A Critical Comparison of Clinical Decision Instruments for Computed Tomographic Scanning in Mild Closed Traumatic Brain Injury in Adolescents and Adults

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Study objective: A number of clinical decision aids have been introduced to limit unnecessary computed tomographic scans in patients with mild traumatic brain injury. These aids differ in the risk factors they use to recommend a scan. We compare the instruments according to their sensitivity and specificity and recommend ones based on incremental benefit of correctly classifying patients as having surgical, nonsurgical, or no intracranial lesions.

Methods: We performed a secondary analysis of prospectively collected database from 7,955 patients aged 10 years or older with mild traumatic brain injury to compare sensitivity and specificity of 6 common clinical decision strategies: the Canadian CT Head Rule, the Neurotraumatology Committee of the World Federation of Neurosurgical Societies, the New Orleans, the National Emergency X-Radiography Utilization Study II (NEXUS-II), the National Institute of Clinical Excellence guideline, and the Scandinavian Neurotrauma Committee guideline. Excluded from the database were patients for whom the history of trauma was unclear, the initial Glasgow Coma Scale score was less than 14, the injury was penetrating, vital signs were unstable, or who refused diagnostic tests. Patients revisiting the emergency department within 7 days were counted only once.

Results: The percentage of scans that would have been required by applying each of the 6 aids were Canadian CT head rule (high risk only) 53%, Canadian (medium & high risk) 56%, the Neurotraumatology Committee of the World Federation of Neurosurgical Societies 56%, New Orleans 69%, NEXUS-II 56%, National Institute of Clinical Excellence 71%, and the Scandinavian 50%. The 6 decision aids' sensitivities for surgical hematomas could not be distinguished statistically ($P>.05$). Sensitivity was 100% (95% confidence interval [CI] 96% to 100%) for NEXUS-II, 98.1% (95% CI 93% to 100%) for National Institute of Clinical Excellence, and 99.1% (95% CI 94% to 100%) for the other 4 clinical decision instruments. Sensitivity for any intracranial lesion ranged from 95.7% (95% CI 93% to 97%) (Scandinavian) to 100% (95% CI 98% to 100%) (National Institute of Clinical Excellence). In contrast, specificities varied between 30.9% (95% CI 30% to 32%) (National Institute of Clinical Excellence) and 52.9% (95% CI 52% to 54) (Scandinavian).

Conclusion: NEXUS-II and the Scandinavian clinical decision aids displayed the best combination of sensitivity and specificity in this patient population. However, we cannot demonstrate that the higher sensitivity of NEXUS-II for surgical hematomas is statistically significant. Therefore, choosing which of the 2 clinical decision instruments to use must be based on decisionmakers' attitudes toward risk. [Ann Emerg Med. 2009;53: 180-188.]

0196-0644/$-see front matter

doi:10.1016/j.annemergmed.2008.01.002

INTRODUCTION

Background

Mild traumatic brain injury is commonly defined as Glasgow Coma Scale (GCS)[1] score on hospital arrival of 13 to 15. In 1975, Reilly et al[2] in Glasgow reported on a group of patients who deteriorated and died, despite having been thought to have mild traumatic brain injury. Because all of these patients were conscious at some point after their injuries, their condition was termed "talk and die." A similar cohort was found in the United States in the National Traumatic Coma Data Base.[3] The majority of patients in both reports had traumatic intracranial hematomas. In a more comprehensive study, it was found that these patients, rather than the more seriously injured, caused most of the interhospital variation in traumatic brain injury

Editor's Capsule Summary

What is already known on this topic

Numerous clinical decision aids exist to help decide which head injury patients might benefit from cranial computed tomography.

What question this study addressed

The performance of 6 decision aids when retrospectively applied to a 7,955-patient Italian database of head-injured patients with a Glasgow Coma Scale score of 14 or 15.

What this study adds to our knowledge

The 6 aids performed similarly in detecting surgical and nonsurgical (cerebral contusion, subarachnoid hemorrhage, etc) lesions. It is difficult to know whether small differences in sensitivity and specificity among these instruments reflect their inherent quality or the idiosyncrasies of their retrospective application to this database.

How this might change clinical practice

This study does not change practice. Physicians who want to use a decision aid can choose freely among these 6.

mortality.[4] Traumatic brain injury victims harboring hematomas are not readily identified on neurologic examination or skull radiography and often do poorly if diagnosis is delayed,[5,6] whereas prompt hematoma evacuation is usually lifesaving.

Cranial computed tomography (CT) scanning plays an important role in the assessment of patients with suspected hematoma, and it was hoped that its increasing availability would solve the dilemma of occult hematomas in mildly injured patients. However, there is considerable variability in the use of CT scanning for evaluating mild traumatic brain injury. Patients continue to deteriorate and even die after what appears clinically to be mild traumatic brain injury.[7] Complications of mild traumatic brain injury are uncommon, and CT scans are expensive. Accordingly, a number of evidence-based clinical decision instruments have been developed to predict the need for CT scans in patients with traumatic brain injury and GCS scores of 14 and 15.[8-16] Some have been externally validated[17-24] and have even been shown to influence clinical practice.[25-31] However, these strategies differ with regard to the specific clinical and demographic factors that constitute indicators for scanning

Importance

Considerable disagreement remains as to the relative merit of the various decision instruments,[32-39] as does concern about their effects on the cost of traumatic brain injury care.[25,26,29,30,40-43] There have been several studies that have compared sensitivity and specificity of subsets of the existing decision aids.[33,44-47] However, the study populations have been relatively small, and no study has shown one strategy to perform significantly better than the others. Thus, clinicians cannot be confident about the aid they should use.

