Pediatr Radiol (2011) 41:971–979
DOI 10.1007/s00247-011-2032-4

ORIGINAL ARTICLE

External validation of the New Orleans Criteria (NOC), the Canadian CT Head Rule (CCHR) and the National Emergency X-Radiography Utilization Study II (NEXUS II) for CT scanning in pediatric patients with minor head injury in a non-trauma center

Jennifer L. Schachar · Richard L. Zampolin · Todd S. Miller · Joaquim M. Farinhas · Katherine Freeman · Benjamin H. Taragin

Received: 29 September 2010 / Revised: 9 January 2011 / Accepted: 14 January 2011 / Published online: 5 April 2011

Abstract
Background Head CT scans are considered the imaging modality of choice to screen patients with head trauma for neurocranial injuries; however, widespread CT imaging is not recommended and much research has been conducted to establish objective clinical predictors of intracranial injury (ICI) in order to optimize the use of neuroimaging in children with minor head trauma.
Objective To evaluate whether a strict application of the New Orleans Criteria (NOC), Canadian CT Head Rule (CCHR) and National Emergency X-Radiography Utilization Study II (NEXUS II) in pediatric patients with head trauma presenting to a non-trauma center (level II) could reduce the number of cranial CT scans performed without missing clinically significant ICI.
Materials and methods We conducted an IRB-approved retrospective analysis of pediatric patients with head trauma who received a cranial CT scan between Jan. 1, 2001, and Sept. 1, 2008, and identified which patients would have required a scan based on the criteria of the above listed decision instruments. We then determined the sensitivities, specificities and negative predictive values of these aids.
Results In our cohort of 2,101 patients, 92 (4.4%) had positive head CT findings. The sensitivities for the NOC, CCHR and NEXUS II were 96.7% (95%CI 93.1–100), 65.2% (95%CI 55.5–74.9) and 78.3% (95%CI 69.9–86.7), respectively, and their negative predictive values were 98.7%, 97.6% and 97.2%, respectively. In contrast, the specificities for these aids were 11.2% (95%CI 9.8–12.6), 64.2% (95%CI 62.1–66.3) and 34.2% (95%CI 32.1–36.3), respectively. Therefore, in our population it would have been possible to scan at least 10.9% fewer patients.
Conclusions The number of cranial CT scans conducted in our pediatric cohort with head trauma would have been reduced had any of the three clinical decision aids been applied. Therefore, we recommend that further validation and adoption of pediatric head CT decision aids in non-trauma centers be considered to ultimately increase patient safety while reducing medical expense.

Keywords Pediatrics · Head trauma · Clinical decision aids · CT scan utilization

J. L. Schachar
Department of Radiology,
Albert Einstein College of Medicine,
Bronx, NY, USA

R. L. Zampolin · T. S. Miller · J. M. Farinhas · B. H. Taragin (✉)
Department of Radiology,
Albert Einstein College of Medicine and Montefiore Medical Center,
111 East 210th St.,
Bronx, NY 10467, USA
e-mail: btaragin@montefiore.org

K. Freeman
Department of Biostatistics,
Albert Einstein College of Medicine and Montefiore Medical Center,
Bronx, NY, USA

Prévalence prétest : An CT de 5%
NOC: Sens 96,7% Spec. 11,2 % => LR+1,1, LR- 0,29=> probabilité d'anomalie au CT si test + de: 5,4% et si test - de:1,5%
CCHR: Sens 65,2% Spec. 64,2% => LR+1.82, LR- 0.54 => probabilité d'anomalie au CT si test + de: 8,7% et si test - de:2,8%
NEXUSII: Sens 78,3% Spec. 34,2% => LR+1,2, LR-0,63 => probabilité d'anomalie au CT si test + 5,9% de: et si test - de:3,2%

Introduction

Head trauma is one of the most common injuries in the pediatric age group and is a significant cause of childhood death and disability worldwide. Events causing traumatic brain injury (TBI) are responsible for 435,000 emergency department visits, 37,000 hospital admissions and 2,685 deaths annually among children ages 0 to 14 years [1]. Mild head trauma has been defined as loss of consciousness (LOC) <15 min or post-traumatic amnesia <1 h and a Glasgow coma scale (GCS) score between 13 and 15 [2]. The recognition of mild head trauma is crucial as it is very common [3] and is subsequently responsible for three-quarters of intracranial injuries (ICI) [4]. Furthermore, the greatest reduction in mortality rates in TBI patients results not from treating patients with severe head injuries but rather from preventing those with mild head injuries from deteriorating as a consequence of increased intracranial pressure or seizure [5].

