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Validation of the "CHIIDA" and application for PICU triage in children with complicated mild traumatic brain injury☆

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ABSTRACT

Background: The Children's Intracranial Injury Decision Aid (CHIIDA) was developed to predict which patients with complicated mild traumatic brain injury (cmTBI; GCS ≥13 with depressed skull fracture or intracranial injury) would achieve the composite outcome of neurosurgical intervention, intubation >24 h, or death. The study also explored the CHIIDA as a triage tool to determine need for PICU care. The purpose of this study is to externally validate the CHIIDA and assess its effects on PICU triage.
Methods: Retrospective cohort study (January 2016 to December 2017) to validate the CHIIDA to predict the composite outcome and assess its effects as a PICU triage tool at a level 1 pediatric trauma center.
Results: Of 345 patients with cmTBI, the composite outcome occurred in 16 patients (4.6%). At a cutoff score of 2, the CHIIDA predicted the composite outcome with a sensitivity of 94% (95% CI 67–99%) and specificity of 69% (95% CI 64–74%), similar to the original study. Using the same cutoff score for PICU triage resulted in 48 (71%) more patients admitted to PICU.
Conclusions: In our cohort, the CHIIDA predicted the composite outcome well. If applied as a triage tool, it would have resulted in increased unnecessary PICU admissions.
Level of Evidence: Level III, prognosis

1. Background

Traumatic brain injury (TBI) is a common pediatric diagnosis leading to 60,000 hospitalizations annually [1,2]. Children with mild TBI (GCS 13-15) account for approximately one third of TBI admissions annually, although there is limited research describing how children hospitalized with mild TBI should be managed [3,4].

Prior studies have identified which children with mild TBI should undergo head computed tomographic (CT) imaging [5–7], and developed decision tools for use in deciding the disposition of patients with normal imaging results [8]. Less research has been dedicated to the management of patients with complicated mild TBI (cmTBI), patients with mild TBI and positive imaging results. There remains significant variability in the treatment and disposition of patients found to have complicated mild TBI (cmTBI) [9–13]. Data from our own institution have shown that many patients with cmTBI may not need to be observed in the pediatric intensive care unit (PICU) setting [13].

Admission to PICU level care for observation of children with cmTBI permits early detection of neurologic decline; however, intensive care beds are a limited resource for hospitals and pose significant financial and emotional strain for patients and their families [14–20]. There are growing adult data suggesting stable patients with cmTBI do not need ICU level care [21,22]. Pediatric data from retrospective, single center studies with relatively small patient volumes support the concept of observation outside of the PICU; however, were not broadly generalizable [23–25]. Recently, data from the Pediatric Emergency Care Applied Research Network (PECARN), a consortium of 25 hospitals, were used to develop a tool that could be used to help determine which patients with cmTBI should be triaged to the PICU and which could be observed in a lower acuity setting [26]. The Children's Intracranial Injury Decision Aid (CHIIDA) was designed to identify a group of children with high or low risk for the composite outcome of requiring neurosurgical intervention, intubation for >24 h related to TBI, or death from TBI. In the derivation study, the authors applied the CHIIDA to the decision of triage to the

Abbreviations: CHIIDA, Children's Intracranial Injury Decision Aid; cmTBI, complicated mild traumatic brain injury; GCS, Glasgow Coma Score; PICU, Pediatric Intensive Care Unit; PCH, Primary Children's Hospital; TBI, traumatic brain injury; ICU, intensive care unit; PECARN, Pediatric Emergency Care Applied Research Network; AIS, Abbreviated Injury Score.

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general ward or PICU and found a large potential reduction in the rate of PICU admissions [26].

Triage practices vary among trauma centers; therefore, the CHIIDA requires external validation prior to its clinical application. The goals of this study were to validate the ability of the CHIIDA to predict the composite outcome at our center and assess the impact of using the CHIIDA as a tool to assist in PICU triage for patients with cmTBI.

2. Methods

This was a retrospective cohort study of patients with cmTBI evaluated in the emergency department at Primary Children's Hospital (PCH) between January 1, 2016 and December 31, 2017. PCH is an American College of Surgery verified level 1 pediatric trauma center located in Salt Lake City, UT with 1000 trauma evaluations annually. The University of Utah institutional review board approved this study (IRB#00105264).

