

Original Investigation

Isolated Loss of Consciousness in Children With Minor Blunt Head Trauma

Lois K. Lee, MD, MPH; David Monroe, MD; Michael C. Bachman, MD; Todd F. Glass, MD; Prashant V. Mahajan, MD, MPH, MBA; Arthur Cooper, MD; Rachel M. Stanley, MD, MHSA; Michelle Miskin, MS; Peter S. Dayan, MD, MSc; James F. Holmes, MD, MPH; Nathan Kuppermann, MD, MPH; for the Traumatic Brain Injury (TBI) Working Group of the Pediatric Emergency Care Applied Research Network (PECARN)

IMPORTANCE A history of loss of consciousness (LOC) is frequently a driving factor for computed tomography use in the emergency department evaluation of children with blunt head trauma. Computed tomography carries a nonnegligible risk for lethal radiation-induced malignancy. The Pediatric Emergency Care Applied Research Network (PECARN) derived 2 age-specific prediction rules with 6 variables for clinically important traumatic brain injury (ciTBI), which included LOC as one of the risk factors.

OBJECTIVE To determine the risk for ciTBIs in children with isolated LOC.

DESIGN, SETTING, AND PARTICIPANTS This was a planned secondary analysis of a large prospective multicenter cohort study. The study included 42 412 children aged 0 to 18 years with blunt head trauma and Glasgow Coma Scale scores of 14 and 15 evaluated in 25 emergency departments from 2004-2006.

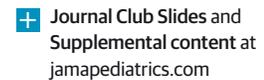
EXPOSURE A history of LOC after minor blunt head trauma.

MAIN OUTCOMES AND MEASURES The main outcome measures were ciTBIs (resulting in death, neurosurgery, intubation for >24 hours, or hospitalization for ≥ 2 nights) and a comparison of the rates of ciTBIs in children with no LOC, any LOC, and isolated LOC (ie, with no other PECARN ciTBI predictors).

RESULTS A total of 42 412 children were enrolled in the parent study, with 40 693 remaining in the current analysis after exclusions. Of these, LOC occurred in 15.4% (6286 children). The prevalence of ciTBI with any history of LOC was 2.5% and for no history of LOC was 0.5% (difference, 2.0%; 95% CI, 1.7-2.5). The ciTBI rate in children with isolated LOC, with no other PECARN predictors, was 0.5% (95% CI, 0.2-0.8; 13 of 2780). When comparing children who have isolated LOC with those who have LOC and other PECARN predictors, the risk ratio for ciTBI in children younger than 2 years was 0.13 (95% CI, 0.005-0.72) and for children 2 years or older was 0.10 (95% CI, 0.06-0.19).

CONCLUSIONS AND RELEVANCE Children with minor blunt head trauma presenting to the emergency department with isolated LOC are at very low risk for ciTBI and do not routinely require computed tomographic evaluation.

JAMA Pediatr. doi:10.1001/jamapediatrics.2014.361
Published online July 7, 2014.

 Journal Club Slides and Supplemental content at jamapediatrics.com

Author Affiliations: Author affiliations are listed at the end of this article.

Group Information: The members of the Traumatic Brain Injury (TBI) Working Group of the Pediatric Emergency Care Applied Research Network (PECARN) are listed at the end of this article.

Corresponding Author: Lois K. Lee, MD, MPH, Division of Emergency Medicine, Boston Children's Hospital, 300 Longwood Ave, Boston, MA 02115 (lois.lee@childrens.harvard.edu).

Head trauma in children is common and accounts for more than a half million emergency department (ED) visits annually in the United States.¹ The overall risk for traumatic brain injury (TBI) in children after blunt head trauma is low, with the estimated prevalence for TBI requiring neurosurgical intervention ranging from 0.6% to 8.3%.²⁻⁶ In children with minor blunt head trauma (defined by Glasgow Coma Scale [GCS] scores of 13-15), the risks are substantially lower.⁷⁻¹⁴ Nevertheless, failing to detect a clinically significant TBI can have devastating consequences,^{2,15,16} and fear of missing these rare injuries has been the main factor driving an increase in the use of computed tomography (CT) imaging over the past 2 decades.¹⁷⁻¹⁹ With the growing awareness of the malignancy risks associated with ionizing radiation exposure from CT,²⁰⁻²³ the use of emergent CT in head-injured children has been scrutinized.²²

Of the clinical factors that strongly influence the use of CT after blunt head trauma, a history of loss of consciousness (LOC) is among the most frequent.^{11,16,24-30} Clinicians' concerns about LOC increase with longer LOC duration; however, there is little evidence to support this concern when LOC occurs in isolation.^{2,16,31} Although LOC after blunt head trauma has been identified as a predictor for TBI in several previous multivariable analyses,^{2,14,26,30} the importance of a history of isolated LOC (without other symptoms or signs of TBI) as a predictor for clinically important TBIs (ciTBIs) is unclear. Clinical prediction rules derived from large multicenter studies aid the clinician in real-time evidence-based decision making regarding the use of cranial CTs in children with blunt head trauma.^{2,12,13}

We previously derived and validated 2 age-specific clinical prediction rules for identifying children at very low risk for ciTBIs in 42 412 children with minor blunt head trauma in the Pediatric Emergency Care Applied Research Network (PECARN).¹² Although a history of LOC was identified as a predictor of ciTBI in the prediction rules, the importance of isolated LOC and its association with ciTBI was not previously investigated. The objective of this study was to determine the risk for ciTBI in children with isolated LOC.

