Prevalence of Brain Injuries and Recurrence of Seizures in Children With Posttraumatic Seizures

Mohamed K. Badawy, MD, Peter S. Dayan, MD, MSc, Michael G. Tunik, MD, Frances M. Nadel, MD, Kathleen A. Lillis, MD, Michelle Miskin, MS, Dominic A. Borgialli, DO, MPH, Michael C. Bachman, MD, Shireen M. Atabaki, MD, MPH, John D. Hoyle, Jr., MD, James F. Holmes, MD, MPH, Nathan Kuppermann, MD, MPH, for the Pediatric Emergency Care Applied Research Network (PECARN)

ABSTRACT

Objectives: Computed tomography (CT) is often used in the emergency department (ED) evaluation of children with posttraumatic seizures (PTS); however, the frequency of traumatic brain injuries (TBIs) and short-term seizure recurrence is lacking. Our main objective was to evaluate the frequency of TBIs on CT and short-term seizure recurrence in children with PTS. We also aimed to determine the associations between the likelihood of TBI on CT with the timing of onset of PTS after the traumatic event and duration of PTS. Finally, we aimed to determine whether patients with normal CT scans and normal neurological examinations are safe for discharge from the ED.

Methods: This was a planned secondary analysis from a prospective observational cohort study to derive and validate a neuroimaging decision rule for children after blunt head trauma at 25 EDs in the Pediatric Emergency Care Applied Research Network. We evaluated children < 18 years with head trauma and PTS between June 2004 and September 2006. We assessed TBI on CT, neurosurgical interventions, and recurrent seizures within 1 week. Patients discharged from the ED were contacted by telephone 1 week to 3 months later.

Results: Of 42,424 children enrolled, 536 (1.3%, 95% confidence interval [CI] = 1.2%–1.4%) had PTS. A total of 466 of 536 (86.9%, 95% CI = 83.8%–89.7%) underwent CT in the ED. TBIs on CT were identified in 72 (15.5%, 95% CI = 12.3%–19.1%), of whom 20 (27.8%, 95% CI = 17.9%–39.6%) underwent neurosurgical intervention

From the Department of Pediatrics, University of Texas Southwestern Medical School (MKB), Dallas, TX; the Department of Pediatrics, Columbia University College of Physicians and Surgeons (PSD), New York, NY; the Departments of Emergency Medicine and Pediatrics, NYU School of Medicine (MGT), New York, NY; the Department of Pediatrics, University of Pennsylvania, School of Medicine (FMN), Philadelphia, PA; the Departments of Pediatrics and Emergency Medicine, State University of New York at Buffalo School of Medicine and Biomedical Sciences (KAL), Buffalo, NY; the Department of Pediatrics, University of Utah and PECARN Data Coordinating Center (MM), Salt Lake City, UT; the Department of Emergency Medicine, University of Michigan School of Medicine and Hurley Medical Center (DAB), Flint, MI; the Departments of Emergency Medicine and Pediatrics, Newark Beth Israel Medical Center (MCB), Newark, NJ; the Departments of Pediatrics and Emergency Medicine, George Washington University School of Medicine (SMA), Washington, DC; the Division of Emergency Medicine, Michigan State University School of Medicine/ Helen Devos Children's Hospital (JDH), Grand Rapids, MI; and the Department of Emergency Medicine (JFH, NK) and the Department of Pediatrics (NK), University of California, Davis School of Medicine, Sacramento, CA.

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Address for correspondence and reprints: Nathan Kuppermann, MD, MPH; e-mail: nkuppermann@ucdavis.edu. Twitter: @nkuppermann.
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and 15 (20.8%, 95% CI = 12.2%–32.0%) had recurrent seizures. Of the 464 without TBIs on CT (or no CTs performed), 457 had recurrent seizure status known, and five (1.1%, 95 CI = 0.4%–2.5%) had recurrent seizures; four of five presented with Glasgow Coma Scale scores < 15. None of the 464 underwent neurosurgical intervention. We found significant associations between likelihood of TBI on CT with longer time until the PTS after the traumatic event (p = 0.006) and longer duration of PTS (p < 0.001).

Conclusions: Children with PTS have a high likelihood of TBI on CT, and those with TBI on CT frequently require neurosurgical interventions and frequently have recurrent seizures. Those without TBIs on CT, however, are at low risk of short-term recurrent seizures, and none required neurosurgical interventions. Therefore, if CT-negative and neurologically normal, patients with PTS may be safely considered for discharge from the ED.

