Annals of Internal Medicine | ARTICLE

Predicting Intracranial Traumatic Findings on Computed Tomography in Patients with Minor Head Injury: The CHIP Prediction Rule

Marion Smits, MD; Diederik W.J. Dippel, MD, PhD; Ewout W. Steyerberg, MD, PhD; Gijs G. de Haan, MD; Helena M. Dekker, MD; Pieter E. Vos, MD, PhD; Digna R. Kool, MD; Paul J. Nederkoorn, MD, PhD; Paul A.M. Hofman, MD, PhD; Albert Twijnstra, MD, PhD; Hervé L.J. Tanghe, MD; and M.G. Myriam Hunink, MD, PhD

Background: Prediction rules for patients with minor head injury suggest that the use of computed tomography (CT) may be limited to certain patients at risk for intracranial complications. These rules apply only to patients with a history of loss of consciousness, which is frequently absent.

Objective: To develop a prediction rule for the use of CT in patients with minor head injury, regardless of the presence or absence of a history of loss of consciousness.

Design: Prospective, observational study.

Setting: 4 university hospitals in the Netherlands that participated in the CT in Head Injury Patients (CHIP) study.

Patients: Consecutive adult patients with minor head injury (≥16 years of age) with a Glasgow Coma Scale (GCS) score of 13 to 14 or with a GCS score of 15 and at least 1 risk factor.

Measurements: Outcomes were any intracranial traumatic CT finding and neurosurgical intervention. The authors performed logistic regression analysis by using variables from existing prediction rules and guidelines, with internal validation by using bootstrapping.

Results: 3181 patients were included (February 2002 to August 2004): 243 (7.6%) had intracranial traumatic CT findings and 17 (0.5%) underwent neurosurgical intervention. A detailed prediction rule was developed from which a simple rule was derived. Sensitivity of both rules was 100% for neurosurgical interventions, with an associated specificity of 23% to 30%. For intracranial traumatic CT findings, sensitivity and specificity were 94% to 96% and 25% to 32%, respectively. Potential CT reduction by implementing the prediction rule was 23% to 30%. Internal validation showed slight optimism for the model's performance.

Limitation: External validation of the prediction model will be required.

Conclusion: The authors propose the highly sensitive CHIP prediction rule for the selective use of CT in patients with minor head injury with or without loss of consciousness.

Ann Intern Med. 2007;146:397-405. www.annals.org
For author affiliations, see end of text.

Minor head injury is one of the most common injuries seen in western emergency departments, with an estimated incidence of 100 to 300 per 100 000 people (1). Patients with minor head injury include those with blunt injury to the head who have a normal or minimally altered level of consciousness on presentation in the emergency department, that is, a Glasgow Coma Scale (GCS) score of 13 to 15, and a maximum loss of consciousness of 15 minutes, posttraumatic amnesia for 60 minutes, or both (2).

Intracranial complications after minor head injury are infrequent but commonly require in-hospital observation and occasionally require neurosurgical intervention (3, 4). The imaging procedure of choice for reliable, rapid diagnosis of intracranial complications is computed tomography (CT) (5, 6). Because most patients with minor head injury do not show traumatic abnormalities on CT, it seems inefficient to scan all patients with minor head injury to exclude intracranial complications. Of the published prediction rules for the selective use of CT in patients with minor head injury, the New Orleans Criteria (NOC) and the Canadian CT Head Rule (CCHR) have been externally validated (7–9). Researchers in internal and external validation studies have shown that both rules identify 100% of patients requiring neurosurgical intervention and most patients with traumatic intracranial findings on CT (3, 10–12). The external validation studies, however, yielded lower specificities than the development studies (10, 12). The originally reported specificities were probably too optimistic because of their partial derivation from data sets that were also used for the model development (13). Also, in both studies researchers included only a subset of patients with minor head injury. Most notably, researchers developed the NOC and the CCHR for patients with minor head injury who have a history of loss of consciousness or amnesia, which many of these patients presenting to emergency departments do not have. Generalizability of the NOC and the CCHR is therefore limited.

We aimed to develop a widely applicable and easy-to-implement prediction rule for the selective use of CT in all patients with minor head injury with or without a history of loss of consciousness. To avoid optimism for the model's performance, we used penalty factors and internal val-

See also:

Print
Editors' Notes 398
Summary for Patients I-55

Web-Only
Appendix Tables
Conversion of figures and tables into slides

Context

Available prediction rules to guide selective use of computed tomography in patients with minor head injuries were developed for use in patients with a history of loss of consciousness.

Contribution

This prospective study included 3181 adults with minor head injury with or without loss of consciousness. A prediction rule based on risk factors (such as age; Glasgow Coma Scale score; skull fracture; and posttraumatic vomiting, amnesia, or seizure) successfully identified patients who had intracranial computed tomography findings (sensitivity, approximately 95%) or neurosurgical intervention (sensitivity, 100%).

Caution

External validation in different populations is needed before widespread application of the rule.

—The Editors

idation by using bootstrapping procedures to attain more realistic predictions of the model's performance in an external patient population (13).