Goals of This Investigation

In this study, we use data from 7,955 adolescent and adult patients with mild traumatic brain injury to evaluate the operating characteristics of 6 of these decision instruments that are commonly used to determine the need for CT scanning in patients presenting with this condition.

MATERIALS AND METHODS

Study Design and Setting

This is a secondary analysis of a prospectively collected, mild closed head injury database of adolescents and adults. The database was compiled from consecutive patients encountered between January 1999 and June 2003. The original purpose of the database was a comparison of 2 decision instruments used to predict the need for CT scans in this patient group and was published previously.[44]

Selection of Participants and Interventions

The database was assembled from consecutive patients at least 10 years of age who attended a regional Italian trauma center (Dipartimento Emergenza Azienda USL, Forlì, Italy) within 24 hours of traumatic brain injury. Each patient was enrolled in a prospective registry, using a detailed protocol. Patients were excluded from the study if they had an unclear history of trauma as the primary event, had unstable vital signs, had a GCS score less than 14, had penetrating traumatic brain injury, or had refused diagnostic studies or treatment. Duplicate records that represented participants reattending for postconcussive syndrome within 7 days of previous admission for mild head injury were also excluded. The protocol based decision for a cranial CT scan on the recommendations of the Neurotraumatology Committee of the World Federation of Neurosurgical Societies.[13] All patients considered medium or high risk (Table 1) received scans, and others were discharged home with written instructions for observation and return to the emergency department (ED) for continued or new complaints. All who returned to the ED received CT scans.

Methods of Measurement and Outcome Measures

Follow-up to determine final outcome of the traumatic brain injury was conducted by ED personnel at 6 months after injury. A systematic review of regional records for death or traumatic brain injury–related medical complications was done for all patients identified as having intracranial injuries. Then a structured telephone interview was performed to determine Glasgow Outcome Scale score (the primary outcome) and

Table 1. Findings used by 7 clinical decision rules for CT scanning in mild traumatic brain injury.

Clinical Finding	Canadian	NCWFNS	New Orleans	NEXUS-II	NICE	Scandinavian
GCS score	<15 At 2 h	<15	<15	Abnormal alertness, behavior	<15 At 2 h	<15
Amnesia	Retrograde >30 min*	Any	Antegrade	—	Retrograde >30 min	Any
Suspected fracture	Open, depressed, basal	Any	Any injury above clavicles	Any	Open, depressed, basal	Basal, depressed, confirmed
Vomiting	Recurrent	Any	Any	Recurrent	Recurrent	—
Age, y	≥65	—	>60	≥65	≥65[†]	—
Coagulopathy	—	Any	—	Any	Any[†]	Any
Focal deficit	—	Any	—	Any	Any	Any
Seizure	—	History	Any	—	Any	Any
LOC	If GCS=14	Any	—	—	—	Any
Visible trauma	—	—	Above clavicles	Scalp hematoma	—	Multiple injuries
Headache	—	Any	Severe	—	—	—
Injury mechanism	Dangerous*[‡]	—	—	—	Dangerous[†‡]	—
Intoxication	—	Abuse history	Drug, alcohol	—	—	—
Previous neurosurgery	—	Yes	—	—	—	Shunt

NCWFNS, Neurotraumatology Committee of the World Federation of Neurosurgical Societies; *NICE,* National Institute of Clinical Excellence; —, indicates the item is not considered an indication for CT scanning by author(s) of the rule; *LOC,* loss of consciousness.
*Used to determine medium risk for the Canadian Rule.
†CT scan only if also loss of consciousness or any amnesia.
‡Dangerous injury mechanism=ejected from motor vehicle, pedestrian struck by motor vehicle, fall of >3 feet or 5 steps.

whether delayed surgery had been performed. The original study was approved by the institutional review board. All identifying characteristics were removed from the original database before the present analysis, thus exempting it from institutional review board approval.

We defined 3 outcome categories for the analysis: a surgical intracranial lesion is an intracranial hematoma large enough to require surgical evacuation; a nonsurgical lesion is an intracranial abnormality diagnosed on CT scan (cerebral contusion, subarachnoid hemorrhage, etc) that does not require surgical treatment. All other subjects were considered to have no lesion. We elected not to consider fractures as lesions unless they were associated with intracranial abnormality on CT scan. We recognize that depressed skull fractures may require operative intervention. However, this is often for cosmetic reasons or to prevent infection. In contrast to an intracranial hematoma, an isolated depressed fracture is not considered a risk to life or to neurologic function.

We evaluated 6 clinical decision strategies that are commonly used to determine whether to obtain a CT scan in patients presenting with mild traumatic brain injury. These include the Canadian CT Head Rule (Canadian),[14] the Neurotraumatology Committee of the World Federation of Neurosurgical Societies,[13] the New Orleans,[10] the National Emergency X-Radiography Utilization Study II (NEXUS-II)[12], the National Institute of Clinical Excellence,[9] and the Scandinavian Neurotrauma Committee guidelines (Scandinavian).[11] The risk factors used by the aids are summarized in Table 1.