2.1. Patients

Patients with cmTBI were identified from the PCH trauma database. The database is maintained by a dedicated trauma registrar who prospectively records data on all patients with a traumatic injury who present to the PCH emergency department or are admitted to the hospital.

To be included in the cohort, patients had to be 0–18 years of age, with a nonpenetrating head injury, a GCS of 13–15, and a positive CT scan. A positive CT scan was defined as having evidence of intracranial injury, defined as intracranial hemorrhage, cerebral edema, skull diastasis, midline shift, pneumocephalus, depressed skull fracture (defined as at least the width of the skull), traumatic infarction, diffuse axonal injury, herniation, shear injury, or sigmoid sinus thrombosis.

To match the CHIIDA cohort, we excluded children with a nonhead injury with AIS > 2, or who presented to the emergency department >24 h after injury. We additionally excluded patients with missing clinical data or initial head CT imaging, patients with trivial injury history (ground level fall or running into stationary object), injury secondary to suspected child abuse, and patients with known bleeding disorders, or pre-existing comorbid neurological disease (brain tumor, ventricular shunt). These criteria mimic those used in the original PECARN head injury data cohort used in the development and internal validation of the CHIIDA score [26].

2.2. Data source

Data were abstracted from the PCH trauma database, trauma intake note, radiology reports, and the inpatient medical record including the neurosurgery consult notes. Data elements abstracted from the trauma intake note included the GCS at arrival to the PCH emergency department and clinical findings of altered mental status, defined as somnolence, agitation, or amnesia. Head CT data were obtained from the initial pediatric radiologist clinical reading as this is the reading available for clinical decisions about ED disposition. The head CT clinical readings for all potential patients identified by the initial trauma database query were reviewed by authors KN and BF to ensure presence of intracranial injury as described above. Data elements collected from patients' medical records included emergency department disposition, need for intubation, need for neurosurgical intervention, length of PICU and hospital stay, and discharge location.

2.3. CHIIDA score

The CHIIDA score assigns points to each of four clinical variables shown to predict the composite outcome (Fig. 1). The total score ranges from 0 to 24, with higher scores indicating greater clinical risk or likelihood of experiencing the composite outcome. Greenberg et al., noted cutoffs of 0 and 2 points to be the most predictive of the composite outcome. A cutoff of >0 had sensitivity 93.2% (95% CI 84.7–97.7%), specificity 55.5% (95% CI 51.9–59.0%), positive predictive value 16.6% (95% CI 13.2–20.6%), and negative predictive value 98.8% (95% CI 97.3–99.6%). A cutoff >2 had sensitivity 86.6% (95% CI 76.3–93.2%), specificity 70.4% (95% CI 67.0–73.6%), positive predictive value = 21.7% (95%CI 17.1–26.9%) and negative predictive value = 98.2% (95% CI 96.7–99.1%) [26].

CHIIDA Point Values for Different Risk Factors	
Depressed skull fracture	**7**
Midline shift	**7**
Epidural hematoma	**5**
GCS Score:	
13	**5**
14	**2**
Total Score:	**0-24**

Fig. 1. CHIIDA point values for different risk factors.

2.4. Outcomes

The primary outcome was the ability of the CHIIDA to predict the composite outcome in our population. The secondary outcome was to determine the potential change in the rate of PICU admission when using the CHIIDA score to guide triage versus the actual triage location.

2.5. Statistical analysis

Summary data are presented as median values with interquartile ranges (IQR) or as counts with percentages as appropriate. Comparisons of the demographic, injury, and clinical data were made between patients without the composite outcome [(−) Outcome] and with the composite outcome [(+) Outcome]. Categorical data were compared with the chi-squared and Fisher's exact test as appropriate. Continuous variables were compared using the Mann–Whitney U test. Additionally, the categorical variables for the total cohort developed from PCH were compared to the cohort published by Greenberg et al. [26] from which the CHIIDA was derived. All comparisons were 2 sided with a p value of 0.05 used for significance.