Blunt head trauma is a major cause of morbidity and mortality in children, accounting for more than 600,000 emergency department (ED) visits annually in the United States.[1] Posttraumatic seizures (PTS) are associated with 0.6% to 4% of all episodes of pediatric head trauma.[2,3] PTS are often described as immediate (occurring within 24 hours of the injury), early (occurring between 24 hours and 7 days after the injury), or late (occurring more than 7 days after the injury).[4,5] Other researchers have defined the PTS as immediate if the seizure occurs after the traumatic event but before ED presentation.[6] Children with PTS have an increased risk of traumatic brain injury (TBI) visualized on cranial computed tomography (CT) scanning.[4–7] The risk of PTS has also been shown to increase with increasing severity of head trauma; however, PTS may also occur in children with minor head trauma.[4–6]

The frequency of TBIs on CT in children with PTS has not been precisely quantified, with reported estimates ranging from as low as 2% to as high as 16%.[7–10] Hospitalization of children with PTS occurs in 48% to 80%,[6,11] mostly to monitor for seizure recurrence or clinical deterioration or because of the need for neurosurgery.[4] For children with immediate PTS and normal CT scans, however, two studies have suggested that the risk of seizure recurrence may be low enough to safely discharge these patients home from the ED.[6,11]

In the large cohort of children with blunt head trauma in the Pediatric Emergency Care Applied Research Network (PECARN) TBI study, which was conducted to identify those at risk of clinically important TBI, PTS did not appear as an independent predictor in the age-dependent prediction rules (Table 1).[12] This is likely due to correlation with other more common PECARN TBI rule risk factors that would include patients with PTS such as history of loss of consciousness (LOC) or signs of altered mental status. However, the specific impact of the timing, duration, and other characteristics of the PTS on clinical outcomes, including TBI on CT and seizure recurrence, remains unclear, and clinical decision making based on PTS remains a dilemma.

Table 1
PECARN Head Trauma Prediction Rule Variables*

	Age Younger Than 2 Years	Age 2 Years and Older
1.	GCS < 15 or abnormal mental status	GCS < 15 or abnormal mental status
2.	Palpable/suspected skull fracture	Signs of basilar skull fracture
3.	History of LOC ≥ 5 sec	History of any LOC
4.	Severe mechanism of injury†	Severe mechanism of injury†
5.	Acting abnormally per parent	Severe headache
6.	Tempero/parietal/occipital scalp hematoma	History of emesis

GCS = Glasgow Coma Scale; LOC = loss of consciousness; PECARN = Pediatric Emergency Care Applied Research Network.
*Absence of all of the PECARN Head Trauma Prediction Rule variables indicates very low risk for clinically important TBI.
†Severe mechanism defined by motor vehicle crash with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by a motorized vehicle; falls greater than 5 feet for patients 2 years and older or falls greater than 3 feet for those younger than 2 years; or head struck by a high-impact object.

For children evaluated in the ED following a PTS, we sought to determine the prevalence of TBIs on CT, the rate of neurosurgical interventions, and the frequency of recurrent seizures within 1 week. We also sought to evaluate the effect of timing and duration of the PTS, and the initial Glasgow Coma Scale (GCS) score on clinical outcomes. This would help inform clinical decision making in the ED regarding CT use, disposition, and acute prognosis. Finally, we aimed to determine whether patients with normal CT scans and normal neurological examinations are safe for discharge from the ED.

METHODS

Study Design

We performed a planned secondary analysis of data from a prospective observational cohort study to derive and validate a neuroimaging decision rule for children after blunt head trauma at 25 EDs in PECARN.[12] The study was approved by the institutional review board at each participating site. Detailed methods are described elsewhere.[12] Methods specific for this subanalysis, however, are described below.

Selection of Participants

The study population comprised children younger than 18 years of age with blunt head trauma resulting from nontrivial mechanisms of injury and evaluated between June 2004 and September 2006. As opposed to the PECARN TBI prediction rule study in which only children with GCS scores of 14 or 15 were included, in the current subanalysis we included children with the full range of GCS scores from the parent study. Children were included in the study population if they had one or more PTS documented on the case report form and were evaluated within 24 hours of injury. Patients were excluded from the parent study (and therefore this subanalysis) for any of the following: 1) presence of a preexisting neurological disease, 2) history of ventricular shunt placement, 3) presence of a coagulopathy, or 4) transfer from another facility with neuroimaging already performed.[12] For this subanalysis, we also excluded patients with known seizure disorders.

Data Collection and Processing

Physicians documented patient history and physical examination findings onto structured case report forms before knowledge of any imaging studies (if performed). The patient's level of consciousness was measured by the initial GCS score for children >= 2 years and the pediatric GCS for children < 2 years. A PTS was defined as a witnessed seizure episode that occurred after the traumatic event. We categorized PTS with regard to the timing of the first seizure: 1) immediate (on impact), 2) within 30 minutes, or 3) more than 30 minutes after the traumatic event. We documented the seizure duration as less than 1 minute, 1 to 4 minutes, 5 to 15 minutes, or more than 15 minutes.

Decisions regarding CT use and hospitalization were at clinician discretion. CT results were obtained from the dictated reports by radiologists at each site. For hospitalized patients, we reviewed the medical records after hospital discharge to identify recurrent seizures while hospitalized or any neurosurgical interventions. For patients discharged from the ED, we performed structured follow-up telephone calls 1 week to 3 months after the ED visit to determine any neuroimaging, recurrent seizures, or neurosurgery after ED discharge. If unavailable after six telephone attempts, we mailed a survey consisting of the same questions. If the survey was not returned, we reviewed the medical records, trauma registries, and morgue records to identify any patients with potentially missed outcomes.[12]

