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Implementation of Pediatric Emergency Care Applied Research Network (PECARN) guidelines for traumatic brain injury in a rural tertiary care center

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Abstract

Objectives: To evaluate changes in imaging practices for pediatric head trauma following publication of the Pediatric Emergency Care Applied Research Network (PECARN) guidelines, explore areas for quality improvement regarding neuroradiology referrals. We also sought to determine the prevalence of incidental findings discovered on CTs attained for minor head trauma and ascertain disposition in these cases.

Methods: This retrospective study was conducted at a rural academic center and included 156 children who received CTs for head trauma between 2005 and 2015. Subjects were divided into two groups: pre-PECARN publication and post-PECARN publication. Electronic medical records were reviewed to determine whether or not head CTs were obtained according to PECARN guidelines. The proportion of scanned cases and incidental findings in each group were then compared.

Results: Significantly more subjects met PECARN criteria for head CT during the pre-PECARN period (67.1% vs 50.6%, p=0.04). Among those who met PECARN criteria, severe mechanism of injury was the most common criterion met in both groups (43.8% pre-PECARN and 26.5% post-PECARN). Nine (5.7%) subjects had incidental findings (similar for both study periods), of which three prompted additional diagnostic testing or invasive intervention. Among those who did not meet PECARN criteria, the most common mechanism of injury was fall (< 3 feet).

Conclusions: Implementation of PECARN guidelines at our center remained limited in the five years after publication of this practice guide. Clinically insignificant incidental findings were often detected and may heighten patient anxiety.

Key words: head trauma, computed tomography, children, PECARN

Introduction

Traumatic brain injury (TBI) is a common cause of morbidity, mortality, and visits to the emergency department (ED) within the pediatric population worldwide. In the US alone, there are greater than 60,000 hospital admissions, 600,000 ED visits, and 6200 deaths annually associated with pediatric TBI [1]. Identifying subjects with TBI who require immediate intervention is critical. Computed tomography (CT) is often the study of choice for detecting TBI because it is highly sensitive to acute intracranial bleed and facilitates the process of determining who requires neurosurgical intervention or observation in the hospital [2-4]. The use of CT has risen exponentially since its inception in the early 1970s. This increase is attributable to efficiency, CT technology advances, wider availability, and increased accessibility in the ED [5,6].

Studies have shown that roughly a quarter of CT scans may be un-necessary [7]. CT scans must be ordered judiciously for pediatric patients because children exposed to ionizing radiation are at relatively increased risk of malignancy [6,8]. Aside from greater tissue susceptibility, this relationship may simply reflect that infants and children have more time than adults to develop cancer. Children are often scanned with adult CT settings, which increases radiation exposure. It is unclear how often technicians adjust settings whenever a pediatric patient is scanned [8-10]. Head CT is the most widely performed CT for children and is associated with the highest risk of brain cancer and radiation-induced leukemia [11]. The population most commonly evaluated with head CT are children with minor TBI or Glasgow Coma Scale (GCS) of 14 to 15. In one large study, only a small fraction (<1/200) of these scans were positive for traumatic injury [12]; very few children with minor TBI ultimately require neurosurgery [12, 13], though the clinical predictors for infants may be less reliable [14].

An additional "complication" of obtaining CT scans is the discovery of incidental findings. The clinical importance of incidental findings is often unclear [15]. Their detection increases patient and family anxiety, and may also increase costs for additional diagnostic work-up or management. There is

currently limited knowledge regarding the detection and management of incidental findings in the setting of head CT scans in infants.

To reduce the number of inappropriately obtained CT scans, the Pediatric Emergency Care Applied Research Network (PECARN) created an algorithm in 2009 to identify children with low risk trauma for whom head CT may be avoided. The algorithm contains a set of predictors such as altered mental status, skull fracture, severe mechanism of injury, and loss of consciousness, and separates children into high, intermediate, or low risk of "clinical important TBI" (ciTBI), defined as TBI requiring neurosurgery, hospital admission for two or more nights, intubation for greater than 24 hours, or death. These criteria are limited to pediatric patients with GCS 14 to 15. Application of PECARN criteria could decrease pediatric head CTs by 20-25%, and fewer than 1/5000 cases of ciTBI would be missed in children under two years of age; fewer than 1/2000 cases of ciTBI would be missed in children older than two [16]. In addition, application of PECARN criteria could preclude 60 pediatric radiation-induced cancers and decrease healthcare costs by $27 million in the US annually [1, 17].