Methods

Study Design

We performed a planned subanalysis of a large prospective observational cohort study of children younger than 18 years of age with blunt head trauma enrolled in the 25 participating PECARN EDs between 2004 and 2006. Institutional review board approval was obtained for the study protocol at each participating institution. Waiver of consent or verbal consent for telephone follow-up was obtained, depending on the institution. The detailed methods from the parent study have been previously published.¹² Methods for the current substudy are summarized here.

Inclusion and Exclusion Criteria

Children with blunt head trauma evaluated within 24 hours of injury and presenting with GCS scores of 14 and 15 were eligible for enrollment. We excluded children with histories of

Table 1. Definitions of Isolated LOC and the PECARN ciTBI Prediction Rules

Age Group	Isolated LOC Defined by the PECARN Rules (PECARN-Isolated LOC)	Expanded Definition of Isolated LOC (Expanded-Isolated LOC)
Children <2 y	LOC > 5 s; none of the other age-specific PECARN predictors ¹² : altered mental status, ^a nonfrontal scalp hematoma, severe mechanism of injury, ^b palpable skull fracture, and acting abnormally according to parent	Any duration LOC; none of the other age-specific PECARN clinical predictors (from PECARN-isolated LOC) excluding mechanism of injury ^c ; none of the following: seizure, neurologic deficit, signs of basilar skull fracture, any scalp hematoma, any traumatic scalp finding (eg, abrasion, ecchymosis, and laceration), and history of vomiting
Children ≥2 y	Any LOC; none of the other age-specific PECARN predictors ¹² : altered mental status, ^a history of vomiting, signs of basilar skull fracture, severe mechanism of injury, ^b and severe headache	Any LOC; none of the other age-specific PECARN clinical predictors (from PECARN-isolated LOC) excluding mechanism of injury ^c ; none of the following: seizure, neurologic deficit, palpable skull fracture, any scalp hematoma, any traumatic scalp finding (eg, abrasion, ecchymosis, and laceration), any headache, amnesia, and acting abnormally according to parent

Abbreviations: ciTBI, clinically important traumatic brain injury; LOC, loss of consciousness; PECARN, Pediatric Emergency Care Applied Research Network.

^a Altered mental status was defined as follows: Glasgow Coma Scale score = 14, agitation, somnolence, repetitive questioning, or slow response to verbal communication.¹²

^b Severe mechanism of injury was defined as follows: motor vehicle crash with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by a motorized vehicle; falls of greater than 3 feet (for <2 years old) or falls of greater than 5 ft (for ≥2 years old); or struck by a high-impact object.¹²

^c Severe mechanism of injury was not included in this definition because it is not a sign or symptom of TBI.

trivial injury mechanisms, defined as ground-level falls or running into stationary objects, and with no signs or symptoms of head injury except for scalp abrasions or lacerations. We also excluded children with penetrating trauma, significant comorbidities (eg, bleeding disorders and ventricular shunts), pre-existing neurologic disorders complicating assessment, or neuroimaging obtained at a transferring hospital.

LOC Definitions

We considered a history of LOC to be present if there was any period of unconsciousness reported after the traumatic event. The treating staff physician completed a structured data collection form for all enrolled patients, including whether there was a history of LOC, with options to answer yes, no, suspected, or unknown. For purposes of analysis, a response of suspected LOC was considered to be LOC. The duration of LOC was marked as either less than 5 seconds, 5 seconds to less than 1 minute, 1 to 5 minutes, more than 5 minutes, or unknown. On the case report form, clinicians were also asked to indicate the most important indications influencing their decisions to obtain cranial CT scans from a list of options.

We previously found the interrater reliability for the LOC variable to be substantial.³² The interrater reliability was moderate for children younger than 2 years ($\kappa = 0.54$) and nearly perfect for children 2 years and older ($\kappa = 0.93$).^{32,33} The interrater reliability for LOC duration for children younger than 2 years was $\kappa = 0.48$ and for children 2 years and older was $\kappa = 0.87$.^{32,33} Furthermore, in the parent study, we found that LOC (in addition to 5 other factors) was included as a significant predictor of ciTBI for both age-specific clinical prediction rules, with different parameters by age group (Table 1).¹²

For the purposes of the current analysis, we defined *isolated LOC* in 2 ways to correspond with 2 possible clinician interpretations of isolated LOC: (1) isolated LOC defined by the PECARN rules (PECARN-isolated LOC): isolated LOC with no other PECARN ciTBI age-specific predictors¹² and (2) expanded definition of isolated LOC (expanded-isolated LOC): isolated LOC with no other PECARN age-specific clinical predictors and no other clinical factors identified in other pediatric studies of TBI (Table 1).^{2,6,7,11,31,34} One important distinction between the 2 definitions is that severe mechanism of injury is included as 1 of the 6 PECARN ciTBI predictors in PECARN-isolated LOC (Table 1).¹² The more extensive list of variables defining expanded-isolated LOC did not include mechanism of injury because it is not a clinical sign or symptom of head injury.¹² Because the exact mechanism of injury is sometimes unclear in the history (eg, height of fall or speed of motor vehicle), this variable was excluded from the expanded-isolated LOC definition so that it would characterize only the clinical presentation of the child. Children were excluded from these analyses if data were missing on any of the age-specific PECARN predictors for PECARN-isolated LOC or any of the PECARN clinical predictors or more than 1 of the variables among the other factors for expanded-isolated LOC.

