A Clinical Decision Rule for Cranial Computed Tomography in Minor Pediatric Head Trauma

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Objectives: To develop a sensitive clinical decision rule with a high negative predictive value for the use of cranial computed tomography (CT) in minor pediatric head trauma, to identify clinical features predictive of neurosurgical intervention, and to assess clinicians' predictive abilities to determine the presence or absence of intracranial injury based on history and physical examination alone.

Design: Prospective observational study.

Setting: Four level I pediatric trauma centers.

Participants: One thousand patients younger than 21 years with minor head trauma undergoing cranial CT.

Main Outcome Measure: Intracranial injury as demonstrated by CT and neurosurgical intervention.

Results: Of 1000 patients in the study, the mean age was 8.9 years, and 64.1% were male; 6.5% (65 of 1000) had positive findings on CT, and 9.2% (6 of 65) of these required neurosurgical intervention. Recursive partitioning identified the following variables in the decision rule: dizziness, skull defect, sensory deficit, mental status change, bicycle-related injury, age younger than 2 years, Glasgow Coma Scale score less than 15, and evidence of a basilar skull fracture. For detection of intracranial injury, the decision rule had a sensitivity of 95.4% (95% confidence interval [CI], 86.2%-98.8%), a specificity of 48.9% (95% CI, 46.6%-52.1%), and a negative predictive value of 99.3% (95% CI, 98.1%-99.8%).

Conclusions: We developed a sensitive clinical decision rule with a high NPV for detection of intracranial injury in minor pediatric head trauma. If validated, this rule could provide a useful adjunct to the physician's clinical assessment by reducing variations in practice and unnecessary cranial CT.

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HEAD TRAUMA IS THE MOST common cause of trauma-related morbidity in children, accounting for more than 1 million emergency department visits per year in the United States.[1,2] Computed tomography (CT) has added substantially to the management of head trauma in adults and children by allowing earlier detection of intracranial injuries (ICIs). Cranial CT is obtained liberally in pediatric and adult patients with head trauma because evidence suggests that patients can be safely discharged home after negative findings on CT provided that the patients are neurologically normal.[3-5] Minor head trauma has been defined as a history of a loss of consciousness (LOC) or posttraumatic amnesia and a Glasgow Coma Scale score greater than 12.[3,6] Approximately 83% to 97% of CT findings are negative in the setting of minor head trauma.[7] Recommendations in adults with minor head trauma range from obtaining cranial CT in every patient with LOC and amnesia for the event, to imaging only those patients with LOC longer than 5 minutes or with focal neurologic deficits.[3,8-12] Clinical criteria for neuroimaging after minor head trauma in children remain unclear, and there is no consensus regarding patient selection for CT.[13-17] While some authors emphasized LOC, amnesia, skull fracture, scalp lacerations, or changes in behavior as reliable indicators of ICI, others found no consistent clinical predictors of positive CT findings in children who do not otherwise have grossly obvious signs of intracranial pathologic conditions.[18-24] Clinical decision aids for neuroimaging derived in recent prospective studies[25-29] will need to be further validated before they can be widely implemented by clinicians.

The frequency of pediatric CT almost doubled between 1996 and 1999, with approximately 2.7 million cases of pediatric CT performed annually in the United States.[30-32] Early exposure to radiation poses a significant associated risk. Estimated lifetime cancer mortality risk from CT may be an order of magnitude higher in a 1-year-old child than in an adult.[31-33] With radiation-attributable cancer risk as high as 1 case in 1400 among infants exposed to cranial CT,[31,33] the National Cancer Institute and the Food and Drug Administration have made recommendations to decrease radiation exposure and the risk of subsequent cancers by eliminating unnecessary CT.[32,34] Cost-benefit analyses of the liberal use of CT in closed head trauma have shown additional costs and risks for the many patients in the pediatric population who require sedation for the procedure.[35] Increased length of stay in the emergency department and potential parental dissatisfaction must also be considered.

Variation in practice with respect to CT of the child with minor head trauma persists.[36] Clinical decision rules seek to reduce variability in medical management by providing evidence-derived guidelines for clinical care, improving the overall efficacy of health care.[37,38] The Canadian CT Head Rule was developed to address variation in clinical management and neuroimaging in adult blunt head trauma, the effects of which are under investigation.[6,39,40] Similar studies[41,42] have resulted in improved testing strategies for ankle injuries, bacteremia, and simple febrile seizures. The primary objective of our study was to develop a clinical decision rule for the use of cranial CT in minor pediatric head trauma that is highly sensitive and has a high negative predictive value (NPV) for the prediction of acute ICI. Secondary objectives were (1) to identify clinical features predictive of neurosurgical intervention and (2) to assess clinicians' predictive abilities to determine the presence or absence of ICI based on history and physical examination alone.

