Implementation of a Clinical Decision Support System for Children With Minor Blunt Head Trauma Who Are at Nonnegligible Risk for Traumatic Brain Injuries

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Study objective: To determine the effect of providing risk estimates of clinically important traumatic brain injuries and management recommendations on emergency department (ED) outcomes for children with isolated intermediate Pediatric Emergency Care Applied Research Network clinically important traumatic brain injury risk factors.

Methods: This was a secondary analysis of a nonrandomized clinical trial with concurrent controls, conducted at 5 pediatric and 8 general EDs between November 2011 and June 2014, enrolling patients younger than 18 years who had minor blunt head trauma. After a baseline period, intervention sites received electronic clinical decision support providing patient-level clinically important traumatic brain injury risk estimates and management recommendations. The following primary outcomes in patients with one intermediate Pediatric Emergency Care Applied Research Network risk factor were compared before and after clinical decision support: proportion of ED computed tomography (CT) scans, adjusted for age, time trend, and site; and prevalence of clinically important traumatic brain injuries.

Results: The risk of clinically important traumatic brain injuries was known for 3,859 children with isolated findings (1,711 at intervention sites before clinical decision support, 1,702 at intervention sites after clinical decision support, and 446 at control sites). In this group, pooled CT proportion decreased from 24.2% to 21.6% after clinical decision support (odds ratio 0.86; 95% confidence interval 0.73 to 1.01). Decreases in CT use were noted across intervention EDs, but not in controls. The pooled adjusted odds ratio for CT use after clinical decision support was 0.73 (95% confidence interval 0.60 to 0.88). Among the entire cohort, clinically important traumatic brain injury was diagnosed at the index ED visit for 37 of 37 (100%) patients before clinical decision support and 32 of 33 patients (97.0%) after clinical decision support.

Conclusion: Providing specific risks of clinically important traumatic brain injury through electronic clinical decision support was associated with a modest and safe decrease in ED CT use for children at nonnegligible risk of clinically important traumatic brain injuries. [Ann Emerg Med. 2019;73:440-451.]

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INTRODUCTION

Background

Blunt head trauma in children is a leading cause of emergency department (ED) visits in the United States, with recent estimates as high as 837,000 per year (nearly 3% of all pediatric ED visits).[1,2] Cranial computed tomography (CT) use for children with minor blunt head trauma remains variable and unnecessarily high.[3-7] The low yield of CT persists for children with minor blunt head trauma (Glasgow Coma Scale [GCS] scores 14 to 15), with clinically important traumatic brain injuries being noted in less than 1% of patients and neurosurgery prevalence estimated at 0.1%.[5,8,9]

During the last decade, there has been an effort to derive, validate, and implement prediction rules that might safely and efficiently decrease unnecessary CT scan

Editor's Capsule Summary

What is already known on this topic

The PECARN head trauma rule was designed to identify children at very low risk for clinically important traumatic brain injuries, but many children are classified as being at intermediate risk.

What question this study addressed

What is the effect of providing risk estimates of clinically important traumatic brain injury and recommendations using computerized clinical decision support on computed tomography (CT) scan use for children with isolated risk factors?

What this study adds to our knowledge

This secondary analysis of a nonrandomized clinical trial with concurrent controls showed a decrease in CT use from 24.2% to 21.6% in children with one isolated PECARN risk factor after implementation of decision support.

How this is relevant to clinical practice

Provision of specific risks of clinically important traumatic brain injuries for children with head trauma and one isolated risk factor modestly and safely decreases CT scan use, though the effect was heterogeneous.

use.[5,10,11] Recently published Centers for Disease Control and Prevention guidelines recommend the routine use of such prediction rules in the ED.[12] However, previous efforts to implement the regular use of head injury prediction rules in the ED have had variable success at changing imaging practices.[13-16] Our group reported the results of an implementation study of the Pediatric Emergency Care Applied Research Network (PECARN) clinically important traumatic brain injury clinical prediction rules, using a multifaceted intervention centered around the use of computerized clinical decision support.[8] We found that providing CT recommendations based on the PECARN clinically important traumatic brain injury prediction rule risk factors was associated with small but variable decreases in CT use for patients at very low risk of clinically important traumatic brain injuries (ie, those with no PECARN risk factors). This initial article did not examine in detail the outcomes for patients who were not at very low risk of clinically important traumatic brain injuries. In particular, we previously did not explore CT use when clinicians were provided risk-factor-specific clinical decision support.

Importance

A challenging subset of children with minor head trauma is those who do not meet very-low-risk criteria for clinically important traumatic brain injuries but rather have one or more "intermediate" PECARN risk factors. These include factors such as severe mechanism of injury, history of vomiting (2 to 17 years), or nonfrontal scalp hematoma (<2 years).[17-19] According to the PECARN prediction rule data, such patients are at nonnegligible but still low risk of clinically important traumatic brain injury (0.2% to 0.7%). Although the PECARN rules were intended to identify individuals at very low (near-zero) risk of clinically important traumatic brain injuries who do not need CT scans, they were not meant to imply the *necessity* of obtaining CT scans in patients with nonnegligible but low risk for clinically important traumatic brain injuries. Concern has been raised that broad and inappropriate application of the PECARN rules in this way could increase head CT use in patients with one or more intermediate PECARN risk factors.[20]

A period of ED observation without routine CT scanning is a reasonable diagnostic alternative for patients with one intermediate PECARN risk factor.[15] However, it is not known whether providing clinicians with specific risks for clinically important traumatic brain injuries and recommendations in regard to the suitability for observation will safely decrease or perhaps increase the use of CT imaging for patients with only one intermediate PECARN risk factor.

