The Effect of Patient Observation on Cranial Computed Tomography Rates in Children with Minor Head Trauma

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ABSTRACT

Background: Management of children with minor blunt head trauma often includes a period of observation to determine the need for cranial computed tomography (CT). Our objective was to estimate the effect of planned observation on CT use for each Pediatric Emergency Care Applied Research Network (PECARN) traumatic brain injury (TBI) risk group among children with minor head trauma.

Methods: This was a secondary analysis of a prospective observational study at 10 emergency departments (EDs) in Australia and New Zealand, including 18,471 children <18 years-old, presenting within 24 hours of blunt head trauma, with GCS scores of 14-15. The planned observation cohort was defined by those with planned observation and no immediate plan for cranial CT. The comparison cohort included the rest of the patients, who were either not observed or for whom a decision to obtain a cranial CT was made immediately after ED assessment. The outcome clinically important TBI (ciTBI) was defined as death due to head trauma, neurosurgery, intubation for > 24 hours for head trauma, or hospitalization for ≥ 2 nights in association with a positive cranial CT scan. We estimated the odds of cranial CT use with planned observation, adjusting for patient characteristics, PECARN TBI risk group, history of seizure, time from injury, and hospital clustering, using a generalized linear model with mixed effects.

Results: The cranial CT rate in the total cohort was 8.6%, and 0.8% had ciTBI. The planned observation group had 4,945 (27%) children compared to 13,526 (73%) in the no planned observation group. Cranial CT use was significantly lower with planned observation (adjusted odds ratio [OR] 0.2, [95% CI: 0.1-0.1]), with no difference in missed ciTBI rates. There was no difference in the odds of cranial CT use with planned observation for the group at very low risk for ciTBI (adjusted OR 0.9, [95% CI: 0.5-1.4]). Planned observation was associated with

significantly lower cranial CT use in patients at intermediate-risk (adjusted OR 0.2, [95% CI: 0.2-0.3]) and high-risk (adjusted OR 0.1, [95% CI: 0.0-0.1]) for ciTBI.

Conclusion: Even in a setting with low overall cranial CT rates in children with minor head trauma, planned observation was associated with decreased cranial CT use. This strategy can be safely implemented on selected patients in the PECARN intermediate and higher-risk groups for ciTBI.

INTRODUCTION

Minor head trauma in children is a common emergency department (ED) presentation and is frequently defined by a Glasgow Coma Scale (GCS) score of 14-15 following head trauma.^{1,2} Cranial computed tomography (CT) to diagnose traumatic brain injury (TBI) after trauma is the current gold standard investigation, however, the ionizing radiation exposure is associated with an increased risk of lethal malignancies.³⁻⁶ There has been concern about increasing CT rates in children presenting to EDs in the United States from 1998 to 2008.^{7,8} Retrospective studies on cranial CT trends in pediatric EDs have noted considerably higher rates in the U.S. (27.6% in

2007 to 30.2% in 2015)⁹ compared with Australia (9.5% in 2001 to 9.6% in 2010).¹⁰ This difference has been confirmed with prospective studies in children reporting lower non-risk-adjusted cranial CT rates in Australia (8.3%) compared to the U.S. (35.3%), with similar rates of clinically important traumatic brain injuries (ciTBIs).^{1,11} Clinical decision rules (CDRs) have been developed and validated, to aid clinical decision-making, improve the sensitivity of identifying patients with TBI and optimize cranial CT rates by decreasing unnecessary CT scans.^{1,11-14}

With the Choosing Wisely campaign, the American Academy of Pediatrics and the American College of Emergency Physicians have endorsed the benefit of an observation period for the management of pediatric head injury.^{15,16} Observation reduces cranial CT scan rates for children with minor blunt head trauma, with no significant impact on the delayed diagnosis of ciTBI.^{17,18} One investigation of 40,113 children reported that observation was associated with lower cranial CT use when compared with those not observed (adjusted odds ratio [OR] 0.53).¹⁷ In a subsequent study of 1,605 patients, every hour increase in ED observation was associated with decreased cranial CT rates across all 3 risk groups of children with minor head trauma at risk for ciTBI in the clinical decision rule derived by the Pediatric Emergency Care Applied Research Network (PECARN): very low-risk (adjusted OR 0.47), intermediate-risk (adjusted OR 0.28), and high-risk (adjusted OR 0.11).¹⁸