Outcome Measures and Definitions

We analyzed 2 outcome measures: (1) ciTBI and (2) TBI on CT. Clinically important TBI was defined as (1) death from intracranial injury, (2) any neurosurgical intervention, (3) intubation longer than 24 hours for the head injury, or (4) hospitalization for 2 nights or longer owing to the head injury in association with TBI on CT.¹² Traumatic brain injury on CT included any traumatic intracranial injury and skull fractures depressed at least the width of the table of the skull.¹²

Data Analysis

For purposes of analysis, the study cohort was divided into children younger than 2 years and those 2 years and older, as per the PECARN ciTBI rules. We first calculated the risk for TBI on CT and ciTBI for all patients with histories of LOC, regardless of the presence of other risk factors. For the analysis of TBI on CT, we only included children who had CT scans performed; all of the children with ciTBI had CT scans performed. We then conducted a bivariable analysis comparing the rates of TBI on CT and ciTBI in children with PECARN-isolated LOC vs nonisolated LOC. We calculated frequencies and 95% CIs for categorical variables and the median and interquartile ranges for continuous variables. We then calculated the rates and 95% CIs for TBI on CT and ciTBI for those with expanded-isolated LOC.

Because of the relatively small sample sizes in the younger age group, we used exact methods to calculate the estimates of relative risk. We also calculated the risk for ciTBI for PECARN-isolated LOC plus 1 additional age-specific PECARN predictor. Finally, we calculated the risk for TBI on CT and ciTBI stratified by the duration of LOC. We used StatXact (version 8.0) to calculate the relative risk estimates in the younger age group. We used SAS/STAT software (version 9.2; SAS Institute Inc) for all other analyses.

Results

Study Population

We enrolled 42 412 children in the parent study (74.4% of 57 030 eligible children). There were similar rates of TBI on CT between the enrolled and missed eligible patients.¹² In the current analysis, we excluded 1719 children (4.1%) with missing information regarding the presence or absence of a history of LOC. Of the 40 693 remaining children (95.9%), the clinician indicated yes or suspected LOC after head injury for 6286 (15.4%). Among the 13 637 children with cranial CT performed, 5010 (36.7%) had histories of LOC. Of these 13 637 children imaged with cranial CT, 3797 (27.8%) had LOC recorded by the clinician as one of the most important indications influencing their decision to obtain a CT scan.

For the 6286 children with any history of LOC, the median age was 12.7 years (interquartile range, 7.2-15.4 years); 5745 (91.4%) were 2 years and older; 66.2% were boys; and 92.6% had GCS scores of 15. For children without histories of LOC, the median age was 4.7 years (interquartile range, 1.7-10.4 years), and 97.9% had GCS scores of 15. Clinically important TBI occurred in 159 children (2.5%) with any history of LOC and in 162 children (0.5%) with no history of LOC (rate difference, 2.0%; 95% CI, 1.7-2.5). Among children with any LOC and no CT performed, none had ciTBI. There was no statistically significant difference in the rate of TBI on CT between the children with (5.1%) and without (4.9%) histories of LOC (rate difference, 0.2%; 95% CI, -0.6 to 1.0).

PECARN-Isolated LOC and TBI

For the primary analysis, we focused on children with LOC but no other PECARN predictors (PECARN-isolated LOC). Of the 6286 children with histories of LOC, 436 (6.9%) were excluded because of missing data, most ($n = 312$) of these patients were missing the severity level of the headache, leaving 5850 children (93.1%) for analysis. Furthermore, PECARN-isolated LOC was present in 2780 (47.5%) of these 5850 patients, of whom 2623 (94.4%) were 2 years and older and 1993 (71.7%) had cranial CT scans performed. The rate of TBI on CT was 1.9% (95% CI, 1.4-2.6; 38 of 1993), and the rate of ciTBI was 0.5% (95% CI, 0.2-0.8; 13 of 2780). With PECARN-isolated LOC, the risk for TBI on CT and ciTBI was significantly lower than in patients with histories of nonisolated LOC (ie, those having other PECARN ciTBI predictors; Table 2). The rates of ciTBI in children with LOC (LOC >5 seconds for children <2 years and any LOC for children ≥ 2 years) plus 1 additional age-specific PECARN ciTBI predictor are presented in Table 3. The eTable

Table 2. Comparison of Children With PECARN-Isolated LOC vs Children With LOC and Other PECARN Predictors by Age Group

Outcome	Age Group, y	No.	No./No. (%) [95% CI]		Relative Risk (95% CI)
			PECARN-Isolated LOC (n = 2780)	Non-isolated LOC With Other PECARN Predictors (n = 3070)	
TBI on CT (246 of 4723 with CT scans)	<2	354	2/90 (2.2) [0.3-7.8]	24/264 (9.1) [5.9-13.2]	0.24 (0.02-0.87)
	≥2	4369	36/1903 (1.9) [1.3-2.6]	184/2466 (7.5) [6.5-8.6]	0.25 (0.18-0.36)
ciTBI (150 of 5850)	<2	504	1/157 (0.6) [0.0-3.5]	17/347 (4.9) [2.9-7.7]	0.13 (0.005-0.72)
	≥2	5346	12/2623 (0.5) [0.2-0.8]	120/2723 (4.4) [3.7-5.2]	0.10 (0.06-0.19)

Abbreviations: ciTBI, clinically important traumatic brain injury; CT, computed tomography; LOC, loss of consciousness; PECARN, Pediatric Emergency Care Applied Research Network; TBI, traumatic brain injury.