The Canadian rule is a 7-item rule that stratifies patients into low-, medium-, and high-risk lesion categories. High-risk patients are at greatest risk for requiring neurosurgical intervention, whereas medium-risk patients are likely to have both surgical and nonsurgical lesions. CT is considered mandatory for high-risk patients and is recommended for medium-risk patients. For our evaluation, we estimate 2 sets of test characteristics, one set when CT is ordered for high-risk patients but not for medium-risk patients (referred to as Canadian high-risk rule) and a second set when CT is ordered for all high- and medium-risk patients (referred to as Canadian medium- and high-risk rule).

The Neurotraumatology Committee of the World Federation of Neurosurgical Societies instrument is an 11-item strategy that stratifies patients into low-, medium-, and high-risk categories. Low-risk patients are sent home without radiologic imaging. Both medium- and high-risk patients receive CT imaging (the difference between the risk groups is observed in follow-up after CT).

The New Orleans strategy is an 8-item aid that was originally devised for the management of patients with GCS scores of 15. Possession of any one of the clinical items indicates the need for a CT scan before hospital discharge. Although not addressed by the authors, we have expanded it to include CT scanning for all patients presenting with GCS scores of 14.

The NEXUS-II instrument contains 7 items, the presence of any of which indicates the need for a scan.

The National Institute of Clinical Excellence is a 9-item strategy that identifies patients in need of CT scans. A scan is indicated for a patient whose mild traumatic brain injury is accompanied by any of the risk factors.

Finally, the Scandinavian guideline is a 9-item strategy that recommends a CT scan for all patients with mild traumatic brain injury and at least 1 risk factor. If no such factors are present, hospital discharge is recommended.

All 6 instruments consider GCS score either at presentation or 2 hours after injury, but none of the 6 aids consider all of the same findings. All 6 consider suspected fracture (any; open, depressed, basal; or basal, depressed, or radiologically confirmed) or injury above the clavicles an indication for CT scanning. Five of the 6 aids consider amnesia or vomiting. For example, only NEXUS-II fails to consider amnesia. Four strategies each consider age, coagulopathy, focal deficit, and seizure (eg, the Neurotraumatology Committee of the World Federation of Neurosurgical Societies and Scandinavian instruments fail to consider age; the Canadian rule and New Orleans aids omit coagulopathy). Three each consider loss of consciousness and visible trauma; 2 each consider headache, injury mechanism, intoxication, and previous neurosurgery. Coagulopathy, focal deficit, and injury mechanism are all defined the same way by the 2 to 4 aids that use them. None of the remaining 11 findings are defined exactly the same way by all of the aids that use them (eg, the Canadian rules consider retrograde amnesia >30 minutes, the New Orleans aid considers antegrade amnesia, and the Scandinavian guideline considers any amnesia).

Primary Data Analysis

We assessed individual patient characteristics relevant to each of the decision aids from the database, as summarized below. All analyses were done with Stata 9.0 (StataCorp, College Station, TX).

We assessed the operating characteristics of individual findings that were used in at least 1 of the aids by reporting the proportion of patients with the finding stratified by outcome (eg, the proportion of patients with hematoma who had a GCS score <15 on admission to the ED, the proportion of patients with nonsurgical lesions who had a GCS score <15 on admission, and the proportion of patients with no lesion who had a GCS score <15 on admission). These data provide evidence about the predictive ability of individual characteristics included in the instruments but do not report on the operating characteristics of the strategies themselves.

We also assessed these operating characteristics by calculating the area under the receiver operating characteristic curve for the individual findings. Areas are reported for hematoma versus other diagnosis, any lesion versus no lesion, and hematoma versus nonsurgical lesion. These areas, which range between 0.5 and 1.0, represent a summary measure of the sensitivity and specificity of the characteristics.[48] We identified the most discriminating characteristics as those with receiver operating characteristic areas greater than 0.7.

We assessed the operating characteristics of the aids by reporting their sensitivity and specificity. Sensitivities were calculated for hematomas, nonsurgical lesions, and any lesion; specificities were calculated for no lesion and for no hematoma. These different categorizations allow the assessment of the aids' abilities to identify hematomas, as well as any lesions. We derived 95% confidence intervals for the single proportions representing sensitivity and specificity by use of a formula by Fleiss.[49] We tested for statistically significant differences between the aids' sensitivities and specificities by use of Fisher exact tests. We also assessed the value of potential tradeoffs between sensitivity and specificity by use of a formula that takes into account the probability of lesions and the incremental benefits associated with both the correct identification of a lesion and the avoidance of an unnecessary evaluation.[50] This formula equates the expected value of correctly diagnosing a patient needing treatment with the expected value of correctly limiting the use of medical services for a patient without a lesion. We also summarized which patients would have received CT scans had each of the decision strategies been followed.

Finally, we report on the characteristics of the 5 patients whose hematomas were missed by 1 or more decision instruments.