The PECARN criteria have been validated worldwide in both developed and developing countries and can reliably guide the decision as to which pediatric patients require imaging following minor head injuries [9, 18-21]. However, PECARN application varies across different institutions and the extent of its implementation is unclear. The primary aim of this quality improvement study was to retrospectively evaluate PECARN implementation at a rural academic center following publication of guidelines in 2009. Two secondary aims of this study were to investigate the prevalence and management of incidental findings detected on pediatric head CTs obtained for minor head trauma, and to assess the use of rapid MRI protocols that could obviate anesthesia requirement for MRI in this age group.

Materials and Methods

Patient population

The use of human subjects and analyses included in this study were approved by the Institutional Review Board at the University of Vermont. We retrospectively identified all patients who received neuroimaging at the University of Vermont Medical Center between 2005 and 2015. The PECARN study was published in September of 2009. To account for delay in implementation of new study results, subjects evaluated between 2005 and 2010 were defined as the pre-PECARN group and subjects evaluated between 2010 and 2015 were defined as the post-PECARN group. Subjects aged 0-3 y (an age group considered at greatest risk of radiation-induced malignancies [6,8]) who presented within 24 h of head injury with Glasgow Coma Scale (GCS) 14 or higher were included in the study.

Subjects were divided into three age brackets: 0-1y, 1-2 y, and 2-3 y to assess for possible difference in trends depending on age group. In keeping with the PECARN study, those who received neuroimaging at another facility before arrival or had penetrating trauma, known brain tumors, pre-existing neurological disorders, ventricular shunts, coagulopathies, or GCS < 14 were excluded. Although the PECARN study excluded patients with ground-level falls and those who ran into stationary objects, we included these patients because they had documented head impact of some nature. All data from this study were acquired from review of electronic medical records.

PECARN criteria

The original PECARN study introduced a set of prediction rules that divided patients into three management groups depending on age and clinical presentation. Separate rules were derived for children aged less than 2 years and those 2 to 18 years (fig 1). Each group was associated with a different level of risk of ciTBI as defined above. CT is recommended for children with high risk of ciTBI. Either CT or observation is recommended for those with intermediate risk of ciTBI and CT is not recommended for those with low risk of ciTBI. Predictors of high ciTBI risk include GCS<=14, altered mental status (agitation, somnolence, repetitive questioning, or slow response), palpable skull fracture (if < 2y), and basilar skull fracture (if ≥ 2y). Predictors of intermediate ciTBI include severe mechanism of

injury, loss of consciousness (LOC), non-frontal hematoma (if < 2y), not acting normally per parents (if < 2y), vomiting (if ≥ 2y), and severe headache (if ≥ 2y). Severe mechanism of injury was defined as motor vehicle crash (with patient ejection, passenger death, roll over, or pedestrian or bicyclist struck by vehicle), falls greater than 3 ft (if < 2y) or 5 ft (if ≥ 2y), or head struck by high-impact object [16]. We defined cases as meeting PECARN criteria if they were in either the high or intermediate ciTBI risk groups. Subjects in the low ciTBI risk group were defined as not meeting PECARN criteria.

CT findings

Each patient's head CT report was reviewed for radiologists' identification of positive and incidental findings. A positive finding on CT scan was defined according to the original PECARN study: intracranial hemorrhage or contusion, cerebral edema, traumatic infarction, diffuse axonal injury, shearing injury, sigmoid sinus thrombosis, midline shift, diastasis of skull, pneumocephalus, or skull fracture. We defined incidental findings as any nontraumatic abnormality visualized on head CT whether or not further work-up or intervention was done. Subjects' charts were reviewed to determine how each incidental finding was managed. Findings that were identified prior to the study period were not included. In keeping with previous studies, we excluded sinusitis as an incidental finding because sinusitis is so commonly identified on pediatric head imaging [22].