METHODS

We enrolled a prospective convenience sample of patients from birth to 21 years of age with closed head trauma undergoing cranial CT. Patients were enrolled from 1 of 4 participating level I pediatric trauma centers between March 1, 1997, and March 30, 2000. Patients were excluded from enrollment if they had a prior CT scan at a referring hospital and if they had a Glasgow Coma Scale score (GCS) less than 13 determined by the treating physician at the participating trauma center. The institutional review boards of all sites approved the project. Because this was an observational study, a waiver of informed consent was allowed.

A standardized data collection survey was completed by a pediatric emergency medicine–trained attending or fellow physician (including S.M.A., J.J.B, K.E.S., M.A.C., and J.M.C. and others) before cranial CT. A pilot study using this instrument was performed from January 4, 1997, to February 25, 1997. Clinical variables for the final survey were obtained by literature review and by group consensus among a panel of pediatric emergency medicine–trained physicians (including S.M.A., K.E.S., M.A.C., and J.M.C. and others). A witness cosignature on survey completion was required before access to CT results, ensuring that predictor variables from clinical and historical findings of the examining physician were recorded without knowledge of the outcome of CT. Variables assessed included amnesia, dizziness, headache, intoxication, lethargy, seizure, vomiting, behavior change, scalp hematoma, scalp lacerations, palpable skull defect, mechanism of injury, sensory or motor deficit, signs of basilar skull fracture, and the presence and duration of LOC. Loss of consciousness was determined by witnessed report, and behavior change was defined as any change in behavior by report of the patient's parent or caregiver. Amnesia, dizziness, and headache were determined by patient report. Other signs and symptoms were determined by the treating physician.

Included in the data collection was the physician's estimate of the probability of ICI. We obtained data on the patient's procedures, final disposition, length of hospital stay, and other diagnostic test results by medical record review. A pediatric neuroradiologist interpreted cranial CT images. Intracranial injury was defined as subdural, epidural, subarachnoid, intraparenchymal, and intraventricular hemorrhages, as well as contusions and cerebral edema. The secondary outcome was defined as the performance of any neurosurgical procedure, including craniotomy, craniectomy, evacuation, or intracranial pressure monitoring.

Commercially available software (SPSS version 20; SPSS Inc, Chicago, Illinois) was used for statistical analysis. Univariate analyses were used to determine the strength of association between each variable and the primary outcome to select the best variables for the multivariate analyses. The univariate techniques were chosen according to the type of data (χ^2 test with continuity correction for nominal data, Mann-Whitney test for ordinal variables, and unpaired 2-tailed *t* test for continuous variables, using pooled or separate variance estimates as appropriate).

Those variables found to be strongly associated ($P < .05$) with the outcome measure were combined using recursive partitioning analyses. Recursive partitioning is a multivariate statistical approach that creates a branching decision tree by dividing the patient population into subgroups with and without the outcome of interest based on the contents of predictor variables in the subgroups. Recursive partitioning was performed using commercially available software (KnowledgeSEEKER version 3.1; Angoss Software International, Toronto, Ontario, Canada).[38]

The derived decision rule was cross-validated by comparing the classification of each patient with his or her actual status for the primary outcomes, allowing an estimate of the sensitivity and specificity of the rule with 95% confidence intervals (CIs). Clinicians' predictions of ICI were scored on a 5-point Likert-type scale (very likely, likely, unable to determine, unlikely, and very unlikely).

Sample size calculations were based on prior data estimating a 12% incidence of positive CT findings among patients with head trauma having a GCS of 13 to 15.[7] We determined that we would need approximately 1040 patients to create a decision rule with a lower 95% CI for sensitivity.

RESULTS

Demographic data and clinical findings of the study group are given in **Tables 1**, **2**, and **3**. There were 1151 patients enrolled initially. One hundred fifty-one patients had a GCS less than 13 and were excluded from further analysis. Of the remaining 1000 patients, the mean age was 8.9 years, 64.1% were male, and 18.8% of patients were younger than 2 years. Slightly more than half (54.6%) arrived via the emergency medical services system.

