1)
Walked or ran into stationary object	11 (1.0)	3 (0.5)	8 (1.6)	1 (0.4)	7 (2.9)
Fall from elevation	750 (69.6)	425 (75.5)	325 (63.2)	180 (69.0)	142 (57.7)
Fall downstairs	49 (4.6)	21 (3.7)	28 (5.5)	13 (5.0)	14 (5.7)
Assault	21 (2.0)	8 (1.4)	13 (2.5)	6 (2.3)	6 (2.4)
Object struck head	80 (7.4)	27 (4.8)	53 (10.3)	22 (8.4)	31 (12.6)
Other	94 (8.7)	43 (7.6)	51 (9.9)	24 (9.2)	25 (10.2)
Symptoms and signs†					
PECARN risk factors for children <2 years old					
Severe mechanism of injury‡	268/1077 (24.9)	268/563 (47.6)	0/514 (0)	0/261 (0)	0/246 (0)
Acting abnormally per guardian	176/1044 (16.9)	176/530 (33.2)	0/514 (0)	0/261 (0)	0/246 (0)

Table 1. Continued.

Characteristic	Total (n=1081)	Did Not Meet PECARN Low-Risk Criteria[§] (n=567)	Met PECARN Low-Risk Criteria[§] (n=514)	Met PECARN Low-Risk Criteria and Had No Other Clinical Findings[‖,¶] (n=261)	Met PECARN Low-Risk Criteria But Had Other Clinical Findings[‖,¶] (n=246)
Loss of consciousness ≥5 sec	26/1032 (2.5)	26/518 (5.0)	0/514 (0)	0/261 (0)	0/246 (0)
Glasgow Coma Scale score=14	92/1081 (8.5)	92/567 (16.2)	0/514 (0)	0/261 (0)	0/246 (0)
Other signs of altered mental status	177/1077 (16.4)	177/563 (31.4)	0/514 (0)	0/261 (0)	0/246 (0)
Palpable skull fracture	13/1080 (1.2)	13/566 (2.3)	0/514 (0)	0/261 (0)	0/246 (0)
Nonfrontal scalp hematoma	223/1078 (20.7)	223/564 (39.5)	0/514 (0)	0/261 (0)	0/246 (0)
Other findings (not in the PECARN rule)					
Neurologic deficit	2/1064 (0.2)	2/556 (0.4)	0/508 (0)	0/261 (0)	0/244 (0)
Abrasion/laceration or nonscalp hematoma above the clavicle	262/868 (30.2)	106/397 (26.7)	156/471 (33.1)	0/261 (0)	156/203 (76.9)
Vomiting	123/1077 (11.4)	78/565 (13.8)	45/512 (8.8)	0/261 (0)	45/245 (18.4)
Frontal scalp hematoma	126/1078 (11.7)	57/564 (10.1)	69/514 (13.4)	0/261 (0)	69/246 (28.1)
Signs of basilar skull fracture	1/1073 (0.1)	1/561 (0.2)	0/512 (0)	0/261 (0)	0/246 (0)
Loss of consciousness <5 sec	10/1078 (0.9)	7/564 (1.2)	3/514 (0.6)	0/261 (0)	3/246 (1.2)

*All results are provided as n (%). For mechanism of injury and symptoms and signs, denominators vary due to missing data.
†Patients may have more than one symptom or sign.
‡Severe mechanism of injury is defined as motor vehicle crash with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by a motorized vehicle; falls of more than 3 feet; or head struck by a high-impact object.
§Low-risk criteria include nonsevere mechanism of injury, Glasgow Coma Scale score of 15, and absence of the following: other signs of altered mental status, palpable skull fracture, loss of consciousness ≥5 seconds, parental report of acting abnormally, and nonfrontal scalp hematoma.
‖Other findings include loss of consciousness <5 seconds, any vomiting, abrasions/lacerations/nonscalp hematomas above the clavicle, frontal scalp hematomas, neurologic deficit on examination, and signs of basilar skull fractures.
¶Last 2 columns do not sum to 514 because of infants with missing clinical findings. To meet the definition of "Met PECARN Low-Risk Criteria and Had No Other Clinical Findings", we required that patients have no missing clinical findings. We allowed for patients with missing variables in the last column if at least one "Other Clinical Finding" was present.