Statistical methods

Demographics, descriptive statistics, and PECARN criteria were calculated. Percentages were computed for categorical variables and were compared with two-proportion z-test to determine differences between pre-PECARN and post-PECARN study groups. Categorical independent variables with binary dependent variables were analyzed with Fisher's exact test or chi-square. An alpha level of 0.05 was used for all statistical tests. Statistical calculations were performed in Excel.

Results

Patient population

Characteristics of the study population are summarized in Table 1. Of the 1,421 subjects screened in the radiology data-set, 233 received imaging studies for head trauma; 107 were performed pre-PECARN and 126 were performed post-PECARN. Out of these 233 imaging studies, 30 (12.9%) were excluded because they were MRIs, follow-ups, or imaging of the spine. Another 47 (20.2%) were excluded because they had neuroimaging done at outside hospitals before transfer, presented more than 24 hours after head trauma, or had coagulopathies or insufficient documentation (fig. 2). In the pre-PECARN group, 52.1% of subjects were female and in the post-PECARN group, 48.2% of subjects were female. When combining both groups, most subjects fell into the 0-1y age bracket (42.3%).

PECARN criteria

Surprisingly, more subjects met PECARN criteria for head CT during the pre-PECARN than post-PECARN period (67.1% vs 50.6%, p=0.04). No subjects in either group met criteria for either intermediate or high risk ciTBI (none required neurosurgery, hospital admission for two or more nights, intubation for greater than 24 hours, or died). More subjects were discharged from the ED post-PECARN than pre-PECARN but this was not statistically significant (80.5% vs 77.6%, p=0.6). Fewer subjects were admitted to the hospital for observation post-PECARN than pre-PECARN but this was also not statistically significant (19.4% vs 22.4%, p=0.6). No admitted cases stayed in the hospital for more than one night.

In the pre-PECARN cohort, 25 (34.2%) subjects met criteria for inclusion in the high (4.3% or 4.4% depending on age) ciTBI risk group. Of these subjects, 6 (8.2%) had GCS=14, 25 (34.2%) had altered mental status, 0 (0.0%) had palpable skull fracture, and 0 (0.0%) had a clinical diagnosis of basilar skull fracture. There were 24 (32.9%) subjects in the intermediate (0.9%) ciTBI risk group. Of these, 4 (5.5%) had occipital or temporal or parietal hematoma, 6 (8.2%) had LOC, 32 (43.8%) had severe mechanism of injury, 5 (6.8%) were not acting normally per parent, 15 (20.5%) had vomiting, and 2 (2.7%) had

headache. There were 24 (32.9%) patient in the low (<0.02% or <0.05% depending on age) ciTBI risk group.

In the post-PECARN cohort, 21 (25.3%) subjects met criteria for inclusion in the high ciTBI risk group. Of these subjects, 5 (6.0%) had GCS=14, 21 (25.3%) had altered mental status, 0 (0.0%) had palpable skull fracture, and 0 (0.0%) had basilar skull fracture. There were 21 (25.3%) subjects in the intermediate ciTBI risk group. Of these, 10 (12.0%) had occipital or temporal or parietal hematoma, 5 (6.0%) had LOC, 22 (26.5%) had severe mechanism of injury, 4 (4.8%) were not acting normally per parent, 8 (9.6%) had vomiting, and 1 (1.2%) had headache. There were 41 (49.9%) cases in the low ciTBI risk group. The proportion of subjects who received non-indicated head CTs was significantly higher post-PECARN than pre-PECARN (49.4% vs 32.9%, p=0.04).

Among those who met PECARN criteria, severe mechanism of injury was the most prevalent PECARN predictor in both groups (43.8% pre-PECARN and 26.5% post-PECARN). Fall > 3 feet (in 0-2 year olds) was the most common severe mechanism of injury (49.0% pre-PECARN and 42.9% post-PECARN). Among those who did not meet PECARN criteria, the most prevalent mechanism of injury was fall < 3 feet for both groups (58.3% pre-PECARN and 36.6% post-PECARN). Table 2 lists the different mechanisms of injury in each group.