Goals of This Investigation

Our primary aim was to determine whether providing clinical decision support with risk estimates of clinically important traumatic brain injuries and recommendations, including an option for ED observation, would affect the CT use for children with minor blunt head trauma who have one intermediate PECARN risk factor for clinically important traumatic brain injury. Our secondary aims were to determine the effect of the clinical decision support on hospital admission and ED length of stay; CT use for children with more than one intermediate PECARN risk factor, a high-risk factor, or both; and the frequency of missed clinically important traumatic brain injuries. We hypothesized that providing specific risk estimates for patients at nonnegligible risk of clinically important traumatic brain injuries would not increase CT use or be associated with missed clinically important traumatic brain injuries.

MATERIALS AND METHODS

Study Design and Setting

We performed a planned secondary analysis of a nonrandomized multicenter pragmatic trial with concordant controls at 13 US EDs from November 2011 to June 2014. The methods for the parent study have been reported previously; methods specific to this secondary analysis are described below.[8]

We included 5 PECARN sites and 8 sites in a Northern California Kaiser Permanente ED research network (Clinical Research on Emergency Services and Treatments Network [KP CREST Network]). The PECARN sites included 4 freestanding children's hospital EDs and 1 pediatric ED within a general hospital. All sites (other than the PECARN control pediatric ED) used Epic (Verona, WI) as their ED electronic health record. There were 5 "analytic units" in the KP CREST Network, consisting of 3 pairs of general EDs, with the same physicians staffing paired sites, and 2 unpaired EDs. Two KP CREST Network general EDs (one of the "paired analytic units") and one PECARN site served as control EDs to track secular trends of CT use. Each site's institutional review board approved the study, with a waiver of written informed consent.

Selection of Participants

The study was a pragmatic trial using a convenience sample. Clinicians were prompted in the electronic health record to complete a head trauma template that was designed for the study to collect data on all PECARN risk factors for the 2 PECARN age groups (<2 years and 2 to 17 years).[10] Providers were alerted to the presence of a potentially eligible patient by a best practice alert in Epic and could opt in or out of enrollment through completion of the template.[21] All types of clinicians (attending physicians, fellow and resident physicians, nurses, nurse practitioners, and physician assistants) could complete the template, but were not mandated to do so. Follow-up qualitative assessment indicated that the implementation of the tool was well received by providers and that its use was enhanced by the presence of clinical site champions.[22] Research coordinators assessed the frequency of patients missed from enrollment through manual review of the electronic health record for (initially) a full month of enrollment and subsequently for 1 randomly sampled day of each 2-week period of enrollment. We recorded the characteristics and outcomes of the missed eligible population in the parent study cohort, as previously reported.[8]

Patients younger than 18 years were eligible if they had experienced nontrivial minor blunt head trauma, defined by GCS scores of 14 to 15, within 24 hours of ED presentation. Exclusion criteria and the methods to determine eligibility have been previously described.[8,21] Our data collection template did not include a means of collecting the specific duration since head injury, only that the injury occurred within the previous 24 hours.

In this analysis, we examined the cohort of patients who were at nonnegligible risk of clinically important traumatic brain injuries, defined as having one or more age-based PECARN risk factors, which could be intermediate or high risk (Figure 1). Of this subset, we were particularly interested in patients who had one isolated intermediate-risk factor for clinically important traumatic brain injuries, for whom the risk of such injury ranged from 0.2% to 0.7% (specific risk percentages in Figure 1) and for whom clinicians received clinical decision support during the intervention phase of the trial.[17-19,23-25]