Sixty-five patients (6.5%) had positive findings on CT indicating ICI (Table 2), and 9.2% (6 of 65) of these required subsequent neurosurgical intervention (0.6% overall in the study group). Intracranial hemorrhages were the most frequent types of ICI, with a finding of subdural hematoma in 26 of 65 patients with ICI (40.0%). As expected, multiple intracranial injuries were also common, occurring in 14 of 65 patients (21.5%). One pa-

Table 1. Characteristics of the Entire Study Group vs the Patients With Intracranial Injury

Characteristic	No. (%) of Study Group (N=1000)	No. (%) of Patients With Intracranial Injury (n=65)
Age, y		
<2	188 (18.8)	27 (41.5)
≥2	812 (81.2)	38 (58.5)
Male sex	641 (64.1)	40 (61.5)
Method of arrival		
Ambulance	445 (44.5)	32 (49.2)
Helicopter	101 (10.1)	8 (12.3)
Other	454 (45.4)	25 (38.5)

Table 2. Cranial Computed Tomographic Findings in the Patients With Intracranial Injury[a]

Finding	No. (%) of Patients With Intracranial Injury (n=65)
Subdural hematoma	26 (40.0)
Contusion	18 (27.7)
Subarachnoid hematoma	15 (23.1)
Epidural hematoma	11 (16.9)
Cerebral edema	2 (3.1)
Other intracranial injury	8 (12.3)

[a] Some patients had more than 1 intracranial injury.

tient had an equivocal CT finding that suggested artifact or contusion. To determine a conservative decision rule, we elected to include this patient in the group with ICI. Of 65 patients who had positive CT findings, 6 patients required neurosurgical intervention (during the admission): 5 patients underwent craniectomy with evacuation, and 1 patient received placement of an intracranial pressure monitor.

Table 3 gives the association of each predictor variable with the outcome of ICI using odds ratios (ORs) and 95% CIs. Among 10 categories denoting injury mechanism, falls were the primary cause of minor head trauma in our population, accounting for 44.4% of total cases, with an OR for ICI of 2.10 (95% CI, 1.26-3.52). Motor vehicle crashes were the second most common cause of injury (20.4%) but were unassociated with ICI (OR, 0.45; 95% CI, 0.20-1.01). Seizure, skull defect, sensory deficit, scalp laceration, and mental status change demonstrated higher risk for ICI than other symptoms of concern such as LOC, headache, and vomiting. Children younger than 2 years were more likely to have a positive CT finding (OR, 3.42; 95% CI, 2.03-5.75).

Recursive partitioning resulted in the following rule for optimal prediction of ICI (**Figure**): dizziness, sensory deficit, GCS less than 15, mental status change, bicycle-related injury, age younger than 2 years, skull defect on examination, and evidence of a basilar skull fracture (Battle sign, rhinorrhea, hemotympanum, periorbital ecchymosis, or cerebrospinal fluid otorrhea). In this decision rule, pediatric patients who meet GCS definitions for minor head trauma and have at least 1 of the historical or clinical criteria listed are at higher risk for ICI. Children without any of these risk factors are unlikely to have ICI.

Table 3. Univariate Association of Predictor Variables

Variable	Patients Without Intracranial Injury (n=935)	Patients With Intracranial Injury (n=65)	Odds Ratio (95% Confidence Interval)
From the History			
Mechanism of injury			
Motor vehicle crash	**197**	**7**	0.45 (0.20-1.01)
Restrained	55	2	0.51 (0.12-2.13)
Unrestrained	60	2	0.46 (0.11-1.94)
Pedestrian struck	82	3	0.50 (0.15-1.64)
Fall	404	40	2.10 (1.26-3.52)
Intentional injury	24	1	0.59 (0.08-4.45)
Contact	88	3	0.47 (0.14-1.51)
Child abuse	5	0	. . .
Bicycle	57	5	1.28 (0.50-3.32)
Other	156	8	0.70 (0.33-1.50)
Unknown	4	1	3.64 (0.40-33.0)
Loss of consciousness	311	15	0.60 (0.33-1.09)
Amnesia	301	15	0.63 (0.35-1.14)
Mental status change	139	18	2.19 (1.24-3.89)
Lethargy	263	24	1.50 (0.89-2.52)
Seizure	50	7	2.14 (0.93-4.92)
Headache	358	17	0.57 (0.32-1.01)
Vomiting	315	17	0.70 (0.39-1.23)
Dizziness	94	5	0.75 (0.29-1.90)
Drug or alcohol intoxication	8	1	1.81 (0.22-14.7)
From the Physical Examination			
Sensory deficit	4	2	7.39 (1.33-41.1)
Skull defect	24	5	3.16 (1.17-8.58)
Basal skull fracture	22	3	2.01 (0.59-6.89)
Scalp			
Hematoma	248	28	2.10 (1.26-3.50)
Laceration	96	2	0.28 (0.07-1.15)
Glasgow Coma Scale score			
15	806	46	0.39 (0.21-0.72)
14	104	13	1.99 (0.96-3.87)
13	25	6	4.46 (1.42-11.78)

