Original Article

Clinical Decision Rules for Paediatric Minor Head Injury: Are CT Scans a Necessary Evil?

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Abstract

Introduction: High performing clinical decision rules (CDRs) have been derived to predict which head-injured child requires a computed tomography (CT) of the brain. We set out to evaluate the performance of these rules in the Singapore population. Materials and Methods: This is a prospective observational cohort study of children aged less than 16 who presented to the emergency department (ED) from April 2014 to June 2014 with a history of head injury. Predictor variables used in the Canadian Assessment of Tomography for Childhood Head Injury (CATCH), Children's Head Injury Algorithm for the Prediction of Important Clinical Events (CHALICE) and Pediatric Emergency Care Applied Research Network (PECARN) CDRs were collected. Decisions on CT imaging and disposition were made at the physician's discretion. The performance of the CDRs were assessed and compared to current practices. Results: A total of 1179 children were included in this study. Twelve (1%) CT scans were ordered; 6 (0.5%) of them had positive findings. The application of the CDRs would have resulted in a significant increase in the number of children being subjected to CT (as follows): CATCH 237 (20.1%), CHALICE 282 (23.9%), PECARN high- and intermediate-risk 456 (38.7%), PECARN high-risk only 45 (3.8%). The CDRs demonstrated sensitivities of: CATCH 100% (54.1 to 100), CHALICE 83.3% (35.9 to 99.6), PECARN 100% (54.1 to 100), and specificities of: CATCH 80.3% (77.9 to 82.5), CHALICE 76.4% (73.8 to 78.8), PECARN high- and intermediate-risk 61.6% (58.8 to 64.4) and PECARN high-risk only 96.7% (95.5 to 97.6). Conclusion: The CDRs demonstrated high accuracy in detecting children with positive CT findings but direct application in areas with low rates of significant traumatic brain injury (TBI) is likely to increase unnecessary CT scans ordered. Clinical observation in most cases may be a better alternative.

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Key words: Brain injuries, Children, Prediction rules, Traumatic brain injury

Introduction

Head injury is a common complaint in the paediatric emergency department (ED), accounting for approximately 500,000 paediatric ED visits a year in the United States.[1] While most head-injured children do not require treatment and may be discharged after a period of observation, an estimated 4% to 7% have intracranial injuries and only 0.5% require neurosurgical intervention.[2,3] Intracranial injuries can result in long-term morbidity and mortality.[4,5]

Clinical assessment in young children frequently poses a challenge to the emergency physician, due to their variable and non-specific complaints postinjury,[6] especially in the preverbal age group.[7] The fastest definitive diagnostic tool for intracranial lesions is the computed tomography (CT) scan. It allows for intracranial injuries to be promptly diagnosed, and guides further intervention. However, the radiation from CT has been shown to increase the risk of future radiation-induced malignancies.[8-11] This leads to the current difficulty the ED physician faces when deciding whether or not, and when to order a CT scan of the brain.

To standardise and guide the usage of CT, independent clinical decision rules (CDRs) have been developed to guide physicians on which child should receive a CT in the presence of traumatic head injury. Of the numerous CDRs

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developed, the Canadian Assessment of Tomography for Childhood Head Injury (CATCH),[12] Children's Head Injury Algorithm for the Prediction of Important Clinical Events (CHALICE)[13] and Pediatric Emergency Care Applied Research Network (PECARN)[14] CDRs are considered to be of high quality as they were powered by large research networks.

These rules have been reported to have good performance in other populations.[15-17] Notably, a paper has also compared the 3 CDRs and their performances with that of physician practice.[17] Given the low rate of positive CTs however, others have advocated a period of monitoring to allow for imaging to be performed with greater discretion.[18]

We were interested to find out if these rules (CATCH, CHALICE and PECARN) could be applied to the Singapore population, given our current healthcare practices and CT rates. We hypothesise that its direct application would lead to a significant increase in CT scans ordered.

Materials and Methods

Study Design

This study is part of an ongoing prospective observational cohort study among head-injured children in our population. We prospectively collected data from patients who presented to the paediatric ED at KK Women's and Children's Hospital (KKH) with a history of head injury from April 2014 to July 2014. KKH sees approximately 175,000 visits at the ED each year. Patients were included if they: 1) aged less than 16; 2) had a presenting complaint of head injury; and 3) presented to the ED within 72 hours after injury. The exclusion criteria included: 1) children aged 16 and above; 2) presentation to ED more than 72 hours after injury; 3) bleeding disorders or usage of anticoagulants; 4) brain tumours; 5) ventricular shunts; and 6) previous neuroimaging. There was no intervention in this study. Decisions on neuroimaging and subsequent disposition of the patients were made at the discretion of the physician. This study was approved by the local Institutional Review Board.