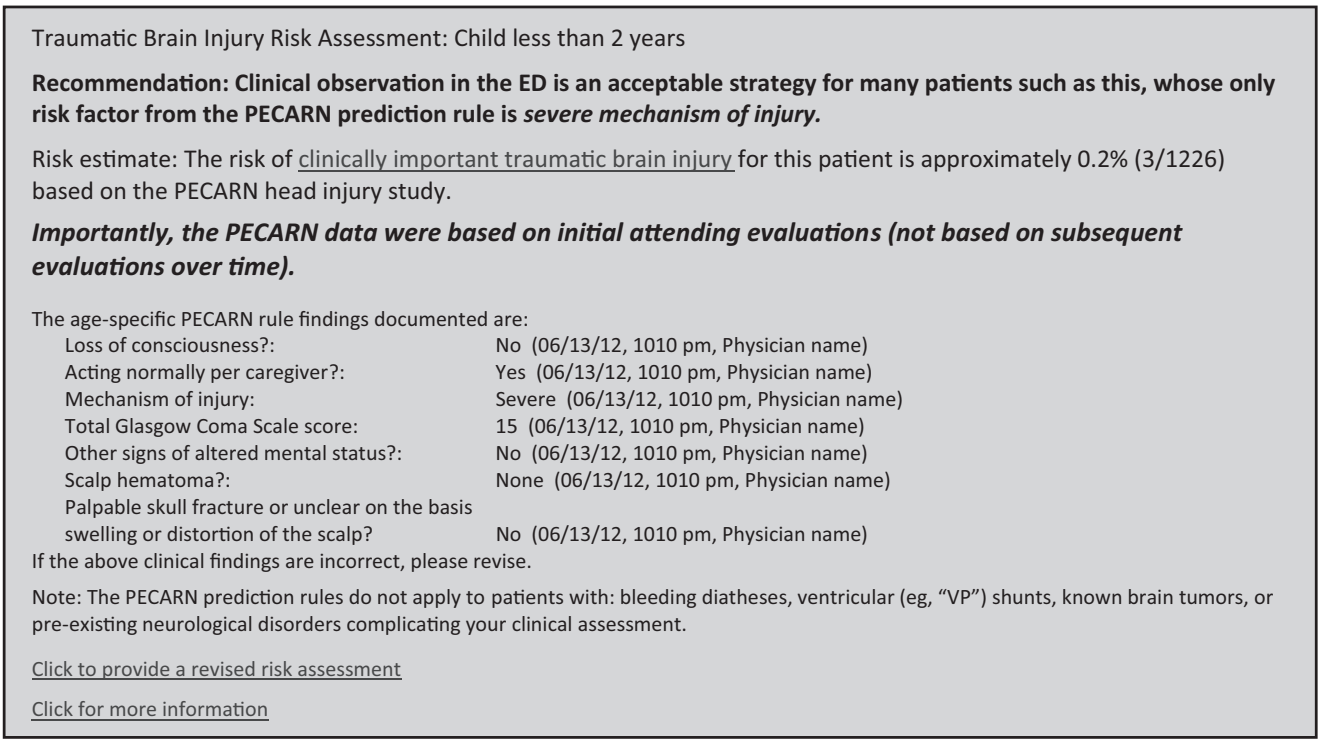
Interventions

During the study period, November 2011 to June 2014, the control sites did not systematically implement any interventions to assist in CT decisionmaking for children with head trauma (this was monitored by lead and site investigators). At the intervention sites, the duration of the research study before the intervention (9.6 to 15.7 months) and after it (10.1 to 15.7 months) varied according to the site's readiness to implement the clinical decision support.

In accordance with the data from the original PECARN prediction rule study, we provided clinicians clinical decision support for the risks of clinically important traumatic brain injuries for patients with one intermediate prediction rule risk factor if the upper boundary of the 95% confidence interval (CI) was less than 2% from the point estimate of the clinically important traumatic brain injury risk.[17-19,23-25] For these patients, we also provided a statement in regard to ED observation as an acceptable management strategy in lieu of cranial CT (Figure 1). There were some PECARN risk factors for which we could not give precise risks of clinically important traumatic brain injuries because of the infrequency of those factors, and therefore the upper boundary of the 95% CI of risk was greater than 2% from the risk point estimate. For all patients, we provided a statement about clinical predictors that placed patients at higher risk for clinically important traumatic brain injury (eg, altered mental status, signs of skull fracture).

Methods of Measurement and Outcome Measures

The primary study outcome was the proportion of ED cranial CTs obtained. The secondary outcomes were


Traumatic Brain Injury Risk Assessment: Child less than 2 years

Recommendation: Clinical observation in the ED is an acceptable strategy for many patients such as this, whose only risk factor from the PECARN prediction rule is *severe mechanism of injury.*

Risk estimate: The risk of clinically important traumatic brain injury for this patient is approximately 0.2% (3/1226) based on the PECARN head injury study.

Importantly, the PECARN data were based on initial attending evaluations (not based on subsequent evaluations over time).

The age-specific PECARN rule findings documented are:

Loss of consciousness?:	No (06/13/12, 1010 pm, Physician name)
Acting normally per caregiver?:	Yes (06/13/12, 1010 pm, Physician name)
Mechanism of injury:	Severe (06/13/12, 1010 pm, Physician name)
Total Glasgow Coma Scale score:	15 (06/13/12, 1010 pm, Physician name)
Other signs of altered mental status?:	No (06/13/12, 1010 pm, Physician name)
Scalp hematoma?:	None (06/13/12, 1010 pm, Physician name)
Palpable skull fracture or unclear on the basis swelling or distortion of the scalp?	No (06/13/12, 1010 pm, Physician name)

If the above clinical findings are incorrect, please revise.

Note: The PECARN prediction rules do not apply to patients with: bleeding diatheses, ventricular (eg, "VP") shunts, known brain tumors, or pre-existing neurological disorders complicating your clinical assessment.

Click to provide a revised risk assessment

Click for more information

Figure 1. Example of recommendations, risk estimates, and other information provided in clinical decision support for patients with a single intermediate PECARN risk factor. Risk of clinically important traumatic brain injury provided in clinical decision support is based on having a single PECARN factor present. For children younger than 2 years, examples of single intermediate-risk factors (with risk of ciTBI in parentheses) are as follows: severe mechanism of injury (0.2%, as shown as in example above); temporal, parietal, or occipital scalp hematoma (0.5%); and not acting normally according to parent (0.2%). For children aged 2 to 17 years, examples of single intermediate-risk factors (with risk of ciTBI in parentheses) are as follows: severe mechanism of injury (0.3%), any loss of consciousness (0.5%), and vomiting since injury (0.7%). *CDS*, Clinical decision support; *ciTBI*, clinically important traumatic brain injury.

hospital admission proportion, the ED length of stay for patients discharged home, and the proportion of patients with missed clinically important traumatic brain injury during the index ED visit. We defined ED length of stay as the time between ED arrival and discharge per electronic health record electronic time stamps (up to a maximum of 24 hours). As in the original PECARN study, we defined clinically important traumatic brain injury as death from traumatic brain injury, neurosurgical procedure for traumatic brain injury, intubation for at least 24 hours for traumatic brain injury, or hospitalization greater than or equal to 2 nights because of the head trauma in association with traumatic brain injury on CT.[10] Sample size considerations were based on the parent study cohort.[8]

Primary Data Analysis

We conducted the primary analysis on children with one intermediate PECARN risk factor for clinically important traumatic brain injury for whom clinical decision support was provided, detailing the specific risk of clinically important traumatic brain injury. We compared pre– and post–clinical decision support implementation, combining data from all sites. Patients with incomplete or missing data were excluded. We fit logistic regression models that included both intercept and slope terms to account for secular trend, site, and patient age group (<2 years and 2 to 17 years). If the slope for time trend was significant (at a conservative $P<.10$), pre- and postintervention slope terms were included in the final model. The postintervention intercept, representing the effect of clinical decision support implementation, was the main predictive term of interest for the primary outcome measure. We conducted similar (planned) analyses within subgroups of patients cared for in the pediatric EDs and general EDs. We also conducted separate regression analyses for patients with each of the 6 intermediate PECARN risk factors for whom we could provide specific, precise risks of clinically important traumatic brain injury. Pooled control-site secular trends were assessed by comparing early with late study periods that separated the control period according to the midpoint of the overall study period.