METHODS

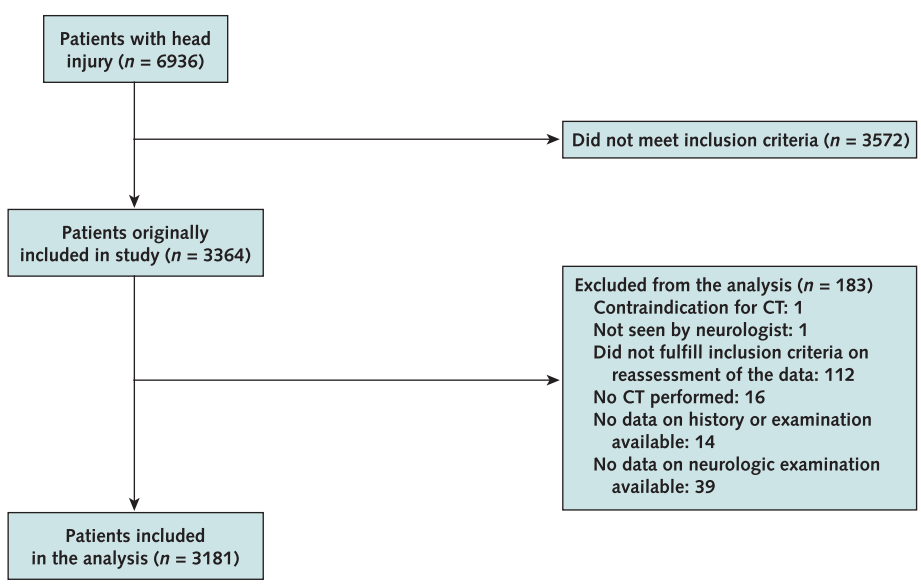
Patients

We prospectively collected data on consecutive patients in 4 university hospitals in the Netherlands that were participating in the CT in Head Injury Patients (CHIP) study (**Figure 1**) (14). Inclusion criteria included initial presentation within 24 hours of blunt injury to the head, a minimum age of 16 years, and a Glasgow Coma Scale (GCS) score of 13 to 14 or a GCS score of 15, with at least 1 of the following risk factors: history of loss of consciousness, short-term memory deficit, amnesia for the traumatic event, posttraumatic seizure, vomiting, severe headache, clinical evidence of intoxication with alcohol or drugs, use of anticoagulants or history of coagulopathy, external evidence of injury above the clavicles, and neurologic deficit. Exclusion criteria were transfer from another hospital, contraindications for CT, or concurrent injuries precluding a head CT at presentation.

A neurologist or a neurologist-in-training under telephone supervision of a neurologist examined patients, after which a head CT was performed as soon as possible, in accordance with the current Dutch guidelines (15). We performed head CT according to a routine trauma protocol, with a maximum slice thickness of 5 mm infratentorially and 8 mm supratentorially, without intravenous contrast administration. A neuroradiologist or a trauma radiologist (9 in total, not blinded to the patients' history and clinical findings) interpreted scans in brain and bone window settings.

The institutional review board waived patient informed consent after review of our study protocol because current Dutch guidelines and European Federation of Neurological Societies' guidelines recommend routine head CT for patients meeting our inclusion criteria (15, 16).

Figure 1. **Study flow diagram.**



The number of patients presenting with head injury is an estimate based on the proportion of patients included out of the total number of trauma patients seen by a neurologist or neurologist-in-training in the emergency department of the participating center that included most patients. CT = computed tomography.

Definitions

We considered a patient to have a history of loss of consciousness when a witness or the patient reported it. We defined short-term memory deficit as persistent anterograde amnesia. We deemed amnesia present for the traumatic event if the patient could not recall the entire traumatic event. We defined posttraumatic seizure as a seizure witnessed or suspected after the injury and vomiting as an episode of emesis after the traumatic event. We classified headache as being either diffuse or localized. We evaluated the presence and severity of intoxication clinically by evidence of slurred speech, alcoholic fetor, or nystagmus; we did not perform routine blood toxicology tests. Anticoagulant treatment included only coumarin derivatives. We scored the use of platelet aggregation inhibitors (for example, aspirin and clopidrogel), but we did not consider it to be a risk factor. We assessed noniatrogenic coagulopathy, which we considered a risk factor, by patient history, but we did not perform routine blood coagulation tests. We defined external evidence of injury as clinically significant discontinuity of the skin or extensive bruising. We classified injury suspect of a fracture as clinical signs of fracture, whereas we classified other injuries, such as contusions, lacerations, or abrasions, as contusion. We defined focal neurologic deficit as any abnormality on routine clinical neurologic examination that indicated a focal cerebral lesion.

Data Collection

We collected data on patient and trauma characteristics, symptoms, and risk factors; physical and neurologic examination; CT findings; and neurosurgical intervention. Examining physicians entered data on patient history and examination into a database (OpenSDE, Erasmus MC–University Medical Center Rotterdam, Rotterdam, the Netherlands) before the patient underwent CT. If this interfered with their clinical workflow, they entered the data after the CT (17). The reading radiologist added the CT findings. We collected data on neurosurgical intervention, additional CT scans performed, and the clinical outcomes of patients by searching the hospital's patient information system.

Outcome Measures

Our primary outcome measure for this analysis was any intracranial traumatic finding on CT, which included all neurocranial traumatic findings except for isolated linear skull fractures. A secondary outcome measure was neurosurgical intervention contingent to initial CT. We defined neurosurgical intervention as any neurosurgical procedure (craniotomy, intracranial pressure monitoring, elevation of skull fracture, or ventricular drainage) within 30 days of the traumatic event.

Risk Factors

We selected all of the risk factors from the NOC and the CCHR (7, 9): age, headache, vomiting, intoxication, persistent anterograde amnesia, retrograde amnesia more than 30 minutes, injury above the clavicles (including clinical signs of skull or basal skull fracture), GCS score less than 15 at 2 hours postinjury, and dangerous trauma mechanism (pedestrian vs. vehicle, fall from height, and ejected from motor vehicle). We tested other risk factors from clinical guidelines for the use of CT in minor head injury (15, 16, 18–21) for additional effects. We combined the variables cyclist versus vehicle and pedestrian versus vehicle into 1 variable (pedestrian or cyclist vs. vehicle) for statistical analysis because they are similar trauma mechanisms.

