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Pediatric Emergency Care Applied Research Network head injury prediction rules: on the basis of cost and effectiveness

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Background/aim: Head injuries are commonly seen in the pediatric population. Noncontrast enhanced cranial CT is the method of choice to detect possible traumatic brain injury (TBI). Concerns about ionizing radiation exposure make the evaluation more challenging. The aim of this study was to evaluate the effectiveness of the Pediatric Emergency Care Applied Research Network (PECARN) rules in predicting clinically important TBI and to determine the amount of medical resource waste and unnecessary radiation exposure.

Materials and methods: This retrospective study included 1041 pediatric patients presented to the emergency department. The patients were divided into subgroups of "appropriate for cranial CT", "not appropriate for cranial CT" and "cranial CT/observation of patient; both are appropriate". To determine the effectiveness of the PECARN rules, data were analyzed according to the presence of pathological findings

Results: "Appropriate for cranial CT" results can predict pathology presence 118,056-fold compared to the "not appropriate for cranial CT" results. With "cranial CT/observation of patient; both are appropriate" results, pathology presence was predicted 11,457-fold compared to "not appropriate for cranial CT" results.

Conclusion: PECARN rules can predict pathology presence successfully in pediatric TBI. Using PECARN can decrease resource waste and exposure to ionizing radiation.

Key words: Pediatric Emergency Care Applied Research Network, cost, effectiveness, computed tomography

1. Introduction

Head injuries are one of the most common reasons for children to present to the emergency department (ED) (1). In the United States, blunt head trauma is the cause of more than 450,000 pediatric ED visits per year (2). Traumatic brain injury (TBI) is also an apparent reason for death and disability in children, with reports of more than 7000 deaths and 60,000 hospitalizations annually in the United States (3). Over the last decade there has been an increase in annual pediatric ED visits because of head injuries (1). More than 90% of pediatric TBIs are minor head injuries and clinically important traumatic brain injuries (ciTBIs) constitute the minority (4). Noncontrast enhanced cranial computed tomography (CT) is the method of choice to detect a possible TBI, and many children presenting at EDs with blunt head trauma are evaluated with CT scans (5%–70%) (5).

Concerns about ionizing radiation exposure and body movements make the evaluation of children with minor head trauma via CT more challenging. Emergency physicians have to be sensitive about the balance between missing a clinically significant traumatic brain injury and the potential risk of malignancy associated with ionizing radiation exposure (6). In 2009, using a large prospective cohort study about children with minor blunt head trauma, the Pediatric Emergency Care Applied Research Network (PECARN) stated age-based TBI clinical prediction rules to differentiate children who need a cranial CT scan from those for whom it may not be necessary (1). This rule was created according to the results of a study that included 42,412 patients examined in 25 different emergency centers in the United States. In the above-mentioned study, pediatric patients younger than 18 years having a Glasgow Coma Scale (GCS) score of 14 or 15 within 24 h after injury were divided into two main groups: those >2 years of age and those aged ≤2 years. The following criteria were stated as prediction rules for excluding ciTBI: normal mental status, no scalp hematoma except frontal, no loss of consciousness or a loss of consciousness for less than 5 s, nonsevere injury mechanisms, no palpable skull fracture, and normal activity as reported by parents (7).

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The aim of this retrospective study was to evaluate the effectiveness of the PECARN rules in the prediction of ciTBI. It was also aimed to determine the amount of medical waste and unnecessary radiation exposure and to provide some insight into unnecessary cranial CT imaging.

2. Materials and methods

2.1. Study design and setting

The study protocol was approved by the Institutional Review Board of our hospital. Informed consent of the patients or their parents for participation was not required because of the design of the study.

A retrospective study was made of children with minor blunt head trauma who presented at the ED between September 2015 and July 2016. The physical examination notes of children who underwent cranial CT examination after head injury were evaluated to define the necessity for head CT according to the PECARN rules. Currently, in our pediatric ED, PECARN scoring is not being used effectively to determine head CT necessity.

The CT scanner available in our hospital is a 16-slice GE Optima CT540, and cranial CT examinations were obtained without contrast administration.