brain injuries on CT (5.1%, 95% CI 2.5% to 9.1%), and 9 had skull fractures (4.6%, 95% CI 2.1% to 8.5%). Two of the 9 infants with skull fractures also had traumatic brain injuries on CT (22.2%, 95% CI 2.8% to 6.0%). There were no infants who met the PECARN low-risk criteria who had skull fractures that by themselves met the definition of traumatic brain injury on CT or clinically important traumatic brain injury. Of the 261 infants who were classified as low risk by the PECARN criteria and had no other clinical signs or symptoms, none had clinically important traumatic brain injury (95% CI 0 to 1.4%), and the rate of traumatic brain injury on CT was 4.9% (95% CI 1.3% to 12.0%). When we removed the 44 infants with mechanisms of injury that were not expected to occur in this age group (eg, bike rider struck by an automobile, fall to ground from standing/walking/running, or walked/ran into stationary object), the results were unchanged (data available on request).

The characteristics of the 10 infants who were low risk by the PECARN criteria and found to have traumatic brain injuries on CT are noted in Table 3, including the 1 infant with clinically important traumatic brain injury. The most common mechanism of injury in these infants was a fall less than 3 feet. Eight of the infants were younger than 2 months old. The most common symptoms or signs among these infants were abrasions/lacerations or hematomas above the clavicle, excluding hematomas of the scalp. Four of the 10 infants were asymptomatic, meaning that they met PECARN low-risk criteria and also had none of the following: loss of consciousness of any duration, vomiting, abrasions/lacerations/hematomas above the clavicle other than on the scalp, frontal scalp hematomas, neurologic deficits on

Table 2. Risk of clinically important traumatic brain injury, traumatic brain injury on CT, and skull fracture based on PECARN predictors and other clinical findings.*

Outcome	Did Not Meet PECARN Low-Risk Criteria	Met PECARN Low-Risk Criteria	Met PECARN Low-Risk Criteria and Had No Other Findings[§,‖]	Met PECARN Low-Risk Criteria But Had Other Clinical Findings[§,‖]
Clinically important traumatic brain injury	24/567 (4.2%; 2.7–6.2)	1/514 (0.19%; 0.0–1.1)	0/261 (0%; 0–1.4)	1/246 (0.4%; 0–2.2)
<1 mo	8/141 (5.7%; 2.5–10.9)	1/141 (0.7%; 0.0–3.9)	0/88 (0%; 0.0–4.1)	1/51 (2.0%; 0.05–10.4)
1–2 mo	9/239 (3.8%; 1.7–7.0)	0/206 (0%; 0.0–1.8)	0/100 (0%; 0.0–3.6)	0/103 (0%; 0.0–3.5)
2–3 mo	7/187 (3.1%, 1.5–7.6)	0/167 (0%; 0.0–2.2)	0/73 (0%: 0.0–4.9)	0/92 (0%; 0.0–3.9)
Traumatic brain injury on CT	93/436 (21.3%; 17.6–25.5)[‡]	10/197 (5.1%; 2.5–9.1)[‡]	4/82 (4.9%; 1.3–12.0)	6/114 (5.3%; 2.0–11.1)
<1 mo	20/105 (19.1%; 12.0–27.9)	4/63 (6.4%; 1.8–15.5)	2/31 (6.5%; 0.8–21.4)	2/31 (6.5%; 0.8–21.4)
1–2 mo	41/182 (22.5%; 16.7–29.3)	4/80 (5.0%; 1.4–12.3)	2/35 (5.7%; 0.7–19.2)	2/45 (4.4%; 0.5–15.1)
2–3 mo	32/149 (21.5%; 15.2–28.9)	2/54 (3.7%; 0.5–12.7)	0/16 (0%; 0.0–20.6)	2/38 (5.3%; 0.6–17.7)
Skull fracture on CT[†]	122/436 (28.0%; 23.8–32.5)	9/197 (4.6%; 2.1–8.5)	3/82 (3.7%; 0.8–10.3)	5/114 (4.4%; 1.4–9.9)
<1 mo	26/105 (24.8%; 16.9–34.1)	6/63 (9.5%; 3.6–19.6)	2/31 (6.5%; 0.8–21.4)	3/31 (9.7%; 2.0–25.8)
1–2 mo	55/182 (30.2%; 23.7–37.5)	2/80 (2.5%; 0.3–8.7)	1/35 (2.9%; 0.1–14.9)	1/45 (2.2%; 0.1–11.8)
2–3 mo	41/149 (27.5%; 20.5–35.4)	1/54 (1.9%; 0.0–9.9)	0/16 (0%; 0–20.6)	1/38 (2.6%; 0.1–13.8)