Table 3. Risk for ciTBI with PECARN-Isolated LOC Plus 1 Additional Age-Specific PECARN ciTBI Prediction Rule Factor

PECARN ciTBI Clinical Predictor	No./No. (%) [95% CI]
Children <2 y of age	
Isolated LOC>5 s	1/157 (0.6) [0-3.5]
Plus 1 additional PECARN clinical predictor ^a	
Altered mental status	0/16 (0) [0-20.6]
Nonfrontal scalp hematoma	0/16 (0) [0-20.6]
Severe mechanism of injury	2/51 (3.9) [0.5-13.5]
Not acting normally per parent	0/20 (0) [0-16.8]
Children ≥2 y of age	
Isolated LOC	12/2623 (0.5) [0.2-0.8]
Plus 1 additional PECARN clinical predictor	
Altered mental status	13/695 (1.9) [1.0-3.2]
History of vomiting	3/321 (0.9) [0.2-2.7]
Clinical signs of basilar skull fracture	2/20 (10.0) [1.2-31.7]
Severe mechanism of injury	13/539 (2.4) [1.3-4.1]
Severe headache	0/121 (0) [0-3.0]

Abbreviations: ciTBI, clinically important traumatic brain injury; LOC, loss of consciousness; PECARN, Pediatric Emergency Care Applied Research Network.

^a There were no patients who were younger than 2 years of age who only had LOC and a palpable skull fracture.

in the Supplement provides descriptions of the 13 children with PECARN-isolated LOC and ciTBIs. All had other clinical factors previously shown to be associated with TBI but no other PECARN clinical predictors.

Expanded-Isolated LOC and TBI

For the second analysis, we focused on children meeting the expanded-isolated LOC definition (LOC in the absence of any other clinical predictor identified in a pediatric TBI study) because many clinicians may consider a factor isolated only in the absence of any other studied and reported risk factors, independent of ciTBI prediction rules.³⁵ For this analysis, of the 6286 children with histories of LOC, 154 (2.4%) were excluded because of missing data, most (n = 105) of these patients were missing the variable of whether or not they had a headache, leaving 6132 children (97.6%) for analysis. Expanded-isolated LOC was present in 576 (9.4%) of these patients, of whom 432 (75.0%) were 2 years and older and 326 (56.6%) had cranial CT scans performed. The rate of TBI on CT was 0.9%

(95% CI, 0.2-2.7; 3 of 326) and that of ciTBI was 0.2% (95% CI, 0.0-1.0; 1 of 576). To explore the importance of the duration of LOC and TBI, we reported the rates of TBI on CT and ciTBI for children with any history of LOC, regardless of the presence or absence of other symptoms, and for children with expanded-isolated LOC, stratified by duration of LOC (Table 4). The duration of LOC did not significantly affect the risk for ciTBI in those with expanded-isolated LOC, although the numbers in each duration category of LOC were small.

Discussion

Loss of consciousness is common in children with blunt head trauma and is an important factor influencing CT use for these children.^{2,11,24-26,28,36} A history of LOC was reported in 15.4% of children enrolled in this large prospective cohort. Furthermore, a history of LOC was identified as one of the primary indications for obtaining cranial CT in nearly 30% of children who were imaged with CT. The overall risk for ciTBI for children with histories of LOC was higher than that for children without LOC but this included children with other signs and symptoms of TBI in addition to LOC. Children with PECARN-isolated LOC and no other PECARN ciTBI predictors had a very low rate of ciTBI (0.5%), and this rate was even lower in children with the expanded definition of isolated LOC (0.2%). There was incremental risk for ciTBI with the addition of 1 PECARN predictor in conjunction with a history of LOC. Given that a history of LOC has a very strong influence on imaging decisions,^{9,16,24-26,30,37,38} these findings highlight the need for clinicians to determine whether LOC occurred with or without other ciTBI risk factors when deciding on CT use.

We defined isolated LOC in 2 ways but focused on those patients with LOC but no other PECARN ciTBI predictors (PECARN-isolated LOC). Although a history of LOC is one of the PECARN predictors, the presence of LOC alone does not place a child at high risk.¹² With more widespread use of the age-specific PECARN ciTBI prediction rules in clinical practice,³⁹⁻⁴³ further defining the importance of each PECARN predictor in isolation, particularly LOC, is important.⁴⁴ Because ciTBI is very uncommon in children with isolated LOC, routine CT scanning is unlikely to be beneficial, and a period of observation prior to CT decision making may safely decrease CT use.^{39,45,46}

Table 4. ciTBI and TBI on CT by Duration of LOC for All Children with LOC Regardless of Age