We explored the relationship between planned ED observation and cranial CT use in children with minor blunt head trauma in a clinical setting with low baseline cranial CT rates. Additionally, we stratified patients according to their risk for ciTBI and estimated the effect of ED observation on CT rates for children in the different PECARN-defined TBI risk groups (Table 1) and the impact of observation on missed ciTBI rates.¹

METHODS

Study Design

This was a planned secondary analysis of a prospective cohort study of children younger than 18 years of age with minor blunt head trauma, enrolled between April 2011 and November 2014 in 10 pediatric EDs in Australia and New Zealand which are members of the Pediatric Research in

Emergency Departments International Collaborative (PREDICT) network.¹⁹ The primary study was designed to validate 3 clinical head injury decision rules: PECARN (USA), CATCH (Canada), and CHALICE (UK).^{1,12,13,20} The individual hospital ethics committee for each participating site approved the study. The details of the study protocol have been previously published.²⁰

Study Setting and Population

The participating EDs were a combination of 2 mixed and 8 free-standing children's hospital EDs across Australia and New Zealand. The treating clinicians enrolled patients presenting to the ED with blunt head trauma. A standardized case report form was completed recording demographic, epidemiologic, and clinical information. After the initial ED assessment, clinicians documented responses to two questions that were not mutually exclusive: if they planned to observe the patient ("Do you intend to observe the patient in ED for head injury? yes/no"), and if they planned to obtain immediate neuroimaging ("Do you intend to perform neuroimaging for this patient? yes/no") -- if yes, ("What neuroimaging do you intend to perform? CT, MRI, US, Skull X-ray"). Based on the responses, the planned observation cohort included those with planned observation and no immediate plan for cranial CT. The comparison cohort included the rest of the patients, who were either not observed or for whom a decision to obtain a cranial CT was made immediately after ED assessment. Planned ED observation was defined as "yes" to the question, "Do you intend to observe the patient in ED for head injury?"

Study Protocol

Inclusion criteria: All children younger than 18 years of age presenting to the ED after sustaining blunt head trauma of any severity were enrolled in the primary study.¹¹ For this sub-analysis, we selected the cohort of children with GCS scores of 14-15 presenting within 24 hours of head trauma, to enable direct comparison with prior published results. Children with multiple ED visits, with different episodes of head trauma, were eligible for enrollment at each visit.

Exclusion criteria: Published in the primary study,¹¹ which included patients with trivial facial trauma, if they presented to the ED with neuroimaging for head trauma before study enrollment, and those with history of blunt head trauma who left the ED without being seen by a physician.

Study Measures

Physicians recorded ED data, and research assistants recorded the data regarding hospital management and conducted structured telephone follow-up on all patients who did not get

neuroimaging in the ED 14-90 days after the initial ED visit. Results of cranial CTs performed on patients who re-presented to the ED were reviewed by the site investigators. Neuroimaging and neurosurgery reports were reviewed for any patients identified on the follow-up telephone call to have had medical visits outside the original study hospital. Patients who were admitted to the hospital or discharged from ED after a cranial CT was obtained, did not receive a follow-up phone call.

All site investigators and research coordinators were trained at the central site prior to commencing the study. Site clinicians and research assistants were trained by the site investigators and research coordinators using standardized teaching materials in 1-hour sessions. This was repeated as needed for new staff throughout the study period. Site investigators and research coordinators participated in annual updates. The central study coordinator conducted annual site visits for oversight, compliance, and ongoing updates of site personnel.²⁰

Timing of events was calculated in hours using information collected on case report forms, including time from injury to ED arrival, time from ED arrival to physician evaluation, ED length of stay (LOS), and total LOS. We defined ED LOS as the interval of time from ED arrival until ED discharge. Data on admission rates included those admitted to short-stay units for observation, hospital wards, or pediatric intensive care units (PICU). The short-stay unit admitted patients with anticipated LOS <24 hours. The location of the short-stay units varied across the participating hospitals (part of ED, separate unit in ED, or a hospital ward). As a result, for those patients admitted to observation units, but not the hospital wards or PICU, the ED LOS was the interval of time from ED arrival until hospital discharge. Total LOS was defined as the time from ED arrival to hospital discharge.

To minimize any potential selection bias between the two study cohorts, we stratified the population by their risk for ciTBI using the age-based PECARN TBI risk groups: very low, intermediate, and high (Table 1).¹ Children with no predictors for ciTBI were classified as very low risk. Children with 1 or more risk factors were classified as intermediate or high risk, depending on the specific risk factor, according to the original PECARN paper.¹ We analyzed CT use for each of the PECARN TBI risk groups.