Outcome Measures

The main outcome measures were the presence of TBIs on CT, any neurosurgical interventions, and recurrent seizures within 1 week of the ED visit. The 1-week evaluation of recurrent seizure was assessed at the time of the predetermined follow-up telephone call, which was initiated 1 week after the ED visit. The first week after head trauma is also the timing of what some investigators consider an "early" PTS.[4,5] TBI on CT was defined as the presence of any intracranial hemorrhage, cerebral edema, pneumocephalus, skull fracture depressed by at least the width of the skull, or traumatic skull diastasis. Neurosurgical interventions were defined by any of the following: intracranial pressure monitoring, elevation of depressed skull fracture, ventriculostomy, hematoma evacuation, lobectomy, tissue debridement, or dura repair.[12]

Data Analysis

We described the data using counts, percentages, and exact binomial 95% confidence intervals (CIs) for categorical variables and the median and interquartile range for continuous variables. We determined the rates of TBIs on CT by increasing duration of seizure and timing of seizure, with their accompanying 95% CIs. We compared the rate of TBIs on CT by seizure characteristics using the exact version of the Mantel-Haenszel chi-square test. We also determined the frequency of TBIs on CT in patients with PTS but who did not have any of the six predictors in the age-appropriate PECARN TBI prediction rule, to adjust for other indicators of injury severity.[12] In addition, we compared the rates of TBIs on CT in children with PTS with initial GCS scores of 15 versus those with GCS scores ≤ 14, and also compared the rates of our outcomes on children with histories of PTS but no PECARN risk factors (except histories of LOC) with children with isolated histories of LOC (and no PTS) using Fisher's exact test. We performed this final analysis to assess the difference in risk of TBI in patients with PTS (with no PECARN findings except a history of LOC) versus those children with isolated histories of LOC (i.e., no other PECARN findings and no PTS). Finally, because CT scans were not mandated and to account for all patients with PTS, we compared patients who received CT scans with those who did not receive CT scans in the ED. Data analysis was performed using SAS statistical software (version 9.3, SAS Institute, Inc.).

RESULTS

Characteristics of Study Subjects

A total of 43,904 (77%) of 57,030 eligible patients were enrolled into the parent study. Of these patients, 42,424 (96.6%) had GCS scores recorded and were without prior histories of seizure disorders, ventricular shunts, or coagulopathies and had their PTS status recorded (Figure 1). A total of 536 (1.3%, 95% CI = 1.2%–1.4%) had PTS, and these patients comprised the study population. Of those patients with PTS, 400 (74.6%) had GCS scores of 15 in the ED, 38 (7.1%) had GCS scores of 14, and 98 (18.3%) had GCS scores of 3 to 13. Injuries were most often caused by falls or participation in sports activities (Table 2).

A total of 466 (86.9%, 95% = CI 83.8%–89.7%) of the 536 patients with PTS underwent CT scans in the ED. Characteristics of the 466 patients undergoing CT scans in the ED along with the 70 patients not undergoing cranial CT in the ED are displayed in Table 3. Patients undergoing CT were older, more likely to have lower initial GCS scores, more likely to have their PTS > 30 minutes after the injury event, and more likely to be hospitalized.

A total of 351 (75.6%) of the 464 patients without TBIs on CT (or no CT performed) were discharged from the ED. Telephone or mail follow-up was obtained on 279 (79.5%) of these patients and 72 (20.5%) had their medical records, trauma registries, and morgue records reviewed to identify subsequent neurosurgical procedures or recurrent seizures.

Frequency of TBIs on CT

Seventy-two (15.5%, 95% CI = 12.3%–19.1%) of the 466 patients with PTS undergoing ED CT scans had TBIs on CT. The types of TBIs detected on CT are described in Table 4. Cerebral contusions and subarachnoid hemorrhages were the most common CT findings. A total of 332 (71.2%) of the 466 patients undergoing ED CT scans presented with GCS scores of 15, and 20 of these 332 patients (6.0%, 95% CI =