LOC Characteristic	No./No. (%) [95% CI]			
	All Children With Any LOC (n = 6286)		Expanded-Isolated LOC (n = 576)	
	ciTBI	TBI on CT	ciTBI	TBI on CT
Any LOC, irrespective of duration	159/6286 (2.5) [2.2-2.9]	258/5010 (5.1) [4.6-5.8]	1/576 (0.2) [0.0-1.0]	3/326 (0.9) [0.2-2.7]
Duration of LOC				
<5 s	9/907 (1.0) [0.5-1.9]	19/552 (3.4) [2.1-5.3]	0/125 (0) [0.0-2.9]	0/46 (0) [0-7.7]
5 s-<1 min	29/1822 (1.6) [1.1-2.3]	52/1354 (3.8) [2.9-5.0]	0/219 (0) [0.0-0.7]	1/114 (0.9) [0-4.8]
1-5 min	30/1065 (2.8) [1.9-4.0]	50/900 (5.6) [4.2-7.3]	0/81 (0) [0.0-4.5]	1/54 (1.9) [0-9.9]
>5 min	8/209 (3.8) [1.7-7.4]	13/184 (7.1) [3.8-11.8]	0/25 (0) [0.0-13.7]	0/19 (0) [0-17.6]
Unknown/missing	83/2283 (3.6) [2.9-4.5]	124/2020 (6.1) [5.1-7.3]	1/126 (0.8) [0.0-4.3]	1/93 (1.1) [0-5.8]

Abbreviations: ciTBI, clinically important traumatic brain injury; CT, computed tomography; LOC, loss of consciousness; TBI, traumatic brain injury.

Parents are often disturbed by witnessing LOC in their children, and clinicians frequently obtain cranial CT scans based on this history.^{9,16,24,26,30,37,38} A history of LOC has been suggested as an indication for CT in prior studies.^{9,16,26,30,37,38} Many of these previous studies were limited by small sample sizes, retrospective designs, nonstandard definitions of TBI, differing inclusion criteria and definitions of other signs and symptoms of TBI, and varying outcome definitions. However, to our knowledge, other studies have not demonstrated that LOC is associated with a substantially increased risk for TBI (in particular ciTBI), especially in those patients with normal cranial and neurologic examination findings.^{3,5,7,8,11,13,35}

Furthermore, and more importantly, prior to the current study, there had been very limited data regarding the risk for ciTBI in the setting of isolated LOC. A few small studies have reported no TBIs in children with isolated LOC after blunt head trauma.^{8,35} Although LOC was a ciTBI predictor in the parent PECARN study, in the current subanalysis, we demonstrated that when LOC occurs in isolation, with no other clinical risk factors, the risk for ciTBI is remote.

Many studies attempting to derive clinical prediction rules for cranial CT evaluation after blunt head trauma, including several large prospective studies, have not identified LOC as an important factor.^{3,4,7,11,13} One large, prospective, multicenter study included LOC longer than 5 minutes in their 14-variable rule, which was developed to identify children at high risk for ciTBI who should undergo cranial CT evaluation. However, in that study, there was no description of children with TBIs who had LOC in isolation.² In the current study, LOC longer than 5 minutes' duration was very uncommon, and in the expanded-isolated group, there was only 1 child with ciTBI, whose duration of LOC was unknown.

This study had several potential limitations. First, not all children had cranial CT scans performed during their ED evalu-

ations because this decision was at the discretion of treating clinicians. However, all children in the study had clinical follow-up, allowing for accurate assessment of ciTBI. In addition, the presence or absence of LOC was recorded for most (95.9%) of the study population; thus, even with complete data, the results would be unlikely to change. Because we would not be able to determine whether LOC was isolated owing to missing data, we were unable to analyze a small percentage of children in the 2 analyses as follows: 436 (6.9%) in the PECARN-isolated LOC group and 154 (2.4%) in the expanded-isolated LOC group. It is also possible that clinicians completing case report forms may have had different interpretations of a history of LOC. These differences are likely to be minimal because site investigators received training in data collection and had access to a study manual of operations providing the LOC definition. Also, a previous analysis of this study population determined good to excellent interrater reliability for the LOC variable.³² Finally, in spite of the large total number of patients enrolled in the study, the number of children younger than 2 years with PECARN-isolated or expanded-isolated LOC from which to determine risks for this age group was relatively small.

Conclusions

Children with isolated LOC after blunt head trauma, with normal physical examination findings and no other signs or symptoms of ciTBI, are at very low risk for ciTBI and do not routinely require cranial CT evaluation. In these children, clinical observation for the development of other signs or symptoms of ciTBI prior to CT decision making may be an effective management strategy to avoid the radiation risks of CT. Emergent neuroimaging can be safely avoided in the absence of development of other clinical signs of ciTBI.

ARTICLE INFORMATION

Accepted for Publication: February 25, 2014.