2.2. Study population

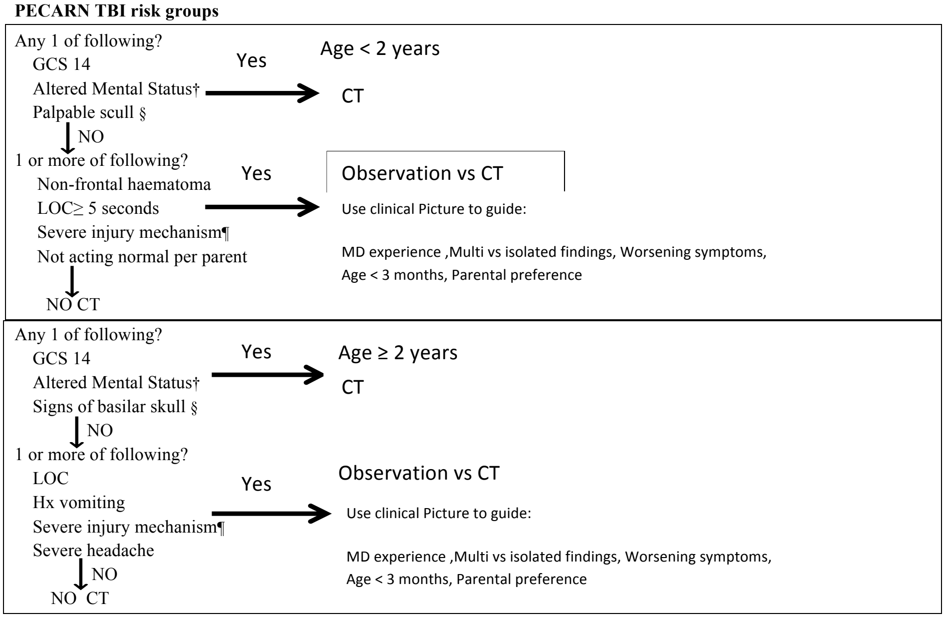
The study included all children (<18 years of age) with blunt head trauma and an initial GCS of ≥14 who presented at the pediatric ED within 24 h of injury. Children with a trivial injury mechanism (ground-level falls, running into stationary objects, with no signs of TBI other than scalp abrasions and lacerations), neurological comorbidities, bleeding disorders, or suspected child abuse were excluded from the study. Cases were also excluded when there was insufficient information for PECARN scoring (Table 1) in the electronic archive.

Table 1. PECARN TBI age-based clinical prediction rules for children withminor blunt head trauma and initial GCS ≥14.

Inclusion criteria
- Age <18 years of age
- Blunt head trauma within 24 h
- Initial Glasgow Coma Score ≥14

Exclusion criteria
- Neurological comorbidities
- Bleeding disorders
- Suspected child abuse
- Lack of enough information for PECARN scoring

PECARN TBI risk groups



†GCS 14, agitation, sleepiness, slow response or repetitive questioning.
§Retroauricular bruising (battle sign), periorbital bruising (raccoon eyes), cerebrospinal fluid otorrhoea or haemotympanum.
¶Motor vehicle crash with patient ejection, death of another passenger or rollover, pedestrian or bicyclist without helmet struck by motorised vehicle, falls (of >3 feet for children <2 years of age or >5 feet for children ≥2 years) or head struck by high impact object. GCS, Glasgow Coma Score; PECARN, Pediatric Emergency Care Applied Research Network; TBI, traumatic brain injury.

2.3. Data collection

A retrospective search was made of all the electronic archives of pediatric patients who underwent cranial CT examination. Those who presented at the ED with blunt head trauma and had enough information for PECARN scoring were selected for evaluation in the study. The electronic archives and all the CT images were evaluated by three radiologists, with experience of 25 years, 3 years, and 4 years, respectively. The data obtained were reviewed separately by all three radiologists in order to observe interobserver agreement. All images were obtained from the picture archiving communication systems of our hospital. According to the information in the PECARN rules, the population was divided into three groups: 1) "appropriate for cranial CT", 2) "not appropriate for cranial CT", and 3) "cranial CT/observation of the patient; both are appropriate". The pathologies found after the CT exam were also noted. Pathologies detected by cranial CT were classified in five major groups: 1) nondisplaced fracture, 2) displaced fracture, 3) intracranial hemorrhage, 4) intracranial hemorrhage and nondisplaced fracture, and 5) intracranial hemorrhage and displaced fracture. Patients with both displaced and nondisplaced fractures were classified in the displaced fracture group. Brain contusion cases were classified in the hemorrhage group. The opinions of the radiologists about the diagnostic quality of the CT images (satisfactory, moderate, poor) and approximate time for discharge from hospital (≤1 h, >1 h, ≥1 week) were also noted.