*Cell contents are n/N (%; 95% exact binomial CI).
[†]Outcome includes infants with any skull fractures on CT, including those who met criteria for traumatic brain injury and/or clinically important traumatic brain injury.
[‡]Denominator includes all infants <3 months old without missing data who also had CT performed.
[§]Other findings include loss of consciousness <5 seconds, any vomiting, abrasions/lacerations/nonscalp hematomas above the clavicle, frontal scalp hematomas, neurologic deficit on examination, and signs of basilar skull fractures.
[‖]Last 2 columns do not sum to 514 because of infants with missing clinical findings.

examination, or signs of basilar skull fracture. Nine of the 10 infants with traumatic brain injuries on CT who met the low-risk PECARN criteria did not have documented scalp hematomas.

We performed a sensitivity analysis in which those infants who were excluded due to missing PECARN variables (n=65) were included in the group of patients who did not meet low-risk criteria. This changed the clinically important traumatic brain injury rate in this group from 4.2% to 3.8% and the traumatic brain injury on CT rate from 21.5% to 20.1%. When the excluded infants were instead included in the low-risk group, the clinically important traumatic brain injury rate in that group changed from 0.19% to 0.17% and the traumatic brain injury on CT rate changed from 5.1% to 4.7%.

LIMITATIONS

Our study is not without limitations. We did not have granular details on mechanisms of injury other than the general category and whether the mechanism was in the PECARN high-risk stratum or not. In our primary analysis, we also chose to include 44 infants whose mechanisms of injury were inconsistent with age (eg, bike rider struck by an automobile, fall to ground from standing/walking/running, or walked/ran into stationary object) because these mechanisms may have represented the caregiver's mechanism of injury in conjunction with the infant rather than that of the infant. It is possible that these mechanisms were reported incorrectly, but our study results were unchanged when these infants were excluded from the analysis.

In addition, the PECARN head trauma low-risk criteria should not be applied to patients with suspected abusive head trauma due to unreliable parent histories regarding the mechanism of injury, timing of the event, or patient symptoms.[15] We do not know whether some infants in our study sample had CTs obtained due to concern for nonaccidental head trauma. As clinicians tend to be cautious in the care of infants, we also cannot be certain that some infants were not hospitalized for 2 or more nights based on age alone rather than for concerning signs and symptoms, although that was specified in the PECARN study protocol.[16] The PECARN public use data set neither contains information regarding the duration of hospitalization for those infants who did not meet the definition of clinically important traumatic brain injury but had intracranial injuries nor does it contain data on skull fractures diagnosed by plain radiograph as opposed to skull fractures diagnosed by CT. Finally, clinicians did not obtain CTs for all patients; the clinicians' decisions to

Table 3. Infants who met PECARN low-risk criteria and were found to have traumatic brain injury on CT.