Data Collection

A standardised electronic template was filled for every head-injured child. Data were collected including patient demographics, predictor variables, and outcome measures. Predictor variables as published in the above CDRs included (from history): headache, vomiting, loss of consciousness, amnesia, seizure, mechanism of injury; and (from physical examination) Glasgow Coma Scale (GCS) score, abnormal mental status, neurological deficit, skull fracture and scalp haematoma. Physicians working in the ED underwent a training session in regard to completion of the form and they recorded the presence or absence of the predictor variables after assessing the patient.

Outcome Measures

The primary outcome was defined as the presence of positive findings on CT. These included epidural haemorrhage, subdural haemorrhage, subarachnoid haemorrhage, intraparenchymal haematoma, cerebral oedema, depressed fracture, and contusion. A follow-up call was given to patients discharged from the ED after 72 hours, to assess for any evolution of symptoms or attendance at another hospital. We also surveyed the current rate of CT usage and the projected CT rate if each of the CDRs were applied.

Data Analysis

The CDRs were retrospectively applied to the study cohort and were considered to be positive for recommending a CT scan when at least 1 of the predictor variables was present. Performance of the CDRs was assessed using descriptive statistics to generate sensitivity, specificity, positive predictive and negative predictive values. Ninety-five percent confidence intervals (CI) were provided for each measure of accuracy described using STATA v12 (Stata Corp, College Station, Tx, USA).

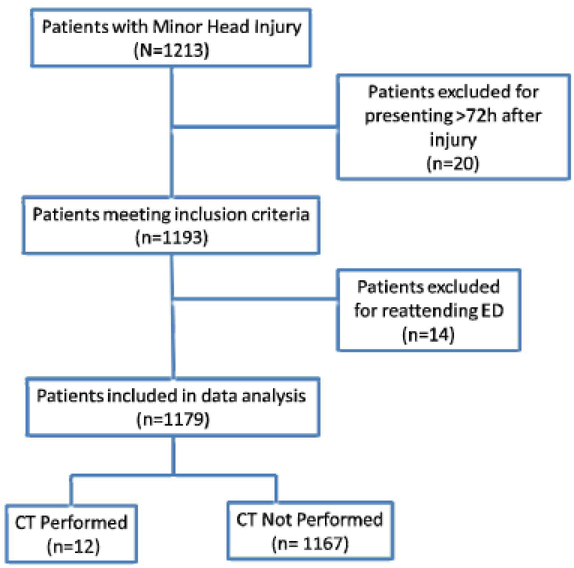

Fig. 1. Study flow diagram.
CT: Computed tomography; ED: Emergency department

Results

Patient Characteristics

A total of 1213 patients presented to the ED with minor head injury. Twenty were excluded because they presented more than 72 hours after the injury, and 14 patients who reattended at the ED were also excluded (Fig. 1). In the latter group, only signs and symptoms from their first attendance were included in the study. There were no events among these 14 patients who reattended. In total, 1179 patients were included in the study and analysed. The largest majority presented within 24 hours of injury, whereas 154 (13.1%) presented 24 to 72 hours after injury, and 21 (1.8%) had an unknown time/date of injury. Of the patients analysed, 12 underwent CT, with 6 patients having positive findings on CT. In the 12 patients who had CTs performed, 7 had signs of altered mental status, 5 had signs of basal skull fracture and 4 had loss of consciousness for more than 5 seconds. Finally, 1 had monocular diplopia. The positive CT findings in the 6 patients are described as follows: 1 left temporal bone fracture extending to the mastoid process, 1 mildly depressed occipital skull vault fracture, 1 cerebral contusion, 1 pneumocephalus with haemoantrum, 2 intracranial haemorrhages, and 1 with midline shift. Of the 12 patients, only 1 patient underwent neurosurgical intervention in the form of a craniotomy and monitoring for intracranial pressure.

Patient characteristics were assessed and compared with the original derivation cohorts in the CDRs (Tables 1 and 2). The distribution of gender and GCS value are generally comparable to that of the derivation cohorts. However, the mean age (4.4) of our study cohort was lower. Of interest, we had a large number of children (n = 387) aged less than 2 years among those who presented to our ED with head injury, comprising 32.8% of the included patients.