RESULTS

Characteristics of Study Subjects

Data were collected for a total of 9,464 patient encounters. Records for 1,509 were excluded from further review for the reasons listed above. This left a total of 7,955 patients in the sample. The median age was 44 years (interquartile range 27 to 71 years), and 55.5% of the patients were men. The median injury-to-admission time was 60 minutes (interquartile range 42 to 110 minutes). Intracranial lesions were found in 6.7% of patients (1.4% hematomas requiring evacuation and 5.3% nonsurgical lesions). Median time from injury to presentation at the ED was 60 minutes; 3.6% of the injuries were due to assaults, 38.9% to falls, 48.6% to motor vehicle crashes, 1.6% to sports injuries, and 7.3% to work accidents. CT scans were performed on 4,177 (52.5%) patients. Other patients were meant to receive CT, although when the study was started, CT scanning was not available out of hours but only on demand, according to the severity of trauma judged by the attending physician. Glasgow Outcome Scale at 6 months was obtained for 514 (96.8%) of the 531 patients with intracranial lesions. Further details of this sample are reported elsewhere.[18]

Table 2 shows the sensitivities for hematoma and for nonsurgical lesions and the specificities for no lesion for the individual findings included in one or more of the 6 decision aids, stratified by outcome (columns 2 to 4). It also reports the areas under the receiver operating characteristic curves for each of the findings for discriminating between hematomas and all other diagnoses (column 5), between lesions (hematomas and nonsurgical lesions) and no lesions (column 6), and between hematomas and nonsurgical lesions (column 7). If the primary objective of the strategy is to maximize the use of CT scans among those with hematomas while minimizing the use of these scans among patients with other outcomes, the most discriminating individual findings (receiver operating characteristic areas >0.7) are GCS score less than 15 on ED admission (receiver operating characteristic area 0.92), any headache (0.858), focal deficit

Table 2. Operating characteristics of individual findings included in one or more of the 6 decision rules.

Finding	Sensitivity, Hematoma n=107	Sensitivity, Nonsurgical Lesion, n=424	Specificity, No Lesion, n=7,424	Area Under Receiver Operating Characteristic Curves: Hematoma vs Other Diagnosis*	Any vs No Lesion	Hematoma vs Nonsurgical Lesion
GCS score <15						
On ED admission	90.7	72.4	97.0	0.920	0.865	0.591
At 2 h	78.5	62.5	97.7	0.865	0.817	0.580
Amnesia						
Antegrade	57.0	26.4	89.2	0.727	0.609	0.653
Retrograde	50.5	46.7	64.1	0.570	0.558	0.519
Any	73.8	67.0	56.9	0.647	0.626	0.534
Suspected fracture						
Basilar	24.3	15.1	99.9	0.617	0.584	0.546
Depressed	11.2	1.7	100.0	0.514	0.506	0.510
Open	2.8	0.7	100.0	0.556	0.518	0.548
Any	40.2	32.1	99.1	0.688	0.664	0.541
Vomiting						
Multiple	26.2	13.9	97.4	0.615	0.569	0.561
Any	46.7	25.0	95.5	0.706	0.624	0.609
Age, y						
>60	31.8	45.0	66.3	0.513	0.543	0.564
≥65	29.9	36.1	85.3	0.570	0.601	0.531
Coagulopathy	10.3	13.2	97.3	0.535	0.55	0.515
Focal deficit	54.2	43.2	98.8	0.754	0.721	0.555
Seizure						
By history	1.9	2.8	97.5	0.503	0.501	0.505
Any	4.7	9.7	99.3	0.517	0.540	0.525
Loss of consciousness						
If GCS score <15	47.7	37.7	98.7	0.722	0.692	0.550
Any	57.0	54.0	82.5	0.688	0.686	0.515
Visible trauma						
Above clavicles	41.1	35.6	76.0	0.582	0.564	0.528
Multiple injuries	29.9	19.1	81.3	0.556	0.513	0.554
Scalp	10.3	9.0	93.6	0.519	0.514	0.507
Headache						
Severe	43.0	10.8	94.3	0.685	0.558	0.661
Any	89.7	44.3	83.4	0.858	0.684	0.727
Dangerous injury mechanism	59.8	41.7	88.9	0.735	0.671	0.590
Intoxication						
Drug or alcohol	14.0	30.9	97.0	0.548	0.622	0.416
Abuse history	32.7	26.2	91.6	0.617	0.595	0.533
Previous neurosurgery						
CSF shunt	0.0	0.0	100.0	0.500	0.500	0.500
Any	2.8	3.8	98.0	0.504	0.508	0.505

CSF, Cerebrospinal fluid.
*Other=no lesion or intracranial lesion other than hematoma.

(0.754), dangerous injury mechanism (0.735), antegrade amnesia (0.727), loss of consciousness if GCS score is less than 15 (0.722), and any vomiting (0.706). On the other hand, suspected depressed fracture, age greater than 60 years, coagulopathy, seizure by history and any seizure, visible trauma to the scalp, CSF shunt, and previous neurosurgery by themselves had little or no discriminating ability.

Only GCS score less than 15 on ED admission or after 2 hours (receiver operating characteristic area 0.865 and 0.817, respectively) and focal deficit (0.721) had receiver operating characteristic areas greater than 0.7 for discriminating between intracranial lesions and no lesions. Findings with receiver operating characteristic areas greater than 0.65 included loss of consciousness if GCS score less than 15 (0.692), any headache (0.684), dangerous injury mechanism (0.671), and any suspected fracture (0.664). Any headache had a receiver operating characteristic area of 0.727 for discriminating between hematomas and nonsurgical lesions, and antegrade amnesia had an area of 0.653. Otherwise, there were no variables that strongly discriminated between these 2 outcomes.

Table 3. Operating characteristics for the 6 decision rules for CT scanning in mild traumatic brain injury.