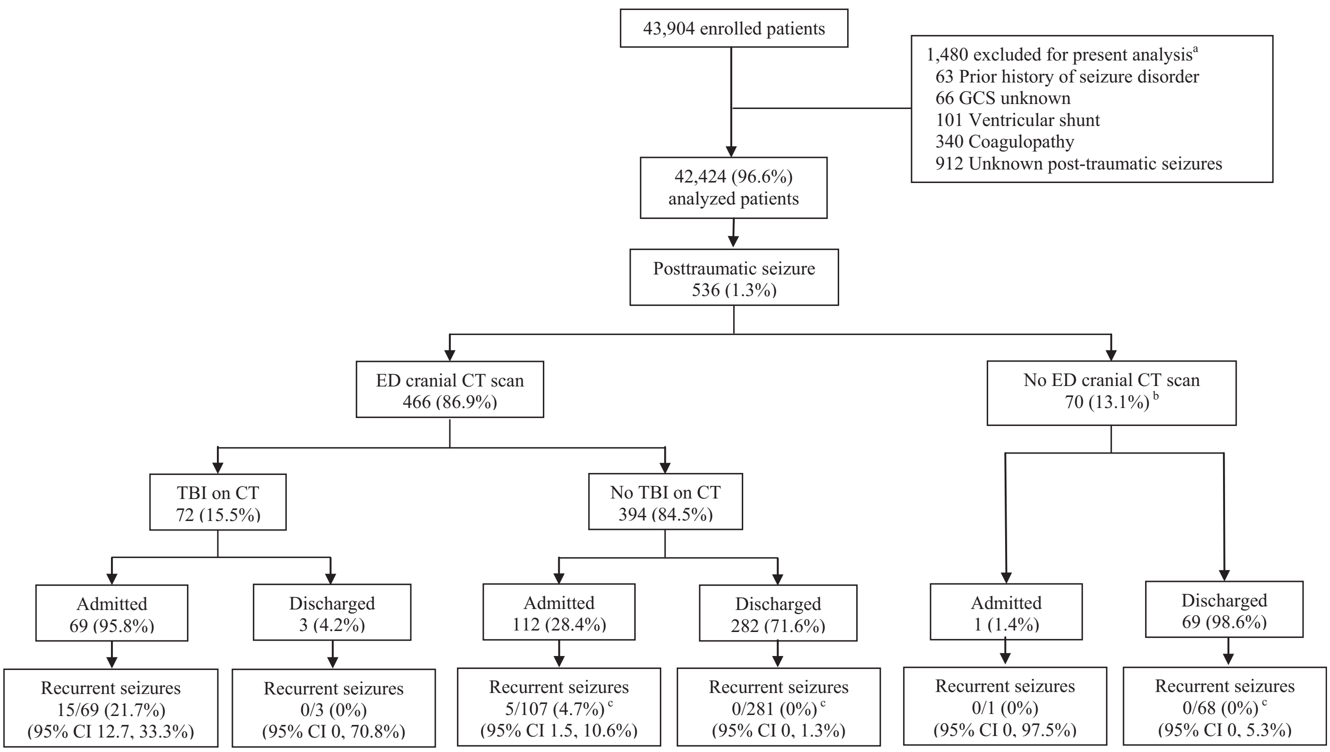

Figure 1. Patient flowchart. CT = computed tomography; TBI = traumatic brain injury. [a]Two patients had more than one exclusion. [b]Of the 70 patients without an ED CT scan, one had GCS of 13, one had GCS of 14, and 68 had GCS of 15. [c]Seven patients did not have any information about recurrent seizures.

Table 2
Characteristics of Children With PTS

Patient characteristics	*N* = 536
Age (y), median (IQR)	4.9 (2.2–12.7)
Male	344 (64.2)
GCS score	
3–13	98 (18.3)
14	38 (7.1)
15	400 (74.6)
Mechanisms of injury	
Fall from an elevation	166 (31.0)
Fall from standing/walking/running	118 (22.0)
Sports	49 (9.1)
Fall down stairs	35 (6.5)
Assault	29 (5.4)
Walked or ran into stationary object	23 (4.3)
Bike collision or fall from bike while riding	18 (3.4)
Occupant in MVC	17 (3.2)
Other wheeled transport crash	16 (3.0)
Pedestrian struck by moving vehicle	15 (2.8)
Object struck head—accidental	11 (2.1)
Bike rider struck automobile	6 (1.1)
Other	29 (5.4)
Unknown mechanism	4 (0.7)

Data are reported as median (IQR) or number (%).
IQR = interquartile range; MVC = motor vehicle collision; PTS = posttraumatic seizures.

3.7%–9.2%) had TBIs on CT. The clinical characteristics of these 20 patients as well as the types of CT findings are described in Table 5. All but one had a PECARN TBI risk factor documented, and most had reported histories of LOC. Of the 134 patients with GCS scores $\leq$ 14 and CT scans performed, 52 (38.8%, 95% CI = 30.5%–47.6%) had TBIs on CT (rate difference compared to those with GCS scores of 15: 32.8%, 95% CI = 23.0%–42.2%).

The rate of TBIs on CT was higher in children in whom the seizure occurred a longer interval after the traumatic event (Figure 2). The rate of TBIs on CT also increased as the seizure duration increased (Figure 3). However, the 95% CIs greatly overlapped between categories. A total of 102 (82.3%) of the 124 patients who had PTS that were both immediate and of <1-minute duration had CT scans performed in the ED. Of these 102 patients, four (3.9%, 95% CI = 1.1%–9.7%) had TBIs on CT. The GCS scores at ED presentation of these four patients was GCS 13 (n = 1) and GCS 15 (n = 3). Of the 124 patients, none underwent neurosurgery, and one (0.8%, 95% CI = 0.02%–4.4%) had a recurrent seizure.

Of patients with PTS and none of the six age-specific predictors in the PECARN TBI prediction rules recorded,[12] the rates of TBI on CT were as follows: For children younger than 2 years, there were 29 with PTS and none of the age-appropriate PECARN rule predictors recorded. Twenty-one of these 29 patients had ED CT scans performed and none had TBIs on CT (0%, 95% CI = 0%–16.1%). Of the children 2 years and older, there were 22 with PTS and none of the age-appropriate PECARN rule predictors recorded. Fifteen of these 22 patients had ED CT scans performed and one had a TBI on CT (6.7%, 95% CI = 0.2%–32.0%). This one patient developed a seizure of 5 to 15 minutes' duration within 30 minutes of the traumatic event, had pneumocephalus on CT, and was discharged home from the ED.