Significant differences also exist in the mechanism of injury (MOI) across all age groups where falls contributed to a large majority (81.3%) in the study cohort as compared to 44.9% in CATCH and 51.0% in PECARN. CHALICE had a fall rate of 0.6%, but this could be attributed to their stronger criterion for fall, requiring a fall more than 3 metres in height. For children aged below 2, the MOI are as follows: 362 falls (93.5%), 1 road traffic accident (RTA) (0.3%), 1 non-accidental injury (NAI) (0.3%), and 23 others (5.9%). Of note, we had a low event rate in our population, with a positive CT rate of only 0.5%.

Performance of Clinical Decision Rules

The performance of the CDRs in detecting positive CT findings was compared and evaluated using descriptive statistics (Table 3). CATCH and PECARN demonstrated excellent sensitivity (100%) (54.1 to 100), accurately

Table 1. Comparison of Patient Characteristics in Our Study Cohort versus Derivation Cohorts in Clinical Decision Rules

Characteristics	Study Cohort (n = 1179)	CATCH (n = 3866)	CHALICE (n = 22,772)	PECARN (n = 42,412)
Mean age	4.4	10*	5.7	7.1
Number of patients <2 years	387 (32.8)	277 (7.2)	6229 (27.4)	10,718 (25.3)
Gender				
Male	880 (74.6)	2505 (64.8)	14,767 (64.8)	NR
Female	299 (25.4)	1361 (35.2)	7941 (34.9)	
GCS				
13	1 (0.1)	95 (2.5)	73 (0.3)	0
14	17 (1.4)	282 (7.3)	229 (1.0)	1341 (3.2)
15	1158 (98.2)	3489 (90.2)	21,996 (96.7)	41,071 (96.8)
Mechanism of injury				
Fall	959 (81.3)	1737 (44.9)	129 (0.6)†	21,629 (51.0)
Road traffic accident	21 (1.8)	687 (17.8)	204 (0.9)	8064 (19.0)
Struck by object/projectile	14 (1.2)	447 (11.6)	456 (2.0)	3124 (7.4)
CT performed	12 (1.0)	2043 (52.8)	766 (3.4)	14,969 (35.3)
CT positive§	6 (0.5)	159 (4.1)	281 (1.2)	780 (1.8)
Neurosurgical intervention‡	1 (0.1)	24 (0.6)	157 (0.7)	60 (0.1)

CATCH: Canadian Assessment of Tomography for Childhood Head Injury; CHALICE: Children's Head Injury Algorithm for the Prediction of Important Clinical Events; PECARN: Pediatric Emergency Care Applied Research Network; CT: Computed tomography; GCS: Glasgow Coma Scale; NR: Not reported
*Median age.
†Fall >3 m.
‡Includes neurosurgery and intubation for monitoring of intracranial pressure.
§Any abnormality on CT scan.

Table 2. Signs and Symptoms of Patients in Study Cohort versus Derivation Cohorts in CDRs

Characteristics	Study Cohort (n = 1179)	CATCH (n = 3866)	CHALICE (n = 22,772)	PECARN (n = 42,412)
Loss of consciousness	27 (2.3)	1267 (32.8)	1185 (5.2)	6286 (14.8)
Vomiting	208 (17.6)	1582[†] (40.9)	2498 (11.0)	5557 (13.1)
Stiffening/jerking of limbs	7 (0.6)	152[‡] (3.9)	96[‡] (0.4)	NR
Altered mental status[*]	12 (1.0)	419[§] (10.8)	NR	5487 (12.9)
Headache	160 (13.6)	623[||] (16.1)	4783 (21.0)	12,675 (29.9)
Scalp haematoma	297 (25.2)	1256 (32.5)	52[¶] (0.2)	16,715 (39.4)

CATCH: Canadian Assessment of Tomography for Childhood Head Injury; CHALICE: Children's Head Injury Algorithm for the Prediction of Important Clinical Events; PECARN: Pediatric Emergency Care Applied Research Network; CDR: Clinical decision rules; NR: Not reported

[*]Altered mental status includes irritability, agitation, somnolence, repetitive questioning and slow response to verbal communication.

[†]≥2 episodes of vomiting.

[‡]Seizure after head injury in patients without history of epilepsy.

[§]Irritability.

[||]Worsening headache.