We determined the sensitivity, specificity, and positive and negative predictive values with exact 95% confidence intervals of the CHIIDA to predict the composite outcome at cutoffs of 0 and 2.

The CHIIDA score cutoffs of 0 and 2 were then used as thresholds to determine triage to the PICU. Consistent with the methods of Greenberg et al., patients taken immediately to the OR from the emergency department were combined with the group triaged to the PICU for this analysis. The difference in number of admissions to the PICU based on the CHIIDA prediction versus actual triage was calculated.

Analyses were conducted using SPSS Version 25 (IBM) and STATA Version 15 (StataCorp, College Station, TX).

3. Results

3.1. Patient population

The initial PCH trauma database query identified 577 potential patients with mild TBI. After initial screening, 232 patients were excluded and 345 patients met all inclusion criteria (Fig. 2). Of the 345, 16 (4.6%) experienced the composite outcome. Most patients (n = 294, 85.3%) had a GCS of 15. The most common abnormal CT findings included non-depressed skull fracture (n = 231, 67%), subdural hematoma (n = 110, 31.9%), and subarachnoid hemorrhage (n = 81, 23.5%). The majority of patients, n = 277 (80.4%) were triaged to home, an observation unit, or the general inpatient pediatric ward. Sixty-nine (19.7%) patients were triaged directly to the OR or to the PICU. Population demographics, clinical characteristics, and CT findings are shown in Table 1.

3.2. Performance of CHIIDA to predict composite outcome

CHIIDA scores ranged from 0 to 19 in both the (−) Outcome group [median = 0 (IQR 0–5)] and in the (+) Outcome group [median = 7 (IQR 6–12)] ($p < 0.001$). Compared to the (−) Outcome group, patients in the (+) Outcome group were older [median age 10.5 years (IQR 5.7–15.7) vs 4.6 years (IQR 0.8–11.2), ($p = 0.006$)] and were more likely to have altered mental status (69% vs 41%, $p = 0.037$). CT imaging showed that patients in the (+) Outcome group were more likely to have epidural hematoma (56% vs 16%, $p < 0.001$), midline shift (31% vs 3%, $p < 0.001$), and depressed skull fracture (44% vs 11%, $p < 0.001$). All (+) Outcome group patients required neurosurgical intervention; there were no intubations >24 h or deaths in the cohort (Table 2).

CHIIDA scores of >0 and > 2 had good sensitivity and moderate specificity for predicting the composite outcome in our population as shown in Table 3. Both cutoff scores performed well in correctly identifying children without the composite outcomes (negative predictive value = 99% (95% CI 97–99%) for both cutoffs), but performed poorly for correctly identifying those with the outcome (at >0 positive predictive value = 11% (95% CI 6–17%) and at >2 positive predictive value = 12% (95% CI 8–20%).

3.3. Performance of CHIIDA as triage tool

To determine the utility of the CHIIDA as a PICU triage tool, we compared the CHIIDA's prediction of the need for PICU admission to our observed patient disposition at the cutoffs of >0 and > 2.

Applying a cutoff score of >0 for PICU admission to our population would have resulted in 9 patients being reassigned from the PICU to the ward and 83 patients from the ward to the PICU. This would have resulted in net 74 more patients (109% increase) admitted to the PICU. Similarly, if a cutoff score of >2 was applied, a net of 48 patients (71% increase) would have been admitted to the PICU. Table 4 summarizes the observed triage location versus the CHIIDA-directed decisions (Table 4).

As triaging a patient who ultimately had the composite outcome to a lower level of observation may delay care and impact clinical outcome, we examined whether any patient that CHIIDA directed triage would have placed in the general ward experienced the composite outcome.