Patient	Age	Sex	Mechanism of Injury	Symptoms and Signs	Findings on CT	Clinically Important Traumatic Brain Injury*
1	<1 mo	M	object struck head accidentally	abrasion/laceration on frontal scalp	skull fracture and intracerebral hematoma	Yes, hospitalized ≥2 nights
2	<1 mo	M	fall <3 ft	None	subdural hematoma	No
3	<1 mo	M	fall <3 ft	None	skull fracture and subarachnoid hemorrhage	No
4	<1 mo	M	object struck head accidentally	abrasion/laceration/ hematoma on face	cerebral edema and subarachnoid hemorrhage	No
5	1–2 mo	F	fall <3 ft	abrasion/laceration/ hematoma on face and abrasion/laceration on frontal scalp	intracerebral hematoma and extraaxial hematoma	No
6	1–2 mo	M	walked or ran into stationary object	abrasion/laceration/ hematoma on face and frontal scalp hematoma	extraaxial hematoma and subdural hematoma	No
7	1–2 mo	M	Other	None	cerebral contusion	No
8	1–2 mo	M	fall <3 ft	None	subdural hematoma	No
9	2–3 mo	M	fall <3 ft	vomiting and abrasion/ laceration/hematoma on face	extraaxial hematoma	No
10	2–3 mo	F	Other	abrasion/laceration on parietal scalp	subarachnoid hemorrhage	No

*Clinically important traumatic brain injury was defined as death from the traumatic brain injury, traumatic brain injury requiring neurosurgical procedure, intubation for at least 24 hours for the traumatic brain injury, or hospitalization for 2 or more nights because of head trauma in association with traumatic brain injury on CT.

obtain CTs may have varied based on their perceptions of the severity of the infants' signs or symptoms. Therefore, the true prevalence of traumatic brain injuries on CT could be higher or lower.

DISCUSSION

Among infants <3 months old who sustain minor blunt head trauma, our analysis suggests that the PECARN prediction rules are highly sensitive to identify those at low risk of clinically important traumatic brain injuries. However, the rate of traumatic brain injuries on CT in this low-risk group was more than 5%, suggesting the need to maintain a low threshold for CT. The rate of traumatic brain injury on CT remained nearly 5% in those infants who both met the PECARN low-risk criteria and had no other clinical findings suggestive of traumatic brain injury. The risk of clinically important traumatic brain injuries in those young infants who did not meet the PECARN low-risk criteria was higher than that reported from the overall PECARN cohort.[2] Although CT use should be minimized due to the risks of radiation, the substantial prevalence of clinically important traumatic brain injuries and traumatic brain injuries on CT in those who did not meet the PECARN low-risk criteria suggests that CT use in this population is often appropriate. Despite the lack of definitive data regarding the long-term effects of specific traumatic CT findings in this young age group, traumatic brain injuries in childhood have been associated with neurocognitive impairments.[17-19] Infants found to have any traumatic brain injury on CT may warrant close developmental follow-up.

Prior studies have shown a relationship between age and risk of traumatic brain injury after minor head trauma, with younger infants at higher risk.[3] Even seemingly asymptomatic infants have an increased risk of traumatic brain injury compared to asymptomatic older infants and children.[4,5,20] In our study, several infants with no symptoms or seemingly minor findings (such as abrasions/lacerations) had important CT findings, including extraaxial hematomas, but these infants did not have clinically important traumatic brain injuries. Although the characteristics of scalp hematomas may help differentiate those with and without traumatic brain injuries,[21] several infants in our study with traumatic brain injuries on CT had no scalp hematomas. Infants younger than 3 months have also been found to have a higher prevalence of skull fractures after head trauma than

older children, even in the absence of scalp hematomas.[22] Skull fractures occur commonly in young infants, as little resultant force appears necessary for the skull deformation needed to cause fractures.[23] Some data suggest that ultrasound can be used to accurately diagnose skull fractures[24-26] but is limited in its ability to detect traumatic brain injuries that are not in the ventricular and periventricular regions,[27] although advances are being made in detection.[28] Rapid MRI performed without sedation has high sensitivity in detecting traumatic brain injuries in children but has not been evaluated specifically in young infants.[29,30]

Although our sample size did not allow us to precisely determine the risk of clinically important traumatic brain injury and traumatic brain injury on CT in infants with specific isolated PECARN rule findings (eg, solely having a severe mechanism of injury), prior data suggest that individual PECARN rule findings have somewhat different risk profiles for traumatic brain injury. In the cohort of children <2 years old in the PECARN data set, clinically important traumatic brain injuries occurred in 0.3%, 0.2%, 0%, and 0.6% of those with an isolated severe mechanism of injury, isolated parental report of acting abnormally, isolated history of vomiting, and isolated history of loss of consciousness, respectively.[6,8,12,13] The degree to which these data apply to infants <3 months old is unclear; however, prior studies suggest that younger infants with isolated small scalp hematomas are at higher risk of traumatic brain injury on CT compared to older infants and children.[6,21,31,32] One study demonstrated that among infants younger than 2 years with isolated scalp hematomas, clinically important traumatic brain injuries occurred in 2.2% of those <3 months old, compared to 0.3% of children between 3 and 24 months old.[6]