[¶]Bruise/swelling or laceration >5 cm in children aged <1 year.

detecting all the 6 patients with positive CT findings. CHALICE had slightly lower sensitivity (83.3%) (35.9 to 99.6), failing to detect 1 of the patients with positive CT findings. This patient presented with a history of persistent irritability and agitation. CATCH and CHALICE demonstrated similar specificity (80.3% [77.9 to 82.5] and 76.4% [73.8 to 78.8] respectively), modestly being able to identify patients with negative CT findings. PECARN showed a relatively lower specificity (61.6%) (58.8 to 64.4) for its high- and intermediate-risk criteria. By using only the high-risk criteria, PECARN had a very high specificity of 96.7% (95.5 to 97.6). All three CDRs demonstrated low PPV (<3%), indicating an extremely low likelihood of a positive initial diagnosis based on CT findings. Of note, using only the high-risk criteria for PECARN yielded a PPV of 13.3% (5.1 to 26.8). All 3 CDRs demonstrated high NPV (>99.9%).

Projected CT Rate

Of the 1179 patients in the study cohort, 12 underwent CT scan. Six out of the 12 had positive CT findings. This

Table 3. Performance of Clinical Decision Rules for Prediction of Injury in Study Cohort

CDR	CT Findings		Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
	Positive	Negative[*]				
CATCH						
Positive	6	231	100	80.3	2.5	100
Negative	0	942	(54.1 – 100)[†]	(77.9 – 82.5)[†]	(0.9 – 5.4)[†]	(99.6 – 100)[†]
CHALICE						
Positive	5	277	83.3	76.4	1.8	99.9
Negative	1	896	(35.9 – 99.6)[†]	(73.8 – 78.8)[†]	(0.6 – 4.1)[†]	(99.4 – 100)[†]
PECARN high- and intermediate-risk						
Positive	6	450	100	61.6	1.3	100
Negative	0	723	(54.1 – 100)[†]	(58.8 – 64.4)[†]	(0.5 – 2.8)[†]	(99.5 – 100)[†]
PECARN high-risk only						
Positive	6	39	100	96.7	13.3	100
Negative	0	1134	(54.1 – 100)[†]	(95.5 – 97.6)[†]	(5.1 – 26.8)[†]	(99.7 – 100)[†]

CATCH: Canadian Assessment of Tomography for Childhood Head Injury; CHALICE: Children's Head Injury Algorithm for the Prediction of Important Clinical Events; PECARN: Pediatric Emergency Care Applied Research Network; CDR: Clinical decision rules; CT: Computed tomography; NPV: Negative predictive value; PPV: Positive predictive value

[*]Assumption of negativity based on resolution of symptoms and absence of clinical deterioration.

[†]95% CIs are in the brackets.

gives rise to a CT ordering rate of 1% and CT positivity rate of 0.5% in the study cohort.

If the CDRs were to be applied, there would be a significant increase in the number of CT being ordered (Table 4). Using CATCH, 237 (20.1%) patients met the criteria for a CT. However, if only the high-risk variables were used, the number would be reduced to 67 (5.7%). CHALICE demonstrated similar CT recommendation rates with 282 (23.9%) patients meeting the criteria. PECARN stratified the patients into high-, intermediate- and low-risk. For the intermediate-risk category, PECARN recommended either CT or observation. If only the high-risk group was sent for CT, 45 patients would be subjected to CT (3.8%) and 411 patients (34.9%) would require observation. However, if both the high-risk and intermediate-risk patients were sent for CT, this would give rise to a CT rate of 38.7% (or 456 patients).

Discussion

There is a very low prevalence of significant traumatic brain injury (TBI) in our population. Most of the head-injured children brought to the ED had sustained minor injuries from falls. This was especially true for children aged less than 2 years, with falls making up 96% of the MOI. There was a much lower injury rate from RTA at 1.8%. We also note that our baseline CT rate is much lower than those of other centers (as high as 52.8% in the case of CATCH),[12] and postulate that this could be due to 2 reasons: 1) very low prevalence of moderate – severe head injuries, 2) the viable alternative of observation with the intent of performing the CT at a later time if new symptoms or signs evolve. In this study, 195 (16.5%) patients were admitted for observation. This strategy of "watchful waiting" could have played a part in reducing the CT rate.

