Evaluation of a Modified Prediction Instrument to Identify Significant Pediatric Intracranial Injury After Blunt Head Trauma

Benjamin C. Sun, MD, MPP
Jerome R. Hoffman, MA, MD
William R. Mower, MD, PhD

From the Robert Wood Johnson Clinical Scholars Program (Sun), and the Emergency Medicine Center (Hoffman, Mower), University of California at Los Angeles, Los Angeles, CA.

Study objective: We evaluate the effect of a modification of the University of California–Davis Pediatric Head Injury Rule on the ability of the decision instrument for pediatric head injury to predict clinically important intracranial injury in an external cohort.

Methods: We analyzed data prospectively recorded in 1,666 pediatric patients enrolled in the derivation set of the National Emergency X-Radiography Utilization Study II (NEXUS II). Treating physicians at 21 emergency departments recorded the presence or absence of clinical predictors on all patients who received a head computed tomography (CT) scan after experiencing blunt head trauma. Predictors included 3 exact elements of the University of California–Davis Rule (abnormal mental status, signs of skull fracture, and scalp hematoma in children ≤2 years of age), some with different wording, and 2 modified elements with new definitions (the presence of high-risk vomiting or severe headache, rather than any vomiting or headache).

Results: A significant intracranial injury was identified by CT in 138 (8.3%) patients. Sensitivity of the modified instrument to detect significant intracranial injury was 90.4% (95% confidence interval [CI] 85.4% to 95.4%); 13 children with such an injury were misclassified as low risk. Specificity of the modified instrument was 42.7% (95% CI 40.1% to 45.3%).

Conclusion: In the NEXUS II cohort, a modified version of the University of California–Davis Rule misclassified a substantial proportion of pediatric patients with clinically important blunt head injury. Although we cannot evaluate the exact University of California–Davis Rule, we demonstrate that using stricter definitions of "headache" and "vomiting" and different wording than in the original study may have unintended or negative consequences. We emphasize the importance of careful attention to precise definitions of clinical predictors when a decision instrument is used. [Ann Emerg Med. 2007;49:325-332.]

0196-0644/$-see front matter

doi:10.1016/j.annemergmed.2006.08.032

SEE EDITORIAL, P. 333.

INTRODUCTION

Background and Importance

Pediatric blunt head trauma is an important cause of death and disability in children, accounting for an estimated 3,000 deaths, 29,000 hospitalizations, and 400,000 emergency department (ED) visits per year.[1] Cranial computed tomography (CT) is commonly ordered in the evaluation of pediatric blunt head trauma, and between 7% and 12% of CT scans reveal clinically important intracranial injury.[2-7]

CT scanning, however, may be associated with increased risks of long-term cancer,[8] need for sedation,[9] prolonged ED evaluation, and additional health care costs. Furthermore, emergency physicians demonstrate significant variability in deciding whether to order a CT scan for children with blunt head trauma.[10] Previous studies have attempted to identify clinical criteria that could safely reduce CT imaging in such patients, although many of these were limited by small sample size, restricted selection criteria, retrospective design, or univariate data analyses.[5,7,9,11-20]

Recently, investigators at University of California–Davis derived a decision instrument from a prospective cohort that included 1,271 children who received cranial CT after blunt head trauma.[3] The study excluded children with "trivial head injury," including ground-level falls and trauma resulting from walking or running into a stationary object if the only abnormal finding was a scalp laceration or abrasion. CT scans were

Editor's Capsule Summary

What is already known about this topic

Many decision rules are promulgated, some of them differing only in apparently insignificant ways; few enjoy widespread adoption by clinicians. Little is known about how "minor" changes in variables studied affect the performance of a particular rule.

What question this study addressed

This analysis of the NEXUS II database examined whether a rule that used modified language ("severe or progressive headache" in place of "headache" and "recurrent, forceful or projectile vomiting" in place of "vomiting") applied retrospectively to their patient population had sensitivity for important intracranial pathology similar to the definitions used by the developers of the original rule at the University of California–Davis.

What this study adds to our knowledge

These investigators report a sensitivity of 90% for the reworded rule in contrast to the original unaltered rule's sensitivity of 99%. It is not certain whether this difference is due to differences in the wording of the 2 rules, differences in the 2 patient populations, differences in the providers, or random variation.