For the detection of ICI in 1000 study patients, the decision rule had a sensitivity of 95.4% (95% CI, 86.2%-98.8%), a specificity of 48.9% (95% CI, 45.6%-52.1%), and an NPV of 99.3% (95% CI, 98.1%-99.8%) (Figure). Three of 65 patients who had ICI findings on CT were not identified by the decision rule, although none required neurosurgical intervention. **Table 4** gives a description of these patients, including the patient with the equivocal CT finding of contusion vs artifact.

The sensitivity of the clinician's predictions of ICI based on history and physical examination was 14.8% (95% CI, 7.1%-27.7%), which was significantly lower compared with that of the decision rule (95.4%) (**Table 5**).

COMMENT

We developed a clinical decision rule for cranial CT in minor pediatric head trauma with high sensitivity for the

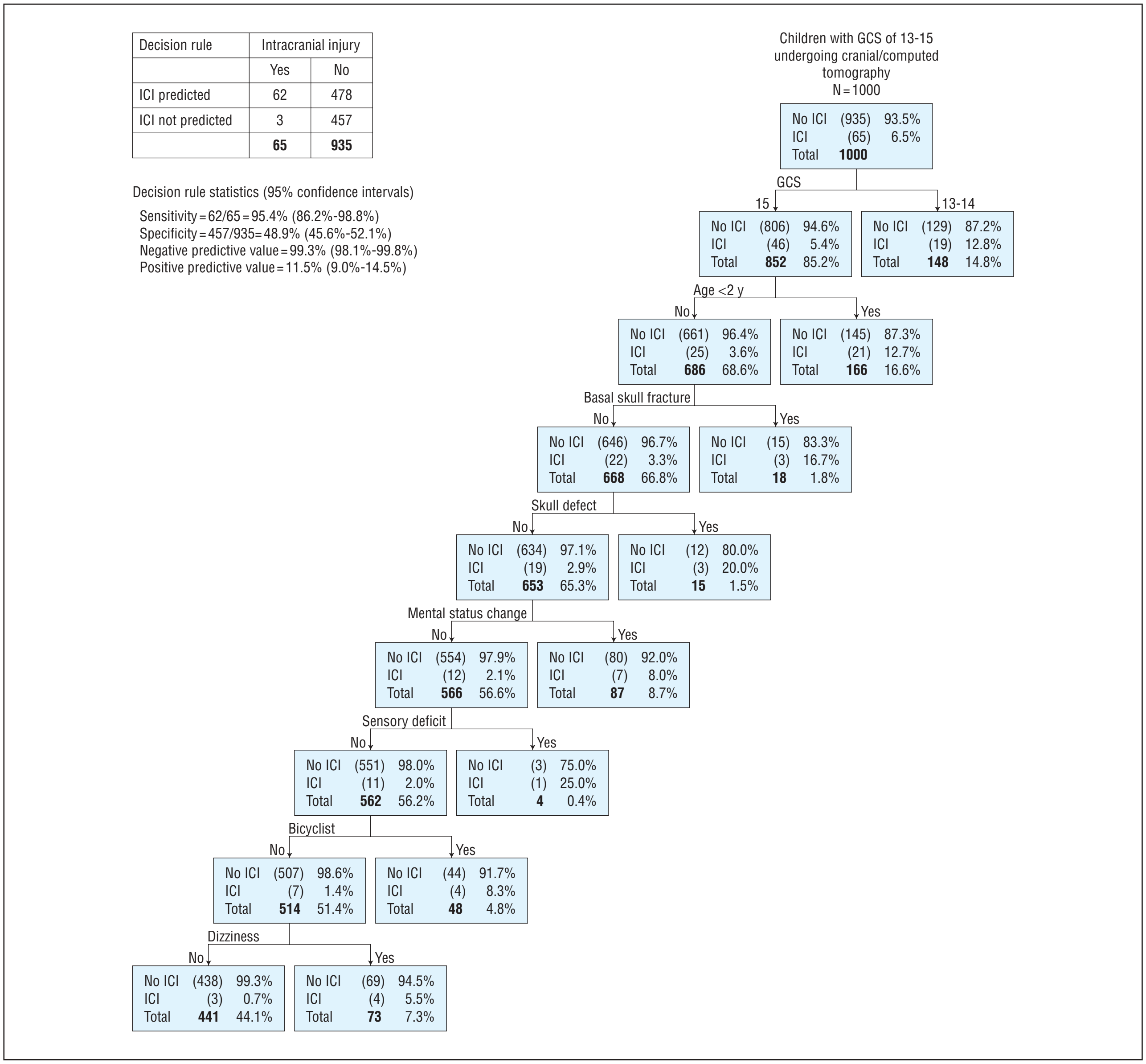

Figure. Pediatric head computed tomography decision rule. GCS indicates Glasgow Coma Scale score; ICI, intracranial injury.

detection of ICI. In this study, the clinical decision rule was found to be far more sensitive than the clinician's overall judgment of whether an ICI would be demonstrated on CT and had better NPV for the outcomes of interest. We believe that the liberal use of cranial CT, as recommended by several previous retrospective studies,[12,15] does not outweigh the costs and risks associated with this procedure compared with the overall incidence of clinically significant ICI. Children without any of the 8 risk factors in our decision rule are at low risk for ICI and their conditions can be managed with close outpatient observation. Blind application of the rule to all patients with minor head trauma is not recommended. Given that the cohort of patients enrolled in this study all underwent CT, we selected for patients who were likely at higher risk for ICI. This clinical decision rule should be used as an additional tool to help guide clinicians who are considering cranial CT in a child with minor head trauma.

The clinical decision rule derived in this study is based on prospectively collected data and is consistent with expert consensus on several fronts. In our study, sensory deficit, GCS less than 15, palpable skull defect, mental status change, age younger than 2 years, and signs of basilar skull fracture were associated with higher risk for ICI than other signs or symptoms of concern such as LOC, amnesia, headache, and vomiting. Stiell et al[6] published a decision rule for CT in adults with minor head injury. High-risk factors in this rule were age 65 years or older, signs of basilar skull fracture, 2 or more episodes of vomiting, suspected open or depressed skull fracture, and failure to reach a GCS of 15 within 2 hours. We similarly found that signs of basilar or depressed skull fracture contributed to our decision rule, which is also consistent with the association between skull fracture in children and increased ICI risk found by Oman et al,[27] Dunning et al,[28] and Quayle et al.