	Sensitivity (95% CI)			Specificity (95% CI)	
Strategy	Hematoma	Nonsurgical Lesion	Any Lesion	No Hematoma	No Lesion
Canadian (high-risk only)	0.99 (0.94–1.00)	0.97 (0.94–0.98)	0.97 (0.95–0.98)	0.48 (0.47–0.49)	0.51 (0.49–0.52)
Canadian (medium/high risk)	0.99 (0.94–1.00)	0.99 (0.97–1.00)	0.99 (0.98–1.00)	0.45 (0.44–0.46)	0.47 (0.46–0.48)
Neurotraumatology Committee of the World Federation of Neurosurgical Societies	0.99 (0.94–1.00)	0.95 (0.93–0.97)	0.96 (0.94–0.97)	0.45 (0.44–0.46)	0.47 (0.46–0.48)
New Orleans	0.99 (0.94–1.00)	0.99 (0.97–1.00)	0.99 (0.98–1.00)	0.31 (0.30–0.32)	0.33 (0.32–0.34)
Nexus-II	1.00 (0.97–1.00)	0.97 (0.94–0.98)	0.97 (0.96–0.98)	0.44 (0.43–0.46)	0.47 (0.46–0.48)
National Institute of Clinical Excellence	0.98 (0.93–1.00)	1.00 (0.99–1.00)	0.99 (0.98–1.00)	0.29 (0.28–0.30)	0.31 (0.30–0.32)
Scandinavian	0.99 (0.94–0.99)	0.95 (0.92–0.97)	0.96 (0.93–0.97)	0.50 (0.49–0.51)	0.53 (0.52–0.54)

Table 3 compares the operating characteristics of the 6 decision instruments. Although NEXUS-II missed no hematomas, National Institute of Clinical Excellence missed 2, and the remaining aids each missed 1 (but not generally the same) hematoma, there was insufficient power to conclude that any of the aids differed in their ability to correctly classify those with hematoma (minimum $P=.50$ [Fisher exact], between NEXUS-II and National Institute of Clinical Excellence). Thus, the principal tradeoff between the aids is in their correct classification of those with nonsurgical lesion and with no lesion.

National Institute of Clinical Excellence correctly classified all patients with nonsurgical lesions, and except for the Canadian medium- and high-risk and New Orleans aids ($P=.12$), its ability to correctly classify these lesions was significantly greater ($P<.000$) than that of the other aids. The Canadian medium- and high-risk rules and New Orleans aid had a significantly greater ability to correctly classify nonsurgical lesions (P ranging between .000 and .03) than did the Canadian high-risk, Neurotraumatology Committee of the World Federation of Neurosurgical Societies, NEXUS, and Scandinavian guidelines. The Canadian high-risk, Neurotraumatology Committee of the World Federation of Neurosurgical Societies, NEXUS-II, and Scandinavian aids could not be statistically distinguished from one another in their ability to correctly classify nonsurgical lesions.

The Scandinavian guideline correctly classified 52.9% of those with no lesion, which was significantly more than all other aids ($P=.004$ versus Canadian high risk; $P<.000$ for all other aids). The Canadian high-risk rule's 50.5% correct classification rate was significantly greater ($P<.000$) than all of the other aids except the Scandinavian guideline. The Canadian medium- and high-risk, Neurotraumatology Committee of the World Federation of Neurosurgical Societies, and NEXUS-II correctly classified approximately 47% of those with no lesion and could not be distinguished statistically from one another. Finally, the New Orleans and National Institute of Clinical Excellence aids correctly classified approximately 31% of those with no lesion, and their correct classification rates were significantly lower than those of the other 5 aids ($P<.000$). Table 4 summarizes the numbers of patients meeting CT scan criteria for each of the decision instruments. It shows the numbers of patients with and without lesions each strategy would have correctly and incorrectly categorized. The Scandinavian guideline would have recommended the fewest CT scans (4,005), whereas the National Institute of Clinical Excellence guidelines would have recommended the most (5,659).

Five patients with surgical hematomas would have been missed by at least 1 of the decision aids. Only 1 would have been missed by more than 1 strategy. A 91-year-old with no other findings would have been missed by both the Neurotraumatology Committee of the World Federation of Neurosurgical Societies and the Scandinavian aids. A patient whose GCS score on admission (30 minutes after injury) was 14 but improved to 15 by 2 hours would have been missed by both Canadian rules. This patient also had coagulopathy. One patient whose amnesia was retrograde only would have been missed by the New Orleans aid. Finally, 2 patients who presented with a history of loss of consciousness, but were otherwise neurologically normal, would have been missed by National Institute of Clinical Excellence.

LIMITATIONS

An important limitation of this study is that not all patients received CT scans and that follow-up is incomplete. Therefore, we cannot be certain that all patients with intracranial lesions are included. The data used for our analysis were originally collected prospectively to evaluate a less comprehensive set of decision aids. The database may thus not contain the precise data elements required by the other decision instruments. For example, the 2 Canadian rules require that a GCS score be obtained 2 hours after injury. In contrast, our database records the later score 2 hours after ED admission, a difference that may affect our results somewhat. Our retrospective analysis assumes each decision aid would be applied as written, a situation that rarely occurs in clinical use. Another limitation with our study is that we could not evaluate the prediction rule Smits et al[16]

Table 4. Number of recommendations for CT scanning, stratified by outcome.