Statistical Analysis

We based sample size on an estimated 25 variables for multivariable logistic regression analysis. For reliable analysis, we required at least 10 events of the primary outcome measure per variable, that is, 250 events for 25 variables (22). Given an incidence of traumatic findings on CT of 8% to 10%, we needed to include 3125 patients.

We assumed that missing data were missing at random, and we imputed them on the basis of the available data means to avoid bias (23–27). The proportion of imputed data was 3.8%, which included items documented as unknown and items that were not documented. Of all cases, 1956 (62%) were complete. Loss of consciousness and posttraumatic amnesia had the highest proportion of missing or unknown data (18% and 10%, respectively). We imputed both as present on the basis of the available variable means and as consistent with clinical practice. We used the entire data set, after missing value imputation, for all analyses.

We evaluated the study sample for demographic characteristics, mechanism of injury, traumatic findings, neurosurgical intervention, GCS scores, and the presence of risk factors.

We tested associations of each risk factor with the primary outcome measure using chi-square tests for nominal variables, the Mann–Whitney U test for ordinal variables, and the unpaired 2-tailed *t*-test for continuous variables by using SPSS software, version 12.0 (SPSS Inc., Chicago, Illinois). We calculated odds ratios with the Nagelkerke R^2 to compare the predictive strengths of the variables (28).

We used restricted cubic spline functions to assess the linearity of effect for continuous variables (29). We selected variables for the final prediction model on the basis of the statistical and clinical criteria. We used multivariable logistic regression with backward stepwise selection with a *P* value greater than 0.05 for removal of variables, but we forced variables that we considered to have great clinical relevance back into the model. We assessed additional risk factors from clinical guidelines for possible additional effects. We entered separately methodological variables that we considered to be clinically irrelevant into the final model to assess unexpected effects. We did not examine interaction terms but relied on the main effects of the predictors (22). We calculated odds ratios based on the mod-

Table 1. **Patient Characteristics***

Characteristic	Value	GCS Score of 15, *n (%)*	GCS Score of 14, *n (%)*	GCS Score of 13, *n (%)*
Mean patient age (range), *y*	41 (16–102)			
Men, *n (%)*	2246 (70.5)			
Median duration to presentation (range), *h*	1 (0–23.3)			
Intracranial traumatic CT findings				
Absent		2327 (94.5)	491 (86.4)	120 (79.5)
Present		135 (5.5)	77 (13.6)	31 (20.5)
Neurosurgical intervention				
Absent		2452 (99.6)	563 (99.1)	149 (98.7)
Present		10 (0.4)	5 (0.9)	2 (1.3)

* CT = computed tomography; GCS = Glasgow Coma Scale.

el's regression coefficients to optimize the estimated effects of each variable in the study population.

To improve the model's predictions for future similar patient populations, we estimated the final model's regression coefficients by using penalized maximum likelihood procedures (13, 30). We determined the penalty factor by optimizing Akaike information criterion (31).

Performance

We calculated a linear predictor as the sum of each penalized β-coefficient multiplied by the corresponding variables' values. We constructed receiver-operating characteristic (ROC) curves for both outcome measures by using this linear predictor. We defined a cutoff score for a CT scan indication as the point at which sensitivity for neurosurgical intervention was 100% at maximum specificity because this identifies all very high-risk patients, that is, those requiring neurosurgical intervention. Using this cutoff score, we calculated the sensitivity and specificity (and their 95% CIs) for both outcome measures and potential CT scan reduction due to implementing this model (32). We refer to this prediction model as the detailed prediction model.

We also constructed a simple prediction model from the detailed model. We identified major and minor risk factors on the basis of the rounded, penalized β-coefficients and 100% sensitivity for neurosurgical intervention. For the simple prediction model, we categorized continuous variables at suitable cutoff values. We calculated ROC curves and sensitivities and specificities (and their 95% CIs) for both outcome measures (32).

Internal Validation

We assessed internal validity with a bootstrapping procedure for a realistic estimate of the performance of both prediction models in similar future patients. We repeated the entire modeling process, including variable selection and optimum penalty factor search, in 200 samples drawn with replacement from the original sample. We determined the performances of the selected prediction model and the simple rule that were developed from each bootstrap sample in the original sample (30, 33). Performance measures included the average area under the ROC curve, sensitivity and specificity for both outcome measures, and CT reduction at 100% sensitivity for neurosurgical interventions within each bootstrap sample. We validated this by using Harrell's Design library and S-PLUS software, version 6.0 (Insightful Inc., Seattle, Washington).

Role of the Funding Sources

This research was supported by a grant from College voor Zorgverzekeringen (CVZ) and Radiologisch onderzoek Nederland (RADION). The work of the authors was independent of the funding sources. The funding organizations had no involvement in the study design; data collection, analysis, or interpretation; or in the decision to publish the manuscript.

RESULTS

Between 11 February 2002 and 31 August 2004, an estimated 6936 patients with head injury presented to the emergency departments of the participating centers. We did not include 3572 of these patients because they did not meet the inclusion criteria. Of the 3364 patients originally included in the study, we excluded 183 from further analysis for various reasons (**Figure 1**), leaving 3181 patients for the data analysis.