Table 3 lists the characteristics of subjects who met and did not meet PECARN criteria for head CT. When combining pre-PECARN and post-PECARN groups, subjects who met PECARN criteria (n=91) and subjects who did not meet PECARN criteria (n=65) did not differ on the basis of age, sex, history of nan-accidental trauma, or ordering provider. However, within the post-PECARN group, there were significantly more males who received non-indicated head CTs (65.9% vs 50.0%, p=0.01). Pre-PECARN, there were two subjects (both age 0-1 yr) with history of non-accidental trauma who met criteria; one patient had an occipital hematoma for inclusion in the 0.9% ciTBI risk group and the other patient had altered mental status for inclusion in the 4.4% ciTBI risk group. Comparing cases that did vs. did not

meet PECARN criteria for imaging, there was no difference in the proportion of ordering clinicians who were based in the ED vs. pediatricians.

CT abnormalities

The pick-up rate for positive CT findings was 17.8% pre-PECARN and 7.2% post-PECARN (p=0.04). The most common positive finding was skull fracture. The remaining positive findings included intracranial hemorrhage or contusion, subdural hematoma, and subgaleal hematoma. None of the subjects had traumatic infarction, sigmoid sinus thrombosis, diffuse axonal injury, pneumocephalus, midline shift, brain herniation, or skull diastasis.

Incidental findings

The proportion of subjects with incidental findings was larger post-PECARN (7.2%) than pre-PECARN (4.1%) but this did not differ significantly (p=0.4). In the pre-PECARN group, no further work-up was done for one patient with subarachnoid space enlargement and one patient with pineal cyst. One patient had low-lying cerebellar tonsils for which an MRI was obtained. The abnormality was determined to be a type I Chiari malformation and no further work-up was done. In the post-PECARN group, no further work-up was done for subjects with mega cisterna magna, prominent cerebellar tonsils, extra-axial fluid suggestive of benign external hydrocephalus, and prominent ventricles. One patient had an invasive dermoid cyst that required surgical resection. Another patient had a suspected cribriform plate mass for which MRI was obtained. The suspected mass was determined to be motion artifact and no further work-up was done. In summary, 3 (33.3%) of incidental findings prompted additional diagnostic testing or invasive intervention. The remaining 6 (66.7%) prompted only routine follow-up.

Discussion

Tools for predicting risk of ciTBI such as the PECARN criteria are useful for reducing CT use in pediatric patients. Although these criteria are reliable and have been validated in various studies, we

suspect that, as at our center, knowledge and implementation of the PECARN study remain limited. Many pediatric head scans for the assessment of trauma do not meet these criteria [18-21]. In our study population, more subjects received non-indicated head CTs following publication of the PECARN criteria.

Most of the ordering clinicians were ED physicians (74.0% pre-PECARN and 53.0% post-PECARN). We suspect that many of those ordering head CT scans for low risk falls in infants may be concerned that clinical indicators of a significant imaging finding may be un-reliable in this age group. Studies have shown that knowledge of PECARN criteria effectively reduces inappropriate CT scanning [9,23,24]. Yet one 2019 study revealed that the PECARN criteria did not significantly change ED physicians' head CT ordering practices [25].

Of note, there were 12 subjects excluded in the post-PECARN group for receiving MRI while none of the subjects included in the pre-PECARN group received MRI. Some studies suggest that increased use of MRI may be commensurate with efforts to decrease CT use [27]. The sensitivity and specificity of a MRI protocol for pediatric TBI are reasonable for detecting ciTBI, and have the added benefit of not requiring sedation or ionizing radiation [28]. Reasons for variation in practice relative to evidence-based guidelines include length of time to obtain scans, patient intolerance, and technology availability [28-30]. More studies need to be conducted to better characterize use of MRI for pediatric TBI. It will also be useful for future studies to validate that PECARN predictions regarding percentage of cases meeting the definition of ciTBI. Proper implementation of the PECARN criteria could also decrease costs by reducing the number of patients who are admitted from the ED for continued observation [9].