The primary outcome measures were CT and ciTBI rates. Secondary outcome measures were ED and total LOS, rates of TBI on cranial CT, and hospital admission. The ED clinician's initial assessment of the patient's GCS score, attending radiologist reports of the CT scans, and operative reports of neurosurgical interventions were used for each site.

The outcome, cranial CT, was defined as present if the patient underwent the imaging study during ED or short stay evaluation. The outcome, ciTBI, was defined as death as a result of intracranial injury, neurosurgical intervention, intubation for longer than 24 hours for TBI or hospital admission for 2 nights or longer in association with TBI on CT.¹ Neurosurgical intervention for TBI included intracranial pressure monitoring, elevation of depressed skull fracture, ventriculostomy, hematoma evacuation, lobectomy, tissue debridement, dura repair, and other procedures.¹ Missed ciTBI was defined as the diagnosis of ciTBI on a follow-up ED visit or identified on the follow-up phone call, with no cranial CT performed on the initial ED visit. TBI on CT was defined as intracranial hemorrhage or contusion, cerebral edema, traumatic infarction, diffuse axonal injury, shearing injury, sigmoid sinus thrombosis, midline shift of intracranial contents or signs of brain herniation, diastasis of the skull, pneumocephalus, and skull fracture depressed by at least the width of the table of the skull.¹ The attending radiologists at each hospital site were blinded to the study hypothesis and patient cohorts.

Data Analysis

The focus of this analysis was a comparison of the cohort with planned observation, and the cohort who were either not observed or for whom a decision to obtain a CT was made immediately after ED evaluation. We described these cohorts with population proportions and 95% confidence intervals (CI). Additionally, we compared the distribution of patients within each PECARN ciTBI risk group between the two cohorts. We performed a bivariate analysis of rates of CT scans, ciTBI, missed ciTBI, TBI on CT, and hospital admission between the 2 cohorts, and for each PECARN TBI risk group. The proportion of patients with return ED visits was calculated for those with follow-up phone calls.

We compared the time in hours as a categorical variable using median with interquartile range, and rate difference using the Hodges-Lehmann method, which accounts for different population

distributions in the two cohorts.²¹ The total LOS (hours) was compared, as well as ED LOS, LOS for each PECARN TBI risk group, and LOS in patients who had cranial CT scans.

Using a generalized estimating equation model, we estimated cranial CT use with multivariable logistic regression adjusting for patient demographics, PECARN TBI risk group, history of seizure, and time from injury. History of seizure was not included as a risk factor for ciTBI in the PECARN head injury rules.¹ The investigators subsequently described the importance of recurrent seizures as a risk factor associated with TBI on CT.²² In the current study, history of seizure had a significant bivariate relationship with CT use. Therefore, it was included in the multivariate analysis. Because planned observation and cranial CT rates could be correlated with clinician practice within a hospital site, we controlled for hospital site as a random effect (with random intercept). Furthermore, because clinician practice could vary across the study time-period (2011 – 2014), we adjusted for the calendar year as a fixed effect, with 2011 as a reference. We investigated variance inflation factor values to check for multicollinearity between the variables, and model residuals and leverage to ensure the absence of outliers and influential cases. Overall model performance was evaluated via assessment of classification and calibration (prediction accuracy). Additionally, we performed a sensitivity analysis of the regression model by adjusting for the individual signs and symptoms and mechanism of injury, instead of the individual PECARN TBI risk groups. Finally, we estimated the adjusted odds (OR) of CT use with planned observation for each PECARN TBI risk group.

Sample size calculations were performed and published in the primary study,^{11,20} and no additional computations were performed for this planned sub-analysis. Additionally, there were sufficient events in the outcome measure of cranial CT use (8.6%, 1579 patients), such that including the 7 covariates ensured a robust regression model. Data analysis was performed with Stata (version 13; StataCorp, College Station, TX) for the analysis. This manuscript is reported following the STROBE statement.²³

RESULTS

Characteristics of study subjects

Of the 20,137 enrolled patients in the primary study,²⁴ 18,781 (93.3%) presented within 24 hours of sustaining head trauma, with GCS scores of 14-15 (Figure). Documented planned observation and cranial CT status was available for 18,471 (91.7%) of enrolled patients, and all subsequent analyses were performed on this cohort. There were no differences in demographic characteristics, cranial CT or ciTBI rates between the 310 (1.5%) patients with no documented observation plan and the analytic cohorts.