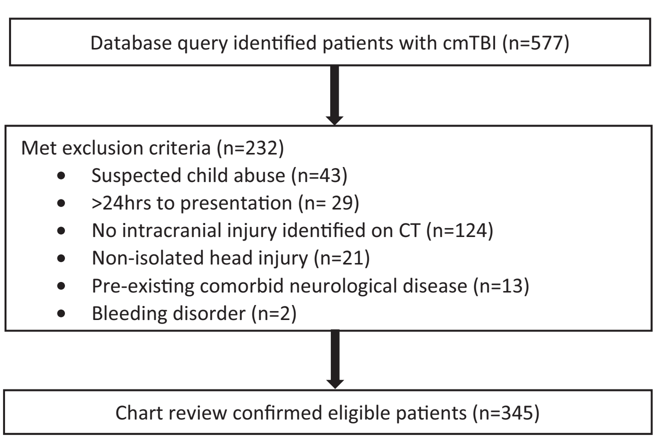

Fig. 2. Study flow diagram.

Table 1
Population demographic characteristics, clinical characteristics, CT findings and emergency department disposition.

	− Outcome (n = 329)	+ Outcome (n = 16)	P Value
Age, years (IQR)	4.6 (0.8–11.22)	10.5 (5.7–15.7)	0.006
Female, n (%)	120 (36.6)	3 (18.8)	0.187
Race, n (%)			0.107
White	315 (96)	14 (87.2)	
American Indian	0	0	
Native Hawaiian/Pacific Islander	5 (1.5)	1 (6.3)	
Asian	2 (0.6)	1 (6.3)	
Black/African American	6 (1.8)	0	
Unknown	1 (0.3)	0	
Mechanism of Injury, n (%)			
Fall	188 (57.1)	7 (43.8)	0.526
MVC	25 (7.6)	3 (18.8)	
Bike	26 (7.9)	0	
Sports	35 (10.6)	2 (12.5)	
Struck by/against	23 (7)	2 (12.5)	
Animal	6 (1.8)	1 (5.9)	
Outdoor Vehicle	20 (6.1)	1 (5.9)	
Auto-ped	6 (1.8)	0	
Presenting GCS, n (%)			
15	282 (85.7)	12 (75)	0.433
14	34 (10.3)	3 (18.8)	
13	13 (4)	1 (6.3)	
Neurologic deficit present, n (%)	3 (0.9)	1 (6.3)	0.174
Altered mental status present, n (%)	135 (41)	11 (68.8)	0.037
Vomiting present, n (%)	136 (41.3)	10 (62.5)	0.121
Computed tomographic findings, n (%)			
Epidural hematoma	53 (16.1)	9 (56.3)	< 0.001
Subarachnoid hemorrhage	78 (23.7)	3 (18.8)	0.772
Subdural hematoma	107 (32.5)	3 (18.8)	0.288
Extraaxial hemorrhage	1 (0.3)	0	1
Midline shift	9 (2.7)	5 (31.3)	<0.001
Cerebral edema	19(6)	6(38)	<0.001
Pneumocephalus	76 (23.1)	2 (12.5)	0.54
Depressed skull fracture	37 (11.2)	7 (43.8)	0.002
Diastasis	3 (0.9)	0	1
Nondepressed skull fracture	225 (68.4)	6 (37.5)	0.014
Intraparenchymal hemorrhage	53 (16.1)	2 (12.5)	1
Intraventricular hemorrhage	4 (1.2)	1 (6.3)	0.212
Emergency department disposition, n (%)			<0.001
Home	10 (3)	0	
Admission to Observation	5 (1.5)	0	
Admission to Pediatric Ward	260 (79)	2 (12.5)	
Admission to PICU	53 (16.2)	10 (62.5)	
Taken to OR	1 (0.3)	4 (25)	

IQR = interquartile range, MVC = motor vehicle crash, GCS = Glasgow Coma Scale, PICU = pediatric intensive care unit, OR = operating room.

One patient was identified. The initial CT scan demonstrated a subarachnoid hemorrhage. The patient experienced worsening headaches, repeat imaging obtained was notable for an epidural hematoma which was evacuated and the patient was admitted to the PICU postoperatively without complications.

To understand differences between our population and the original derivation cohort that may affect the performance of the CHIIDA, we compared our cohort to that of Greenberg et al.'s population. As shown in Table 5, the PCH cohort had higher GCS scores, a higher percentage of white patients, fewer patients with altered mental status, and were less likely to be admitted to the OR or PICU.

4. Discussion

The goals of our study were to compare the ability of the CHIIDA score to predict the composite outcome of need for neurosurgery, intubation >24 h, or death within the population of children with cmTBI at

Table 2
PCH outcomes.