2.4. Outcome measures

The primary outcome measure was presentation at the pediatric ED with blunt head trauma and undergoing head CT scan for this trauma. The secondary outcome measure was the suitability of the patient for cranial CT according to the PECARN scoring and the presence of pathologies detected by cranial CT.

2.5. Statistical analysis

Statistical analyses were performed using SPSS 21.0 (IBM Corp., Armonk, NY, USA). The conformity of the data to normal distribution was evaluated with the Kolmogorov–Smirnov test. Numerical variables with normal distribution were stated as mean ± standard deviation and those not with normal distribution were stated as median values (min–max). Categorical variables were shown as number (n) and percentage (%) and were compared using Fisher exact or chi-square tests as appropriate. Skewed continuous parameters were evaluated with the Mann–Whitney U test. To analyze independent predictors of the presence of pathological findings on cranial CT, multivariable logistic regression analysis was applied. ROC curve analysis was applied for diagnostic evaluation of PECARN scoring.

Interobserver agreement about the classification of patients into PECARN subgroups (1- "appropriate for cranial CT", 2- "not appropriate for cranial CT", 3- "cranial CT/observation of the patient; both are appropriate") was evaluated by the Fleiss kappa method.

A two-tailed value of $P < 0.05$ was considered statistically significant.

3. Results

3.1. Patients

A total of 1547 patients with blunt head trauma and an initial Glasgow Coma Score of ≥14, who presented at the pediatric ED within 24 h of injury, were initially evaluated for the study. Of these, 506 met the exclusion criteria, leaving a population of 1041 for evaluation comprising 338 females (32.5%) and 703 males (67.5%) with a median age of 7 years (range: 0–18 years). The patient distribution according to PECARN subgroups is shown in Table 2.

Cranial CT revealed pathological findings in 206 patients (19.8%). The distribution of pathological findings is shown in the Figure.

Table 2. Patients' distribution according to PECARN subgroups.

	CT results		
	Normal n = 835	Pathologic n = 206	
PECARN subgroups, n (%)			
Appropriate for cranial CT	10 (1.2)	96 (46.6)	<0.001*
Not appropriate for cranial CT	766 (91.7)	52 (25.2)	
Cranial CT/following the patient, both are appropriate	59 (7.1)	58 (28.2)	

*P < 0.05 indicates statistical significance.