How this might change clinical practice

This study points out that decision rules may be specific to particular circumstances, and performance may vary when elements are modified or when they are applied in different settings. This limited generalizability may explain some of the resistance to their adoption by clinicians.

performed at the discretion of treating physicians. The University of California–Davis Rule identified 5 clinical predictors of intracranial injury on CT, including abnormal mental status, clinical signs of skull fracture, history of vomiting, scalp hematoma in children younger than 2 years, and headache. These criteria identified 97 of 98 children with traumatic brain injury on CT scan (sensitivity 99%; 95% confidence interval [CI] 94% to 100%) and demonstrate the potential to safely reduce imaging in patients with none of the criteria (specificity 25.8%; 95% CI 23.3% to 28.4%). The University of California–Davis derivation study is part of the American Board of Emergency Medicine's Life Long Self-Assessment program.[21]

However, it is possible that some patients with isolated mild headache or a single episode of vomiting did not receive CT imaging in the University of California–Davis derivation study. Because children with any headache or vomiting are not considered to be low risk by the University of California–Davis criteria, application of this decision instrument may have the potential to increase the number of head CT scans ordered for pediatric head trauma.

Goals of This Investigation

We assessed a modified version of the University of California–Davis Rule that used stricter definitions of "headache" and "vomiting." The pediatric subset of the National Emergency X-Radiography Utilization Study II (NEXUS II) includes prospective data on a large cohort of children who received head CT scan after blunt head injury. Because NEXUS II did not collect the same elements used for the University of California–Davis rule, we had to modify 2 predictors in NEXUS II, including presence of "high-risk" vomiting and "severe" headache, in place of any vomiting or headache as used in the University of California–Davis derivation set. Additionally, the wording of some other questions also differed between the 2 studies, as shown in Table 1.

MATERIALS AND METHODS

Study Design and Setting

NEXUS II is a multicenter, prospective, observational study of all blunt head trauma victims who had a cranial CT as part of their ED evaluation.[22,23] The 21 participating centers represent a wide variety of facilities, including university hospitals, community hospitals with and without teaching programs, public hospitals and private hospitals, and hospitals with all levels of trauma categorizations. Study sites are organized into geographic regions distributed across the United States. The institutional review boards of all participating centers approved this study.

Selection of Participants

The NEXUS II cohort consisted of all acute blunt head trauma patients undergoing CT head imaging at participating centers. Patients with a delayed presentation or without blunt trauma were excluded. Clinicians made imaging decisions according to their clinical judgment and not by study protocol. Patients were enrolled from May 1999 to December 2000. This study analyzes the subgroup of patients who were younger than 18 years.

Methods of Measurement

Treating physicians completed a standardized data form before ordering head CT, and they indicated whether each of the candidate criteria was present, absent, or unable to be determined. Definitions of relevant criteria in both the University of California–Davis and NEXUS II studies are presented in Table 1. Definitions of signs of skull fracture and scalp hematoma in age younger than 2 years were similar in the University of California–Davis and NEXUS II studies. For children older than 2 years, the definitions of abnormal mental status were similar in the 2 studies. For children younger than 2 years, the definition of abnormal mental status in the University

Table 1. Candidate predictors and definitions.

Variable	University of California–Davis Definition	NEXUS II Definition
Scalp hematoma	Scalp hematoma	Refers to swelling felt to be a result of hematoma formation over any portion of the bony calvarium. Injuries that do not involve the calvarium, including hematomas limited to the face and neck, are not considered scalp hematomas
Skull fracture	Includes palpable skull fracture, retroauricular bruising, periorbital bruising, hemotympanum, or cerebrospinal fluid otorrhea or rhinorrhea	Includes but not limited to any signs of basilar skull fracture, such as periorbital or periauricular ecchymoses, hemotympanum, and drainage of clear fluid from ears and nose; and signs of depressed skull fracture including a palpable step-off of skull
Abnormal mental status	Positive for any of the following: GCS score <15 (absence of spontaneous eye opening, normal orientation, ability to follow commands) Pediatric GCS score <15 in preverbal children (absence of spontaneous eye opening, appropriate coos, normal spontaneous movement) Patient is confused, somnolent, repetitive, or slow to respond to verbal communication	Abnormal mental status. Positive for any of the following: GCS score <15 (absence of spontaneous eye opening, normal orientation, ability to follow commands) Abnormal alertness. Includes but not limited to delayed or inappropriate response, excessive somnolence, to inability remember 3 objects at 5 minutes; or perseverating speech Abnormal behavior. Includes but not limited to excessive agitation, inconsolability, and violent activity
Vomiting	History of vomiting	Includes but not limited to recurrent, projectile, or forceful emesis after trauma, or vomiting associated with altered sensorium
Headache	Headache	Includes but not limited to any head pain deemed by the patient to be severe or progressive in nature