Our pick-up rates for CT findings were 17.8% pre-PECARN and 7.2% post-PECARN, consistent with the 6% to 30% pick-up rate seen in other studies [16, 25]. A higher number of subjects with non-severe mechanisms of injury underwent head CT in the post-PECARN group. This may explain the decrease in positive CTs post-PECARN.

In our study, 5.7% of our cases had incidental findings, which is roughly equivalent to the 4% pick-up rate found in other studies [22]. Although an incidental finding of a dermoid cyst may have been lifesaving for one patient, further work-up was not pursued for most of our subjects with incidental findings. Two subjects received additional work-up with MRI and they ultimately did not require further management other than follow-up. Clearly, reducing CT use may reduce costs and patient anxiety by preventing discovery of clinically insignificant incidental findings. In contrast to previous studies which revealed that female gender was associated with higher risk of receiving non-indicated head CT scans, a higher number of males received non-indicated CT in our study [25]. However, given our small sample size, our findings could be attributable to chance alone.

Upon interviewing various healthcare clinicians at our institution, we discovered that many were unaware of imaging guidelines used for pediatric head trauma. EHR programming constitutes an area that can be explored for quality improvement. Our center has begun an effort to inform ordering clinicians about PECARN guidelines through the electronic health record (EHR). Just as medication safety improved following EHR modification [26], EHR prompts have been associated with reduced CT use and no increase in missed ciTBIs [23, 24].

Limitations

Inferences drawn from this study are limited by its retrospective nature. Specifically, histories and physical were not as well documented prior to our medical center's acquisition of electronic medical records. Some PECARN-related criteria were not recorded as well as others, including identification of "severe headache." The exact heights of falls were not consistently documented and had to be estimated. There could have been inconsistencies among radiologists' interpretations, and follow-up studies prompted by incidental findings may have been inconsistently documented

Our sample size is small in part because, we included subjects up to only 3 years of age, while other studies included subjects up to 18 years of age. Exclusion of children who did not receive head

scans for ciTBI also contributed to our small sample size. It could be interesting to compare characteristics between those who were scanned and those who were not scanned. Finally, our study period includes subjects from 2005 to 2015. We suspect that more clinicians have become aware of the PECARN criteria in the last 4 years.

Conclusions

Our retrospective study demonstrates limited implementation of PECARN criteria, as clinicians continue to excessively scan young patients relative to widely accepted practice standards. Clinicians' level of comfort with pediatric trauma cases and limited awareness of evidence-based guidelines likely contribute to this observation. Clinically insignificant incidental findings are often detected and may produce heightened patient anxiety. Although this study was conducted at a single institution and may not be generalizable to other facilities, results highlight areas for improvement likely relevant to other health care centers. Areas for quality improvement include promoting awareness and implementation of PECARN criteria by educating ED clinicians and generalists and programming the electronic health record to include PECARN criteria.