All model selection processes were similar, adjusting for time (from clinical decision support implementation), site

clinical decision support status (before or after), age (<2 years or 2 to 17 years), and site, when appropriate; models that were "age specific" inherently controlled for age, and inclusion of site depended on the number of observations in each group. The predictor variables were chosen a priori and the theoretical underpinnings were based on previous work by our group and that of others.[3,10,16,26] We also assessed the interaction between implementation of clinical decision support and secular trend. Multicollinearity and model fit were assessed by adding and removing variables in the models and looking at goodness-of-fit statistics and model residuals.

Modeling for ED length of stay for discharged patients was similarly adjusted and a logarithmic transformation was used because of the skewed distribution of this outcome variable. Site was included as a predictor as long as the model converged without observed separation. Model results for dichotomous variables are presented as unadjusted and adjusted odds ratios (aORs) with 95% CIs, and length-of-stay results are presented descriptively with medians and as means for length-of-stay ratios. For all analyses, $P<.05$ was considered significant. As a sensitivity analysis, the regression models were modified for the CT and length-of-stay outcomes by addition of a variable for the highest level of provider experience based on who completed the clinical decision support template (hierarchically categorized as attending faculty, fellow, nurse practitioner or physician assistant, resident, nurse, or other).

All analyses were performed with SAS (version 9.4; SAS Institute, Inc., Cary, NC).

RESULTS

Characteristics of Study Subjects

Clinicians entered data into the electronic health record template for 28,669 patients (Figure 2). Of 19,029 patients (72.4%) who had minor, nontrivial head trauma and complete PECARN risk factor data, 5,804 (30.5%) had nonnegligible risks of clinically important traumatic brain injuries, given the presence of any PECARN traumatic brain injury risk factors; 5,169

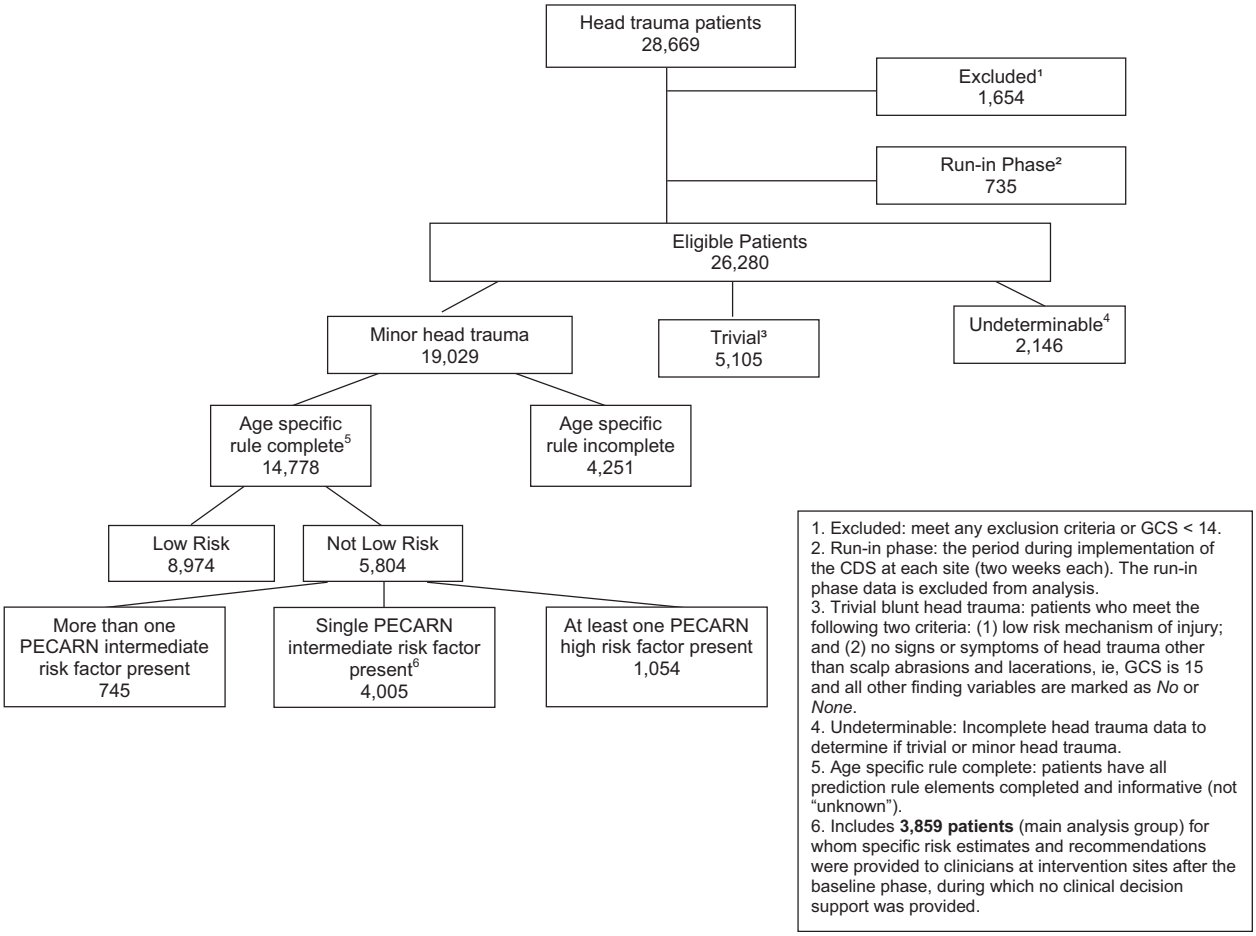


Figure 2. Study flow.

were at intervention EDs and 635 were at control EDs. There were 4,005 patients with a single intermediate PECARN risk factor, of whom 3,859 had specific risk estimates that were known. Of these 3,859 patients, 1,702 were cared for at intervention sites in the post–clinical decision support phase, during which clinicians were provided recommendations with specific risk estimates. We did not have any missing or incomplete outcome data (CT, length of stay, admission, and lost to follow-up for clinically important traumatic brain injuries) for patients analyzed.