In conclusion, the PECARN traumatic brain injury low-risk criteria accurately identified infants younger than 3 months at low risk of clinically important traumatic brain injuries. However, infants at low risk for clinically important traumatic brain injuries remained at risk for traumatic brain injuries on CT, suggesting the need for a cautious approach in these youngest infants.

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Author contributions: ZA, NK, and PSD conceptualized and designed the study. ZA performed data analysis and drafted the initial manuscript. DJT verified data analysis. All authors reviewed and revised the manuscript, approve the final manuscript as submitted, and agree to be accountable for all aspects of the work. ZA takes responsibility for the paper as a whole.

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REFERENCES

1. Chen C, Shi J, Stanley RM, et al. U.S. trends of ED visits for pediatric traumatic brain injuries: implications for clinical trials. *Int J Environ Res Public Health*. 2017;14:414.
2. Kuppermann N, Holmes JF, Dayan PS, et al. Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet*. 2009;374:1160-1170.
3. Greenes DS, Schutzman SA. Clinical indicators of intracranial injury in head-injured infants. *Pediatrics*. 1999;104:861-867.
4. Greenes DS, Schutzman SA. Occult intracranial injury in infants. *Ann Emerg Med*. 1998;32:680-686.
5. Schutzman SA, Barnes P, Duhaime AC, et al. Evaluation and management of children younger than two years old with apparently minor head trauma: proposed guidelines. *Pediatrics*. 2001;107:983-993.
6. Dayan PS, Holmes JF, Schutzman S, et al. Risk of traumatic brain injuries in children younger than 24 months with isolated scalp hematomas. *Ann Emerg Med*. 2014;64:153-162.
7. Miglioretti DL, Johnson E, Williams A, et al. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. *JAMA Pediatr*. 2013;167:700-707.
8. Nishijima DK, Holmes JF, Dayan PS, et al. Association of a guardian's report of a child acting abnormally with traumatic brain injury after minor blunt head trauma. *JAMA Pediatr*. 2015;169:1141-1147.
9. Dayan PS, Holmes JF, Atabaki S, et al. Association of traumatic brain injuries with vomiting in children with blunt head trauma. *Ann Emerg Med*. 2014;63:657-665.
10. Nigrovic LE, Schunk JE, Foerster A, et al. The effect of observation on cranial computed tomography utilization for children after blunt head trauma. *Pediatrics*. 2011;127:1067-1073.
11. Powell EC, Atabaki SM, Wootton-Gorges S, et al. Isolated linear skull fractures in children with blunt head trauma. *Pediatrics*. 2015;135:e851-e857.