Descriptive data

The overall cranial CT rate was 8.6% (range 2-16% across the different hospitals), with a ciTBI rate of 0.8% and 0.1% of patients receiving a neurosurgical intervention. Cranial CT rates for each of the PECARN TBI risk groups varied significantly as those at higher risk were more likely to undergo CT: very low-risk group (1.8% CT rate), intermediate-risk group (10.3% CT rate) and high-risk group (43.1% CT rate). Similarly, the ciTBI rates varied significantly, with 0.01% in the PECARN very low-risk group, 0.6% in the intermediate-risk and 6.3% in the high-risk group.

The strategy of planned observation was made for 4,945 (26.8%) patients (Table 2), with a range of 21% to 49% across the participating hospitals. Those in the planned observation cohort were slightly older and included 33.0% at very low risk, 54.9% at intermediate risk, and 12.2% at high-risk for ciTBI.

The median time from injury to ED arrival in the cohort with planned observation was not statistically different from those with no observation (Table 3). The increase in ED LOS with cranial CT use was significant with planned observation, and for each of the PECARN risk groups. The total LOS was greater with planned observation for patients at very low-risk and intermediate-risk, and lower for those at high-risk for ciTBI than those with no planned observation.

Main Results

The unadjusted cranial CT rate was significantly lower in those with planned observation (4.4%) than those in the no planned observation cohort (10.1%), as was the ciTBI rate (0.4% vs. 0.9%;

Table 2). There was a significant difference in the ward and PICU admission rates for the patients with planned observation (6.4% and 0.3%) compared to those not observed (4.0% and 0.1%). There was no difference in the rates of missed ciTBI between the cohorts. Two patients in the intermediate PECARN risk group, both with planned observation, were admitted for ciTBI at the follow-up ED visit. Neither patient required neurosurgery. The details of these patients have been published.²⁴ There were no deaths in either cohort.

PECARN TBI Risk Groups

There was no difference in the unadjusted cranial CT, ciTBI, and TBI on CT rates for the cohorts with and without planned observation, for the group at very low risk for ciTBI (Table 2). The planned observation group at intermediate risk for ciTBI had significantly lower CT use (4.4%) than the group without planned observation (13.3%), and there were no differences in rates of ciTBI (0.5% vs. 0.6%) or TBI on CT (0.7% vs. 1.1%). The planned observation group at high risk for ciTBI had significantly lower cranial CT use (11.7%) than those without planned observation (62.5%), with significantly lower rates of ciTBI (1.2% vs. 9.4%) and TBI on CT (2.0% vs. 14.1%).

Multivariable Analysis

After adjusting for age, sex, PECARN TBI risk group, history of seizure, calendar year, and time from injury, the cohort with planned observation had significantly lower cranial CT use (adjusted OR 0.2, [95% CI: 0.1-0.2]; Table 4). Additionally, there was no evidence of multicollinearity, with variance inflation factor of less than 1.5 for all variables in the model (except the non-independent calendar years variable). A sensitivity analysis of the generalized linear model, adjusting for the mechanism of injury and individual signs and symptoms of TBI rather than PECARN risk group produced similar results (adjusted OR 0.2, [95% CI: 0.1-0.2]; Supplement 1). Good model fit was found, and the classification rate was high (94%; sensitivity 38%, specificity 99%). There was no difference in cranial CT use across calendar years for the total cohort and each individual PECARN TBI risk group.

Multivariate logistic regression for each of the PECARN TBI risk groups demonstrated that planned observation was significantly associated with lower CT use in patients at intermediate-risk (adjusted OR 0.2, [95% CI: 0.2-0.3]) and high-risk (adjusted OR 0.1, [95% CI: 0.0-0.1]) for ciTBI (Supplement 1). Good model fit was found, with high classification rates: high risk 83%

(sensitivity 78%, specificity 86%); intermediate risk 90% (sensitivity 7.5%, specificity 99%). The difference in cranial CT use between those with and without planned observation at very low risk for ciTBI was not significant (adjusted OR 0.9, [95% CI: 0.5-1.4]), with a poor model fit.