Cranial computed tomographic (CT) scans are considered the imaging modality of choice to screen patients with head trauma for neurocranial injuries [1]. Head CT scans are very sensitive for detecting lesions requiring acute intervention [2]. Patients with a normal head CT scan have a subsequent negligible risk of delayed complications [6] and in a series of 1,788 patients with a negative scan, only 5 (0.28%) went on to develop complications, yielding a 99.7% negative predictive power for a preliminary normal head CT scan [7]. Of note, this study was conducted on patients ages 16 years and older, while our study evaluates the pediatric population, ages 0 to 21. As a consequence of the high sensitivity associated with cranial CT scans, clinicians tend to order head CT scans liberally in an effort to mitigate the risks associated with unrecognized ICI. In fact, the use of head CT scans has doubled in frequency from 1995 to 2003 [8] with nearly half of all pediatric blunt head trauma visits including a head CT scan [9]. When compared with its use for minor head injury in adults, the use of head CT scans in the pediatric population is even more prevalent as a result of those patients limited verbal and cognitive skills [3]. Despite the fact that head CTs have become the diagnostic reference standard for acute head trauma, disadvantages with this form of imaging exist. First, cranial CT scans are a costly hospital resource and a strain on emergency and radiology departments. Additionally, the radiation exposure associated with CT may increase the incidence of malignancies, especially in the more radiosensitive pediatric population. A recent estimate of the risk of developing cancer after one cranial CT scan depends on the age of the child at the time of the scan but ranges from 1:2,000 to 1:5,000 [10]. Moreover, of all the pediatric head CT scans conducted for trauma annually in the United States, less than 10% demonstrate TBI [11]. Therefore, widespread CT imaging is not recommended and much research has been conducted to ascertain objective clinical predictors of ICI in order to optimize the use of neuroimaging in children with head trauma.

Most agree that emergent neuroimaging is required in the setting of head trauma with an associated seizure, focal neurological deficit or prolonged diminished level of consciousness [12]; however, since a GCS score of 15 does not rule out an acute brain injury, the appropriate use of CT scanning in children presenting with more subtle signs of head trauma remains controversial. Whereas many neurosurgeons believe that all patients with head injury should receive a cranial CT scan despite their associated clinical findings [13], other clinicians recommend a more selective use of CT with minor head injury. Accordingly, a number of evidence-based clinical decision instruments have been published to facilitate screening and triage of minor head trauma patients. These aids differ with respect to their definitions of clinical risk factors proposed to be correlated with ICI, as well as the number, set and combination of risk factors. Correspondingly, each decision instrument is associated with its own sensitivity and specificity for discriminating clinically relevant ICI diagnosed via cranial CT. Three of the most commonly cited independently validated decision aids—the New Orleans Criteria (NOC), the Canadian CT Head Rule (CCHR) and the National Emergency X-Radiography Utilization Study II (NEXUS II)—have been introduced to provide decision support regarding the utilization of cranial CT scans in an effort to limit their use in patients with minor head trauma.

Unfortunately, despite the numerous studies conducted on this subject, there is insufficient evidence to definitively determine the correct criteria for the use of head CT scans in patients with minor head trauma. We aim to evaluate whether a strict application of the above mentioned aids in pediatric patients with head trauma presenting to a non-trauma (level II) pediatric emergency department could reduce the number of cranial CT scans in this population without missing any clinically significant ICI.

Materials and methods

A radiology information system database was used to identify a cohort of pediatric patients, ages 0 to 21, seen in a single pediatric emergency department from Jan. 1, 2001, until Sept. 1, 2008, who presented with a history of head trauma and who received a cranial CT scan (Minor Trauma Retrospective Chart Review—MTRCR). The pediatric emergency department was a large urban tertiary level II pediatric trauma center that treats 150–200 patients a day and approximately 60,000 each year, ranging from infants to adolescents. It receives about 82,000 ambulance arrivals, very few of which are referred from other emergency departments. Attendings affiliated with this emergency department were trained in pediatrics and pediatric emergency medicine. During their ED visits, patients were seen by medical students, residents, fellows and attendings.

Patients were excluded from the study if they had an unclear history of trauma or did not receive a diagnostic head CT scan. Therefore, of the 6,057 pediatric patients who presented with a chief complaint of head trauma during the above stated time period, only the 2,101 patients who received a cranial CT scan based on the assessment of the respective attending physician were included in the study. The remaining 3,956 patients were assessed clinically. It was determined that based on the presentation of their minor injuries, no further testing was necessary. Because of this, no additional information regarding these patients, including what type of injuries they sustained, was garnered. Of note, the decision to image patients within this pediatric emergency department is left to the discretion of the attending physician and their interpretation of the specific clinical scenario at hand without the assistance of department-mandated clinical decision aids or previously defined standards of head trauma. Our study specifically focused on the patient population chosen for imaging by the emergency room attending physician's clinical impression to evaluate whether the number of patients imaged would change in our pediatric population had previously validated decision criteria been applied at presentation. Additionally, repeat head CT scans ordered to assess the progression of an ICI and patients returning for follow-up visits after the precipitating trauma were not included as new patients in our analysis.