There were 187 patients with histories of PTS and no PECARN TBI risk factors other than reported histories of LOC and 2,543 patients with histories of isolated LOC (and no PTS). Of the patients with PTS and no PECARN TBI risk factors except LOC, 150 (80.2%, 95% CI = 74.5%–85.9%) had ED CT scans performed compared to 1,799 (70.7%, 95% CI = 68.9%–72.5%) of the 2,543 patients with isolated LOC and no PTS. Eight (5.3%, 95% CI = 2.3%–10.2%) of the 150 patients with PTS and reported histories of LOC had TBIs on CT compared to 29 (1.6%, 95% CI = 1.1%–2.3%) of the 1,799 isolated LOC patients (p = 0.006). Rates of neurosurgical interventions (0/187 vs. 1/2,543), however, were not different between these groups.

Neurosurgical Interventions

A total of 20 (27.8%, 95% CI = 17.9%–39.6%) of the 72 patients with PTS who had TBIs on CT underwent neurosurgery. One (5.0%, 95% CI = 0.1%–24.9%) of these 20 patients presented with a GCS score of 15 (patient described in Table 5). However, that patient had multiple PECARN findings and was also described to have altered mental status.

Recurrent Seizures

The rate of recurrent seizures is presented in Figure 1. Fifteen (20.8, 95% CI = 12.2%–32.0%) of the 72 patients with TBIs on CT had recurrent seizures. Of the 394 patients who were imaged with CT and who did not have TBIs on CT, 388 had recurrent seizure status known. The rate of recurrent seizures by presenting GCS score in these 388 patients was as follows: GCS scores of 3 to 13, recurrent seizure rate of three in 50 (6.0%, 95% CI =1.3%–16.6%), GCS scores of 14, recurrent seizure rate of one in 28 (3.6%, 95% CI = 0.1%–18.4%), and GCS scores of

Table 3
Comparison of Children With PTS With ED CT Versus No ED CT Obtained

	ED CT obtained (*n* = 466)	No ED CT obtained (*n* = 70)	Risk Difference, % (95% CI)
Age (y), median (IQR)	5.6 (2.3 to 13.5)	3.1 (1.8 to 5.6)	
GCS score			
3–13	97 (20.8%) (95% CI = 17.2% to 24.8%)	1 (1.4%)* (95% CI = 0% to 7.7%)	19.4% (6.9% to 31.7%)
14	37 (7.9%) (95% CI = 5.7% to 10.8%)	1 (1.4%) (95% CI = 0% to 7.7%)	6.5% (–6% to 19%)
15	332 (71.2%) (95% CI = 66.9% to 75.3%)	68 (97.1%) (95% CI = 90.1% to 99.7%)	–25.9% (–38.1% to -13.4%)
Seizure timing			
Immediately	197/414 (47.6%) (95% CI = 42.7% to 52.5%)	33/57 (57.9%) (95% CI = 44.1% to 70.9%)	–10.3% (–24.1% to 3.6%)
Within 30 min	162/414 (39.1%) (95% CI = 34.4% to 44.0%)	23/57 (40.4%) (95% CI = 27.6% to 54.2%)	–1.2% (–15.1% to 12.6%)
>30 min	55/414 (13.3%) (95% CI = 10.2% to 16.9%)	1/57 (1.8%) (95% CI = 0% to 9.4%)	11.5% (–2.3% to 25.2%)
Unknown	52/466 (11.2%) (95% CI = 8.4% to 14.4%)	13/70 (18.6%) (95% CI = 10.3% to 29.7%)	–7.4% (–19.9% to 5.2%)

CT = computed tomography; IQR = interquartile range; GCS = Glasgow Coma Scale; PTS = posttraumatic seizure.
*Clinician determined that the patient had seizure-like activity or a breath-holding spell prior to the head trauma.

Table 4
TBIs on CT in Children With PTS for Whom an ED CT Scan Was Obtained (*n* = 466, 72 [15.5%] with TBIs on CT)

Type of TBI*	N (%)
Cerebral contusion	26 (5.6)
Subarachnoid hemorrhage	25 (5.4)
Subdural hematoma	20 (4.3)
Cerebral edema	15 (3.2)
Intracerebral hematoma	15 (3.2)
Extraaxial hematoma	14 (3.0)
Midline shift	12 (2.6)
Pneumocephalus	12 (2.6)
Epidural hematoma	8 (1.7)
Skull fracture depressed skull width	7 (1.5)
Diastasis of the skull	5 (1.1)
Intraventricular hemorrhage	5 (1.1)
Cerebellar hemorrhage	3 (0.6)
Shear injury	3 (0.6)
Traumatic infarction	2 (0.4)
Diffuse axonal injury	2 (0.4)
Herniation	1 (0.2)

Data are reported as number (%)
PTS = posttraumatic seizure; TBI = traumatic brain injury.
*53 patients had more than one TBI finding on CT.

15, recurrent seizure rate of one in 310 (0.3%, 95% CI = 0%–1.8%).

Of the 464 patients with no TBIs on CT or no CTs performed, 457 had recurrent seizure status known; five of the 457 (1.1%, 95 CI = 0.4%–2.5%) had recurrent seizures. All five of these patients were hospitalized from the ED and are described in Table 6; only one had a GCS of 15 on presentation to the ED. Of those patients discharged from the ED and recurrent seizure status known, none of 349 who either did not have TBI on CT or did not have a CT obtained had recurrent seizures (0%, 95% CI 0%–1.0%). For patients who did not have PTS, none had seizures reported at follow-up.