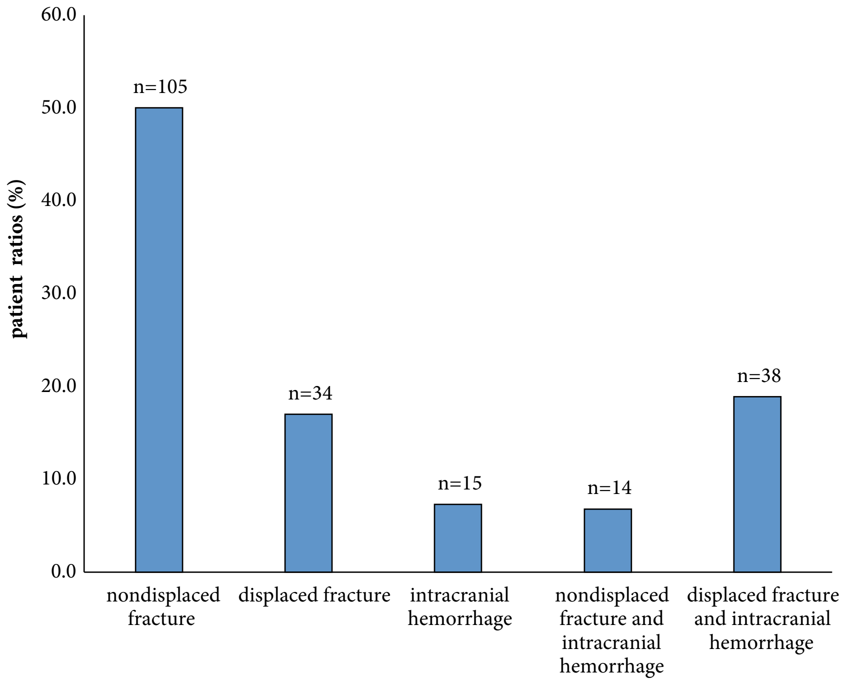


Figure. Distribution of pathologic findings.

The researchers evaluated the quality of examination as satisfactory in 918 patients (88.2%), moderate in 110 patients (10.6%), and poor in 13 patients (1.2%).

3.2. Pathology versus normal

The median age and sex distributions of patients determined with pathology and normal findings were similar. More cases were classified as "appropriate for cranial CT" in the patient group with pathological findings on CT images compared with patients with a normal CT exam. The most frequent indication in the normal CT population was "not appropriate for cranial CT" (Table 3).

In both the normal and pathological CT population, a higher rate of appropriate CT images was determined (91.7% in the normal group, 75.2% in the pathological group).

Patients with a nondisplaced fracture had fewer "appropriate for cranial CT" results and higher "cranial CT/observation of the patient; both are appropriate" than the other pathology subgroups. In the intracranial hemorrhage and displaced fracture pathology subgroup there was a higher rate of "appropriate for cranial CT" results (Table 4).

No significant difference was determined between pathology subgroups in respect to image quality.

3.3. Predicting pathology presence (performance of PECARN)

According to the stepwise logistic regression analysis results, PECARN was an independent predictor for pathology presence. PECARN was able to predict pathology presence with a sensitivity of 74.8% and specificity of 91.7% (AUC ± SE = 0.818 ± 0.016; $P < 0.001$).

It was determined that an "appropriate for cranial CT" result could predict pathology presence 118,056-fold compared to the "not appropriate for cranial CT" result,

Table 3. PECARN subgroups' distribution according to CT results.

CT results	PECARN subgroups			
	Appropriate for CT, n = 106	Not appropriate for CT, n = 818	Cranial CT/following, both are appropriate, n = 117	P
Normal	10 (9.4)	766 (93.6)	59 (50.4)	<0.001*
Pathologic	96 (90.6)	52 (6.4)	58 (49.6)	

* P < 0.05 indicated statistical significance.

Table 4. Distribution of patients according to pathologies detected via cranial CT.

	Nondisplaced fracture, n = 103	Displaced fracture, n = 35	Hemorrhage, n = 15	Nondisplaced fracture and intracranial hemorrhage, n = 14	Displaced fracture and intracranial, n = 39	P
PECARN subgroups, n (%)						
Appropriate for CT	27 (26.2)	23 (65.7)	7 (46.7)	8 (57.1)	31 (79.5)	<0.001*
Not appropriate for CT	35 (34.0)	5 (14.3)	6 (40.0)	2 (14.3)	4 (10.3)	
Cranial CT/following, both are appropriate	41 (39.8)	7 (20.0)	2 (13.3)	4 (28.6)	4 (10.3)	

* P < 0.05 indicated statistical significance.

with a sensitivity of 64.86% and specificity of 98.71% (AUC ± SE = 0.818 ± 0.019; P < 0.001). The "cranial CT/observation of the patient; both are appropriate" result could predict pathology presence 11,457-fold compared to the "not appropriate for cranial CT" result, with a sensitivity of 52.73% and specificity of 99.85% (AUC ± SE = 0.728 ± 0.024; P < 0.001) (Table 5).

3.4. Interobserver agreement for PECARN subgroup classification

We found high interobserver agreement for all three subgroups. Agreement of the three researchers for the :appropriate for cranial CT: subgroup was 91.5% (Fleiss kappa: 0.915; P < 0.001). For the "not appropriate for cranial CT" subgroup, interobserver agreement was 94% (Fleiss kappa: 0.940; P < 0.001). Meanwhile, for the "cranial CT/observation of the patient; both are appropriate" subgroup, it was 96.1% (Fleiss kappa: 0.915; P < 0.001).