Published Online: July 7, 2014.
doi:10.1001/jamapediatrics.2014.361

Author Affiliations: Division of Emergency Medicine, Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts (Lee);

Department of Emergency Medicine, Howard County General Hospital, Columbia, Maryland (Monroe); Departments of Emergency Medicine and Pediatrics, Newark Beth Israel Medical Center, Newark, New Jersey (Bachman); Department of Pediatrics, University of Cincinnati College of Medicine, Cincinnati, Ohio (Glass); Department of Pediatrics, Wayne State University School of

Medicine, Detroit, Michigan (Mahajan); Department of Surgery, Columbia University Medical Center at Harlem Hospital, New York, New York (Cooper); Department of Emergency Medicine, University of Michigan School of Medicine, Ann Arbor (Stanley); Department of Pediatrics, University of Utah, Salt Lake City (Miskin); Division of Emergency Medicine, Morgan Stanley Children's Hospital, Columbia

University College of Physicians and Surgeons, New York, New York (Dayan); Department of Emergency Medicine, University of California, Davis School of Medicine (Holmes, Kuppermann); Department of Pediatrics, University of California, Davis School of Medicine (Kuppermann).

Author Contributions: Ms Miskin and Dr Kuppermann had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Lee, Dayan, Holmes, Kuppermann.

Acquisition, analysis, or interpretation of data: Lee, Monroe, Bachman, Glass, Mahajan, Cooper, Stanley, Miskin, Holmes, Kuppermann.

Drafting of the manuscript: Lee, Kuppermann. *Critical revision of the manuscript for important intellectual content:* All authors.

Statistical analysis: Lee, Miskin, Kuppermann. *Obtained funding:* Kuppermann.

Administrative, technical, or material support: Kuppermann.

Study supervision: Lee, Bachman, Glass, Mahajan, Cooper, Stanley, Dayan, Holmes, Kuppermann.

Conflict of Interest Disclosures: None reported.

Funding/Support: This study was supported by grant R40MC02461 from the Health Resources and Services Administration/Maternal and Child Health Bureau (HRSA/MCHB) Division of Research, Education and Training (DRTE) and the Emergency Medical Services for Children (EMSC) Program. The PECARN is supported by the HRSA/MCHB/EMSC Program through the following cooperative agreements: U03MC00001, U03MC00003, U03MC00006, U03MC00007, U03MC00008, U03MC22684, and U03MC22685. The PECARN is supported by cooperative agreements U03MC00001, U03MC00003, U03MC00006, U03MC00007, U03MC00008, U03MC22684, and U03MC22685 from the EMSC program of the MCHB/HRSA.

Role of the Sponsors: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Group Information: The members of the Traumatic Brain Injury (TBI) Working Group of the Pediatric Emergency Care Applied Research Network (PECARN) are as follows: *Atlantic Health System/Morrisstown Memorial Hospital:* Michael Gerardi, MD; *Bellevue Hospital Center:* Michael Tunik, MD, and James Tsung, MD; *Calvert Memorial Hospital:* Craig Melville, MD; *Children's Hospital–Boston:* Lois K. Lee, MD, MPH; *Children's Hospital of Buffalo:* Kathleen Lillis, MD; *Children's Hospital of Michigan:* Prashant V. Mahajan, MD, MPH, MBA; *Children's Hospital of New York–Presbyterian:* Peter S. Dayan, MD, MSc; *Children's Hospital of Philadelphia:* Frances Nadel, MD, MSCE; *Children's Memorial Hospital:* Elizabeth Powell, MD, MPH; *Children's National Medical Center:* Shireen Atabaki, MD, MPH, and Kathleen Brown, MD; *Cincinnati Children's Hospital Medical Center:* Todd F. Glass, MD, MS; *DeVos Children's Hospital:* John Hoyle, MD; *Harlem Hospital Center:* Arthur Cooper, MD; *Holy Cross Hospital:* Elizabeth Jacobs, MD; *Howard County Medical Center:* David Monroe, MD; *Hurley Medical Center:* Dominic Borgialli, DO; *Medical College of Wisconsin/Children's Hospital of Wisconsin:* Marc Gorelick, MD, and Subhankar Bandyopadhyay, MD;

St Barnabas Health Care System: Michael C. Bachman, MD, and Neil Schamban, MD; *SUNY–Upstate Medical Center:* James Callahan, MD; *University of California Davis Medical Center:* Nathan Kuppermann, MD, MPH, and James F. Holmes, MD, MPH; *University of Maryland:* Richard Lichenstein, MD; *University of Michigan:* Rachel M. Stanley, MD, MHA; *University of Rochester:* Mohamed Badawy, MD, and Lynn Babcock-Cimpello, MD, MS; *University of Utah/Primary Children's Medical Center:* Jeff Schunk, MD; and *Washington University/St Louis Children's Hospital:* Kimberly Quayle, MD, and David Jaffe.

We acknowledge the efforts of the following individuals participating in the PECARN at the time this study was initiated:

PECARN Steering Committee: N. Kuppermann, chair; E. Alpern, J. Chamberlain, J. M. Dean, M. Gerardi, J. Goepf, M. Gorelick, J. Hoyle, D. Jaffe, C. Johns, N. Levick, P. Mahajan, R. Maio, K. Melville, S. Miller (deceased), D. Monroe, R. Ruddy, R. Stanley, D. Treloar, M. Tunik, and A. Walker. *MCHB/EMSC liaisons:* D. Kavanaugh and H. Park.

Central Data Management and Coordinating Center (CDMCC): M. Dean, R. Holubkov, S. Knight, and A. Donaldson.

Data Analysis and Management Subcommittee (DAMS): J. Chamberlain, chair; M. Brown, H. Corneli, J. Goepf, R. Holubkov, P. Mahajan, K. Melville, E. Stremski, and M. Tunik.