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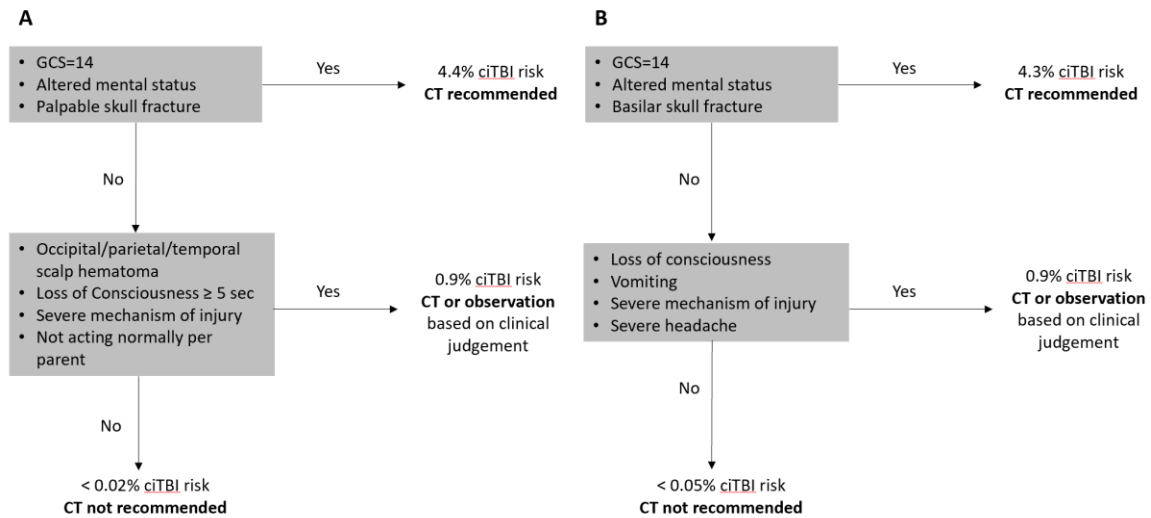
Fig. 1 PECARN algorithm for determining which patients should receive head CT following minor head trauma. A) Criteria for patients aged < 2y B) Criteria for patients aged ≥ 2y [16].
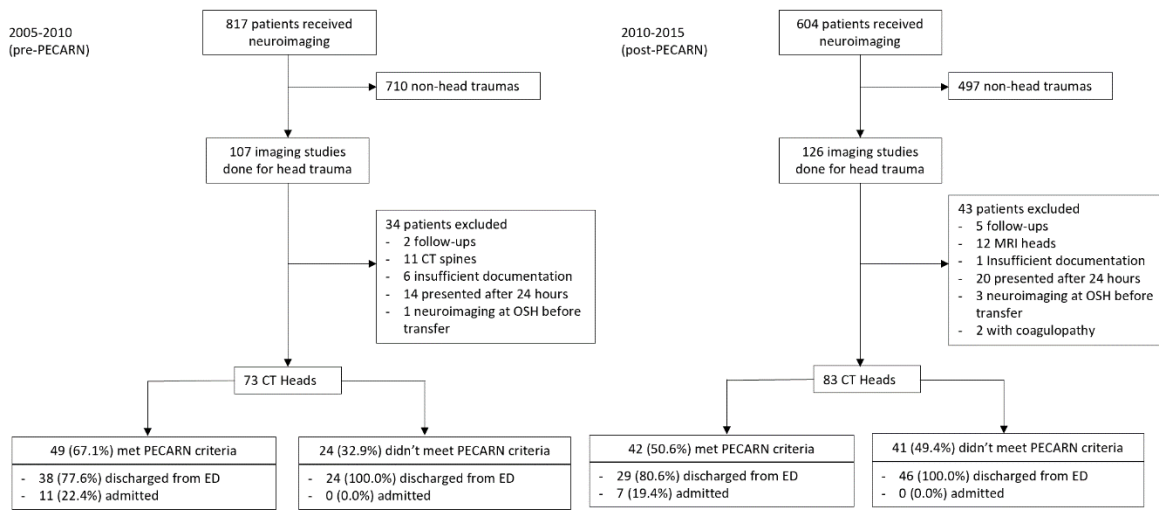
Fig. 2 Flow chart. CT=computed tomography, OSH=outside hospital, ciTBI=clinically important traumatic brain injury (see definition in text)