Table 1 shows that a slightly higher proportion of attending faculty or fellows and a lower proportion of nurses completed the data templates during the intervention phase. At the control sites, data templates were completed more frequently by attending physicians and those with more years in practice compared with intervention sites. There was variation among pediatric

Table 1. Characteristics of setting and providers assessing the 5,804 patients who were not at low risk.

	Intervention EDs		Control EDs	
	Before CDS (%) (N=2,618)	After CDS (%) (N=2,551)	Early (%)* (N=330)	Late (%)* (N=305)
ED type				
General ED	649 (24.8)	584 (22.9)	139 (42.1)	102 (33.4)
Pediatric ED	1,969 (75.2)	1,967 (77.1)	191 (57.9)	203 (66.6)
Highest-level provider who completed head trauma template				
Attending/fellow	1,450 (55.4)	1,523 (59.7)	300 (90.9)	268 (87.9)
NP/PA	133 (5.1)	166 (6.5)	6 (1.8)	15 (4.9)
Resident	420 (16.0)	425 (16.7)	8 (2.4)	16 (5.2)
Nurse	600 (22.9)	423 (16.6)	14 (4.2)	4 (1.3)
Other	15 (0.6)	14 (0.5)	2 (0.6)	2 (0.7)
Board certification of senior-level provider in charge of patient care†				
Pediatrics	533 (20.4)	493 (19.3)	29 (8.8)	32 (10.5)
Emergency medicine	653 (24.9)	673 (26.4)	139 (42.1)	102 (33.4)
Pediatric emergency medicine	1,234 (47.1)	1,222 (47.9)	162 (49.1)	171 (56.1)
Other	143 (5.5)	108 (4.2)	0	0
Missing	55 (2.1)	55 (2.2)	0	0
Years in practice of provider who made decision whether to obtain CT				
0–4.9	932 (35.6)	1,001 (39.2)	101 (30.6)	110 (36.1)
5–9.9	706 (27.0)	681 (26.7)	85 (25.8)	51 (16.7)
10–14.9	485 (18.5)	404 (15.8)	46 (13.9)	60 (19.7)
15–19.9	237 (9.1)	201 (7.9)	86 (26.1)	71 (23.3)
≥20	237 (9.1)	223 (8.7)	12 (3.6)	13 (4.3)
Missing	21 (0.8)	41 (1.6)	0	0
ED factors				
Time of ED presentation				
6 AM–5:59 PM	1,359 (51.9)	1,363 (53.4)	168 (50.9)	138 (45.2)
6 PM–5:59 AM	1,259 (48.1)	1,188 (46.6)	162 (49.1)	167 (54.8)
Day of presentation				
Mon–Fri	1,822 (69.6)	1,798 (70.5)	232 (70.3)	218 (71.5)
Sat–Sun	796 (30.4)	753 (29.5)	98 (29.7)	87 (28.5)
Average monthly ED volume of pediatric patients	5,028.3	4,600.5	2,789.6	3,111.5
Average monthly ED admissions (%)	12.3	12.9	7.3	7.6

NP, Nurse practitioner; *PA*, physician assistant.
*Defined as enrollments before and after the midpoint of the study period.
†Some providers had multiple certifications.

EDs in regard to which providers completed data collection, with some having substantially higher completion by nurses. These findings were consistent in the subgroup with a single intermediate PECARN risk factor (n=3,859) who had specific risk estimates known.

Main Results

Table 2 displays the clinical characteristics and clinically important traumatic brain injury risks of patients at intervention and control sites. These characteristics were similar across time, but the control EDs had higher proportions of patients younger than 2 years and lower proportions of hospital admission across the entire study duration. The characteristics for the subgroup with a single intermediate-risk factor who had specific risk estimates available (n=3,859) were similar before and after clinical decision support. In the larger cohort of the parent study, a random sample of missed eligible patients had characteristics similar to those of the enrolled population, as previously reported and displayed in Table E1 (available online at http://www.annemergmed.com).[8]

Table 2. Characteristics of the 5,804 patients with minor blunt head trauma who were not at low risk of clinically important traumatic brain injuries.

	Intervention EDs		Control EDs	
	Before CDS (%) (N=2,618)	After CDS (%) (N=2,551)	Early (%) (N=330)	Late (%) (N=305)
Age, mean (SD), y	8 (5.7)	8 (5.7)	6 (5.8)	6 (5.9)
<2	553 (21.1)	541 (21.2)	118 (35.8)	107 (35.1)
2–17	2,065 (78.9)	2,010 (78.8)	212 (64.2)	198 (64.9)
Male patients	1,610 (61.5)	1,618 (63.4)	198 (60.0)	175 (57.4)
ED LOS,* median (Q1, Q3), min	166 (112, 238)	182 (119, 260)	167 (82, 262)	176 (108, 253)
Hospital admission	276 (10.5)	257 (10.1)	10 (3.0)	13 (4.3)
Risk group for ciTBI, No. (%)				
1 intermediate-risk factor for ciTBI[†‡]				
Specific risk of ciTBI known[†‡]	1,711 (65.4)	1,702 (66.7)	219 (66.4)	227 (74.4)
Specific risk of ciTBI unknown[†§]	62 (2.4)	68 (2.7)	10 (3.0)	6 (2.0)
>1 intermediate-risk factor for ciTBI	370 (14.1)	306 (12.0)	45 (13.6)	24 (7.9)
≥1 high-risk factor for ciTBI[‖]	475 (18.1)	475 (18.6)	56 (17.0)	48 (15.7)
GCS score 14 or other signs of altered mental status	398 (15.2)	411 (16.1)	40 (12.1)	37 (12.1)
Signs of basilar skull fracture (for patients 2–18 y) or evidence of palpable skull fracture (for those <2 y)	77 (2.9)	64 (2.5)	16 (4.8)	11 (3.6)
ciTBI, n/N (%)				
1 intermediate-risk factor for ciTBI[†‡]				
Specific risk of ciTBI known[†‡]	14/1,711 (0.8)	12/1,702 (0.7)	0/219	0/227
Specific risk of ciTBI unknown[†§]	0/62	0/68	0/10	0/6
>1 intermediate-risk factor for ciTBI	8/370 (2.2)	5/306 (1.6)	0/45	0/24
≥1 high-risk factor for ciTBI[‖]	13/475 (2.7)	15/475 (3.2)	2/56 (3.6)	1/48 (2.1)
GCS score 14 or other signs of altered mental status	10/398 (2.5)	10/411 (2.4)	1/40 (2.5)	0/37
Signs of basilar skull fracture (for patients 2–18 y) or evidence of palpable skull fracture (for those <2 y)	3/77 (3.9)	5/64 (7.8)	1/16 (6.3)	1/11 (9.1)