Table 1 shows patient characteristics. We found intracranial traumatic findings on CT in 243 (7.6%) patients. These findings included depressed skull fractures (19 [7.8%] cases), acute subdural (67 [28%] cases) and epidural (35 [14%] cases) hematomas, traumatic subarachnoid hemorrhage (86 [35%] cases), intraparenchymal lesions (142 [58%] cases) consisting mostly of hemorrhagic contusions (118, [49%] cases), and linear (67 [28%] cases) and skull base fractures (53 [22%] cases) in combination with intracranial lesions. Twelve neurosurgeons performed a neurosurgical intervention in 17 patients for epidural hematoma ($n = 8$), acute subdural hematoma ($n = 3$), depressed skull fracture ($n = 3$), and extra-axial hematoma with a depressed skull fracture ($n = 3$). The procedures consisted of removing the extra-axial clot ($n = 13$) and repairing the depressed skull fracture ($n = 4$). Despite neurosurgical intervention, 1 patient died due to epidural he-

matoma. Thirteen patients had good clinical outcomes (full recovery or minor disability), and 3 patients had moderate clinical outcomes.

Physicians did not treat the remaining 59 patients with subdural or epidural hematoma or depressed fracture neurosurgically but hospitalized most ($n = 54$ [92%]) for clinical observation, during which time the patients remained neurologically stable. Three elderly patients (81 to 82 years of age) exhibited rapid clinical deterioration and extensive intracranial traumatic CT findings, and the attending neurosurgeon considered intervention to be of no avail. All 3 patients died.

One hundred twelve patients received additional CT scans: 81 (72%) to follow a traumatic lesion (intracranial or linear fracture) seen on the initial CT; 3 for non–trauma-related indications (tumor or stroke); 2 for changes in behavior, showing only on the second CT subarachnoid hemorrhage in 1 patient and hypodense lesions consistent with diffuse axonal injury in the other; and 26 for various reasons (for example, headache or dizziness), for which the second CT was negative. Two cases of a dubious intraparenchymal contusion presented on the initial CT; in both cases, the results of the second CT were negative.

Appendix Table 1 (available at www.annals.org) shows results from the univariable analysis. The continuous variables of posttraumatic amnesia, age, and GCS scores showed a reasonably linear association with the probability of intracranial traumatic findings on CT (primary outcome measure). Compared with patients without intracranial traumatic findings on CT, patients with intracranial traumatic CT findings had a longer mean posttraumatic amnesia (75 vs. 17 minutes), were older (48 vs. 41 years of age), had lower mean GCS scores on presentation (14.4 vs. 14.8), and more often showed a deterioration of GCS score after 1 hour (0.04-point deterioration vs. 0.10-point improvement).

We considered all variables shown in **Appendix Table 1** (available at www.annals.org) in the multivariable analysis (**Table 2**). The variables of posttraumatic seizure and persistent anterograde amnesia were not statistically significant, but we retained them in the final model because of their clinical importance.

We entered separately each additional risk factor from clinical guidelines for minor head injury into the model, but none showed a significant additional effect (odds ratio for high-energy accident, 0.99 [$P = 0.97$]; odds ratio for unclear trauma mechanism, 1.38 [$P = 0.47$]; odds ratio for pretraumatic seizure, 0.39 [$P = 0.21$]; and odds ratio for multiple injuries, 1.24 [$P = 0.20$]). The methodological variables, which did not show any significant effects, were the moment of data entry (before or after the CT was performed) ($P = 0.43$) and the participating center ($P = 0.32$).

Figure 2 shows ROC curves of the detailed prediction model. At a linear predictor score of 1.1, sensitivity was 100% for neurosurgical interventions and specificity was 30% (**Appendix Table 2**, available at www.annals.org; **Figure 2**). At this cutoff score, the prediction model missed 14 patients with intracranial traumatic CT findings (sensitivity, 94%). These 14 patients had 19 intracranial nonneurosurgical traumatic CT findings: 1 depressed skull fracture, 4 acute subdural hematomas (all minimal with no mass effect), 8 traumatic subarachnoid hemorrhages, 6 intraparenchymal lesions (5 of which were hemorrhagic contusions), and 4 linear and 3 skull base fractures with additional lesions. The prediction model missed no patient with an epidural hematoma. Physicians admitted 12 (86%) of these patients for clinical observation, and none died. We knew the clinical outcome for 10 patients, and all patients had a good recovery except for 1 who had a minor disability due to an orbital fracture.

Specificities were 30% for neurosurgical interventions and 32% for intracranial CT findings (**Appendix Table 2**, available at www.annals.org; **Figure 2**). Sensitivity for in-

Table 2. **Prediction Model and Rule for the Identification of Intracranial Traumatic Computed Tomography Findings in Patients with Minor Head Injury Based on Multivariable Logistic Regression Analysis***