of California–Davis study included confusion, somnolence, or a pediatric Glasgow Coma Scale (GCS) score of less than 15. NEXUS II collected elements of the adult GCS (spontaneous eye opening, normal orientation, and obeys verbal commands) rather than elements of the pediatric GCS (spontaneous eye opening, coos appropriately, and has normal spontaneous movement). NEXUS II collected data on "high-risk" vomiting and "severe" headache after head trauma, whereas the original University of California–Davis Rule collected data on presence of any vomiting or headache (Table 1). Because NEXUS II did not query the presence of any vomiting or headache, validation of the exact University of California–Davis criteria cannot be performed.

To assess the interrater reliability of clinical predictors in a pediatric blunt head trauma population, a second physician evaluated and completed a data form in a convenience sample of 265 patients across all participating sites.

Outcome Measures

Clinically important intracranial injury was defined through an expert panel process as any injury that may require neurosurgical intervention (craniotomy, intracranial pressure monitoring, mechanical ventilation), lead to rapid clinical deterioration, or result in significant long-term neurologic impairment[24] (Figure 1).

Head CTs were interpreted by clinical radiologists at each site. Copies of all final radiographic readings were collected and abstracted to determine the presence or absence of clinically important intracranial injury. Investigators determined final injury classification while blinded to information about clinical variables.

Primary Data Analysis

We performed univariate analyses to assess for baseline demographic and clinical differences between children with and without significant intracranial injury, and we hypothesized that the University of California–Davis predictors would individually be associated with presence of intracranial injury. Relative risk ratios with 95% CI were calculated for binary, univariate predictors for significant intracranial injury. The κ statistic assessed the interrater reliability of clinical predictors.

In the base case analysis, we analyzed all patients who either had the presence of at least 1 of the 5 high-risk predictors or who had complete data on all 5 predictors. We treated a response of "unable to be determined" as missing data. We determined sensitivity, specificity, negative predictive value, and positive predictive value of the modified University of California–Davis Rule to accurately identify children with significant intracranial injury on head CT.

We performed additional analyses to assess the impact of missing data. To assess the upper bounds of sensitivity of the modified University of California–Davis Rule, we assumed that all missing data represented the presence of a candidate predictor. To assess the upper bounds of specificity, we assumed that all missing data represented the absence of a candidate predictor.

1. Substantial epidural or subdural hematoma (>1.0 cm in width or causing mass effect)
2. Substantial cerebral contusion (>1.0 cm in diameter or >1 site)
3. Extensive subarachnoid hemorrhage
4. Mass effect or sulcal effacement
5. Signs of herniation
6. Basal cistern compression or midline shift
7. Hemorrhage in the posterior fossa
8. Intraventricular hemorrhage
9. Bilateral hemorrhage of any type
10. Depressed or diastatic skull fracture
11. Pneumocephalus
12. Diffuse cerebral edema
13. Diffuse axonal injury

Figure 1. CT findings representing clinically important intracranial injury.

Because NEXUS II did not include data on the pediatric GCS, we performed a sensitivity analysis by excluding the 208 patients who were younger than 2 years.