LOS, Length of stay.
Control groups were defined as enrollments before and after the midpoint of the study period.
*Truncated at 24 hours.
[†]Includes patients for whom all age-specific PECARN prediction rule factors were completed and those who were not at very low risk of ciTBI according to the prediction rules.
[‡]Intermediate-risk factor (ciTBI risk range 0.2% to 0.7%): for children younger than 2 years, occipital or parietal or temporal scalp hematoma, not acting normally per patient, and severe mechanism of injury; for children aged 2 to 18 years, history of LOC (loss of consciousness), history of vomiting, and severe mechanism of injury.
[§]Intermediate-risk factor: for children younger than 2 years, history of LOC greater than or equal to 5 seconds; for children aged 2 to 18 years, severe headache.
[‖]High-risk factors: GCS score 14, other signs of altered mental status, basilar skull fracture finding (for patients 2 to 18 years), and palpable skull fracture (for those <2 years).

For our primary outcome, the pooled CT proportion decreased from 24.2% before clinical decision support to 21.6% after it (post–clinical decision support odds ratio 0.86; 95% CI 0.73 to 1.01). Decreases in CT proportions were noted across intervention EDs, but not in control EDs. Site-specific trend lines for CT use at intervention sites for patients at nonnegligible risk and with a single intermediate-risk factor with specific risk known are displayed in Figures E1 and E2, respectively (available online at http://www.annemergmed.com).

Adjusted pooled analysis revealed a significant decrease in CT use across all intervention EDs (aOR 0.73; 95% CI 0.60 to 0.88) for children who had one intermediate PECARN risk factor (Table 3). Both the pediatric ED and general ED control sites noted nonsignificant increases in CT use. Table E2 (available online at http://www.annemergmed.com) displays the variation in CT use across sites, with significant decreases after clinical decision support only at the 2 larger pediatric ED sites.

In Table 3, we report CT proportions before and after clinical decision support for patients with each of the 6 isolated intermediate PECARN risk factors for whom risk estimates and recommendations were provided. The adjusted analysis demonstrated an overall reduction in

Table 3. Cranial CT use before and after implementation of clinical decision support among all patients not at low risk of clinically important traumatic brain injuries.

EDs	No. of Patients With CT Obtained Before CDS (%)	No. of Patients With CT Obtained After CDS (%)	Unadjusted Odds Ratio (95% CI)	Adjusted Odds Ratio (95% CI)	*P* Value	Akaike's Information Criterion
Specific risk estimates available (n=3,859)						
All intervention EDs*	414/1,711 (24.2)	367/1,702 (21.6)	0.86 (0.73–1.01)	0.73 (0.60–0.88)	<.01	3,537.3
All pediatric EDs*	304/1,291 (23.5)	273/1,288 (21.2)	0.87 (0.73–1.05)	0.68 (0.56–0.84)	<.01	2,607.2
All general EDs*	110/420 (26.2)	94/414 (22.7)	0.83 (0.60–1.14)	0.87 (0.64–1.19)	.38	902.2
Pediatric ED control	23/129 (17.8)	33/158 (20.9)	1.22 (0.67–2.20)	1.22 (0.67–2.24)	.51	274.2
General ED control	21/90 (23.3)	25/69 (36.2)	1.87 (0.93–3.73)	1.76 (0.87–3.55)	.11	190.2
<2 y (intervention sites)	70/329 (21.3)	61/335 (18.2)	0.83 (0.56–1.21)	1.04 (0.48–2.24)	.92	664.8
Isolated severe mechanism of injury	17/102 (16.7)	16/89 (18.0)	1.10 (0.52–2.32)	0.53 (0.11–2.68)	.45	180.0
Isolated scalp hematoma located on temporal, parietal, or occipital lobe	27/120 (22.5)	22/133 (16.5)	0.69 (0.37–1.29)	1.40 (0.39–4.97)	.61	253.4
Isolated, not acting normally according to caregiver	26/107 (24.3)	23/113 (20.4)	0.80 (0.42–1.50)	1.31 (0.38–4.49)	.67	240.0
2–17 y (intervention sites)	344/1,382 (24.9)	306/1,367 (22.4)	0.87 (0.73–1.04)	0.70 (0.50–0.98)	.04	3,007.1
Isolated severe mechanism of injury	81/385 (21.0)	65/275 (23.6)	1.16 (0.80–1.68)	1.25 (0.60–2.63)	.55	701.5
Isolated LOC for any amount of time	149/543 (27.4)	136/588 (23.1)	0.80 (0.61–1.04)	0.60 (0.37–0.97)	.04	1,278.9
Isolated vomiting episode(s) since injury	114/454 (25.1)	105/504 (20.8)	0.79 (0.58–1.06)	0.60 (0.33–1.09)	.09	1,031.6
No specific risk estimates available (n=1,945)						
1 intermediate-risk factor						
Isolated LOC >5 s (<2 y only)	4/20 (20.0)	5/22 (22.7)	1.18 (0.27–5.18)	0.80 (0.07–9.21)	.86	51.1
Isolated severe HA (2–18 y only)	16/42 (38.1)	14/46 (30.4)	0.73 (0.30–1.78)	1.07 (0.22–5.15)	.93	119.3
>1 intermediate-risk factor	218/370 (58.9)	171/306 (55.9)	0.90 (0.66–1.22)	0.95 (0.53–1.71)	.86	925.2
≥1 high-risk factor	303/475 (63.8)	269/475 (56.6)	0.74 (0.57–0.97)	0.67 (0.42–1.07)	.09	1,269.8
GCS score 14 or other signs of altered mental status	244/398 (61.3)	226/411 (55.0)	0.77 (0.58–1.03)	0.64 (0.39–1.04)	.07	1,094.1
Signs of basilar skull fracture (for patients 2–18 y) or evidence of palpable skull fracture (for those <2 y)	59/77 (76.6)	43/64 (67.2)	0.62 (0.30–1.31)	1.00 (0.25–3.92)	.998	172.1