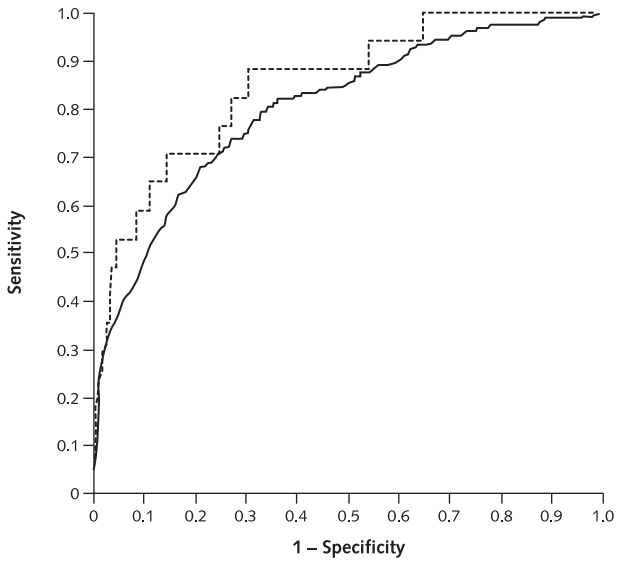
Variable	Odds Ratio (95% CI)†	β-Coefficient‡
Signs of skull fracture	10 (5.9–18)	2.3
GCS score of 13 on presentation	3.9 (2.4–6.6)	1.3
GCS score of 14 on presentation	2.1 (1.4–2.9)	0.7
Persistent anterograde amnesia	1.5 (1.1–2.2)	0.4
Contusion of the skull	1.8 (1.3–2.4)	0.6
Vomiting	2.4 (1.7–3.5)	0.8
Patient age – 16 per 10 y	1.2 (1.1–1.3)	0.2
Posttraumatic amnesia of 2 to <4 h	1.6 (0.6–4.5)	0.4
Posttraumatic amnesia ≥4 h	7.5 (1.5–37)	0.6
Loss of consciousness	1.8 (1.3–2.5)	0.6
Neurologic deficit	1.5 (1.0–2.3)	0.4
Fall from any elevation	1.7 (1.2–2.4)	0.5
Use of anticoagulant therapy	2.4 (1.2–4.6)	0.8
Change in GCS score (1 h after presentation)	0.7 (0.6–0.9)	−0.3
Pedestrian or cyclist versus vehicle	3.6 (2.4–5.3)	1.1
Ejected from vehicle	3.1 (1.3–7.2)	0.8
Posttraumatic seizure	2.3 (0.7–8.2)	0.8
Adjustment for prior probability		
2.5%		−1.2
5.0%		−0.4
7.5%		0.0
10.0%		0.3
12.5%		0.6
15.0%		0.8

* Prediction rule: To determine the need for a CT scan, the coefficients of the risk factors that are present (for continuous variables multiplied by the value of the variable) need to be added. If the sum score is ≥1.1, a CT scan is indicated. The predicted probability of an intracranial traumatic finding on CT adjusted for the prior probability in the patient population equals: $1/(1+e^{-(-4.6\ +\ \text{score}\ +\ \text{adjustment for prior})})$. In our study population, the prior probability of an intracranial traumatic finding on CT was 7.5%, which was based on a case-mix, adjusted estimate. The adjustment factor was then calculated for other prior probabilities that were arbitrarily chosen (that is, 2.5%, 5.0%, 10.0%, 12.5%, and 15.0%). CT = computed tomography; GCS = Glasgow Coma Scale.

† Odds ratios are based on standard maximum likelihood estimation.

‡ Penalized estimation was used for the β-coefficients to improve predictions in future patients with minor head injury (30).

Figure 2. **Receiver-operating characteristic curves of the detailed prediction model.**



The dashed line represents the receiver-operating characteristic (ROC) curve for neurosurgical interventions (area under the curve, 0.85 [95% CI, 0.76 to 0.94]), and the solid line represents the ROC curve for intracranial traumatic CT findings (area under the curve, 0.80 [95% CI, 0.77 to 0.83]).

tracranial traumatic findings on CT reached 100% at a score of 0.05, but specificity was only 0.6% (**Table 3**).

Internal validation of the detailed prediction model using bootstrapping procedures indicated optimism for the area under the ROC curve, which we expected to decrease from 0.85 to 0.83 for neurosurgical interventions and from 0.80 to 0.78 for intracranial traumatic CT findings. We expected 100% sensitivity for neurosurgical interventions in 58% of the bootstrap repetitions.

The simple prediction model consisted of 10 major and 8 minor risk factors (**Table 4**). In the presence of at least 1 major or 2 minor risk factors, sensitivity for neurosurgical interventions was 100%, with a specificity of 23% (**Appendix Table 2**, available at www.annals.org). This model would have missed 9 patients with 13 intracranial traumatic lesions on CT (sensitivity, 96%). These intracranial nonneurosurgical traumatic CT findings included 1 depressed skull fracture, 3 acute subdural hematomas (all minimal with no mass effect), 4 traumatic subarachnoid hemorrhages, 5 intraparenchymal lesions (4 of which were hemorrhagic contusions), and 7 linear and 3 skull base fractures with additional lesions. The simple model missed no patient with an epidural hematoma. Specificity of the simple model for intracranial traumatic lesions was 25% (**Appendix Table 2**, available at www.annals.org). Potential reduction in CT scans with this simple model (23%) was lower than that with the detailed model (30%), although sensitivity for intracranial traumatic CT findings was slightly higher in the simple model (96% vs. 94%).

Internal validation of the simple prediction model using bootstrapping procedures indicated a small optimism for the area under the ROC curve, which we expected to decrease from 0.84 to 0.82 for neurosurgical interventions and from 0.79 to 0.77 for intracranial traumatic CT findings. Using a minimum of 1 major or 2 minor risk factors as a CT indication, we expected 100% sensitivity for neurosurgical interventions in 56% of the bootstrap repetitions (average sensitivity, 96%). When we used only 1 minor risk factor as a CT indication, the model reached 100% sensitivity for neurosurgical interventions in 76% of samples, but at this score the potential CT reduction decreased to 5.8% (95% CI, 5.0% to 6.7%).