	CT Scan Recommended				No CT Scan Recommended			
Decision Aid	Hematoma	Other Lesion	No Lesion	Total	Hematoma	Other Lesion	No Lesion	Total
Canadian (high risk only)	106	410	3,675	4,191	1	14	3,749	3,764
Canadian (medium/high risk)	106	420	3,912	4,438	1	4	3,512	3,517
Neurotraumatology Committee of the World Federation of Neurosurgical Societies	106	404	3,920	4,430	1	20	3,504	3,525
New Orleans	106	420	4,996	5,522	1	4	2,428	2,433
NEXUS-II	107	410	3,950	4,467	0	14	3,474	3,488
National Institute of Clinical Excellence	105	424	5,130	5,659	2	0	2,294	2,296
Scandinavian	106	402	3,497	4,005	1	22	3,927	3,950

recently proposed for traumatic brain injury patients at least 16 years old and with GCS scores of 13 to 15. Although this rule is relevant to our patient population, we are unable to evaluate it, in part because the rule requires evaluation of clinical data that were not collected as a part of the database we used. Missing data elements include specific mechanisms of injury, duration of posttraumatic amnesia, and GCS scores at 1 hour (rather than 2 hours).

An additional limitation is that patients in the database we used may be older (median age 44 years; 16% ≥65 years) than the previously reported population with minor traumatic brain injury. This age difference may mean that aids that use older age as a criterion for CT scans (Canadian, New Orleans, NEXUS-II, and National Institute of Clinical Excellence) may be unfairly advantaged in terms of sensitivity. It also may mean that results from this database are not fully generalizable to other settings. However, the ageing of the population makes the elderly the fastest-growing segment to seek emergency care for traumatic brain injury; hence, their injuries are of growing importance.[51,52]

DISCUSSION

We found that the 6 instruments could not be distinguished statistically in their ability to identify surgical hematoma. Thus, the primary distinguishing characteristics of the aids are their ability to correctly identify nonsurgical lesions versus no lesions. National Institute of Clinical Excellence, the Canadian medium- and high-risk, and the New Orleans aids could not be distinguished statistically from one another in their ability to correctly identify nonsurgical lesions, and all 3 were significantly better at identifying these lesions than were the remaining aids. The Scandinavian guideline was significantly better at identifying patients with no lesions than were the other aids and was followed by the Canadian high-risk rule. The choice among these aids, then, comes down to the benefit and relative frequency of correct classification of those with nonsurgical and no lesions.

In our previous work,[53] we found that identification of nonsurgical lesions had little or no benefit, principally because nonsurgical lesions have few if any long-term sequelae and there is no proven advantage to early treatment. We also found that correct identification of those without lesions avoided extra evaluation costs, including performance of a CT scan, with its attendant exposure to potentially harmful radiation. Although not trivial, the effective dose of radiation caused by a single head CT scan in an adult or older child does not exceed the annual dose from background radiation.[54] In addition, as indicated by the registry data, the probability of no lesion (and thus the number of individuals who can be correctly identified as having no lesion) is substantially greater than the probability of nonsurgical lesions. All 3 of these findings suggest one should weigh gains in specificity more than one does gains in the probability of correctly identifying lesions other than surgical hematomas. For example, suppose that the ratio of the benefit from avoiding the evaluation of a patient without a lesion equals the benefit from correctly identifying a nonsurgical lesion. Suppose also that, as in the registry data we used, the prevalence of no lesion is approximately 17.5 times greater than the prevalence of nonsurgical lesions (93.32% versus 5.33%). In this case, one would equate a 1-percentage-point improvement in specificity to a 17.5-percentage-point improvement in the ability to detect nonsurgical lesions (ie, so long as one gives up less than 17.5 percentage points in the ability to detect nonsurgical lesions to gain 1 percentage point in the ability to identify a patient with no lesion, one should choose the test with the increased specificity). Thus, given that the Scandinavian guideline's specificity is at least 2 percentage points greater than that of all other aids and given that its probability of detecting nonsurgical lesions is no more than 5.2 percentage points less than that of all of the other aids, the evidence supports the adoption of the Scandinavian guideline to determine the need for CT scanning in patients presenting with mild traumatic brain injury.

Although the 6 instruments could not be statistically distinguished in their ability to detect surgical hematoma, 5 of the 6 missed at least 1 hematoma, whereas NEXUS-II did not miss any. Currently, we cannot be confident whether the 1-percentage-point difference in sensitivity exists. Furthermore, given the relative infrequency of events, the high sensitivities, and a sample size requirement of thousands of patients with hematoma, it is unlikely that we will be able to know whether they differ within the foreseeable future. Thus, the decision between the NEXUS-II and Scandinavian aids depends on decisionmakers' attitudes toward risk. They should adopt the Scandinavian guideline if they require statistically significant evidence of a difference between therapies before they recommend one decision aid over another because they can be 95% confident that its specificity is greater than that of all of the other decision aids and its sensitivity cannot be distinguished from that of the other aids. They may, on the other hand, be concerned that the similarity in the aids' sensitivities is due more to an absence of evidence for a difference (because of the relatively small number of hematomas) than it is to an actual absence of a difference. In this case, they may not be willing to risk the 1-percentage-point difference in sensitivity, and thus they may want to adopt the NEXUS-II aid.