This retrospective cohort study was approved by the IRB. Medical charts from 2,101 pediatric patients were abstracted to obtain the clinical criteria defined in the NOC, CCHR and NEXUS II. Since none of the children in our population met the age criteria of the aforementioned decision instruments (greater than 60 years old for the NOC and at least 65 years of age for the CCHR as well as the NEXUS II criteria), we modified the three decision aids appropriately and did not include any age criteria in our analysis. Based on the clinical information, we identified which patients from our cohort would have been classified as either high risk for significant ICI, thereby requiring cranial CT scanning according to the above mentioned decision aids, and those who would have been deemed low risk and would not have required a scan. With regard to the CCHR, we grouped the high- and medium-risk patients together. A guideline was considered positive if a patient fulfilled at least one criterion for a CT scan.

All notes from the emergency department, including the triage nurse's note, the resident's note and the attending physician's note, were reviewed to ascertain the presence of any of the above noted criteria. These notes included structured questions with defined choices, as well as comment areas in which the physician's assessment and plan could be described. The structured portion of the notes helped to ensure the documentation of certain aspects of the history and physical exam, while the comment areas allowed written description of the physician's assessment and plan. Details of the history and physical were documented before any imaging results were known and were therefore used to determine the need for a head CT. Later, the attending physician's final assessment and plan considered all the known information, which typically included the results from the head CT scan. Only notes documented before knowledge of the head CT results were used to determine the presence of a criterion. If a criterion was not noted in the patient's chart, it was assumed to be absent.

We used the most inclusive criteria from all three studies, the NEXUS II criteria, to determine what we would consider a positive cranial CT scan (mass effect, sulcal effacement, herniation, basal cistern compression, midline shift, epidural or subdural hematomas ≥1 cm wide or causing mass effect, cerebral contusion ≥1 cm or more than one site, extensive subarachnoid hemorrhage, hemorrhage in the posterior fossa, intraventricular hemorrhage, bilateral hemorrhage, depressed or diastatic skull fracture, pneumocephalus, diffuse cerebral edema or diffuse axonal injury) (Table 1). Additionally, fellowship-trained neuroradiologists reviewed all head CT scans.

We then calculated the sensitivity, specificity, 95% confidence intervals and negative predictive values (NPV) for each decision aid for predicting clinically relevant ICI diagnosed via cranial CT. We defined clinically relevant ICI as injury requiring neurosurgical intervention, intubation or likely associated with significant neurological impairment. We then compared the criteria in our population and determined the relative number of potentially avoidable cranial CT scans had these decision aids been strictly applied.

Results

Data was collected for 2,101 pediatric patients who received a cranial CT scan for head trauma. Sixty-four percent of the patients were male and the median age of the cohort was 8.4 years, with 24.6% younger than 2 years of age. Positive head CT findings were demonstrated in 92 patients (4.4%), 41 of whom were below age 2 and 3 of whom had a GCS score <13. Of the injuries, 51.3% of them were due to falls, 18.9% to assault, 9.9% to sports, 8.3% to objects that struck the head, 3.6% to motor vehicle accidents, 2.6% to unknown mechanisms of injury, 2.4%

Table 1 Positive head CT findings

NOC	CCHR	NEXUS II
Subdural hematoma	Subdural hematoma (>4 mm thick)	Subdural hematoma (>1 cm wide or causing mass effect)
Epidural hematoma	Epidural hematoma	Epidural hematoma (>1 cm wide or causing mass effect)
Parenchymal hematoma	Intracerebral hematoma	Posterior fossa hemorrhage
		Bilateral hemorrhage
Subarachnoid hemorrhage	Diffuse subarachnoid hemorrhage	Extensive subarachnoid hemorrhage
Cerebral contusion	Cerebral contusion >5 mm in diameter	Cerebral contusion (1 cm in diameter or >1 site)
Depressed skull fracture	Depressed skull fracture	Depressed or diastatic skull fracture
	Pneumocephalus	Pneumocephalus
	Intraventricular hemorrhage	Intraventricular hemorrhage
	Diffuse cerebral edema	Diffuse cerebral edema
		Diffuse axonal injury
		Mass effect or sulcal effacement
		Signs of herniation
		Basal cistern compression or midline shift

New Orleans Criteria (*NOC*), Canadian CT Head Rule (*CCHR*), National Emergency X-Radiography Utilization Study II (*NEXUS II*)

to heavy object that fell on the head, 1.5% to suspected child abuse and 1.4% to other mechanisms of injury. Additionally, 10.9% of patients suffered dangerous mechanisms of injury as defined by the CCHR, of which 83.3% were due to falls from heights greater than three feet or five stairs, 15.4% were pedestrians struck by motor vehicles and 1.3% were occupants ejected from motor vehicles. Regarding GCS, 99.3% of patients had a score of 15, 0.4% had a score of 14 or 13 and 0.3% had a score below 13. Neurosurgical intervention was performed in 18 patients (0.86%) (Table 2).