Composite Outcome	n
Intubation > 24 h related to TBI	0
Death from TBI	0
Neurosurgical Intervention	
Skull fracture elevation	6
Hematoma evacuation	10
EVD/ICP Monitor	1
Decompressive hemicraniectomy	0

TBI = traumatic brain injury, EVD = external ventricular drain, ICP = intracranial pressure.

Table 4
Performance of the CHIIDA as a triage tool.

	Non-PICU Admit	PICU Admit		Non-PICU Admit	PICU Admit
CHIIDA 0	194	9	CHIIDA <2	215	14
CHIIDA >0	83	54	CHIIDA >2	62	49
Net +74 PICU Admissions or 109% increase			Net +48 PICU Admissions or 71% increase		

CHIIDA = Children's Intracranial Injury Decision Aid, PICU = pediatric intensive care unit.

Primary Children's Hospital and then to assess the impact of using the CHIIDA score to guide PICU triage. We found that the CHIIDA score at cutoffs of >0 and > 2 had good sensitivity and moderate specificity to predict patients with the composite outcome, similar to its performance in the original cohort. However, the use of the CHIIDA would have resulted in a large increase in the number of children triaged to the PICU in our cohort (109% increase with a cut off of >0 and 71% increase with a cut off of >2).

The CHIIDA performed similarly in our cohort to the original cohort. This is unsurprising as our cohort was relatively similar to the original cohort although our patients had slightly higher GCS scores and less occurrence of altered mental status. Similar to the study by Greenberg et al., we found the presence of depressed skull fracture, midline shift, and epidural hematoma were factors individually associated with the composite outcome. Unlike the Greenberg study, we did not find an association between presenting GCS and the composite outcome; however, we had less variation in GCS scores in our population. Additional studies have also noted that lower GCS and signs of mass effect identify patients with cmTBI at higher risk for needing ICU level care [21,22,24,25]. Overall, this comparison suggests that the CHIIDA performed well predicting the composite outcome in a new population with slightly different characteristics.

In contrast to Greenberg et al., we found the CHIIDA to be a poor triage tool. Application of the CHIIDA as a triage tool to our population would have resulted in substantial increases in PICU admissions among children who did not require neurosurgical intervention. Specifically, while Greenberg et al. found a 65% decreased rate of PICU when using a cutoff of >2, application to our population would have increased PICU admissions by 71%.

The poor performance of the CHIIDA as a triage tool in our cohort is likely because of institutional variability in triage practice. Triage to the PICU in our cohort was approximately 50% lower than that of the Greenberg et al. cohort and substantially lower than PICU triage rates in other studies of pediatric mild TBI [23–26]. The low triage rate may indicate that many of the patients "safe" for triage to the general ward the CHIIDA could identify were, in fact, already being triaged to the general ward. Essentially, the pretest probability of identifying a patient that could have avoided PICU admission was low, resulting in the poor performance the CHIIDA as a triage tool. Our cohort had a higher percentage of patients with a GCS of 15. The higher GCS score may have led practitioners to feel more comfortable not triaging patients to the PICU. Local practices may have also led to our lower PICU triage rate. As a high-volume trauma center, practitioners may have enhanced abilities to identify subtle findings of patients likely to deteriorate that alter PICU triage practices. An additional consequence of our hospital's high trauma volume is the existence of a neurotrauma general ward unit. This unit is staffed with a dedicated and neurotrauma trained nursing staff which facilitates the early recognition of declining neurologic status. The availability of this resource may increase the comfort of the treating physician to triage their patients away from the PICU. An additional explanation of the different triage rates may be the era when the data for Greenberg et al.'s study were obtained. Greenberg et al. studied a cohort from 2004 to 2006, ten years before our cohort. It is possible that increasing focus in the past decade on hospital efficiencies such as reducing unnecessary ICU days has resulted in a temporal change in triage practices [22–25]. While the PICU triage rate in our hospital is lower than other reported cohorts, it is likely not unique. Wide variation in rates of ICU admission has been noted in the care of adult patients with mild TBI, and a recent article of pediatric intensivists, trauma

Table 3
Performance of the CHIIDA to predict composite outcome with cutoffs of 0 and 2 relative to Greenberg et al.