The Canadian high-risk rule has a better specificity than the NEXUS-II instrument, but it missed 1 patient with hematoma, principally because it uses a 2-hour GCS score less than 15 rather than any GCS score less than 15. According to our findings, the developers of the rule may want to reconsider the use of a 2-hour GCS score in their rule. Changing the GCS score used to indicate the need for CT scanning would have led to the detection of all cases of hematoma. At the same time, it would have reduced the aids' specificity by at most 1 percentage point (Table 2). The resulting 46.9% specificity would still be 2.5 percentage points superior to the 44.4% specificity of the NEXUS-II aid.

In conclusion, we currently are unable to distinguish between the sensitivities of the Scandinavian and NEXUS-II decision instruments. It is unclear whether this finding is due to an absence of a difference or whether it is due to an absence of evidence (ie, too small a sample size) for the difference. Decisionmakers with attitudes towards risk that require evidence of a difference in the sensitivity for hematoma should adopt the Scandinavian guideline because it yields the greatest diminution in the use of CT among those with no lesion with little loss in clinical utility from failing to identify those with lesions. Those whose attitudes toward risk require that we have evidence of an absence of a difference, on the other hand, may want to adopt the NEXUS-II rather than the Scandinavian guideline because NEXUS-II's potentially higher sensitivity would offset its diminished specificity.

Supervising editor: David T. Overton, MD, MBA

Author contributions: SCS conceived of the study. AF and FS collected the original data, constructed the database, and provided data management. HAG provided statistical advice on study design. SCS and HAG analyzed the data. SCS drafted the article, and all authors contributed substantially to its revision. SCS takes responsibility for the paper as a whole.

Funding and support: By *Annals* policy, all authors are required to disclose any and all commercial, financial, and other relationships in any way related to the subject of this article that might create any potential conflict of interest. The authors have stated that no such relationships exist. See the Manuscript Submission Agreement in this issue for examples of specific conflicts covered by this statement.

Publication dates: Received for publication October 31, 2007. Revision received December 18, 2007. Accepted for publication January 7, 2008. Available online March 18, 2008.

Reprints not available from the authors.

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REFERENCES

1. Teasdale G, Jennett B. Assessment of coma and impaired consciousness. A practical scale. *Lancet.* 1974;2:81-84.
2. Reilly PL, Graham DI, Adams JH, et al. Patients with head injury who talk and die. *Lancet.* 1975;2:375-377.
3. Marshall LF, Toole BM, Bowers SA. The National Traumatic Coma Data Bank.Part 2: Patients who talk and deteriorate: implications for treatment. *J Neurosurg.* 1983;59:285-288.
4. Klauber MR, Marshall LF, Luerssen TG, et al. Determinants of head injury mortality: importance of the low risk patient. *Neurosurgery.* 1989;24:31-36.
5. Miller JD, Murray LS, Teasdale GM. Development of a traumatic intracranial hematoma after a "minor" head injury. *Neurosurgery.* 1990;27:669-673.
6. Voss M, Knottenbelt JD, Peden MM. Patients who reattend after head injury: a high risk group. *BMJ.* 1995;311:1395-1398.
7. Dunn LT, Fitzpatrick MO, Beard D, et al. Patients with a head injury who "talk and die" in the 1990s. *J Trauma.* 2003;54:497-502.
8. 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.
9. National Institute for Clinical Excellence. Head Injury Triage, Assessment, Investigation and Early Management of Head Injury in Infants, Children and Adults. Clinical Guideline 56. London, England: National Collaborating Centre for Acute Care at the Royal College of Surgeons of England; 2007.
10. Haydel MJ, Preston CA, Mills TJ, et al. Indications for computed tomography in patients with minor head injury. *N Engl J Med.* 2000; 343:100-105.
11. Ingebrigtsen T, Romner B, Kock-Jensen C. Scandinavian guidelines for initial management of minimal, mild, and moderate head injuries. The Scandinavian Neurotrauma Committee. *J Trauma.* 2000;48:760-766.
12. 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.
13. Servadei F, Teasdale G, Merry G. Defining acute mild head injury in adults: a proposal based on prognostic factors, diagnosis, and management. *J Neurotrauma.* 2001;18:657-664.
14. Stiell IG, Wells GA, Vandemheen K, et al. The Canadian CT Head Rule for patients with minor head injury. *Lancet.* 2001;357:1391-1396.
15. Stiell IG, Lesiuk H, Wells GA, et al. The Canadian CT Head Rule Study for patients with minor head injury: rationale, objectives, and methodology for phase I (derivation). *Ann Emerg Med.* 2001;38:160-169.
16. Smits M, Dippel DW, Steyerberg EW, et al. Predicting intracranial traumatic findings on computed tomography in patients with minor

head injury: the CHIP prediction rule. *Ann Intern Med.* 2007;146:397-405.