DISCUSSION

This multicenter prospective study evaluated the strategy of planned ED observation and cranial CT use in children with minor head trauma. Despite the low baseline cranial CT rate, planned observation of patients was associated with 80% lower adjusted odds of CT use. Although the cohorts with and without planned observation were dissimilar in individual patient characteristics, after adjusting for patient characteristics, signs, symptoms, and risk factors for ciTBI, planned observation was independently associated with lower cranial CT use in all but those at very low risk of ciTBI.

The primary study protocol defined ED observation as an ongoing assessment for less than 6 hours after the initial clinical evaluation. Admission was defined as assessment requiring more than 6 hours to either an observation or short stay unit, inpatient or intensive care unit.²⁰ Although there was no defined period of observation in the study protocol, in a subsequent analysis, a hospital length of stay greater than 4 hours was used as a proxy to evaluate the effect of observation.²⁴ ED length of stay is affected by many factors that are often out of the clinician's control. Therefore, the impact of planned ED observation on CT use in patients for whom there was no plan for an immediate cranial CT, provides the most accurate effect of time on clinical decision-making. The total LOS was greater for the cohort with no planned observation at high risk for ciTBI than those with planned observation. This was likely as a result of more children at high risk for ciTBI getting immediate cranial CTs (62.5%), having TBI on CT (14.1%), or ciTBI (9.4%); either of which may have been associated with hospital admission.

Although the primary study of which this was a sub-analysis was designed to validate the existing head injury decision rules, clinicians did not report using any particular guideline for their decision-making.²⁵ Additionally, with a stable cranial CT rate in the decade prior to the study,¹⁰ and no difference in cranial CT use across calendar years in the current study, suggests

that the clinicians did not alter their practice during the study period. The comparison cohort was comprised of patients with different risk profiles for ciTBI, consisting of those who were either not observed (e.g., asymptomatic children with minor mechanisms of injury) or for whom a decision to obtain a cranial CT was made right after ED evaluation (e.g., symptomatic children at higher risk for TBI). This is similar to a prior study in which 72% of children at very high risk for ciTBI were in the non-observed group.¹⁸ They reported a cranial CT rate of 5% in the patients who were observed prior to the decision of imaging compared with 30% in the non-observed cohort.

Stratifying the cohorts by the PECARN TBI risk groups allowed for a comparison of cranial CT rates in patients at similar risk for ciTBI. There were no differences in the rates ciTBI and TBI on CT for the very low and intermediate-risk patients between the two cohorts, indicating a similar risk profile. After risk adjustment, however, planned ED observation was associated with significantly lower cranial CT use in the groups at intermediate and high risk for ciTBI. The group at very low risk for ciTBI who were observed did not have a statistically lower rate of cranial CT use compared to those not observed. This is not surprising as cranial CT is not recommended in this low-risk group, and therefore it would be unlikely that observation would have much impact.

The results of this study validate the published literature from North America, where ED observation is associated with lower cranial CT rates in children after minor blunt head trauma.^{17,18} Prior research on the CT rates of each of the PECARN TBI risk predictors in the US was reported as 13% of low risk, 54% of intermediate, and 82.5% of high-risk groups.²⁶ Published evidence of the clinical practice in Australia and New Zealand for pediatric minor head trauma termed as “usual care” report lower cranial CT rates than with the use of decision rules.^{10,24} Those publications report much lower CT rates for each of the PECARN TBI risk groups (1.7% of very low risk, 9.9% of intermediate, and 44% of high risk) with similar ciTBI rates.

In addition to differences in clinical practice, this study highlights the use of short-stay units in EDs in Australia and New Zealand. The Australian National Emergency Target (NEAT) or the

4-hour rule was introduced in 2011, and a similar 6-hour target in New Zealand was implemented in 2009, in response to ED overcrowding.^{27,28} These targets/rules require a certain proportion of patients based on their triage acuity to be discharged, admitted or transferred within 4 hours of ED presentation, with a potential loss of financial incentives when 90% of targets are not met. Because admissions to short-stay units stop the NEAT target clock, they are commonly used to decompress the ED. Perhaps developing similar short-stay units in pediatric EDs in North America might aid with longer observation periods of children with minor head trauma and result in fewer CT scans.