Data management and statistical analyses were conducted using SAS software, version 8.02 (SAS Institute, Inc., Cary, NC). Tests characteristics and associated 95% CIs were calculated using a publicly available SAS macro.[25]

RESULTS

Of the overall NEXUS II cohort of 13,728 patients, 1,666 were younger than 18 years and composed the analytic cohort for this study. The age distribution of the pediatric cohort is presented in Appendix E1 (available online at http://www.annemergmed.com). Baseline characteristics of the pediatric study population are presented in Table 2. There were 138 (8.3%) patients with clinically important intracranial injury on head CT. There were no clinically important differences in age, sex, and race/ethnicity between children with and without clinically important intracranial injury. On univariate testing, the presence of abnormal mental status, signs of skull fracture, high-risk vomiting, and presence of at least 1 of the 5 high-risk predictors were highly associated with presence of clinically important intracranial injury. Data were missing for these predictors in 2% to 12% of patients. Specific intracranial injuries are summarized in Table 3.

Interrater reliability of the measurements was moderate, and κ values ranged between 0.54 to 0.75 for each of the 5 high-risk predictors and 0.53 for the presence of any high-risk predictor (Table 4).

The test characteristics of the modified University of California–Davis Rule are presented in Table 5. In the base case analysis, 13 (9%) patients with clinically important intracranial injury had none of the 5 high-risk predictors. The test characteristics of the modified prediction rule were minimally sensitive to different assumptions for handling missing data. None of the misclassified patients were younger than 2 years, and the test characteristics of the modified prediction rule were minimally affected by excluding patients younger than 2 years. Figure 2 describes the injuries of patients who were misclassified as "low risk."

LIMITATIONS

There are a number of limitations to our study. Not all patients with blunt head injury received head CT. However, we performed a single center substudy of 1,266 patients with blunt head injury who did not receive head CT; none of these patients subsequently died, were diagnosed with an intracranial injury, or required a neurosurgical procedure at 3-month follow-up.[23] Thus, we believe the potential effect of selection bias on our reported sensitivity is minimal.

We did not include the need for acute neurosurgical intervention as an outcome. The frequency of neurosurgical procedures in pediatric blunt head trauma is approximately 0.4% to 1.5%,[3,26,27] and derivation of a reliable decision rule to identify neurosurgical intervention would likely require a study with more than 30,000 children. Thus, NEXUS II was not sufficiently powered to assess neurosurgical interventions as an outcome. Furthermore, the definition of acute intervention in the original University of California–Davis study included "hospitalization for 2 or more nights" and "anti-epileptic medication for more than 1 week." Prolonged hospitalization and treatment with antiepileptic medications accounted for 69% of patients requiring acute intervention in the original University of California–Davis study, and it is possible that these outcomes are subject to variations in clinical judgment. Finally, many emergency physicians regard a missed traumatic brain injury that could have been identified on CT scan as unacceptable.[28] Therefore, we believe that CT evidence of intracranial injury is a clinically relevant and important outcome.

Although the definitions for "abnormal mental status" were similar between NEXUS II and the original University of California–Davis study, NEXUS II did not collect data on pediatric GCS score in preverbal patients. However, none of the misclassified patients were younger than 2 years, and excluding children younger than 2 years from our analysis had no important effects on our overall findings. We suspect that children with an abnormal pediatric GCS score were

Table 2. Study population demographics.

Characteristic	Absent Intracranial Injury (n=1,528)	Present Intracranial Injury (n=138)	Relative Risk Ratio (95% CI)
Age (IQR)	10.3 (4.4, 16)	9.6 (4.8, 15.1)	
Male	64%	63%	0.95 (0.7–1.3)
Race/ethnicity, %			
White	49	50	
Black	16	9	
Hispanic	20	23	
Other/unknown	15	17	
Presence of high-risk predictors, %*			
Abnormal mental status	38	75	4.4 (3.0–6.3)
Signs of skull fracture	3	28	6.9 (5.0–9.7)
High risk vomiting	11	24	2.2 (1.6–3.2)
Scalp hematoma in children ≤2 y†	39	57	2.0 (0.5–8.7)
Severe or progressive headache	15	20	1.4 (0.8–2.4)
Any high-risk predictor	61	91	6.4 (3.5–12.0)

*Frequency of missing data: abnormal mental status (7.4%), skull fracture (4.8%), high-risk vomiting (1.6%), scalp hematoma in children ≤2 years (2.5%), severe headache (20.5%).
†Of patients ≤2 years of age, 201 had absent intracranial injury and 7 had present intracranial injury.