DISCUSSION

In this large cohort of children with PTS, 15% had TBIs on CT and those with TBIs on CT frequently required neurosurgery. In addition, 20% of children with PTS and TBIs on CT had short-term recurrent seizures. Children with PTS, but without TBIs on CT, however, very infrequently had short-term seizure recurrence and none required neurosurgical intervention.

Previous studies about children with PTS are few and limited by small sample sizes and/or retrospective designs, which limit the accuracy and precision of the risk estimates described.[5,11] One smaller prospective study, however, had similar results to ours both in terms of prevalence of TBIs on CT and that none of the children without CT abnormalities had recurrent seizures after ED discharge.[6] Comparison and interpretation of existing data are further complicated by varying categorization of seizure timing in relation to the traumatic event.[5,11,13] In this study, patients with immediate seizures had the lowest rate of TBIs on CT, while those with seizures occurring more than 30 minutes after the traumatic event had the highest rate. Moreover, we also demonstrated that a longer duration of seizure was associated with a higher rate of TBIs on CT. Because our study was large, we were more able to identify the frequency and determine the

Table 5
Characteristics of Patients With PTS With TBIs on CT and GCS Scores of 15

Age	Injury Mechanism	Age-specific PECARN Prediction Rule Factor Findings*	CT Findings	Intervention/Disposition
1 mo	Fall from 3–5 feet	AMS; temporal/parietal scalp hematoma; severe mechanism; not acting normally per parent	Extraaxial hematoma	Hospitalization overnight
6 mo	Unknown	Not acting normally per parent	Subdural hematoma	Hospitalization ≥ 2 nights
6 mo	Fall from < 3 feet	LOC > 5 min	Midline shift; subdural hematoma	Hospitalization ≥ 2 nights
1 y	Fall from ground level	LOC 5 sec to <1 min	Subdural hematoma	Hospitalization ≥ 2 nights
3 y	Occupant in MVC	AMS; LOC	Skull fracture depressed skull width	Hospitalization ≥ 2 nights
4 y	Fall from ground level	Vomiting	Extraaxial hematoma; subdural hematoma	Discharge from ED
6 y	Fall from < 3 feet	LOC	Subarachnoid hemorrhage	Hospitalization overnight
7 y	Scooter crash	LOC	Cerebral contusion	Hospitalization ≥ 2 nights
12 y	Fall from 6–10 feet	LOC; severe mechanism	Subarachnoid hemorrhage	Hospitalization overnight
12 y	snowboarding—fell	AMS; LOC	Intracerebral hematoma; subarachnoid hemorrhage	Hospitalization ≥ 2 nights
13 y	Bike collision	LOC	Extraaxial hematoma; midline shift; subdural hematoma	Hospitalization ≥ 2 nights
13 y	Basketball hit head	LOC	Cerebral contusion	Discharge from ED
14 y	Bike collision	AMS; LOC	Epidural hematoma	Hospitalization overnight
14 y	Assault	AMS; LOC	Skull fracture depressed skull width	Hospitalization overnight
14 y	Bike collision	AMS; LOC: signs of basilar skull fx; severe headache	Epidural hematoma; pneumocephalus	Neurosurgery; hospitalization ≥ 2 nights
15 y	Scooter crash	AMS	Intracerebral hematoma; subarachnoid hemorrhage; subdural hematoma	Hospitalization ≥ 2 nights
15 y	Fell playing football	LOC	Extraaxial hematoma; subarachnoid hemorrhage	Hospitalization overnight
16 y	Aerial fall from snowboarding	LOC	Cerebral contusion; subarachnoid hemorrhage	Hospitalization overnight
16 y	Fell while skateboarding	AMS; LOC	Cerebral contusion; intracerebral hematoma	Hospitalization ≥ 2 nights
16 y	Ran into wall playing football	None	Pneumocephalus	Discharged from ED

AMS = altered mental status; LOC = history of loss of consciousness; MVC = motor vehicle collision; PECARN = Pediatric Emergency Care Applied Research Network; PTS = posttraumatic seizure; TBI = traumatic brain injury.
*PECARN prediction rules—1) Patients < 2 years are at very low risk of clinically important TBI if they have none of the following: a severe of mechanism of injury, a history of LOC >= 5 seconds, a GCS score < 15, other signs of altered mental status, acting abnormally per parent, the presence of nonfrontal scalp hematoma, or a palpable skull fracture. 2) Patients 2–18 years are at very low risk of clinically important TBI if they have none of the following: a severe of mechanism of injury, a history of any LOC, a severe headache, any vomiting after the trauma, a GCS score < 15, other signs of altered mental status, or signs of a basilar skull fracture.

reliability of the clinical findings,[14] as well as detect associations that could not be examined in smaller studies. Nevertheless, despite the size of our study, the 95% CIs remained wide around frequencies of TBIs on CT based on seizure characteristics and timing, given the relatively small numbers of patients in different seizure categories.