The increase in lifetime attributable risk of cancer associated with ionizing radiation of cranial CT scans has been reported worldwide.⁴⁻⁶ The cumulative iatrogenic radiation in children might triple the risk of leukemia and brain tumors, a large retrospective study reports.⁶ With increasing awareness of these risks, it has become important to educate health care providers and parents that CT decisions can often be undertaken as a shared decision-making process.²⁹ Furthermore, implementation of clinical decision tools has resulted in decreased CT rates for minor head trauma at pediatric and general EDs.³⁰⁻³³ A recent study of 7 health systems in the US and Ontario report a decreasing trend in cranial CT rates for children <18 years from 2006 to 2016.⁸ However, this has not been the case at the national level in the US, with no apparent decrease in cranial CT rates in children between 2007 and 2015.⁹

The PECARN age-based CDRs identify those patients at very low risk for ciTBI, and for whom cranial CT is usually not recommended.¹ Incorporating decision support in the electronic medical record based on the PECARN rules reduces cranial CT rates in the ED for children at very low risk for ciTBI.³³ The average cranial CT rates across all the intervention EDs decreased from 5.3% to 4.2%. Furthermore, it is possible to achieve overall cranial CT rates of ~15% in all children with minor blunt head trauma with GCS scores of 14-15.³³ We report no benefit from planned observation in patients at very low risk for ciTBI, and cranial CT rate of 1.7%, without any missed ciTBI in this group. Following this analysis, we intend to evaluate the cost-effectiveness of observation as a strategy to reduce CT use while minimizing missed ciTBI.

To our knowledge, this is the first study to validate the impact of planned ED observation as a strategy to lower cranial CT use for each PECARN TBI risk group, in a large cohort of children with minor blunt head trauma. Despite the lower overall use of CT in this study, our findings are in agreement with the previous study of planned observation conducted on a different continent.¹⁷ Selective observation of patients with minor head trauma at intermediate risk of ciTBI could provide time for resolution of symptoms and/or reassurance of the lack of ciTBI and decrease the need for cranial CT. We found no increased risk of missed ciTBI in the observation without a CT cohort, even among selected patients at higher risk of ciTBI. Therefore, this strategy can be safely implemented on selected patients in the PECARN intermediate and higher-risk groups for ciTBI.

LIMITATIONS

Our study has several limitations. First, the questions asked of the clinicians on the case report forms regarding planned observation and planned immediate cranial CT were not mutually exclusive. Additionally, the questions did not clarify the reasons for planned observation, and in particular, the patients for whom the decision to obtain an immediate cranial CT was already made. However, there was no difference in the cranial CT rates between these patients and those who received an immediate cranial CT scan and were not observed. As a result, we believe the effect of observation on the cranial CT rate is accurately reflected in the cohort with planned observation and no plan for immediate cranial CT. Second, there were significant differences between the patients with planned observation and those without planned observation. The patients who received an immediate CT were more symptomatic, with frequent severe mechanisms of injury, and at a higher risk for ciTBI than the cohort with planned observation. Although we used multivariable logistic regression to adjust for risk factors of ciTBI to estimate the independent effect of planned observation on cranial CT use, there could be some unaccounted-for residual confounding or bias.

Third, we did not collect data on the time between physician evaluation to the time of the cranial CT order. Therefore, we cannot measure the incremental effect of observation time on cranial CT use. Further research in this area will guide the recommended length of ED observation. Finally, because we did not have time stamps regarding the time of completion of case report forms, it is

not clear if the decision for neuroimaging was made because of the progression of symptoms or other factors not recorded at the time the case report form was completed. As the data collected were static, we do not know if the data accurately represent the dynamic nature of the evolution of disease and clinicians' decision-making.

CONCLUSION

Planned observation, as a strategy for the management of minor blunt head trauma, is associated with lower cranial CT use, even in a setting of low baseline CT rates. Children at very low risk for ciTBI, do not benefit from observation as a strategy to lower cranial CT use. Our results validate planned observation as an appropriate strategy for selected patients at intermediate and higher risk for ciTBI, with lower adjusted odds of cranial CT use and no significant difference in missed ciTBIs.

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Figure. Patient flow diagram

ED, emergency department; GCS, Glasgow Coma Scale; CT, computed tomography; ciTBI, clinically important traumatic brain injury

Table 1. Children with minor head trauma (GCS $\geq$ 14): PECARN TBI risk groups.