The percentage of scans that would have been recommended based on the three decision aids was 89.1% as per the NOC, 37.1% as per the CCHR (high and medium risk) and 66.3% as per the NEXUS II. The sensitivities for predicting a positive head CT were 96.7% (95%CI 93.1–100) for the NOC, 65.2% (95%CI 55.5–74.9) for the CCHR and 78.3% (95%CI 69.9–86.7) for the NEXUS II. Additionally, the NPV for the above mentioned clinical decision aids were 98.7% for the NOC, 97.6% for the CCHR and 97.2% for the NEXUS II. In contrast, the specificities for these decision aids were 11.2% (95%CI 9.8–12.6) for the NOC, 64.2% (95%CI 62.1–66.3) for the CCHR and 34.2% (95%CI 32.1–36.3) for the NEXUS II (Tables 3, 4 and 5) (Fig. 1).

Two of the 92 patients who had ICI findings on CT met no diagnostic criteria and would not have been identified by any clinical decision instrument. Additionally, 6.2% of the pediatric cohort received a cranial CT scan despite meeting no diagnostic criteria. Therefore, by applying the most conservative decision aid, the NOC (the most sensitive and least specific), in our population it would have been possible to scan at least 10.9% fewer patients during the period of our study without missing any clinically significant ICI (Table 3). Further, if each of the decision aids were applied together as an additional, more stringent set of criteria, a 6.2% reduction in head CT scans could have been achieved during the course of our study (Table 6).

Table 2 Patient demographics

Characteristics	Number of patients (%)
Mean age in years	8.4
Gender:	
Male	1,344 (64%)
Female	757 (36%)
Mechanism of injury:	
Fall	1,078 (51.3%)
Assault	397 (18.9%)
Sports	209 (9.9%)
Struck head on object	174 (8.3%)
Motor vehicle accident	76 (3.6%)
Unknown	55 (2.6%)
Heavy object fall on head	51 (2.4%)
Suspected child abuse	32 (1.5%)
Other	29 (1.4%)
Dangerous mechanism of injury:	228 (10.9%)
Fall from height >3 ft or 5 stairs	190 (83.3%)
Pedestrian struck by motor vehicle	35 (15.4%)
Occupant ejected from motor vehicle	3 (1.3%)
Glasgow Coma Scale:	
15	2086 (99.3%)
13–14	8 (0.4%)
<13	7 (0.3%)

Table 3 New Orleans Criteria

Prévalence prétest : An CT de 5%
NOC:
Sens 96,7%
Spec. 11,2 %
LR+1,1
LR- 0,29
Probabilité d'anomalie au CT
si test + de: 5,4%
si test - de:1,5%

Criteria	NOC%	MTRCR% (N)
Headache	23.7%	42.9% (901)
Vomiting	9.0%	24.8% (522)
Seizure	4.6%	2.5% (53)
Intoxication	34.6%	2.2% (46)
Short-term memory deficit (anterograde amnesia)	1.7%	1.6% (33)
Physical evidence of trauma above clavicles	65%	66.6% (1,400)
Negative for all criteria		10.9% (228)
Meet ≥1 criteria		89.1% (1,873)
Sensitivity		96.7%
Specificity		11.2%
Suggested # head CT		1,873
% Reduction head CT		10.9%

New Orleans Criteria (*NOC*), Minor Trauma Retrospective Chart Review (*MTRCR*)

et risque résiduel de:1,5%

Discussion

In an effort to optimize the use of neuroimaging in children with minor head trauma, a number of evidence-based clinical decision aids have been published. Three of the most frequently referenced, independently validated clinical decision instruments are the New Orleans Criteria (NOC), the Canadian CT Head Rule (CCHR) and the National Emergency X-Radiography Utilization Study II (NEXUS II).