3.5. Approximate duration of hospitalization

The quality of CT images and PECARN subgroup were found to be related to the approximate time to discharge from the hospital.

A "moderate" or "poor" quality score extended discharge time compared to a "good" quality result. Classification in the subgroups of "appropriate for cranial CT" and "cranial CT/observation of the patient; both are appropriate" was also found to extend the estimated time to discharge (Table 6).

4. Discussion

Unlike the trends in other departments, the utilization of imaging in the ED has apparently continued to increase, with a significant amount of that increase on the basis of CT and X-rays (8). Multiple studies have shown that approximately US $20 billion has been spent on unnecessary and duplicated imaging studies (9,10). Studies in the literature have predicted that the elimination of unnecessary imaging could make an annual saving of US $81 billion (8).

Other than the potential waste of financial resources, unnecessary ED imaging increases exposure to ionizing radiation. CT scans constitute the largest source of medical exposure to ionizing radiation in the United States. The utilization of CT increased from 52 CT scans per 1000 patients in 1996 to 149 per 1000 in 2010 (11,12). Of all cancers in the United States, it has been suggested that 1.5%–2% may be caused by radiation from CT scans (13), which makes radiation exposure from unnecessary CT scans a serious problem. There are multiple studies in the literature stating that radiation exposure from multiple

Table 5. Regression analysis results.

Variables	OR	95% CI		P
		Lower	Upper	
PECARN subgroups (ref: not appropriate for cranial CT)				
Appropriate for cranial CT	118.056	57.152	243.862	<0.001*
Cranial CT/following, both are appropriate	11.457	7.054	18.608	<0.001*
	Nagelkerke R^2 = 0.560; P < 0.001*			

* P < 0.05 indicated statistical significance.
OR = Odds ratio; CI = confidence interval.

Table 6. Regression analysis results for approximate time to discharge from hospital.

Variables	OR	95% CI		P
		Lower	Upper	
Time for discharging from hospital				
Pathologic findings (ref: normal)	507.825	55.348	4659.326	<0.001*
Quality of CT images (ref: enough)				
Mediate	2.464	1.794	5.373	0.025*
Poor	11.739	1.510	91.280	0.019*
PECARN subgroups (ref: not appropriate for cranial CT)				
Appropriate for cranial CT	196.914	77.517	500.213	<0.001*
Cranial CT/following, both are appropriate	10.273	5.387	19.589	<0.001*
	Nagelker R^2 = 0.956; P < 0.001*			

* P < 0.05 indicated statistical significance.

CT scans can significantly increase the risk of cancer, especially in the pediatric population or young adults (14). Although technological efforts still concentrate on decreasing the amount of radiation per CT scan, it is clear that any decrease in the number of unnecessary CT scans would be very helpful. To improve the efficiency and appropriateness of CT use in children with minor head trauma, and to help clinicians with CT decision-making, clinical prediction rules were derived and validated by PECARN.

In the current study, the primary aim was to determine the extent of unnecessary pediatric brain imaging, the potential waste of resources, and unnecessary exposure to ionizing radiation, in addition to evaluating the success of the PECARN rules in predicting TBI.

There are other prediction methods for CT use in pediatric TBI, such as the Canadian Assessment of Tomography for Childhood Head injury (CATCH) and the Children's Head Injury Algorithm for the Prediction of Important Clinical Events (CHALICE). However, according to the literature, there are studies showing that physician practice and the PECARN rules outperform the CATCH and CHALICE rules based on the detection of TBI (15). Therefore, the focus was on the PECARN rules in the current study.