12. Lee LK, Monroe D, Bachman MC, et al. Isolated loss of consciousness in children with minor blunt head trauma. *JAMA Pediatr*. 2014;168:837-843.
13. Nigrovic LE, Lee LK, Hoyle J, et al. Prevalence of clinically important traumatic brain injuries in children with minor blunt head trauma and isolated severe injury mechanisms. *Arch Pediatr Adolesc Med*. 2012;166:356-361.
14. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet*. 2007;370:1453-1457.
15. Magana JN, Kuppermann N. The PECARN TBI rules do not apply to abusive head trauma. *Acad Emerg Med*. 2017;24:382-384.
16. Eapen N, Borland ML, Phillips N, et al. Neonatal head injuries: a prospective Paediatric Research in Emergency Departments International Collaborative cohort study. *J Paediatr Child Health*. 2020;56:764-769.
17. Ewing-Cobbs L, Fletcher JM, Levin HS, et al. Longitudinal neuropsychological outcome in infants and preschoolers with traumatic brain injury. *J Int Neuropsychol Soc*. 1997;3:581-591.
18. Ewing-Cobbs L, Miner ME, Fletcher JM, et al. Intellectual, motor, and language sequelae following closed head injury in infants and preschoolers. *J Pediatr Psychol*. 1989;14:531-547.
19. Ewing-Cobbs L, Prasad MR, Kramer L, et al. Late intellectual and academic outcomes following traumatic brain injury sustained during early childhood. *J Neurosurg*. 2006;105(Suppl 4):287-296.
20. Quayle KS, Jaffe DM, Kuppermann N, et al. Diagnostic testing for acute head injury in children: when are head computed tomography and skull radiographs indicated? *Pediatrics*. 1997;99:E11.
21. Schutzman SA, Nigrovic LE, Mannix R. The Infant Scalp Score: a validated tool to stratify risk of traumatic brain injury in infants with isolated scalp hematoma. *Acad Emerg Med*. 2021;28:92-97.
22. Greenes DS, Schutzman SA. Clinical significance of scalp abnormalities in asymptomatic head-injured infants. *Pediatr Emerg Care*. 2001;17:88-92.
23. Duhaime AC, Alario AJ, Lewander WJ, et al. Head injury in very young children: mechanisms, injury types, and ophthalmologic findings in 100 hospitalized patients younger than 2 years of age. *Pediatrics*. 1992;90:179-185.
24. Choi JY, Lim YS, Jang JH, et al. Accuracy of bedside ultrasound for the diagnosis of skull fractures in children aged 0 to 4 years. *Pediatr Emerg Care*. 2020;36:e268-e273.
25. Parri N, Crosby BJ, Mills L, et al. Point-of-care ultrasound for the diagnosis of skull fractures in children younger than two years of age. *J Pediatr*. 2018;196:230-236.e2.
26. Rabiner JE, Friedman LM, Khine H, et al. Accuracy of point-of-care ultrasound for diagnosis of skull fractures in children. *Pediatrics*. 2013;131:e1757-e1764.
27. van Wezel-Meijler G, Steggerda SJ, Leijser LM. Cranial ultrasonography in neonates: role and limitations. *Semin Perinatol*. 2010;34:28-38.
28. Shin SS, Huisman T, Hwang M. Ultrasound imaging for traumatic brain injury. *J Ultrasound Med*. 2018;37:1857-1867.
29. Sheridan DC, Pettersson D, Newgard CD, et al. Can QuickBrain MRI replace CT as first-line imaging for select pediatric head trauma? *J Am Coll Emerg Physicians Open*. 2020;1:965-973.
30. Lindberg DM, Stence NV, Grubenhoff JA, et al. Feasibility and accuracy of fast MRI versus CT for traumatic brain injury in young children. *Pediatrics*. 2019;144:e20190419.
31. Bressan S, Kochar A, Oakley E, et al. Traumatic brain injury in young children with isolated scalp haematoma. *Arch Dis Child*. 2019;104:664-669.
32. Burns EC, Grool AM, Klassen TP, et al. Scalp hematoma characteristics associated with intracranial injury in pediatric minor head injury. *Acad Emerg Med*. 2016;23:576-583.

The 2021 Council Resolutions, including any amendments to the ACEP Bylaws, will be posted to the ACEP Web site at https://www.acep.org/council/ no later than September 23, 2021.

APPENDIX A.

Table E1. Concurrent TBIs in infants with skull fractures who did not meet PECARN low-risk criteria (N = 57)[a].

Intracranial Injury	Number (%) of infants[b]
Subdural hematoma	17 (29.8)
Extra-axial hematoma	16 (28.1)
Subarachnoid hemorrhage	14 (24.6)
Cerebral contusion	9 (15.8)
Intracerebral hematoma	8 (14.0)
Epidural hematoma	7 (12.3)
Diastasis of skull	7 (12.3)
Midline shift/shift of brain structures	3 (5.3)

[a]PECARN public use dataset does not provide all details regarding specific types of fractures incurred (e.g., basilar and linear fractures are not differentiated)
[b]Total exceeds 57 as patients could have multiple intracranial injuries, which are here counted separately