Previous studies suggest that most children with blunt head trauma, normal neurological examinations, and negative CT scans do not require hospitalization.[3,4,15,16] These studies, however, either did not specifically address children with PTS or were small and/or retrospective.[5,11] Some studies suggested that early PTS was the result of severe injuries; others suggested that many with PTS had minor head trauma.[4–7] In this study, more than 80% of children with PTS had minor head trauma, defined by presenting GCS scores of 14 or 15. Additionally, we found that neurologically normal children with PTS and negative CTs did not require neurosurgical interventions and rarely had short-term recurrent seizures. Therefore, although the precision of these conclusions is limited by sample size, it appears that these patients typically do not require hospitalization after their ED evaluations.

Our data support the use of CT scans in children with PTS due to the high rate of TBI on CT. Expert

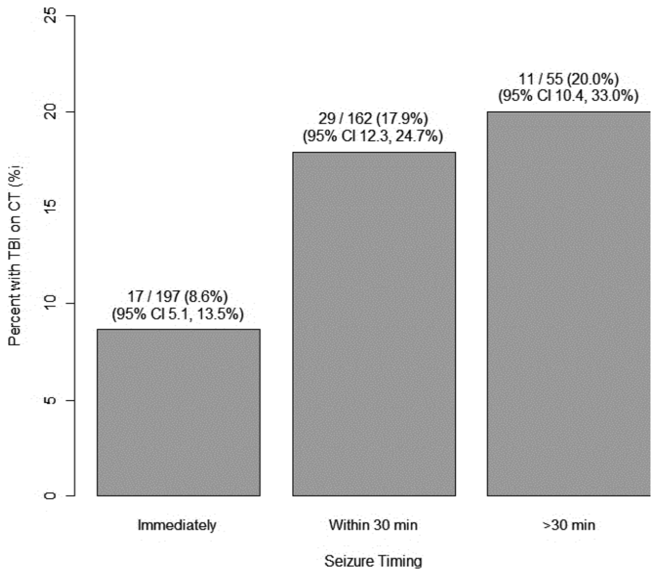

Figure 2. Rate of TBI on CT by timing of PTS after the traumatic event.* CT = computed tomography; PTS = posttraumatic seizure; TBI = traumatic brain injury. *Of the patients with ED CT performed, PTS timing was unknown in 52 patients, of whom 15 had TBI on CT. Exact Mantel-Haenszel chi-square test p = 0.006 for the association between seizure timing and TBI on CT.

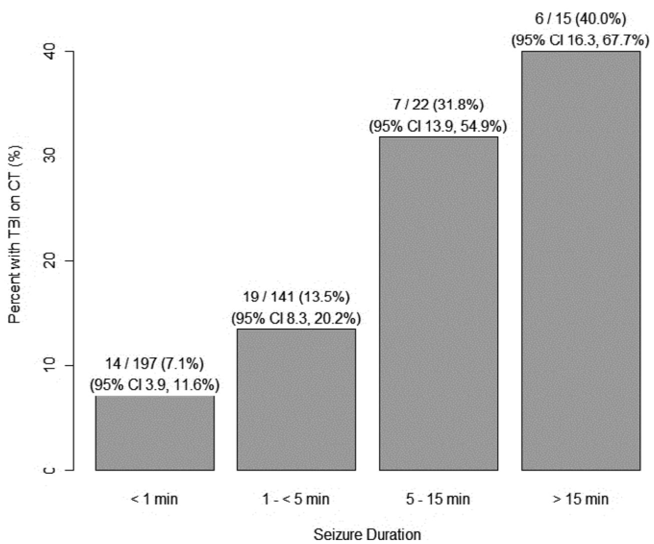

Figure 3. Rate of TBI on CT by duration of PTS.* CT = computed tomography; PTS = Posttraumatic seizure. *Of the patients with ED CT performed, PTS duration was unknown in 91 children, of whom 26 had TBIs on CT. Exact Mantel-Haenszel chi-square test p = < 0.001 for the association between seizure duration and TBI on CT.

consensus opinions consider patients with PTS at high risk for TBI, and PTS is considered an indication for cranial CT.[2,15] CT scans can rapidly identify TBI such that undetected intracranial injury is infrequent.[16] Furthermore, if there are positive findings on CT, these children typically require hospitalization and occasionally need neurosurgical intervention. One prospective study of 63 children with PTS found 16% to have TBI on CT,[6] similar to the rate detected in this study. None of the patients in that study had further seizure activity or required neurosurgical interventions if their CT scans were normal. Other previous studies, however, have focused on specific subpopulations (e.g., infants) and/or were small in size, retrospective in nature, or lacking in statistical power to examine associations adequately.[8,9,11,17,18]

We have previously derived and validated a prediction rule for clinically important TBIs in children with minor head trauma (i.e., GCS scores of 14–15).[12] In that study, PTS was not identified as an independent predictor greatly due to its correlation with the more frequently present finding of a history of LOC or other PECARN risk factors (Table 5). In the PECARN TBI prediction rule, those with LOC were not considered at very low risk of clinically important TBI. A small number of patients with documented PTS were not categorized as having LOC in the parent PECARN study by the treating physicians completing the data collection forms. However, all patients with PTS should be considered to have had histories of LOC. Furthermore, children with PTS and no PECARN risk factors other than histories of LOC had significantly higher rates of TBI on CT than children with histories of LOC without PTS and without any other PECARN risk factors. Therefore, CT scans should be strongly considered for children with PTS even when no PECARN prediction rule factors are present (regardless of whether or not a history of LOC is documented).