Table 3. Significant intracranial injuries on head CT.

Type of Injury	Patients With Significant Intracranial Injury, No. (%)*
Cerebral contusion	68 (49.3)
Subarachnoid hemorrhage	41 (29.7)
Subdural hematoma	38 (27.5)
Depressed skull fracture	30 (21.7)
Epidural hematoma	27 (19.6)
Pneumocephalus	26 (18.8)
Diffuse cerebral edema	19 (13.8)
Intraventricular hemorrhage	10 (7.2)
Other significant cerebral injuries	22 (15.9)

*One hundred thirty-eight patients accounted for a total of 281 significant traumatic brain injuries.

Table 4. Interobserver agreement on presence or absence of predictors (n=265).

Predictor	Subgroup No.	Agreement, %	κ (95% CI)
Abnormal mental status	264	79.2	0.56 (0.5–0.7)
Signs of skull fracture	233	97.8	0.75 (0.5–1.0)
High-risk vomiting	256	93.4	0.73 (0.6–0.9)
Scalp hematoma in a child ≤2 y	169	87.6	0.71 (0.6–0.8)
Severe or progressive headache	199	85.9	0.54 (0.4–0.7)
Any high-risk predictor*	202	83.6	0.53 (0.4–0.7)

*Observation was dropped if either rater did not complete all elements of the modified University of California–Davis Rule and no abnormal findings were present.

appropriately classified by physicians as having abnormal alertness or behavior, which were both components of "abnormal mental status" in the NEXUS II study.

There may be important physiologic differences among infants, preadolescents, and teenagers, and a decision rule to identify pediatric head injury may have various test characteristics that are age dependent. In a post hoc sensitivity analysis, we did not find qualitatively important test differences of the modified University of California–Davis Rule in children aged 2 to 12 years (sensitivity 92%, 95% CI 85% to 98%; specificity 38%, 95% CI 34% to 42%) and aged 12 to 18 years (sensitivity 90%, 95% CI 81% to 98%; specificity 47%, 95% CI 43% to 51%) compared to the overall cohort. Test characteristics of the modified University of California–Davis Rule were more sensitive and less specific in children younger than 2 years (sensitivity 100%, 95% CI 72% to 100%; specificity 11%, 95% CI 6% to 16%); however, the generalizability of this finding is limited, given the small number of children in this subgroup (n=208 with 7 significant intracranial injuries).

The outcomes definitions were different between the 2 studies. The original University of California–Davis Rule considered any intracranial hemorrhage, hematoma, or cerebral edema to be a serious outcome, whereas NEXUS II used a more stringent set of definitions for significant intracranial injury (see Figure 1). However, in a post hoc sensitivity analysis that considered any intracranial hemorrhage, hematoma, or cerebral edema to be a serious outcome (excluding isolated, nondepressed skull fracture), there were no important changes in sensitivity (90.5%; 95% CI 85.8% to 95.3%) or specificity (43.0%; 95% CI 40.4% to 45.6%) of the modified University of California–Davis Rule.

Most important, we were unable to assess the precise University of California–Davis Rule because the data in the 2 studies were differently defined at collection, and thus we can comment directly only on a modified version of that decision instrument.

Table 5. Performance of modified prediction rule to identify significant traumatic intracranial injury.

Assumption	Sensitivity (95% CI)	Specificity (95% CI)	Positive Predictive Value (95% CI)	Negative Predictive Value (95% CI)
Base case	90.4 (85.5–95.4)	42.7 (40.1–45.3)	13.2 (11.0–15.3)	97.9 (96.8–99.0)
Missing predictors set to "present"	90.6 (85.7–95.5)	39.6 (37.1–42)	11.9 (9.9–13.9)	97.9 (96.7–99.0)
Missing predictors set to "absent"	89.1 (83.9–94.3)	46.9 (44.4–49.4)	13.2 (11.0–15.3)	98.0 (96.9–99.0)
Age 2–18, base case assumptions	89.4 (84.0–94.9)	46.1 (43.3–48.9)	14.2 (11.8–16.7)	97.8 (96.5–99.0)