In 2000, Haydel et al. [14] developed and validated the NOC in an effort to distinguish patients with minor head trauma who should undergo a cranial CT scan. The study was conducted in two phases at a large, inner-city, level 1 trauma center over a span of two and a half years. The first phase documented the clinical findings of 520 consecutive patients over the age of 2 who presented with minor head trauma, a normal neurological exam, a normal GCS score and a subsequent head CT scan. The presence of one or more of seven clinical findings (headache, vomiting, drug or alcohol intoxication, anterograde amnesia, post-traumatic seizure, physical evidence of trauma above the clavicles, and age over 60 years) was exhibited in all patients with abnormal head CT scans. A CT scan was considered abnormal if it demonstrated a subdural, epidural or parenchymal hematoma, subarachnoid hemorrhage, a cerebral contusion or a depressed skull fracture. During the second phase, 909 patients were prospectively assessed and 100% sensitivity and 25% specificity for predicting a positive CT scan were ascertained. Furthermore, utilization of the criteria in these patients would have resulted in a 22% reduction in the number of head CT scans conducted [14]. In 2005, the NOC was externally validated in an adult population in a large multicenter study in the Netherlands [15].

Stiell et al. [2] developed a different set of risk factors for ICI, the CCHR, in 2001 with the aim of establishing a highly

Table 4 Canadian CT Head Rule

CCHR
Prévalence prétest : An CT de 5%
Sens 65,2%
Spec. 64,2%
LR+1.82
LR- 0.54
Probabilité d'anomalie au CT
si test + de: 8,7%
si test - de:2,8%

Criteria	CCHR%	MTRCR% (N)
Glasgow Coma Scale <15 (2 h postinjury)	20.2%	0.7% (15)
Open or depressed skull fracture	0.6%	3.0% (62)
Any sign of basal skull fracture	1.8%	1.8% (37)
Vomiting (≥2 episodes)	9.6%	19.7% (413)
Retrograde amnesia (>30 min)	24.6%	8.4% (177)
Dangerous mechanism of injury:	25.4%	10.9% (228)
Pedestrian struck by motor vehicle		
Occupant ejected from motor vehicle		
Fall from height >3 ft or 5 stairs		
Negative for all criteria		62.9% (1,321)
Meet ≥1 criteria		37.1% (780)
Sensitivity		65.2%
Specificity		64.2%
Suggested # head CT		780
% Reduction head CT		62.9%

Canadian CT Head Rule (*CCHR*), Minor Trauma Retrospective Chart Review (*MTRCR*)

Risque résiduel de 2,8%

Table 5 National Emergency X-Radiography Utilization Study II

NEXUSII
Prévalence prétest : An CT de 5%
Sens 78,3%
Spec. 34,2%
LR+1,2
LR-0,63
Probabilité d'anomalie au CT
si test + de 5,9%
si test - de:3,2%

Criteria	NEXUS%	MTRCR% (N)
Skull fracture (basilar or depressed)	3.4%	3.3% (69)
Altered alertness (GCS ≤14, somnolent, disoriented)	30.2%	22.9% (481)
Neurological deficit (CN, cerebellar, gait or motor deficit)	36.1%	26.5% (557)
Persistent vomiting (recurrent, projectile or forceful)	12.1%	19.7% (413)
Significant scalp hematoma	35.3%	26.1% (549)
Abnormal behavior (agitated, uncooperative, violent)	25.1%	0.6% (13)
Coagulopathy (hemophilia, hepatic insufficiency, meds)	1.5%	0.6% (12)
Negative for all criteria		33.7% (707)
Meet ≥1 criteria		66.3% (1,394)
Sensitivity		78.3%
Specificity		34.2%
Suggested # head CT		1394
% reduction head CT		33.7%

National Emergency X-Radiography Utilization Study II (*NEXUS II*), Minor Trauma Retrospective Chart Review (*MTRCR*)

risque résiduel de:3,2%

sensitive clinical decision rule for the use of CT in patients with minor head injury. A prospective cohort study of 3,121 consecutive adult patients with a GCS score between 13 and 15 after minor head trauma seen in 10 Canadian emergency departments yielded five high-risk factors for requiring neurosurgical intervention (GCS <15 2 h after injury, suspected open or depressed skull fracture, any sign of basal skull fracture, ≥2 vomiting episodes, age ≥65 years) and two additional medium-risk factors for brain injury demonstrated on CT (retrograde amnesia >30 min and dangerous mechanism of injury). Cranial CT scans were considered mandatory for high-risk patients and recommended for medium-risk patients. A CT scan was deemed positive if it demonstrated a contusion ≥5 mm in diameter, subarachnoid blood ≥1 mm thick, subdural hematoma ≥4 mm thick, pneumocephaly or a closed depressed skull fracture. The CCHR was found to have 98.4% sensitivity and 49.6% specificity and would have resulted in a 45.7% reduction in the number of CT scans ordered [2]. Smits et al. [15] externally validated the CCHR in an adult population of a large multicenter study in the Netherlands.