According to the literature, without any other change in practice, if CT was not applied in cases not appropriate for cranial CT according to PECARN scoring, pediatric cranial CT use would decrease by 20%–25% and children with ciTBI would rarely be missed. PECARN use in practice would also reduce healthcare costs and exposure to ionizing radiation (4,16). The results of this study are consistent with findings in the literature. PECARN can successfully predict pathology presence. Differing from previous studies in the literature, it was decided to assess PECARN efficacy by a different route in the current study. Generally in the literature, patients have been divided into risk groups, whereas the current study population was divided into groups according to the recommendations of "appropriate for cranial CT" etc., so that the power of the predictivity of PECARN could be determined. Being in the "appropriate for cranial CT" subgroup was found to be the most powerful predictive criterion for having a ciTBI. Classification in the "cranial CT/observation of the patient; both are appropriate" subgroup also increased the risk of having ciTBI, although to a lesser degree than in the "appropriate for cranial CT" subgroup but still to a statistically significant level.

To the best of our knowledge, this study is the first in the English literature to correlate PECARN subgroups with pathology types detected by CT. Patients with displaced fracture and hemorrhage tended to appear in the "appropriate for CT" subgroup, whereas patients with no pathology on CT scan tended to be in the "not appropriate for cranial CT" subgroup. Thus, it can be inferred from the data that PECARN rules can predict serious injuries and exclude normal patients successfully.

Patients with a nondisplaced fracture only had a tendency to be in the "cranial CT/observation of the patient; both are appropriate" subgroup. It could be claimed that PECARN rules are not successful enough to detect nondisplaced fractures. However, in practice, infants with nondisplaced fractures only are admitted for overnight observation regardless of neurological status (17). Therefore, performing cranial CT would not significantly change the medical approach for a nondisplaced fracture, as the patient is kept under observation for at least one night. It could be said that clinicians should be encouraged to choose observation of the patient instead of performing CT in this subgroup.

According to the PECARN rules, in the "not appropriate for cranial CT" subgroup of this study, 766 (91.7%) patients were found to have normal CT results. In the "cranial CT/observation of the patient; both are appropriate" subgroup, 59 (7.1%) patients were normal. Thus, following the PECARN rules, the treatment of 825 (79.2%) patients could be managed without cranial CT. It can be inferred from the data that unnecessary cranial CT imaging entailed a cost of approximately US $13,750–16,500 and a total X-ray dose of 1650–2062 mSv. The main reason for clinicians not using the PECARN rules sufficiently can be said to be overcrowding in the ED. Lack of space and time for the observation of pediatric trauma cases requires the determination of normal cases more quickly, thus gaining more time for more serious cases. Another reason may be insufficient information about the PECARN rules. Further prospective studies about cranial CT ordering processes would be able to better clarify these reasons.

The researchers graded only 13 (1.2%) CT examinations as poor quality. Despite working with a pediatric population and without any sedation, these results can be considered sufficient. The outcome can be explained by the decreased scanning time with multidetector CT technology and the pediatric experience of our center. The quality of CT images is important in another aspect as it was demonstrated that having "moderate" or "poor" image quality extended the approximate duration of hospitalization. This can be explained by the behavior of clinicians, as in cases where a radiologist cannot state an optimal result, clinicians are reluctant to send patients home. It was also detected that being in the "appropriate for cranial CT" and "cranial CT/observation of the patient; both are appropriate" subgroups prolonged hospitalization. Thus, it can be inferred that the PECARN rules also give reliable information about the approximate duration of hospitalization.

We also found high interobserver agreement between researchers from different levels of experience. This shows that PECARN is a reliable and reproducible method for evaluating head trauma.

This study had some limitations. First, patients with electronic archive data insufficient for PECARN scoring were excluded. Second, the radiologists evaluated the CT images retrospectively with no time limitation. Working under the stress of ED conditions and with the need to make a quick evaluation might change the results. Third, PECARN scoring should be applied by clinicians under normal circumstances. A quick but sufficient neurological examination is crucial for proper PECARN scoring and this will undoubtedly be affected by the level of experience of the clinician, but this effect could not be evaluated in this study. Further multidisciplinary prospective studies would be able to clarify a possible relationship.

To conclude, PECARN rules can successfully predict pathology presence in pediatric TBI cases. The PECARN recommendations can also predict the severity of the pathology (the intracranial hemorrhage and displaced fracture pathology subgroup had higher "appropriate for cranial CT" results than the others) and approximate duration of hospitalization. Using PECARN can decrease both resource waste and exposure to ionizing radiation.

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