LIMITATIONS

This study has certain limitations. Cranial CT scans were performed at the discretion of the treating clinicians and not mandated by study protocol. Thus, not all patients were evaluated with CT. We did, however, collect data on clinical outcomes including neurosurgical interventions and recurrent seizures on all patients regardless of CT scanning. Recurrent seizures occurred in 20 patients, all of whom were hospitalized, including five patients without TBI on CT. Hospitalizations were at the discretion of the treating clinicians and we did not collect data on reasons for admissions. Thus, it is not clear why recurrent seizures occurred in admitted patients only. However, most of the admitted patients had TBIs on CT and four of the five patients without TBIs on CT who were hospitalized presented with low GCS scores, which may have contributed to the decision to hospitalize. We also did not collect

Table 6
Characteristics of the Five Patients Without TBIs on CT Who Had Recurrent Seizures*

Age (y)	ED GCS	Injury Mechanism	Timing of Seizure	Duration of Seizure	Repeat CT Scan
3	9	Fall from > 10 feet	Within 30 min of injury	1 to <5 min	Yes: not interpretable
4	10	Fall to ground from standing	>30 min after injury	Unknown	No
4	15	Fall to ground from standing	>30 min after injury	Unknown	No
4	14	TV struck head	>30 min after injury	<1 min	No
5	3	Fall from < 3 feet	Within 30 min of injury	<1 min	No

GCS = Glasgow Coma Scale; TBI = traumatic brain injury; TV = television.
*Seizure timing and duration are for the original seizure, not the recurrent seizure.

data on use of antiepileptic medications, which may have affected the rate of recurrent seizures. Antiepileptic medications, however, are not typically indicated nor used for children with minor head trauma without evidence of TBI on CT.[19] We were not able to obtain telephone or mail follow-up in approximately 21% of patients discharged from the ED to assess for our outcomes including recurrent seizures. Therefore, it is possible that some discharged patients with recurrent seizures were missed. However, for those not reached by telephone or mail, we performed comprehensive medical record, trauma registry, process improvement and morgue review to detect any possible patients discharged from the ED who subsequently developed an outcome of interest. It is highly likely that if a patient with PTS was discharged from the ED had a recurrent seizure, they would have returned to the same PECARN trauma center where they were evaluated and our follow-up process would have captured them. Finally, although this was a large prospective study, our conclusions are tempered by relatively wide CIs around some of the point estimates presented, due to the limited sample sizes in some PTS categories and groupings of children with specific seizure characteristics.

CONCLUSIONS

In conclusion, children with posttraumatic seizures after blunt head trauma have a substantial rate of traumatic brain injuries on computed tomography, regardless of timing and duration of the seizure (although the rate of traumatic brain injuries was associated with longer times after the traumatic event and longer duration of seizure). Therefore, cranial computed tomography scans should be strongly considered in the evaluation of all children with posttraumatic seizures, including those with no PECARN risk factors. Hospitalization of patients with posttraumatic seizures and traumatic brain injuries on computed tomography is typically warranted, because these children are at risk of neurosurgical intervention and recurrence of seizure. In contrast, children with posttraumatic seizures but without traumatic brain injuries on computed tomography scan have a low risk for seizure recurrence or neurosurgical intervention. Therefore, if computed tomography-negative and neurologically normal, children with posttraumatic seizures can be considered for discharge home from the ED with appropriate discharge instructions.

APPENDIX A

Pediatric Emergency Care Applied Research Network (PECARN) Members

Participating centers and site investigators are listed below in alphabetical order: Atlantic Health System/Morristown Memorial Hospital (M. Gerardi); Bellevue Hospital Center (M. Tunik, J. Tsung); Calvert Memorial Hospital (K. Melville); Children's Hospital Boston (L. Lee); Children's Hospital of Michigan (P. Mahajan); Children's Hospital of New York–Presbyterian (P. Dayan); Children's Hospital of Philadelphia (F. Nadel); Children's Memorial Hospital (E. Powell); Children's National Medical Center (S. Atabaki, K. Brown); Cincinnati Children's Hospital Medical Center (T. Glass); DeVos Children's Hospital (J. Hoyle); Harlem Hospital Center (A. Cooper); Holy Cross Hospital (E. Jacobs); Howard County Medical Center (D. Monroe); Hurley Medical Center (D. Borgialli); Medical College of Wisconsin/Children's Hospital of Wisconsin (M. Gorelick, S. Bandyopadhyay); St. Barnabas Health Care System (M. Bachman, N. Schamban); SUNY-Upstate Medical Center (J. Callahan); University of California

Davis Medical Center (N. Kuppermann, J. Holmes); University of Maryland (R. Lichenstein); University of Michigan (R. Stanley); University of Rochester (M. Badawy, L. Babcock-Cimpello); University of Utah/Primary Children's Medical Center (J. Schunk); Washington University/St. Louis Children's Hospital (K. Quayle, D. Jaffe); Women and Children's Hospital of Buffalo (K. Lillis).

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