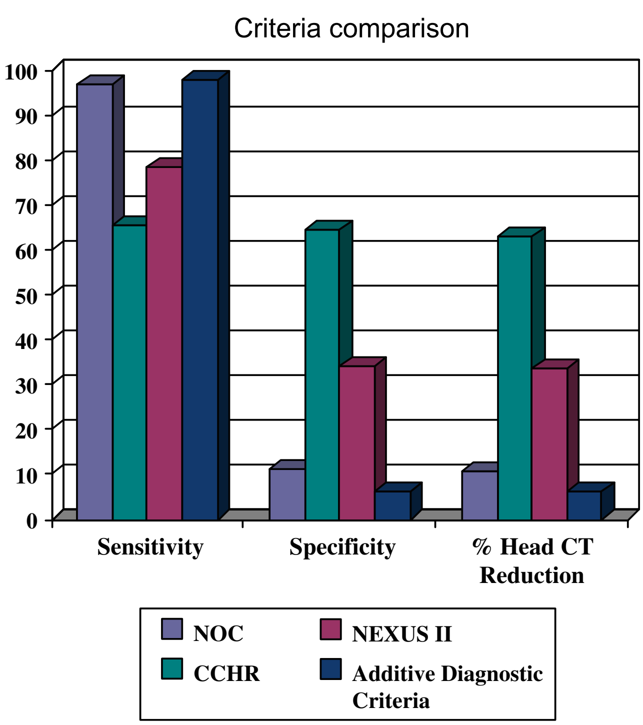

Fig. 1 In our pediatric cohort with minor head trauma, the most sensitive clinical decision aid for predicting a positive head CT was the NOC. In contrast, we found the CCHR to be the most specific and consequently responsible for the greatest percent reduction in head CT scans. Additionally, if each of the decision aids were applied together as a diagnostic criterion, there would have still been a 6.2% reduction in head CT scans

The NEXUS II was developed by Mower et al. [16] in 2005 and used recursive partitioning to ascertain criteria to predict ICI on CT with high sensitivity. This multicenter, prospective, observational study of 13,728 acute blunt head trauma adult and pediatric patients identified eight clinical criteria (skull fracture, scalp hematoma, neurological deficit, altered level of alertness, abnormal behavior, coagulopathy, persistent vomiting and age ≥65 years) to distinguish patients at high risk for ICI from those at low

Table 6 Additive diagnostic criteria

NOC + CCHR + NEXUS II	% (N)
Negative for all criteria	6.2% (131)
False-negatives	0.1% (2)
Meet ≥1 criteria	93.8% (1,970)
Sensitivity	97.8%
Specificity	6.4%
Suggested # head CT	1,970
% reduction head CT	6.2%

New Orleans Criteria (*NOC*), Canadian CT Head Rule (*CCHR*), National Emergency X-Radiography Utilization Study II (*NEXUS II*) risk. A CT scan was considered positive if it demonstrated mass effect, sulcal effacement, herniation, basal cistern compression, midline shift, epidural or subdural hematomas ≥1 cm wide or causing mass effect, cerebral contusion ≥1 cm or more than one site, extensive subarachnoid hemorrhage, hemorrhage in the posterior fossa, intraventricular hemorrhage, bilateral hemorrhage, depressed or diastatic skull fracture, pneumocephalus, diffuse cerebral edema or diffuse axonal injury. This clinical decision instrument demonstrated 98.3% sensitivity and 13.7% specificity but did not detect 1.7% of clinically important ICI [16]. The NEXUS II criteria exhibited a similar high sensitivity of 98.6% for detecting ICI in the pediatric population as it did in the criteria's derivation subject set of both adult and pediatric patients [17].

The number of cranial CT scans conducted in our pediatric cohort with minor head trauma would have been reduced had any of these three clinical decision aids been strictly applied without missing clinically significant ICI. The greatest potential reduction in cranial CT scans was seen when the CCHR criteria was used. Similarly, the CCHR was found to demonstrate the greatest specificity. The NOC decision rule had the highest sensitivity and the greatest NPV. This heightened sensitivity is likely due to the NOC's more inclusive risk factor of physical evidence of trauma above the clavicles, which includes all external injuries above the clavicles, as opposed to the more specific skull fractures or scalp hematomas as seen in the CCHR and NEXUS II criteria. As expected, all guidelines exhibited a trade-off between sensitivity and specificity. The adoption of even the most liberal clinical decision aid, the NOC, with the highest sensitivity and NPV and lowest specificity, would have significantly reduced the number of cranial CT scans conducted in our population without missing clinically significant ICI.