[43] The results of a study conducted by Palchak et al[25] agreed with our findings that abnormal mental status and signs of skull fracture were high-risk factors for traumatic brain injury in children but differed from our study in that they found an increased risk of traumatic brain injury associated with vomiting. Haydel and Shembekar[26] concluded that CT was indicated for minor head trauma if 1 of the following 6 findings was present: emesis, headache, posttraumatic seizure, drug or alcohol intoxication, deficits in short-term memory, or physical evidence of trauma above the clavicles. Davis et al[23] did not find a reliable association between LOC and ICI, although scalp lacerations and neurologic deficits were statistically significant indicators. Similarly, Falimirski et al[18] concluded that LOC alone was not predictive of significant injury and was not an absolute indication for cranial CT. Similar to our study, Greenes and Schutzman[19,20,44] found that those younger than 2 years are at increased risk for ICI, with as many as 48% of injuries being occult or asymptomatic. Several characteristics unique to this younger age group may increase their likelihood of ICI, including higher incidence of skull fractures and increased risk for nonaccidental trauma.[17,20,44,45] Published guidelines have been developed separately for children 2 years and older by the American Academy of Pediatrics and for children younger than 2 years by expert consensus and literature review.[44,46,47] The decision rule derived in our study identifies a cohort of children at low risk for ICI. These data are consistent with previous literature highlighting an increased risk associated with age younger than 2 years.[44-47] Children in this age category fall outside of the low-risk criteria. This does not imply that all patients not meeting low-risk criteria (including age <2 years) should undergo cranial CT. Clinical decision rules are best used for decision support and should not replace clinical judgment.

We found that predictors such as fall, seizure, drug or alcohol intoxication, and scalp hematoma were statistically significant in univariate analysis but did not contribute in multivariate analysis. We also found that bicycle injuries placed children in a higher risk category for ICI. This may be unique to our patient population, most of whose injuries occurred in an urban environment and without protective headgear.