17. Dunning J, Lecky F. The NICE guidelines in the real world: a practical perspective. *Emerg Med J.* 2004;21:404-407.
18. Fabbri A, Servadei F, Marchesini G, et al. Prospective validation of a proposal for diagnosis and management of patients attending the emergency department for mild head injury. *J Neurol Neurosurg Psychiatry.* 2004;75:410-416.
19. Hollander JE, Go S, Lowery DW, et al. Interrater reliability of criteria used in assessing blunt head injury patients for intracranial injuries. *Acad Emerg Med.* 2003;10:830-835.
20. 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.
21. 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:e238-246.
22. 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.
23. Stiell IG, Lesiuk H, Wells GA, et al. Canadian CT Head Rule study for patients with minor head injury: methodology for phase II (validation and economic analysis). *Ann Emerg Med.* 2001;38:317-322.
24. Clement CM, Stiell IG, Schull MJ, et al. Clinical features of head injury patients presenting with a Glasgow Coma Scale score of 15 and who require neurosurgical intervention. *Ann Emerg Med.* 2006;48:245-251.
25. Boyle A, Santarius L, Maimaris C. Evaluation of the impact of the Canadian CT Head Rule on British practice. *Emerg Med J.* 2004;21:426-428.
26. Bramley R, Whitehouse RW, Taylor PM. The Canadian CT Head Rule for patients with minor head injury: consequences for radiology departments in the U.K. *Clin Radiol.* 2002;57:151-152; author reply 152-153.
27. Graham ID, Stiell IG, Laupacis A, et al. Emergency physicians' attitudes toward and use of clinical decision rules for radiography. *Acad Emerg Med.* 1998;5:134-140.
28. Muller K, Waterloo K, Romner B, et al. Mild head injuries: impact of a national strategy for implementation of management guidelines. *J Trauma.* 2003;55:1029-1034.
29. Shravat BP, Huseyin TS, Hynes KA. NICE guideline for the management of head injury: an audit demonstrating its impact on a district general hospital, with a cost analysis for England and Wales. *Emerg Med J.* 2006;23:109-113.
30. Sultan HY, Boyle A, Pereira M, et al. Application of the Canadian CT Head Rules in managing minor head injuries in a UK emergency department: implications for the implementation of the NICE guidelines. *Emerg Med J.* 2004;21:420-425.
31. Viola L, Zotta D, Martino V, et al. Minor head injuries: one year experience according to the new Italian guideline. *Acta Neurochir.* 2000;142:1281-1285.
32. Haydel MJ. The Canadian CT Head Rule. *Lancet.* 2001;358:1013-1014.
33. Haydel MJ. Clinical decision instruments for CT scanning in minor head injury. *JAMA.* 2005;294:1551-1553.
34. Maharaj I, Tosiello L. The Canadian CT Head Rule. *Lancet.* 2001;358:1013; author reply 1014.
35. Schwam E. CT scanning for minor head injury. *JAMA.* 2006;295:497; author reply 497-498.
36. Smits M, Dippel DWJ, Hunink MGM. CT scanning for minor head injury. *JAMA.* 2006;295:497-498.
37. Stiell IG. Clinical decision rules in the emergency department. *CMAJ.* 2000;163:1465-1466.
38. Stiell IG, Clement CM, Rowe BH, et al. CT scanning for minor head injury. *JAMA.* 2006;295:498.
39. Stiell IG, Wells GA. The Canadian CT Head Rule: authors' reply. *Lancet.* 2001;358:1013.
40. Falimirski ME, Gonzalez R, Rodriguez A, et al. The need for head computed tomography in patients sustaining loss of consciousness after mild head injury. *J Trauma.* 2003;55:1-6.
41. Lee JB. NICE head injury guidelines: cost implication for a district general hospital ("six scans to six figures"). *Emerg Med J.* 2004;21:125-126.
42. Macgregor DM, McKie L. CT or not CT—that is the question. Whether 'tis better to evaluate clinically and x ray than to undertake a CT head scan! *Emerg Med J.* 2005;22:541-543.
43. Miller L, Kent RM, Tennant A. Audit of head injury management in accident and emergency at two hospitals: implications for NICE CT guidelines. *BMC Health Serv Res.* 2004;4:7.
44. Fabbri A, Servadei F, Marchesini G, et al. Clinical performance of NICE recommendations versus NCWFNS proposal in patients with mild head injury. *J Neurotrauma.* 2005;22:1419-1427.
45. Ibanez J, Arikan F, Pedraza S, et al. Reliability of clinical guidelines in the detection of patients at risk following mild head injury: results of a prospective study. *J Neurosurg.* 2004;100:825-834.
46. Qushmaq I, Cook DJ. The Canadian CT Head Rule was as sensitive as, but more specific than, the New Orleans Criteria for identifying minor head injury. *ACP J Club.* 2006;144:53.
47. 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.
48. Linden A. Measuring diagnostic and predictive accuracy in disease management: an introduction to receiver operating characteristic (ROC) analysis. *J Eval Clin Pract.* 2006;12:132-139.
49. Fleiss JL. *Statistical Methods for Rates and Proportions.* 2nd ed. New York, NY: Wiley Interscience; 1981:14.
50. Sox HC, Blatt MA, Higgins MC, et al. *Medical Decision Making.* Burlington, MA: Butterworth-Heinemann; 1988:135.
51. Bazarian JJ, McClung J, Shah MN, et al. Mild traumatic brain injury in the United States, 1998-2000. *Brain Inj.* 2005;19:85-91.
52. Mack LR, Chan SB, Silva JC, et al. The use of head computed tomography in elderly patients sustaining minor head trauma. *J Emerg Med.* 2003;24:157-162.
53. Stein SC, Burnett MG, Glick HA. Indications for CT scanning in mild traumatic brain injury: a cost-effectiveness study. *J Trauma.* 2006;61:558-566.
54. Huda W, Vance A. Patient radiation doses from adult and pediatric CT. *AJR Am J Roentgenol.* 2007;188:540-546.