Table 1: Patient characteristics before and after publication of PECARN study

	Pre-PECARN (n = 73) *n* (%)	Post-PECARN (n = 83) *n* (%)
Age		
0-1 yr	25 (34.2)	41 (49.4)
1-2 yr	37 (50.7)	20 (24.1)
2-3 yr	11 (15.1)	22 (26.5)
Sex		
Female	38 (52.1)	40 (48.2)
Male	35 (47.9)	43 (51.8)
ciTBI risk		
High risk	25 (34.2)	21 (25.3)
GCS = 14	6 (8.2)	5 (6.0)
Altered mental status	25 (34.2)	21 (25.3)
Palpable skull fracture	0 (0.0)	0 (0.0)
Basilar skull fracture	0 (0.0)	0 (0.0)
Intermediate risk	24 (32.9)	21 (25.3)
O/P/T hematoma	4 (5.5)	10 (12.0)
LOC	6 (8.2)	5 (6.0)
Severe mechanism	32 (43.8)	22 (26.5)
Not acting normally	5 (6.8)	4 (4.8)
Vomiting	15 (20.5)	8 (9.6)
Severe headache	2 (2.7)	1 (1.2)
Low risk	24 (32.9)	41 (49.4)
ciTBI	0 (0.0)	0 (0.0)
Positive CT	13 (17.8)	6 (7.2)
Incidental findings	3 (4.1)	6 (7.2)

ciTBI=clinically-important traumatic brain injury, GCS=Glasgow Coma Scale,
O/P/T= occipital/parietal/temporal, LOC=loss of consciousness.

Table 2: Mechanisms of injury for patients who met vs. didn't meet PECARN criteria

Pre-PECARN				Post-PECARN			
Met criteria (n = 49)	n (%)	Didn't meet criteria (n = 24)	n (%)	Met criteria (n = 42)	n (%)	Didn't meet criteria (n = 41)	n (%)
Non-severe mechanism*		Fall < 3 ft[a]	14 (58.3)	Non-severe mechanism*		Fall < 3 ft[a]	15 (36.6)
Fall < 3 ft[a]	9 (18.4)	Fall < 5 ft[b]	1 (4.2)	Fall < 3 ft[a]	7 (16.7)	Fall < 5 ft[b]	6 (14.6)
Fall < 5 ft[b]	2 (4.1)	Ground-level fall	7 (29.2)	Fall < 5 ft[b]	6 (14.3)	Ground-level fall	12 (29.3)
Ground-level fall	2 (4.1)	MVA[d]	1 (4.2)	Severe mechanism		MVA[d]	1 (2.4)
Severe mechanism				Fall > 3 ft[a]	18 (42.9)	Ran into stationary object	3 (7.3)
Fall > 3 ft[a]	22 (49.0)			Fall > 5 ft[b]	0 (0.0)		
Fall > 5 ft[b]	2 (4.1)			Blow to head[c]	5 (11.9)		
Blow to head[c]	7 (14.3)			MVA	3 (7.1)		
MVA	3 (6.1)						

MVA=motor vehicle accident. *Patients met PECARN criteria with predictor(s) other than severe mechanism of injury.

[a] age < 2 yr

[b] age > 2 yr

[c] head struck by high-impact object: table, concrete block, TV, dresser, wine bottle, kicked in the head, car door slammed on head

[d] non-severe MVA: drove car into ditch at low speed, T-bone on passenger side

Table 3: Characteristic of patients who met vs. didn't meet PECARN criteria

Characteristics	Pre-PECARN		Post-PECARN	
	Met criteria (n = 49)	Didn't meet criteria (n = 24)	Met criteria (n = 42)	Didn't meet criteria (n = 41)
Age				
0-1 yr	20 (40.8)	5 (20.8)	21 (50.0)	20 (48.8)
1-2 yr	21 (42.8)	16 (66.7)	7 (16.7)	13 (31.7)
2-3 yr	8 (16.3)	3 (12.5)	8 (19.0)	14 (34.1)
Sex				
Female	26 (52.1)	12 (50.0)	16 (44.4)	20 (48.8)
Male	23 (47.9)	12 (50.0)	20 (38.1)	27 (65.9)
NAT	2[a] (4.1)	0 (0.0)	1[b] (2.4)	1 (2.4)
Ordering providers				
ED	34 (69.4)	20 (83.3)	24 (57.1)	20 (48.8)
Pediatrician	6 (12.2)	0 (0.0)	6 (14.3)	9 (22.0)

Data are reported as n (%). NAT=non-accidental trauma. NS= not significant
[a] 1 patient with altered mental status, 1 patient with occipital hematoma
[b] altered mental status