Table 4. Projected CT Rate if Clinical Decision Rules Applied in Study Cohort

Clinical Decision Rule	CT Rate n (%)
CATCH	
High-risk only	67 (5.7)
High- and medium-risk	237 (20.1)
CHALICE	282 (23.9)
PECARN	
High-risk only	
<2 years	20 (1.7)
≥2 years	25 (2.1)
High- and intermediate-risk	
<2 years	166 (14.1)
≥2 years	290 (24.6)

CATCH: Canadian Assessment of Tomography for Childhood Head Injury; CHALICE: Children's Head Injury Algorithm for the Prediction of Important Clinical Events; PECARN: Pediatric Emergency Care Applied Research Network; CDR: Clinical decision rules; CT: Computed tomography

A period of observation may allow the physician to make a more informed decision on neuroimaging in a majority of the head-injured children. Studies have shown that a delayed presentation of severe head injury is very uncommon in children who present with only mild symptoms from minor head injury.[19,20] There is also growing evidence demonstrating that observation before CT is safe in a large majority of patients, especially among those who present with mild symptoms.[21,22] The optimal duration of observation after head injury is however yet to be well-defined and more study in this area could be potentially clarifying.

The CDRs generally performed with high sensitivity and negative predictive value, with PECARN and CATCH detecting all cases. These parameters of performance are especially important because of the implications of misdiagnosis. On the other hand, the results of this study confirmed our hypothesis that direct application of these rules would raise our CT rates significantly. Although the application of the CDRs would have correctly identified the small number of cases with abnormal CT findings, the majority of CT scans would have been unnecessary with resultant radiation exposure and increased healthcare costs. This concern is particularly valid for populations with a very low prevalence of significant TBI. In particular, PECARN performed fairly well in our population, if CT was performed only for the high-risk group and those with intermediate-risk were mostly observed.

A more recent publication in the Annals of Emergency Medicine in 2014[17] compared the performance of the 3 CDRs as well as that of physician estimates. Easter et al's study had a cohort of a similar size, yet a much higher event rate even when simply comparing positive findings on CT. This could possibly be due to variation in injury mechanisms, with Easter's paper reporting much higher frequencies of severe mechanism of injury. As mentioned earlier, our physician CT rates are much more conservative compared to that of the CDRs, whereas in Easter's paper, physician practice had a CT rate very similar to those of the CDRs, and this could be possibly attributed to the much lower frequency of positive events that physicians in our local population are used to. Another possible reason for the difference in results between Easter's and our study is that Easter's study limited the enrolment of children who had apparently trivial injury. In our experience with the local head-injured population, ground level falls have also resulted in intracranial bleeds, hence we were not able to exclude ground level falls. We did, however, exclude children with facial injuries from minor mechanisms.

We also chose to include children whose head injuries occurred up to 72 hours prior to presentation. Both PECARN and CATCH restricted their population to those who presented within 24 hours of presentation, whereas CHALICE did not. We were concerned that placing a strict 24 hour criteria may result in missed cases. In our study, 1 patient who presented with an injury of unknown duration was still sent for CT based on the physician's call. This patient presented with persistent confusion and agitation, and his CT was found to be positive with a subdural bleed. This case suggests that the time interval between injury and presentation is less important than the patient's presenting status.

In some populations, CT scans are unnecessarily done for other reasons. A recent study on a Switzerland population has found that defensive medicine is a major contributor to physicians ordering CT scans, even if not recommended to do so by CDRs.[23] Reasons cited included: "fear of missing an intracranial lesion", "fear of being sued", and "pressure from the patient or relatives". In such a situation, observation may potentially be a safe and cost-saving strategy, reducing unnecessary CT scans in majority of the children with MHI without compromising patient care. Further studies are recommended to evaluate the appropriate duration of clinical observation and the safety profile of this strategy in large-scale cohort populations.

The authors recognise the following limitations of this study. Firstly, in this single-centre study, the number of patients in our study cohort is relatively small in comparison to the CDRs derivation cohorts. This is an early analysis of a prospective cohort study in which we are accruing data on head-injured patients in our population. The small number of events in our population accounted for the wide 95% CIs for the sensitivity values. Also, we recognise that the positive and negative predictive values are dependent on prevalence, for which the event of moderate to severe brain injury is very low in our population. We recognise that given the different healthcare practices and settings, our study results may not be generalisable to all populations, especially to areas with a higher prevalence of severe TBI. Lastly, follow-up was done at 72 hours postdischarge and there may be a small possibility of unreported events that occurred after this period.

Conclusion

The CDRs demonstrated high accuracy in detecting children with positive CT findings but its direct application would likely lead to a significant increase in unnecessary CT scans in our population. Clinical observation in most cases is a viable alternative.

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