1. 2.9 Y.o. with large right epidural hematoma and significant mass shift
2. 4.6 Y.o. with moderate left epidural hematoma
3. 7.4 Y.o. with large right occipitotemporal contusion
4. 7.7 Y.o. with bilateral falcine subdural hematomas
5. 7.8 Y.o. with cerebral contusions and small epidural hematoma
6. 8.4 Y.o. with diastasis of the left lambdoidal suture and nondisplaced occipital fracture
7. 9.9 Y.o. with depressed comminuted skull fracture with associated contusion
8. 12.8 Y.o. with comminuted depressed skull fracture and mild subarachnoid hemorrhage
9. 13.0 Y.o. with nondisplaced right orbital fracture with pneumocephalus
10. 13.5 Y.o. with small right frontal contusion and pneumocephalus
11. 16.5 Y.o. with bilateral petechial hemorrhages
12. 17.5 Y.o. with depressed skull fracture and pneumocephalus
13. 17.8 Y.o. with comminuted depressed skull fracture with small subarachnoid hemorrhage

Y.o., years old.

Figure 2. Patients misclassified as "low risk" in base-case analysis.

DISCUSSION

NEXUS II is a multicenter study that to our knowledge includes the largest published cohort of pediatric blunt head trauma patients for whom head CT scanning was done. The study design maximizes generalizability and allows us to assess the performance of any combination of clinical variables prospectively assessed for this study. Because we did not query 2 of the precise variables used to derive the University of California–Davis Rule, however (and other questions varied slightly in their wording), we can only assess a modified version of that decision instrument. We demonstrate that a modified version of the original University of California–Davis Rule results in misclassification of a significant proportion of children with clinically important intracranial injury in the NEXUS II cohort.

Identification of a reliable set of clinical predictors to identify clinically important intracranial injury in children might safely reduce use of head CT, and the University of California–Davis Rule is an important advance in this endeavor. The original derivation study prospectively collected data on 2,043 children with nontrivial blunt head injury, and a head CT was obtained in 1,271 (62%) patients. The 2 outcome measures included traumatic brain injury identified on CT imaging (excluding isolated skull fractures) and the need for acute intervention (defined as a neurosurgical procedure, persistent neurologic deficit at discharge, treatment with antiepileptic medications for more than 1 week, or hospitalization for 2 or more nights). The 5 clinical predictors of abnormal mental status, signs of skull fracture, scalp hematoma in children 2 years of age or younger, vomiting, or headache demonstrated high sensitivity for both outcomes.

In the original derivation study, the University of California–Davis Rule had a sensitivity of 99% (95% CI 94.4% to 100%) and specificity of 26% (95% CI 23.3% to 28.4%) for identifying children with any traumatic head injury on head CT.[3] In the NEXUS II cohort, a modification of the University of California–Davis Rule demonstrated lower sensitivity (90.4%, 95% CI 85.5% to 95.4%) and higher specificity (42.7%, 95% CI 40.1% to 45.3%) to identify clinically significant intracranial injury.

The NEXUS II measurements of "high risk" vomiting and "severe" headache, rather than any vomiting or headache, may have contributed to lower sensitivity and higher specificity of the modified University of California–Davis rule than in the original study. Because NEXUS II did not include information about the presence of any vomiting or headache, we were unable to assess the exact University of California–Davis Rule. Although these differences may seem subtle, they may have an important impact on the accurate identification of patients with clinically important intracranial injury.

As for any such decision instrument, the University of California–Davis Rule should be applied with careful attention to the exact definitions of clinical predictors. Although we were unable to perform an external validation of the precise original University of California–Davis Rule, such studies are necessary before widespread application of this decision instrument. How much changes in definitions affect performance is not known. These caveats are particularly important in this instance because the University of California–Davis derivation study is now required reading for all board-certified emergency physicians through the American Board of Emergency Medicine's Life Long Self-Assessment program.[21]

In a separate report, we assessed other potential predictors of pediatric head injury in the NEXUS II cohort.[2] A combination of criteria, including evidence of skull fracture, altered level of alertness, neurologic deficit, persistent vomiting, presence of scalp hematoma in any age, abnormal behavior, and coagulopathy, identified significant pediatric intracranial injury with a sensitivity of 98.6% (95% CI 94.9% to 99.8%) and specificity of 15.1% (95% CI 13.3% to 16.9%). These findings will require validation in an external cohort.