DISCUSSION

The highly sensitive CHIP prediction rule for the use of CT is applicable to most patients with minor head injury, including patients without loss of consciousness or posttraumatic amnesia. We present a detailed prediction rule and a simplified prediction rule. The latter is easier to use in a clinical setting, but some information is lost, which is demonstrated by a slightly lower specificity. The former is more complicated, although it is easy to implement in digital patient file systems or to consult online (available at www.marionsmits.net/chip-prediction-rule). It has several advantages, including that no information is lost, prior probabilities of intracranial traumatic CT findings may be considered, and thresholds may be varied.

Researchers have already published 2 high-quality prediction rules for the use of CT in patients with minor head

Table 3. **Specificities, Potential Computed Tomography Reduction, and Cutoff Scores at Several Sensitivities for Intracranial Traumatic Computed Tomography Findings (Detailed Prediction Model)***

Sensitivity for Intracranial Traumatic CT Findings, %	Specificity for Intracranial Traumatic CT Findings (95% CI), %	Reduction in CT Use (95% CI), %	Prediction Rule Cutoff Score
90	40 (37–43)	38 (36–40)	1.26†
92.5	37 (35–40)	35 (33–37)	1.19
95	30 (27–32)	28 (26–29)	1.03
97.5	22 (19–24)	20 (19–22)	0.84
100	0.6 (0.0–2.5)	0.5 (0.3–0.9)	0.05

* CT = computed tomography.
† At this cutoff score, sensitivity for neurosurgical intervention decreases to 94% from 100%. Above the cutoff score, CT is indicated.

injury, the NOC and the CCHR (7, 9). They are highly sensitive to intracranial traumatic CT findings and neurosurgical interventions. We propose a third prediction rule for the selective use of CT in patients with minor head injury, the CHIP prediction rule that is more widely applicable than either the NOC or the CCHR, provides more realistic predictions, and is internally validated. It may greatly reduce the number of CTs for the indication of minor head injury compared with scanning all patients with minor head injury (16, 18, 19). The actual CT reduction will, however, depend on current clinical practice and adherence to the prediction rule.

Researchers developed the NOC and the CCHR in a more restricted population of patients with minor head injury, comprising only 41% to 64% of our study population (10). Unlike the CHIP prediction rule, both previously published rules require that the patient has a history of loss of consciousness or amnesia and normal findings on neurologic examination. Because of these restrictions, generalizability of these prediction rules is limited. The CHIP prediction rule is more widely applicable and is consequently easier to incorporate into clinical guidelines.

In developing our prediction rule, we first selected risk factors that were shown to have a predictive effect in the NOC and the CCHR. We tested additional risk factors in clinical guidelines, but they were not useful in selecting patients for CT. The CHIP prediction rule clearly provides a compromise between the NOC and CCHR rules (**Table 5**). It contains the same risk factors as the CCHR and some additional risk factors from the NOC. The remaining risk factors in the CHIP prediction rule are related to the patient selection criteria of the NOC and CCHR. Loss of consciousness is only a minor risk factor in our model, despite it often being considered a critical risk factor in patients with minor head injury (Smits M, Hunink M, Nederkoon P, et al. Unpublished data). This may be explained by our inclusion criteria, which required the presence of an additional risk factor if a patient had no history of loss of consciousness (18, 34). The effect of loss of consciousness is thus diminished by an a priori increased risk due to the presence of another risk factor.

We reduced the model's optimism by penalizing the regression coefficients to make realistic and reproducible predictions in future similar patients with minor head injury. This results in a more conservative, but also more realistic, estimate of the model's performance. In the development of the NOC and the CCHR, researchers did not perform this penalization, which may explain the lower-than-expected performance in external validation studies (10, 12).

Finally, we validated our prediction rule internally by using a bootstrapping procedure (30, 33). Overall performance (area under the ROC curve) was only marginally lower than that of the original model. Because our prediction model is similar to existing prediction rules, does not seem to be too optimistic, and shows only marginal deterioration of performance in internal validation, we feel that our model is robust and its predictions are realistic.

Table 4. **Simple Prediction Model for Intracranial Traumatic Computed Tomography Findings in Patients with Minor Head Injury***

A CT is indicated in the presence of 1 major criterion
Pedestrian or cyclist versus vehicle
Ejected from vehicle
Vomiting
Posttraumatic amnesia ≥4 h
Clinical signs of skull fracture†
GCS score <15
GCS deterioration ≥2 points (1 h after presentation)
Use of anticoagulant therapy
Posttraumatic seizure
Age ≥60 y
A CT is indicated in the presence of at least 2 minor criteria
Fall from any elevation
Persistent anterograde amnesia‡
Posttraumatic amnesia of 2 to <4 h
Contusion of the skull
Neurologic deficit
Loss of consciousness
GCS deterioration of 1 point (1 h after presentation)
Age 40–60 y

* CT = computed tomography; GCS = Glasgow Coma Scale.
† Any injury that suggests a skull fracture, such as palpable discontinuity of the skull, leakage of cerebrospinal fluid, "raccoon eye" bruising, and bleeding from the ear.
‡ Persistent anterograde amnesia is any deficit of short-term memory.

We chose our indication for CT threshold such that sensitivity for neurosurgical interventions was 100% because we required our model to identify all very high-risk patients. Sensitivity for intracranial traumatic CT findings was somewhat lower, and the question is whether this sensitivity would be acceptable for clinical use. It is difficult to speculate on the clinical outcome of patients who would have been missed if triaged on the basis of the prediction rule. All potentially missed patients in our study population had relatively minor CT findings and required no intervention, suggesting that triaging on the basis of the prediction rule would not have had adverse clinical consequences in terms of clinical outcome. One may argue that a sensitivity of 100% is also required for intracranial traumatic CT findings, but this causes specificity to decrease dramatically. Internal validation suggests that 100% sensitivity for neurosurgical interventions may be a too optimistic expectation in future patients. If definitely no patients with intracranial traumatic CT findings or requiring neurosurgical intervention may be missed, all patients will need to be scanned and a prediction rule will be superfluous. The decision about which threshold to use (that is, the minimum desired sensitivity) should ideally be based on an analysis of the costs and benefits of scanning (35).