Grants and Publications Subcommittee (GAPS): M. Gorelick, chair; E. Alpern, J. M. Dean, G. Foltin, J. Joseph, S. Miller (deceased), F. Moler, R. Stanley, and S. Teach.

Protocol Concept Review and Development Subcommittee (PCRADs): D. Jaffe, chair; K. Brown, A. Cooper, J. M. Dean, C. Johns, R. Maio, N. C. Mann, D. Monroe, K. Shaw, D. Teitelbaum, and D. Treloar.

Quality Assurance Subcommittee (QAS): R. Stanley, chair; D. Alexander, J. Brown, M. Gerardi, M. Gregor, R. Holubkov, K. Lillis, B. Nordberg, R. Ruddy, M. Shults, and A. Walker.

Safety and Regulatory Affairs Subcommittee (SRAS): N. Levick, chair; J. Brennan, J. Brown, J. M. Dean, J. Hoyle, R. Maio, R. Ruddy, W. Schalick, T. Singh, and J. Wright.

Additional Contributions: For their dedicated and diligent work, we thank Sally Jo Zuspan, RN, MSN, for her role in helping to organize the study, and Rene Enriquez, BS, for his assistance with data management (PECARN Data Center, University of Utah). They did not receive compensation from a funding sponsor for their contributions. We also thank the research coordinators in PECARN, without whose dedication and hard work this study would not have been possible, and all the clinicians around PECARN who enrolled children in this study.

REFERENCES

- Faul M, Xu L, Wald MM, Coronado VG. *Traumatic Brain Injury in the United States: Emergency Department Visits, Hospitalizations and Deaths 2002-2006*. Atlanta, GA: Centers for Disease Control and Prevention; 2010.
- Dunning J, Daly JP, Lomas JP, Lecky F, Batchelor J, Mackway-Jones K; Children's head injury algorithm for the prediction of important clinical events study group. Derivation of the children's head injury algorithm for the prediction of

important clinical events decision rule for head injury in children. *Arch Dis Child*. 2006;91(11):885-891.

- Oman JA, Cooper RJ, Holmes JF, et al; NEXUS II Investigators. Performance of a decision rule to predict need for computed tomography among children with blunt head trauma. *Pediatrics*. 2006;117(2):e238-e246.
- Palchak MJ, Holmes JF, Vance CW, et al. A decision rule for identifying children at low risk for brain injuries after blunt head trauma. *Ann Emerg Med*. 2003;42(4):492-506.
- 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(5):11.
- Schunk JE, Rodgeron JD, Woodward GA. The utility of head computed tomographic scanning in pediatric patients with normal neurologic examination in the emergency department. *Pediatr Emerg Care*. 1996;12(3):160-165.
- Atabaki SM, Stiell IG, Bazarian JJ, et al. A clinical decision rule for cranial computed tomography in minor pediatric head trauma. *Arch Pediatr Adolesc Med*. 2008;162(5):439-445.
- Davis RL, Mullen N, Makela M, Taylor JA, Cohen W, Rivara FP. Cranial computed tomography scans in children after minimal head injury with loss of consciousness. *Ann Emerg Med*. 1994;24(4):640-645.
- Halley MK, Silva PD, Foley J, Rodarte A. Loss of consciousness: when to perform computed tomography? *Pediatr Crit Care Med*. 2004;5(3):230-233.
- Hamilton M, Mrazik M, Johnson DW. Incidence of delayed intracranial hemorrhage in children after uncomplicated minor head injuries. *Pediatrics*. 2010;126(1):e33-e39.
- Haydel MJ, Shembekar AD. Prediction of intracranial injury in children aged five years and older with loss of consciousness after minor head injury due to nontrivial mechanisms. *Ann Emerg Med*. 2003;42(4):507-514.
- Kuppermann N, Holmes JF, Dayan PS, et al; Pediatric Emergency Care Applied Research Network (PECARN). Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet*. 2009;374(9696):1160-1170.
- Osmond MH, Klassen TP, Wells GA, et al; Pediatric Emergency Research Canada (PERC) Head Injury Study Group. CATCH: a clinical decision rule for the use of computed tomography in children with minor head injury. *CMAJ*. 2010;182(4):341-348.
- Simon B, Letourneau P, Vitorino E, McCall J. Pediatric minor head trauma: indications for computed tomographic scanning revisited. *J Trauma*. 2001;51(2):231-237, discussion 237-238.
- Dacey RG Jr, Alves WM, Rimel RW, Winn HR, Jane JA. Neurosurgical complications after apparently minor head injury. Assessment of risk in a series of 610 patients. *J Neurosurg*. 1986;65(2):203-210.
- Hahn YS, McLone DG. Risk factors in the outcome of children with minor head injury. *Pediatr Neurosurg*. 1993;19(3):135-142.
- Blackwell CD, Gorelick M, Holmes JF, Bandyopadhyay S, Kuppermann N. Pediatric head

trauma: changes in use of computed tomography in emergency departments in the United States over time. *Ann Emerg Med*. 2007;49(3):320-324.