In Retrospect

Collection of the exact original University of California–Davis predictors would have allowed formal evaluation of the University of California–Davis Rule. However, the NEXUS II study was planned and patient enrollment proceeded before the initiation of the University of California–Davis study, so this could not be done.

In summary, we assessed the performance of a modified version of the University of California–Davis Rule to identify clinically important intracranial injury in a large cohort of children. Modified predictors included presence of high-risk vomiting or severe headache, rather than any vomiting or headache, as in the University of California–Davis derivation study, as well as other changes in wording. This modified decision instrument misclassified a significant number of children with clinically important intracranial injury. It is possible that using the exact University of California–Davis rule would have demonstrated better test characteristics, but it is not possible to determine whether the modifications, differences in the population, or some other variable accounts for the discrepancies. We emphasize that careful attention to the precise definitions of clinical predictors, as well as validation studies of the exact instrument, is essential for safe application of the University of California–Davis Rule and probably most decision rules.

Supervising editor: Kathy N. Shaw, MD, MSCE

Author contributions: BCS, JRH, and WRM conceived the study. JRH and WRM obtained funding for this study and were responsible for data collection. BCS performed the data analysis and drafted the article. All authors contributed substantially to article revisions. BCS takes responsibility for the paper as a whole.

Funding and support: This study was supported in part by the UCLA Robert Wood Johnson Clinical Scholars Program (Sun) and grant RO1 HS09699 (Mower).

Publication dates: Received for publication June 9, 2006. Revisions received July 21, 2006, and August 9, 2006. Accepted for publication August 30, 2006. Available online January 8, 2007.

Reprints not available from authors.

Address for correspondence: Benjamin C. Sun, MD, MPP, Mail Stop 111, Building 500, Wing 3E, West Los Angeles Veterans Affairs Medical Center, 11301 Wilshire Blvd, Los Angeles, CA 90073; 310-268-3002, fax 310-268-4818; E-mail bsun@post.harvard.edu.

REFERENCES

1. National Center for Injury Prevention and Control. Traumatic brain injury in the United States: assessing outcomes in children [Centers for Disease Control and Prevention Web site]. Available at: http://www.cdc.gov/ncipc/tbi/tbi_report/AssessingOutcome-TBI.htm. Accessed April 12, 2006.
2. Oman JA, Cooper RJ, Holmes JF, et al. Performance of a decision rule to predict need for computed tomography among children with blunt head trauma. *Pediatrics.* 2006;117:e238-e246.
3. Palchak MJ, Holmes JF, Vance CW, et al. A decision rule for identifying children at low risk for brain injuries after blunt head trauma. *Ann Emerg Med.* 2003;42:492-506.
4. Davis RL, Mullen N, Makela M, et al. Cranial computed tomography scans in children after minimal head injury with loss of consciousness. *Ann Emerg Med.* 1994;24:640-645.
5. Dietrich AM, Bowman MJ, Ginn-Pease ME, et al. Pediatric head injuries: can clinical factors reliably predict an abnormality on computed tomography? *Ann Emerg Med.* 1993;22:1535-1540.
6. Haydel MJ, Shembekar AD. Prediction of intracranial injury in children aged five years and older with loss of consciousness after minor head injury due to nontrivial mechanisms. *Ann Emerg Med.* 2003;42:507-514.
7. Schynoll W, Overton D, Krome R, et al. A prospective study to identify high-yield criteria associated with acute intracranial computed tomography findings in head-injured patients. *Am J Emerg Med.* 1993;11:321-326.
8. Brenner D, Elliston C, Hall E, et al. Estimated risks of radiation-induced fatal cancer from pediatric CT. *AJR Am J Roentgenol.* 2001;176:289-296.
9. Conners GP, Sacks WK, Leahey NF. Variations in sedating uncooperative, stable children for post-traumatic head CT. *Pediatr Emerg Care.* 1999;15:241-244.
10. Klassen TP, Reed MH, Stiell IG, et al. Variation in utilization of computed tomography scanning for the investigation of minor head trauma in children: a Canadian experience. *Acad Emerg Med.* 2000;7:739-744.
11. Bonadio WA, Smith DS, Hillman S. Clinical indicators of intracranial lesion on computed tomographic scan in children with parietal skull fracture. *Am J Dis Child.* 1989;143:194-196.
12. Greenes DS, Schutzman SA. Occult intracranial injury in infants. *Ann Emerg Med.* 1998;32:680-686.
13. Greenes DS, Schutzman SA. Clinical indicators of intracranial injury in head-injured infants. *Pediatrics.* 1999;104:861-867.
14. Gruskin KD, Schutzman SA. Head trauma in children younger than 2 years: are there predictors for complications? *Arch Pediatr Adolesc Med.* 1999;153:15-20.
15. Hennes H, Lee M, Smith D, et al. Clinical predictors of severe head trauma in children. *Am J Dis Child.* 1988;142:1045-1047.
16. Jeret JS, Mandell M, Anziska B, et al. Clinical predictors of abnormality disclosed by computed tomography after mild head trauma. *Neurosurgery.* 1993;32:9-15.
17. Quayle KS, Jaffe DM, Kuppermann N, et al. Diagnostic testing for acute head injury in children: when are head computed tomography and skull radiographs indicated? *Pediatrics.* 1997;99:E11.
18. Ramundo ML, McKnight T, Kempf J, et al. Clinical predictors of computed tomographic abnormalities following pediatric traumatic brain injury. *Pediatr Emerg Care.* 1995;11:1-4.
19. Rivara F, Tanaguchi D, Parish RA, et al. Poor prediction of