PECARN TBI Risk Group	Children Age <2years	Children Age $\geq$ 2 years
High	Altered mental status*	Altered mental status*
	Palpable skull fracture	Signs of basilar skull fracture [§]
Intermediate	Severe injury mechanism [¶]	Severe injury mechanism [¶]
	History of loss of consciousness $\geq$ 5secs	History of any loss of consciousness
	Non-frontal scalp hematoma	History of vomiting
	Not acting normally per parents	Severe headache in the ED
Very Low	None	None

GCS, Glasgow Coma Scale; PECARN, Pediatric Emergency Care Applied Research Network; TBI, traumatic brain injury; ED, emergency department

* GCS =14, agitation, sleepiness, slow response, or repetitive questioning.

[§] Post-auricular bruising (battle sign), periorbital bruising (raccoon eyes), cerebrospinal fluid otorrhea, or hemotympanum.

[¶] Motor vehicle crash with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by a motorized vehicle; falls of higher than 3 feet for children younger than 2 years of age and higher than 5 feet for children older than 2 years of age; or head struck by a high-impact object.

Table 2. Patient demographics, PECARN TBI risk groups and patient outcomes

	Planned observation	No planned observation	Rate Difference
	n (%)	n (%)	% (95% CI)
	4,945 (26.8)	13,526 (73.2)	-46.4 (-47.8 to -44.9)
Demographic characteristics			
Age (years)			
Mean (SD)	6.2 (5.1)	5.5 (4.4)	0.7 (0.6 - 0.9) ^a
Median (IQR)	4.5 (1.8 - 10.7)	4.0 (1.9 - 8.1)	0.3 (0.2 - 0.4) ^b
Age <2 years	1,393 (28.2)	3,566 (26.4)	1.8 (0.4 - 3.3)
Sex [male]	3,102 (62.7)	8,671 (64.1)	-1.4 (-3.0 to 0.2)
PECARN TBI risk group			
Very low	1,630 (33.0)	8,201 (60.6)	-27.7 (-29.2 to -26.1)
Intermediate	2,714 (54.9)	4,273 (31.6)	23.3 (21.7 - 24.9)
High	601 (12.2)	1052 (7.8)	4.4 (3.4 - 5.4)
CT performed	215 (4.4)	1,364 (10.1)	-5.7 (-6.5 to -5.0)
PECARN TBI risk group			
Very low: n (within-group %)	25 (1.5)	138 (1.7)	-0.2 (-0.8 to 0.5)

Patient Observation and Cranial Computed Tomography Use

Intermediate: n (within-group %)	120 (4.4)	569 (13.3)	-8.9 (-10.2 to -7.6)
High: n (within-group %)	70 (11.7)	657 (62.5)	-50.8 (-54.7 to -46.9)
Patient outcomes			
ciTBI	20 (0.4)	126 (0.9)	-0.5 (-0.8 to -0.3)
Neurosurgical intervention	2 (0.0)	21 (0.2)	-0.1 (-0.2 to -0.0)
Intubation for >24 hours	0 (0.0)	2 (0.0)	0.0 (-0.0 to 0.0)
Hospital admission $\geq$ 2 nights with +CT	20 (0.4)	125 (0.9)	-0.5 (-0.8 to -0.3)
Death from head injury	0	0	-
PECARN TBI risk group			
Very low: n (within group %)	0 (0.0)	1 (0.01)	-0.01 (-0.04 to 0.01)
Intermediate: n (within group %)	13 (0.5)	26 (0.6)	-0.1 (-0.5 to 0.2)
High: n (within group %)	7 (1.2)	99 (9.4)	-8.3 (-10.2 to -6.3)
TBI on CT	32 (0.7)	195 (1.4)	-0.8 (-1.1 to -0.5)
PECARN TBI risk group			
Very low: n (within group %)	0 (0.0)	1 (0.01)	-0.01 (-0.04 to 0.01)
Intermediate: n (within group %)	20 (0.7)	46 (1.1)	-0.3 (-0.8 to 0.1)
High: n (within group %)	12 (2.0)	148 (14.1)	-12.07 (-14.5 to -9.7)
Hospital Admission rate	2,238 (45.3)	1,811 (13.4)	31.9 (30.4 - 33.4)
Short stay admission	2,056 (41.6)	934 (6.9)	34.7 (33.3 - 36.2)
Ward admission	199 (4.0)	864 (6.4)	-2.4 (-3.1 to -1.7)
PICU	3 (0.1)	46 (0.3)	-0.3 (-0.4 to -0.2)
Return ED visit^c	703 (14.9)	1,457 (12.0)	2.8 (1.6 - 3.9)

Missed ciTBI 2 (0.04) 0 (0.0) 0.04 (-0.02 to 0.1)