Of the two patients who had ICI findings on imaging but would not have been identified by any clinical decision instrument, both were discharged from the hospital and neither required neurosurgical intervention. Additionally, 6.2% of the pediatric cohort received a cranial CT scan despite meeting no diagnostic criteria. These patients were likely scanned either as a result of their history of trauma, due to the suspicion of child abuse (12.2% of this group were suspected of suffering from child abuse compared to 1.5% of the entire cohort), or as a consequence of their young age (the mean age for this group was 5.1 years younger than the mean for the cohort as a whole). In addition, while a very small percentage (0.3%) of our patients had a GCS score of less than 13, these patients were included in our head trauma cohort since they were adequately treated in a non-trauma (level II) center. All seven of these patients would have been identified by all three clinical decision aids. Additionally, three of these patients were found to have positive head CT results. Therefore, 3.3% of the 92 patients who had ICI findings on cranial CT scan had GCS scores of less than 13. Moreover, the exclusion of these seven patients would not have significantly altered our statistical findings. Finally, 115 of our patients received repeat head CT scans. While most of these patients were scanned again to monitor the progression of known ICI findings, three of the patients who initially had a negative cranial CT scan were later found to have a positive result. Two of these patients with delayed presentations would have been identified by the NOC as well as the NEXUS II and all three of our clinical decision instruments would have identified the third patient with a positive follow-up head CT scan. Moreover, none of these three patients with delayed presentations required neurosurgical interventions.

Over the course of our study, two new pediatric-based clinical decision aids were published. In October 2009, Kuppermann et al. [18] derived and validated age-specific prediction rules for clinically important ICI in a prospective cohort study that analyzed 42,412 patients younger than 18 years of age in 25 North American emergency departments who presented within 24 h of minor blunt head trauma with GCS scores between 14 and 15. In patients younger than 2 years, a prediction rule that assessed mental status, whether the patient was acting normally according to the parents, LOC, the presence of a scalp hematoma or palpable skull fracture and the mechanism of injury was found to have a sensitivity and NPV of 100%. A slightly lower, but still significant sensitivity and NPV of 96.8% and 99.95%, respectively, was found for the prediction rule indicated for patients between the ages of 2 and 18, which included an assessment for the presence of changes in mental status, LOC, headache, vomiting or basilar skull fracture as well as the mechanism of injury. This highly sensitive, large-scale study supports our findings as the above listed predictors of clinically significant ICI were included in our analysis. It is interesting to consider how well the criterion validated in the study of Kuppermann et al. [18] is represented by the set of decision aids we applied to our population.

Similar, overlap is apparent between our study's risk factors for ICI and those utilized by the CATCH clinical decision rule [19], which was published in February 2010 by Osmond et al. This multicenter prospective cohort study of 3,866 patients 16 years of age and younger with blunt head trauma who presented with a GCS score of 13–15 and LOC, amnesia, disorientation, persistent vomiting or irritability generated a decision rule composed of four high-risk factors (GCS score <15, open skull fracture, worsening headache and irritability) that predict the need for neurological intervention with 100% sensitivity, as well as three medium-risk factors (scalp hematoma, basal skull fracture and a dangerous mechanism of injury) associated with

98.1% sensitivity for predicting brain injury on cranial CT scan. Again, the parallels seen among the clinical variables analyzed in this sensitive, prospectively derived clinical decision instrument and those used in our study serves to strengthen the notion that clinical discussion aids can be successfully used to risk stratify pediatric patients presenting with head trauma. Several limitations to our study exist. First, this study was performed at an inner-city institution with 30% of patients at or below the poverty level and more than 50% people of color, which may call into question the generalizability of the study. Additionally, patients were only enrolled in this study if a head CT was performed, and the decision to scan a patient was made at the discretion of the treating physician and not dictated by a study protocol. Based on this retrospective design information, the population of patients with an indication of head trauma who were not imaged at the discretion of the attending clinician was not evaluated. Such analysis might better be achieved via a prospective follow-up study. Additionally, follow-up to assess for delayed presentations of head injury was also limited to those who received repeat cranial CT scans at our study site. Finally, while most recommendations regarding pediatric head trauma have made specific suggestions for patients younger than 2 years, we did not make such a distinction in our study. It is generally accepted that physicians should have a lower threshold when deciding to scan this pediatric subgroup since preverbal children are more difficult to assess and children younger than 2 years are more vulnerable to skull fracture and ICI after minor mechanisms of injury, asymptomatic ICI and abuse [20]. In fact, Greenes and Schutzman have demonstrated that the younger the child, the greater the risk of brain injury and that the most important clinical indicator of brain injury in infants is the presence of a scalp hematoma, which has been associated with underlying skull fractures [21]. While added attention is warranted in the more vulnerable pediatric population of those younger than 2 years, this is also the most radiosensitive subgroup of patients. It is interesting to note that despite 25% of subjects in our study being younger than 2 years, no significant ICI were missed in this cohort by the additive diagnostic criteria. Similarly, the prospective studies of Kuppermann et al. [18] and Osmond et al. [19] demonstrate the validity of decision criteria for risk stratifying patients younger than 2 years of age.