LOC, Loss of consciousness; *HA*, headache.
All model selection processes are similar, adjusting for time, age, and site when able. Models that are age specific inherently control for age. The inclusion of site depended on the number of observations in each group.
*Adjusted for site; quasilikelihood under the independence model criterion goodness of fit statistic instead of Akaike's information criterion.

Table 4. ED length of stay before and after implementation of clinical decision support for patients with one intermediate PECARN risk factor for whom specific risk estimates and recommendations were given.

EDs	ED LOS Before CDS, N, Median (IQR), Minutes	ED LOS After CDS, N, Median (IQR), Minutes	Adjusted Post/Pre LOS Ratio (95% CI)	*P* Value
All intervention EDs	1,598, 150.0 (97.0–213.0)	1,582, 161.0 (104.0–224.0)	0.94 (0.88–1.01)	.09
All pediatric EDs	1,185, 168.0 (125.0–226.0)	1,175, 182.0 (135.0–240.0)	0.97 (0.91–1.02)	.24
All general EDs	413, 83.0 (47.0–136.0)	407, 87.0 (46.0–135.0)	0.89 (0.78–1.02)	.10
Pediatric ED control	124, 204.0 (130.0–286.5)	154, 210.0 (152.0–266.0)	1.16 (0.88–1.54)	.29
General ED control	89, 71.0 (44.0–104.0)	66, 86.5 (53.0–124.0)	1.08 (0.74–1.57)	.69
All intervention EDs, CT	335, 194.0 (148.0–265.0)	288, 194.5 (133.5–277.5)	0.96 (0.82–1.12)	.62
All intervention EDs, no CT	1,263, 140.0 (88.0–197.0)	1,294, 155.0 (99.0–215.0)	0.96 (0.87–1.06)	.38

Analysis only among patients discharged from the ED, and LOS is truncated at 24 hours.

CT use in the group aged 2 to 17 years (aOR 0.70; 95% CI 0.50 to 0.98; *P*=.04), with the specific risk factor of isolated loss of consciousness demonstrating a significant pre-post change (aOR 0.60; 95% CI 0.37 to 0.97; *P*=.04). There were no statistically significant changes observed in patients younger than 2 years. We also noted several small, nonsignificant decreases in CT proportions after clinical decision support for patients who had neither specific risk estimates nor specific recommendations provided. Table 4 demonstrates a small, nonsignificant increase in length of stay after clinical decision support implementation at intervention sites. Table 5 shows no change in hospital admission after clinical decision support implementation. The results did not appreciably change in sensitivity analyses adjusting for provider type.

Among the 5,804 patients at nonnegligible risk, clinically important traumatic brain injuries were identified at the ED index visit in 37 of 37 (100%) before and 32 of 33 (97.0%) after clinical decision support implementation. The one patient not identified at the index ED visit after clinical decision support implementation was older than 2 years and had a history of loss of consciousness after a skateboard injury and no other PECARN risk factors. The patient had a nondepressed calvarial fracture with a 1.4-cm epidural hemorrhage, was hospitalized for greater than 2 days, was not intubated, and did not have neurosurgery (Table E3, available online at http://www.annemergmed.com).

LIMITATIONS

The limitations in regard to the clinical decision support implementation study have been previously described and largely reflect pragmatic choices made to conduct the trial.[8] Because of the complexities of conducting an electronic health record intervention, the study was not randomized, included only one electronic health record vendor, and allowed variation about which provider type completed the electronic health record data collection template. Although this flexibility facilitated integration within each site's work flow, it may have led to inconsistencies in or omission of clinical documentation of PECARN risk factors and clinically important traumatic brain injury risk assignment. Additionally, the nurses at some sites (pediatric EDs) were more involved in template documentation than those at general ED sites. The strategy of using nurses to collect these data must be weighed against the modest interobserver reliability between nurses and physicians for some clinical findings.[27] Our control sites had a higher overall proportion of general ED providers and

Table 5. Hospital admission before and after implementation of clinical decision support for patients with one intermediate PECARN risk factor for whom specific risk estimates and recommendations were given.

EDs	No. of Patients Admitted Before CDS (%)	No. of Patients Admitted After CDS (%)	Post/Pre Unadjusted Odds Ratio (95% CI)	Adjusted Odds Ratio (95% CI)	*P* Value
All interventions	105/1,711 (6.1)	110/1,702 (6.5)	1.06 (0.80–1.39)	1.02 (0.74–1.41)	.91
All pediatric EDs	99/1,291 (7.7)	104/1,288 (8.1)	1.06 (0.79–1.41)	1.06 (0.75–1.50)	.74
All general EDs	6/420 (1.4)	6/414 (1.4)	1.01 (0.32–3.17)	1.51 (0.38–6.00)	.56
Pediatric ED control	4/129 (3.1)	3/158 (1.9)	0.60 (0.13–2.75)	0.60 (0.13–2.75)	.52
General ED control	0/90	3/69 (4.3)	9.53 (0.48–187.6)	N/A*	.08*

*Fisher's exact test on the raw or unadjusted data because of instability of models.

lower admission proportions (7.9% versus 12.9%) than the intervention sites and appear to be lower-acuity EDs. However, these sites were included in the study primarily for observation of secular trends in CT imaging, and we do not have any reason to believe that such trends would be fundamentally different across our study cohorts.