There are several limitations to our study. The injury rates from our study may underestimate those of the general population. We sought to develop a sensitive decision rule to detect ICI in children with minor head trauma and a GCS of 13 or higher who would undergo CT using pertinent historical and clinical data available to the emergency department physician, including mechanism of injury. This may exclude a proportion of patients with minor head trauma who did not undergo CT and may have had positive findings. However, we presume that the rates of ICI in this population are lower than those in our study group. Enrollment was dependent on practicing clinicians; therefore, we did not capture all eligible children with minor head trauma seen during the study period. We used the classical definition of minor head trauma as those patients with a GCS score exceeding 12. Although we acknowledge that there is some controversy surrounding this definition and that many clinicians believe that a GCS of 13 should be classified as moderate head trauma, we followed the recommendations of Stiell et al.[6]

Table 4. Patients With Positive Intracranial Injury Findings on Computed Tomography in Whom the Decision Rule Was Negative[a]

Age, y	Computed Tomographic Findings	Mechanism of Injury	Symptoms
13.9	Small interhemispheric subdural hemorrhage above and below the tentorium and posterior falx	Fall	Amnesia, loss of consciousness, or headache
2.1	Subarachnoid hemorrhage	Fall	Emesis or behavior change
6.5	Small focus of increased density in the occipitoparietal region representing a small contusion or an artifact	Motor vehicle crash, pedestrian struck	Behavior change

[a] None required neurosurgical intervention.

Table 5. Clinician's Ability to Predict Intracranial Injury[a]

Variable	Intracranial Injury Yes (n=54)	Intracranial Injury No (n=866)
Clinician's prediction of the likelihood of intracranial injury		
Likely	8	64
Unlikely	46	802
Sensitivity	14.8% (95% confidence interval, 7.1%-27.7%)	
Specificity	92.6% (95% confidence interval, 90.6%-94.2%)	
Positive predictive value	11.1% (95% confidence interval, 5.3%-21.3%)	
Negative predictive value	94.6% (95% confidence interval, 85.8%-98.3%)	

[a] Values do not sum to 920 because the clinicians completing the data collection survey did not complete this item.

Methodological advantages of this study over prior investigations are the prospective data collection and multicenter patient enrollment. The patients in this study represent populations from various sites and yield more generalizable results. If validated, our decision rule has the potential to reduce unnecessary cranial CT. The magnitude of this reduction depends on local practice regarding neuroimaging after minor head trauma. In many centers, routine CT in all patients with minor head trauma has emerged as the standard of emergency care. The results of this study suggest that implementation of the decision rule in centers with practice like those in the study would avoid CT in 46.3% of all patients with minor head trauma. Only 0.7% would have missed traumatic CT abnormalities, none of which required surgery. In addition to reducing radiation exposure risk, hospital charges for nonenhanced cranial CT in the United States range from \$500 to \$900; therefore, this could also result in significant cost savings.[48] Assessment of the effectiveness of such a rule requires prospective validation and measure of interobserver reliability, which we plan to perform in a future study.

Despite the importance of this study and others in refining the clinical indicators for CT, 2 important clinical questions remain. First, what is the significance of positive CT findings that do not require neurosurgical intervention? Is the detection of a clinically insignificant intracranial hemorrhage or contusion worth the risks of irradiation and sedation? Second, how useful are negative CT findings in symptomatic children? Prior studies have demonstrated behavioral changes in mildly head-injured patients, and some authors have recommended subsequent neurodevelopmental testing of these patients.[49-51] Attempts should be made to identify children at risk for long-term sequelae who may benefit from neuropsychologic testing and closer outpatient monitoring. In the future, functional imaging and psychometric testing may replace CT for the assessment of the child with minor head trauma.

Given the numbers of closed head injuries in children, if validated and implemented, this study could affect care by reducing unnecessary CT. A decrease in the frequency of cranial CT can lead to a decrease in radiation exposure, health care costs, the use of conscious sedation with its associated risks and costs, and the amount of time each patient spends in the emergency department.

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Author Contributions: Dr Atabaki had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Atabaki, Stiell, and Chamberlain. *Acquisition of data:* Atabaki, Bazarian, Sadow, Camarca, Berns, and Chamberlain. *Analysis and interpretation of data:* Atabaki, Stiell, Bazarian, Vu, and Chamberlain. *Drafting of the manuscript:* Atabaki, Vu, Camarca, and Chamberlain. *Critical revision of the manuscript for important intellectual content:* Atabaki, Stiell, Bazarian, Sadow, Berns, and Chamberlain. *Statistical analysis:* Stiell. *Obtained funding:* Atabaki. *Administrative, technical, and material support:* Sadow. *Study supervision:* Atabaki and Chamberlain.
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