18. Larson DB, Johnson LW, Schnell BM, Salisbury SR, Forman HP. National trends in CT use in the emergency department: 1995-2007. *Radiology*. 2011;258(1):164-173.
19. Smith-Bindman R, Miglioretti DL, Johnson E, et al. Use of diagnostic imaging studies and associated radiation exposure for patients enrolled in large integrated health care systems, 1996-2010. *JAMA*. 2012;307(22):2400-2409.
20. Brenner DJ, Hall EJ. Computed tomography: an increasing source of radiation exposure. *N Engl J Med*. 2007;357(22):2277-2284.
21. Mathews JD, Forsythe AV, Brady Z, et al. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. *BMJ*. 2013;346:f2360.
22. 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(8):700-707.
23. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet*. 2012;380(9840):499-505.
24. Aitken ME, Herrerias CT, Davis R, et al. Minor head injury in children: current management practices of pediatricians, emergency physicians, and family physicians. *Arch Pediatr Adolesc Med*. 1998;152(12):1176-1180.
25. Committee on Quality Improvement, American Academy of Pediatrics, and Commission on Clinical Policies and Research, American Academy of Family Physicians. The management of minor closed head injury in children. *Pediatrics*. 1999;104(6):1407-1415.
26. Dietrich AM, Bowman MJ, Ginn-Pease ME, Kosnik E, King DR. Pediatric head injuries: can clinical factors reliably predict an abnormality on computed tomography? *Ann Emerg Med*. 1993;22(10):1535-1540.
27. Dunning J, Stratford-Smith P, Lecky F, et al; Emergency Medicine Research Group. A

meta-analysis of clinical correlates that predict significant intracranial injury in adults with minor head trauma. *J Neurotrauma*. 2004;21(7):877-885.

28. Lockie FD, Dalton S, Oakley E, Babl FE; Paediatric Research in Emergency Departments International Collaborative (PREDICT). Triggers for head computed tomography following paediatric head injury: comparison of physicians' reported practice and clinical decision rules. *Emerg Med Australas*. 2013;25(1):75-82.
29. Shackford SR, Wald SL, Ross SE, et al. The clinical utility of computed tomographic scanning and neurologic examination in the management of patients with minor head injuries. *J Trauma*. 1992;33(3):385-394.
30. Stein SC, Ross SE. Mild head injury: a plea for routine early CT scanning. *J Trauma*. 1992;33(1):11-13.
31. Rosenthal BW, Bergman I. Intracranial injury after moderate head trauma in children. *J Pediatr*. 1989;115(3):346-350.
32. Gorelick MH, Atabaki SM, Hoyle J, et al; Pediatric Emergency Care Applied Research Network. Interobserver agreement in assessment of clinical variables in children with blunt head trauma. *Acad Emerg Med*. 2008;15(9):812-818.
33. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-174.
34. Schutzman SA, Greenes DS. Pediatric minor head trauma. *Ann Emerg Med*. 2001;37(1):65-74.
35. Palchak MJ, Holmes JF, Vance CW, et al. Does an isolated history of loss of consciousness or amnesia predict brain injuries in children after blunt head trauma? *Pediatrics*. 2004;113(6):e507-e513.
36. Stein SC, Spettell C, Young G, Ross SE. Limitations of neurological assessment in mild head injury. *Brain Inj*. 1993;7(5):425-430.
37. Dunning J, Batchelor J, Stratford-Smith P, et al. A meta-analysis of variables that predict significant intracranial injury in minor head trauma. *Arch Dis Child*. 2004;89(7):653-659.
38. Shackford SR, Wald SL, Ross SE, et al. The clinical utility of computed tomographic scanning

and neurologic examination in the management of patients with minor head injuries. *J Trauma*. 1992;33(3):385-394.

39. ABIM Foundation, American Academy of Pediatrics. Choosing Wisely: five things physician and patients should question. 2013. www.choosingwisely.org. Accessed June 14, 2013.
40. Bressan S, Romanato S, Mion T, Zanconato S, Da Dalt L. Implementation of adapted PECARN decision rule for children with minor head injury in the pediatric emergency department. *Acad Emerg Med*. 2012;19(7):801-807.
41. Munafo S, Pople B, Palomba K, Anderson W, Bastani A. External validation of the PECARN head injury criteria for verbal (age 2-18) children in a community hospital setting. *Acad Emerg Med*. 2013;20:s235.
42. Shah P, Donaldson D, Munafo S, et al. Better than expected: external validation of the PECARN head injury criteria in a community hospital setting. *Acad Emerg Med*. 2012;19(s1):s156.
43. Walker G. PECARN Pediatric Head Injury/Trauma Algorithm. MDCalc website. <http://www.mdcalc.com/pecarn-pediatric-head-injury-trauma-algorithm>. Accessed June 11, 2013.
44. Nigrovic LE, Lee LK, Hoyle J, et al; Traumatic Brain Injury (TBI) Working Group of the Pediatric Emergency Care Applied Research Network (PECARN). 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(4):356-361.
45. Lyttle MD, Crowe L, Oakley E, Dunning J, Babl FE. Comparing CATCH, CHALICE and PECARN clinical decision rules for paediatric head injuries. *Emerg Med J*. 2012;29(10):785-794.
46. Nigrovic LE, Schunk JE, Foerster A, et al; Traumatic Brain Injury Group for the Pediatric Emergency Care Applied Research Network. The effect of observation on cranial computed tomography utilization for children after blunt head trauma. *Pediatrics*. 2011;127(6):1067-1073.