We did not conduct an a priori power analysis because this was a secondary analysis of a parent trial, and our study was underpowered to detect potentially meaningful differences in all outcomes. Although we found that providing specific risk estimates for particular patients was associated with decreased CT use, we were unable to assess all potential confounders that might affect CT use, such as personal perspectives on imaging; organizational initiatives to minimize unnecessary imaging; and family, consultant, or other specialist requests.[28,29] Furthermore, it is possible that some selection bias was introduced by excluding patients enrolled with incomplete PECARN risk factor data. However, the characteristics of our study cohort are quite similar to those of the original PECARN derivation-validation study.[10] Our ED length-of-stay analysis was limited by the lack of data on other variables that could affect length of stay on a patient- or facility-level basis, including indicators of ED crowding and throughput.[30] Finally, although our analytic approach adjusted for secular trends, there could be residual influence on the outcomes noted.

DISCUSSION

In this pragmatic clinical trial, we implemented electronic health record clinical decision support that provided risk estimates of clinically important traumatic brain injury and recommendations emphasizing the option of clinical observation versus cranial CT for children with minor head trauma and a single intermediate PECARN risk factor. This intervention was associated with a small but significant decrease in CT use for children at nonnegligible risk (0.2% to 0.7%) of clinically important traumatic brain injury. Decreased CT use was not observed, however, at the control sites, which is consistent with recent data on temporal trends for CT use in this population.[7] There was no associated increase in CT use or hospitalization for any group of children at nonnegligible risk of clinically important traumatic brain injuries, as might be feared with commensurate implementation of a low-risk prediction rule.[20,31,32] The lack of significant effects of our intervention on ED length of stay was also reassuring, suggesting no significant influence of clinical decision support on duration of ED evaluations. Finally, as in previous investigations, we observed a very low "miss" rate for clinically important traumatic brain injuries after implementation of the clinical decision support, with no missed neurosurgeries, intubations, or deaths.[14,15,33]

The results of our study build on those of other studies in which implementation of clinical decision support for children with minor head trauma was associated with modest but variable decreases in CT use, both for children at near-zero and those at nonnegligible risk of clinically important traumatic brain injuries.[8,14,15,33,34] Across studies, with implementation of clinical decision support CT proportions of less than 15% have been safely achievable for children with minor head trauma.[8,14,15,33] Our study extends previous research by both quantifying the change in CT use according to clinical findings (ie, isolated PECARN risk factors) and noting decreased use in both pediatric and general EDs.

Except for children with isolated severe mechanisms of injury, the absolute decreases in CT proportions observed after clinical decision support were similar (4% to 6%) for all groups of children with isolated PECARN findings for whom risk estimates and recommendations were provided. Previous literature suggests that the differences in risk of clinically important traumatic brain injuries are small among patients with isolated intermediate-risk PECARN factors (0.2% to 0.7%).[17-19,23-25] The safe decrease in CT use among patients with isolated vomiting and isolated loss of consciousness was particularly encouraging, given that physicians often ascribe higher risk to these findings.[35] Previous observational studies have noted safe decreases in CT use when ED clinicians observed children with potentially concerning findings such as headache and vomiting before CT decisionmaking.[36,37] In a single-center quality improvement initiative, investigators noted a 6% decrease in CT use for all children with minor head trauma after implementation of an evidence-based guideline, with larger decreases noted for individual clinicians with higher baseline CT use.[15] Further studies might assess the effect of providing data-driven recommendations about the safe duration of ED observation for patients with particular intermediate-risk factors. For such future endeavors, ED observation time should be calculated as the time from injury rather than a fixed observation period in the ED.[36,38]

Although the effectiveness of clinical decision support to change clinician behavior has varied across studies, a recent review of 23 studies using clinical decision support in EDs noted that those with more rigorous designs showed a trend toward beneficial effects.[39] Compared to prior studies, our intervention was developed to provide clinical decision support early in the ED work flow, before clinician decisionmaking. This aspect of clinical decision support

was also successfully used in a similar general ED setting to implement a decision rule for adults with minor head injury, suggesting the reproducibility of such models across clinical decision support content.[40] Experts continue to call for further study to test the benefits of different work flows and features of electronic health record–based clinical decision support (eg, requiring clinicians to justify overriding advice).[20,21,36,37] Finally, incorporating assistive electronic health record clinical decision support into shared decisionmaking models, including the use of technology to bring easily understandable risk-benefit data to the bedside, holds promise for future iterations of clinical decision support.[41,42]

The implementation of clinical decision support that provided the risks of clinically important traumatic brain injuries and recommendations about the appropriateness of clinical observation in the ED was associated with safe, modest decreases in CT use for children at nonnegligible risk after minor blunt head trauma. This intervention has the potential to safely modify CT decisionmaking for children with minor head trauma, as well as help refine future clinical decision support systems for use in other patient populations.

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Author contributions: NK and PSD conceptualized and designed the study, obtained funding, designed the data collection instruments and intervention, and coordinated and supervised data collection at all sites. DWB, NK, DRV, and PSD designed the analytic plan and article structure and drafted the initial article. All authors approved the final version of the article. RR and TCC carried out the data analyses and revised the article. DWB, DRV, ET, JMH, MS, SJDD, EAA, LT, LB, DGM, SRO, UKC, MDP, MHS, RR, TCC, HSG, and RWG reviewed the article. DWB, DRV, ET, JMH, EAA, LT, LB, DGM, SRO, and UKC helped design the study, data collection instruments, and intervention; each coordinated and supervised data collection at his or her site. MS, SJDD, MDP, MHS, HSG, and RWG designed the study, data collection instruments, and clinical decision support. DWB takes responsibility for the paper as a whole.

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