Increasingly, physicians use prediction rules as decision rules, that is, they now frequently use predicted probabilities of an outcome in the decision-making process

Table 5. **Comparison of the 2 Previously Published Prediction Rules (New Orleans Criteria and Canadian CT Head Rule), Additional Risk Factors from Various Guidelines, and the CT in Head Injury Patients Prediction Rule for Use of Computed Tomography in Patients with Minor Head Injury***

Risk Factor	NOC	CCHR	CHIP†
Headache	Major	–	–
Vomiting	Major	Major (≥2 episodes)	Major
Posttraumatic seizure	Major	Excluded	Major
Intoxication	Major	–	–
Persistent anterograde amnesia	Major	–	Minor
Age	Major (>60 y)	Major (≥65 y)	Major (≥60 y) or minor (40–60 y)
Clinical signs of skull fracture	Major	Major	Major
Contusion of the skull	Major	–	Minor
Signs of facial fracture	Major	–	–
Contusion of the face	Major	–	–
GCS score deterioration	–	Major	Major (≥2 points) or minor (1 point)
Pedestrian versus vehicle	–	Minor	Major (also cyclist)
Ejected from vehicle	–	Minor	Major
Fall from height	–	Minor	Minor
Prolonged posttraumatic amnesia	–	Minor (>30 min)	Major (≥4 h) or minor (2 to <4 h)
GCS score <15 at presentation	Excluded	–	Major
Loss of consciousness	Inclusion	Inclusion	Minor
Neurologic deficit	Excluded	Excluded	Minor
Anticoagulation therapy	–	Excluded	Major
High-energy trauma	–	–	–
Multiple injuries	–	–	–
Pretraumatic seizure	–	–	–
Unclear trauma mechanism	–	–	–

* Dash indicates that the variable is not a risk factor in the model. Excluded = risk factor was not assessed in the development of the prediction rule because patients with this risk factor were excluded from the study; Inclusion = risk factor was not assessed in the development of the prediction rule because it was used as an inclusion criterion for the study; major = risk factor is present in the prediction rule as a major criterion; minor = risk factor is present in the prediction rule as a minor criterion. CCHR = Canadian CT Head Rule; CHIP = CT in Head Injury Patients; GCS = Glasgow Coma Scale; NOC = New Orleans Criteria.
† Applies to both the detailed and the simple rule.

(36). Although we suggest that the CHIP prediction rule may be used as an aid to decide whether to perform a CT, this is valid only under the assumption that accurate predictions improve clinical decisions. Even then, a prediction rule can be used only as a decision-support system because it can only complement, never replace, clinical judgment (36, 37). If clinical suspicion is high, a CT scan is indicated regardless of the prediction rule.

Our study has some limitations. First, although the overall proportion of missing or unknown variables was low, the proportion of patients with at least 1 unknown variable was relatively high. This was mostly because of the difficulty of reliably obtaining a history of loss of consciousness and posttraumatic amnesia, which is a well-known problem in clinical practice. If unknown, these 2 risk factors are assumed to be present, which is how we imputed missing values in our data set and is consistent with clinical practice. A further limitation of our study is that we determined the variables of high-energy accident and pretraumatic seizure on the basis of the description of the trauma mechanism. We included these variables in the univariable analysis because they are commonly considered to be risk factors in the various guidelines for the use of CT in patients with minor head injury. They are not, however, considered to be risk factors in the NOC and the CCHR, and our analysis confirms that they are not relevant after other variables are considered in a multivariable analysis. The lack of toxicology testing is another limitation because we did not obtain objective information on the toxicologic status of patients. However, toxicology screening in a busy emergency department to triage patients would reduce the clinical usefulness of a prediction rule. A further minor limitation is that only university hospitals participated, which may have induced selection bias. Three of the participating hospitals are large inner-city hospitals, and all 4 serve a large, general patient population. To reduce bias, we excluded patients transferred from other hospitals. The final and most important limitation of our study is the lack of external validation. Although we performed internal validation, the model should still be validated in a separate, preferably multicenter, study to assess its generalizability and its effect (37).

We propose the highly sensitive CHIP prediction rule for the use of CT patients with minor head injury. The rule is applicable to a large proportion of patients with minor head injury presenting to the emergency department. It may greatly reduce the number of CTs performed for this indication, and it identifies almost all patients requiring neurosurgical intervention and most patients with an intracranial traumatic finding on CT.

From Erasmus MC–University Medical Center Rotterdam, Rotterdam, the Netherlands; University Medical Center Nijmegen St. Radboud, Nijmegen, the Netherlands; Academic Medical Center, Amsterdam, the Netherlands; and University Hospital Maastricht, Maastricht, the Netherlands.

Acknowledgments: The authors thank Mrs. J. Brauer, research nurse at the Department of Neurology at University Medical Center Nijmegen, St. Radboud; the research nurses at the Department of Radiology at Erasmus MC–Medical Center Rotterdam, Mrs. W.J. van Leeuwen, Mrs. C.H. van Bavel-van Hamburg, and Mrs. B. Tara-Prins, for their invaluable contribution to patient data collection; and Mr. P.I.R. Hilton for developing the online version of the CHIP prediction rule.