Conclusion

Accurate and reliable guidelines for head CT use in pediatric patients with minor head trauma would standardize and improve patient care while decreasing imaging cost and radiation dose. Consequently, our results suggest that all non-trauma centers investigate, via retrospective review, which clinical decision instrument is most applicable to their patient population to maintain a high level of care while attempting to reduce CT utilization. Additionally, further validation and widespread adoption of multicentered, prospectively derived clinical decision criteria for the utilization of head CT scanning in the pediatric population with minor head trauma should ultimately increase patient safety while reducing medical expense without missing clinically significant intracranial injury.

References

1. Langlois JA, Rutland-Brown W, Thomas KE (2004) Traumatic brain injury in the United States: emergency department visits, hospitalizations, and deaths. Atlanta (GA): Centers for Disease Control and Prevention National Center for Injury Prevention and Control Web Site. Available via http://www.cdc.gov/ncipc/ pub-res/TBI_in_US_04/TBI_ED.htm. Accessed 04 Feb 2011
2. Stiell IG, Wells GA, Vandemheen K et al (2001) The Canadian CT Head Rule for patients with minor head injury. Lancet 357:1391–1396
3. Centers for Disease Control and Prevention National Center for Injury Prevention and Control (2003) Report to Congress on mild traumatic brain injury in the United States: steps to prevent a serious public health problem. Atlanta (GA): Centers for Disease Control and Prevention. Available via www.cdc.gov/ncipc/pub-res/mtbi/mtbireport.pdf. Accessed 04 Feb 2011
4. Quayle KS, Jaffe DM, Kuppermann N et al (1997) Diagnostic testing for acute head injury in children: when are head computed tomography and skull radiographs indicated? Pediatrics 99:e11
5. Klauber MR, Marshall LF, Luerssen TG et al (1989) Determinants of head injury mortality: importance of the low risk patient. Neurosurgery 24:31–36
6. Schunk JE, Rodgerson JD, Woodward GA (1996) The utility of head computed tomographic scanning in pediatric patients with normal neurologic examination in the emergency department. Pediatr Emerg Care 12:160–165
7. Livingston DH, Lavery RF, Passannante MR et al (2000) Emergency department discharge of patients with a negative cranial computed tomography scan after minimal head injury. Ann Surg 232:126–132
8. Blackwell CD, Gorelick M, Holmes JF et al (2007) Pediatric head trauma: changes in use of computed tomography in emergency departments in the United States over time. Ann Emerg Med 49:320–324
9. National Center for Health Statistics Centers for Disease Control and Prevention (2002) Emergency Department File. National Hospital Ambulatory Medical Care Survey. Available at: http://www.cdc.gov/nchs/products/elec_prods/subject/nhamcs.htm. Accessed 04 Feb 2011
10. Brenner DJ, Hall EJ (2007) Computed tomography—an increasing source of radiation exposure. N Engl J Med 357:2277–2284
11. Jagoda AS, Cantrill SV, Wears RL et al (2002) Clinical Policy: neuroimaging and decision making in adult mild traumatic brain injury in the acute setting. Ann Emerg Med 40:231–249
12. Marik PE, Varon J, Trask T (2002) Management of head trauma. Chest 122:699–711

13. Shackford SR, Wald SL, Ross SE et al (1993) The clinical utility of computed tomographic scanning and neurologic examination in the management of patients with minor head injuries. J Trauma 35:490–491
14. Haydel MJ, Preston CA, Mills TJ et al (2000) Indications for computed tomography in patients with minor head injury. N Engl J Med 343:100–105
15. Smits M, Dippel DWJ, de Haan GG et al (2005) External validation of the Canadian CT Head Rule and the New Orleans Criteria for CT scanning in patients with minor head injury. JAMA 294:1519–1525
16. Mower WR, Hoffman JR, Herbert M et al (2005) Developing a decision instrument to guide computed tomographic imaging of blunt head injury patients. J Trauma 59:954–959
17. Oman JA, Cooper RJ, Holmes JF et al (2006) Performance of a decision rule to predict need for computed tomography among children with blunt head trauma. Pediatrics 117:e238–e246
18. Kuppermann N, Holmes JF, Dayan PS et al (2009) Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective study. Lancet 374:1160–1170
19. Osmond MH, Klassen TP, Wells GA et al (2010) CATCH: a clinical decision rule for the use of computed tomography in children with minor head injury. CMAJ 182:341–348
20. Schutzman SA, Greenes DS (2001) Pediatric minor head trauma. Ann Emerg Med 37:65–74
21. Greenes DS, Schutzman SA (1999) Clinical indicators of intracranial injury in head-injured infants. Pediatrics 104:861–867