SD, standard deviation; IQR, interquartile range; CI, confidence interval; GCS, Glasgow Coma Scale; PECARN, Pediatric Emergency Care Applied Research Network; TBI, traumatic brain injury; CT, computed tomography; ciTBI, clinically important traumatic brain injury; CI, confidence interval; PICU, pediatric intensive care unit

^a Difference between means (95% CI)

^b Difference between medians (95% CI)

^c If had follow-up interview: Planned observation n=4,773; No planned observation n=12,208

Table 3. Median intervals: planned observation vs. no planned observation

Interval [hours]	Planned observation			No planned observation			Time Difference	
	n	Median	(IQR)	n	Median	(IQR)	Median	95% CI
Injury to ED arrival	4,892	1.3	(0.8 - 2.2)	13,293	1.3	(0.8 - 2.9)	-0.1	(-0.1 to -0.1)
ED arrival to physician evaluation	4,936	0.4	(0.2 - 0.7)	13,502	0.5	(0.2 - 1.0)	-0.1	(-0.2 to -0.1)
ED LOS [hours]								
Overall	4,935	3.7	(2.7 - 5.2)	13,495	1.9	(1.2 - 3.1)	1.7	(1.6 - 1.7)
PECARN TBI Risk Group								
Very low risk	1,628	3.4	(2.4 - 4.5)	8,186	1.6	(1.1 - 2.5)	1.6	(1.5 - 1.7)
Intermediate risk	2,707	3.7	(2.8 - 5.3)	4,261	2.2	(1.3 - 3.5)	1.5	(1.4 - 1.6)
High risk	600	4.4	(3.3 - 7.3)	1,048	3.9	(2.4 - 6.4)	0.7	(0.4 - 0.9)
Cranial CT								

Patient Observation and Cranial Computed Tomography Use

Obtained	213	6.0 (4.0 - 13.0)	1,360	4.9 (3.5 - 7.5)	1.2 (0.6 - 1.9)
Not obtained	4,722	3.6 (2.7 - 5.1)	12,135	1.7 (1.1 - 2.7)	1.8 (1.8 - 1.9)
Total LOS [hours]					
Overall	4,934	3.7 (2.7 - 5.5)	13,484	1.9 (1.2 - 3.3)	1.7 (1.6 - 1.8)
PECARN TBI Risk Group					
Very low risk	1,628	3.4 (2.5 - 4.7)	8,184	1.7 (1.1 - 2.6)	1.6 (1.6 - 1.7)
Intermediate risk	2,706	3.8 (2.8 - 5.6)	4,259	2.2 (1.3 - 3.8)	1.5 (1.4 - 1.6)
High risk	600	4.6 (3.4 - 10.5)	1,041	6.9 (2.9 - 24.9)	-1.5 (-2.3 to -0.9)
Cranial CT					
Obtained	213	11.8 (4.6 - 22.0)	1,351	14.4 (4.5 - 36.6)	-0.7 (-1.9 to 0.3)
Not obtained	4,721	3.7 (2.7 - 5.2)	12,133	1.7 (1.1 - 2.8)	1.8 (1.8 - 1.9)

ED, emergency department; LOS, length of stay; TBI, Traumatic brain injury; PECARN, Pediatric Emergency Care Applied Research Network; CT, computed tomography; IQR, interquartile range; CI, confidence interval

Table 4. Adjusted likelihood of cranial CT use

	Total Cohort	
	N = 17,969	
	AOR (95% CI)	
Age ≥ 2 years	Reference	
<2 years	0.4	(0.4 - 0.5)*
Sex (male)	1.11	(0.97 - 1.3)

PECARN TBI risk

Very low	Reference
Intermediate	8.1 (6.7 - 9.7) *
High	77.0 (62.8 - 94.5) *
History of seizure	4.6 (3.2 - 6.5) *
Time from injury (hours)	1.03 (1.02 - 1.04) *

Observation status

Not observed	Reference
Planned observation	0.2 (0.1 - 0.2) *

Year

2011	Reference
2012	0.9 (0.6 - 1.2)
2013	0.8 (0.6 - 1.0)
2014	0.8 (0.6 - 1.0)

Clustered by hospital site; * $p \leq 0.001$

CT, computed tomography; AOR, adjusted odds ratio; CI, confidence interval; PECARN, Pediatric Emergency Care Applied Research Network; TBI, traumatic brain injury

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