positive computed tomographic scans by clinical criteria in symptomatic pediatric head trauma. *Pediatrics.* 1987;80: 579-584.
20. Simon B, Letourneau P, Vitorino E, et al. Pediatric minor head trauma: indications for computed tomographic scanning revisited. *J Trauma.* 2001;51:231-237.
21. American Board of Emergency Medicine. LLSA 2006 reading list [American Board of Emergency Medicine Web site]. Available at: http://www.abem.org/rainbow/portal/alias_Rainbow/lang_en-US/tabID_3671/DesktopDefault.aspx. Accessed April 16, 2006.
22. Mower WR, Hoffman JR, Herbert M, et al. Developing a clinical decision instrument to rule out intracranial injuries in patients with minor head trauma: methodology of the NEXUS II investigation. *Ann Emerg Med.* 2002;40:505-514.
23. Mower WR, Hoffman JR, Herbert M, et al. Developing a decision instrument to guide computed tomographic imaging of blunt head injury patients. *J Trauma.* 2005;59:954-959.
24. Atzema C, Mower WR, Hoffman JR, et al. Defining "therapeutically inconsequential" head computed tomographic findings in patients with blunt head trauma. *Ann Emerg Med.* 2004;44:47-56.
25. Cha S, Senspe BS. Mayo Clinic Division of Biostatistics. Available at http://www.mayoresearch.mayo.edu/mayo/research/biostat.sasmacros.cfm. Accessed April 16, 2006.
26. Stiell IG, Clement CM, Rowe BH, et al. Comparison of the Canadian CT Head Rule and the New Orleans Criteria in patients with minor head injury. *JAMA.* 2005;294:1511-1518.
27. Smits M, Dippel DW, de Haan GG, et al. External validation of the Canadian CT Head Rule and the New Orleans Criteria for CT scanning in patients with minor head injury. *JAMA.* 2005;294: 1519-1525.
28. Haydel MJ. Clinical decision instruments for CT scanning in minor head injury. *JAMA.* 2005;294:1551-1553.

Appendix E1. Age distribution of study cohort.

Age, y	No. (% of Total)	% With Intracranial Injury
0–2	208 (12)	5.8
2–4	178 (11)	10
4–6	128 (7.7)	11
6–8	115 (6.9)	15
8–10	120 (7.2)	9
10–12	123 (7.4)	11
12–14	171 (10)	6.4
14–16	213 (13)	8.0
16–18	410 (25)	5.9