% (95% CI)	PCH CHIIDA > 0	PCH CHIIDA > 2	Greenberg et al. >0	Greenberg et al. >2
Sensitivity	94 (68–99)	94 (67–99)	93.2 (84.7–97.7)	86.6 (76.3–93.2)
Specificity	61 (56–67)	69 (64–74)	55.5 (51.9–59)	70.4 (67.0–73.6)
Predictive Value				
Positive	11 (6–17)	12 (8–20)	16.6 (13.2–20.6)	21.7 (17.1–26.9)
Negative	99 (97–99)	99 (97–99)	98.8 (97.3–99.6)	98.2 (96.7–99.1)

PCH = Primary Children's Hospital, CHIIDA = Children's Intracranial Injury Decision Aid.

Table 5
Comparison of PCH and Greenberg et al. CHIIDA populations.

	PCH (n = 345)	Greenberg et al. (N = 839)	P value
Age < 2, n (%)	113 (33)	290 (35)	0.55
Female, n (%)	123 (36)	299 (36)	0.996
Race, n (%)			
White	329 (95)	515 (61)	<0.001
Nonwhite	16 (5)	324 (39)	
Presenting GCS, n (%)			
15	294 (85.3)	611 (73)	<0.001
14	37 (10.7)	165 (20)	
13	14 (4.1)	63 (8)	
Median (IQR)	15 (15–15)	15 (14–15)	<0.001
Neurologic Deficit Present, n (%)	4 (1.2)	24 (2.9)	0.08
Altered Mental Status Present, n (%)	146 (42.3)	431 (51)	0.005
Computed tomographic findings, n (%)			
Epidural hematoma	62 (18)	108 (13)	0.023
Subarachnoid hemorrhage	81 (23.5)	163 (19)	0.117
Subdural hematoma	110 (31.9)	207 (25)	0.011
Midline shift	14 (4.1)	58 (7)	0.062
Cerebral Edema	25 (7)	46 (5)	0.2
Pneumocephalus	78 (22.6)	163 (19)	0.217
Depressed skull fracture	44 (12.8)	136 (16)	0.132
Nondepressed skull fracture	231 (67)	362 (43)	<0.001
Emergency department disposition, n (%)	n, %		
High Acuity (OR/PICU)	68 (20)	338 (40)	<0.001
Low Acuity (All other)	277 (80)	501 (60)	

PCH = Primary Children's Hospital, GCS = Glasgow Coma Scale, IQR = interquartile range, OR = operating room, PICU = pediatric intensive care unit.

surgeons, and neurosurgeons also noted variation in PICU triage rates in a standardized case vignette of a patient with cmTBI [12,27].

Our results highlight the importance of analyzing the potential change on local triage rates prior to implementing an externally derived triage tool. This may be especially important in centers with high trauma volume and dedicated neurotrauma nursing units, like our institution, where triage rates are lower. Applying the CHIIDA as a triage tool in such center would unnecessarily increase PICU admission rates. Alternatively, the CHIIDA may be more applicable in centers with lower familiarity with head trauma where high PICU admission rates may be higher. Further study examining the effect of the CHIIDA as a triage tool at centers with high and low PICU triage rates can further identify the correct settings for the implementation of the CHIIDA.

Limitations of our study include the retrospective study design. There are multiple factors affecting management that may not be captured in the medical record such as change in clinical status during transport to our hospital or during evaluation in the emergency department. Additionally, the single center nature of our cohort may limit generalizability.

5. Conclusions

In our population, the CHIIDA correctly identifies patients with cmTBI at low risk of needing neurosurgical intervention. While the CHIIDA may have potential use as a triage tool to reduce unnecessary PICU admission of children with cmTBI at institutions that have high baseline rates of PICU admission, our study highlights that in a center with a low baseline PICU admission rate for this population, use of the CHIIDA may increase PICU use unnecessarily. Application of the CHIIDA and other triage tools should be preceded by an in-depth examination of current, local triage rates before being incorporated into practice.

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Declarations of interest

None.

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