Grant Support: By College voor Zorgverzekeringen (CVZ) (VAZ 01-104) and Radiologisch onderzoek Nederland (RADION).

Potential Financial Conflicts of Interest: None disclosed.

Requests for Single Reprints: M.G. Myriam Hunink, MD, PhD, Department of Epidemiology and Biostatistics and Department of Radiology, Erasmus MC–University Medical Center Rotterdam, PO Box 2040, 3000 CA Rotterdam, the Netherlands; e-mail, m.hunink@erasmusmc.nl.

Current author addresses and author contributions are available at www.annals.org.

References

1. **Cassidy J, Carroll L, Peloso P, Borg J, von Holst H, Holm L, et al.** Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. J Rehabil Med. 2004;Feb(43 Suppl):28-60.
2. **Carroll LJ, Cassidy JD, Holm L, Kraus J, Coronado VG.** Methodological issues and research recommendations for mild traumatic brain injury: the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. J Rehabil Med. 2004(43 Suppl):113-25.
3. **Fabbri A, Servadei F, Marchesini G, Morselli-Labate AM, Dente M, Iervese T, 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;75:410-6.
4. **Af Geijerstam JL, Britton M.** Mild head injury - mortality and complication rate: meta-analysis of findings in a systematic literature review. Acta Neurochir (Wien). 2003;145:843-50; discussion 850.
5. **Af Geijerstam JL, Britton M.** Mild head injury: reliability of early computed tomographic findings in triage for admission. Emerg Med J. 2005;22:103-7.
6. **Dunning J, Lecky F.** The NICE guidelines in the real world: a practical perspective. Emerg Med J. 2004;21:404-7.
7. **Stiell IG, Wells GA, Vandemheen K, Clement C, Lesiuk H, Laupacis A, et al.** The Canadian CT Head Rule for patients with minor head injury. Lancet. 2001;357:1391-6.
8. **Mower WR, Hoffman JR, Herbert M, Wolfson AB, Pollack CV, Jr., Zucker MI.** Developing a decision instrument to guide computed tomographic imaging of blunt head injury patients. J Trauma. 2005;59:954-9.
9. **Haydel MJ, Preston CA, Mills TJ, Luber S, Blaudeau E, DeBlieux PM.** Indications for computed tomography in patients with minor head injury. N Engl J Med. 2000;343:100-5.
10. **Smits M, Dippel DW, de Haan GG, Dekker HM, Vos PE, Kool DR, 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;294:1519-25.
11. **Ibanez J, Arikan F, Pedraza S, Sanchez E, Poca MA, Rodriguez D, 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;100:825-34.
12. **Stiell IG, Clement CM, Rowe BH, Schull MJ, Brison R, Cass D, et al.** Comparison of the Canadian CT Head Rule and the New Orleans Criteria in patients with minor head injury. JAMA. 2005;294:1511-8.
13. **Moons KG, Donders AR, Steyerberg EW, Harrell FE.** Penalized maximum likelihood estimation to directly adjust diagnostic and prognostic prediction models for overoptimism: a clinical example. J Clin Epidemiol. 2004;57:1262-70.
14. **Bossuyt PM, Reitsma JB, Bruns DE, Gatsonis CA, Glasziou PP, Irwig LM, et al.** Towards complete and accurate reporting of studies of diagnostic accuracy: the STARD initiative. Clin Radiol. 2003;58:575-80.
15. **Twijnstra A, Brouwer O, Keyser A, Lanser J, Poels E, Rinkel G, et al.** Guidelines for diagnosis and management of patients with minor head injury. Published in Dutch: Richtlijnen voor diagnostiek en behandeling van patiënten met een licht schedel-hersenletsel. Accessed at www.neurologie.nl/richtlijnen Accessed on 15 December 2006.
16. **Vos PE, Battistin L, Birbamer G, Gerstenbrand F, Potapov A, Prevec T, et al.** EFNS guideline on mild traumatic brain injury: report of an EFNS task force. Eur J Neurol. 2002;9:207-19.
17. **Los RK, van Ginneken AM, de Wilde M, van der Lei J.** OpenSDE: Row modeling applied to generic structured data entry. J Am Med Inform Assoc. 2004;11:162-5.
18. **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;18:657-64.
19. Scottish Intercollegiate Guidelines Network. Early management of patients with head injury. Accessed at www.sign.ac.uk/guidelines/published/index.html on 17 April 2005.
20. National Institute for Health and Clinical Excellence. Head injury: Triage, assessment, investigation and early management of head injury in infants, children and adults. Accessed at www.nice.org.uk on 17 March 2005.
21. **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;48:760-6.
22. **Steyerberg EW, Eijkemans MJ, Harrell FE, Jr., Habbema JD.** Prognostic modeling with logistic regression analysis: in search of a sensible strategy in small data sets. Med Decis Making. 2001;21:45-56.
23. **Little RJ.** Regression with missing X's: a review. J Am Stat Assoc. 1992;87:1227-1237.
24. **van der Heijden GJ, Donders AR, Stijnen T, Moons KG.** Imputation of missing values is superior to complete case analysis and the missing-indicator method in multivariable diagnostic research: a clinical example. J Clin Epidemiol. 2006;59:1102-9.
25. **Donders AR, van der Heijden GJ, Stijnen T, Moons KG.** Review: a gentle introduction to imputation of missing values. J Clin Epidemiol. 2006;59:1087-91.
26. **Kline R.** Principles and Practice of Structural Equation Modeling. 2nd ed. New York: Guildford Pr; 1998:74-7.
27. **Schafer J.** Analysis of Incomplete Multivariate Data. Bury St. Edmunds, Suffolk: Chapman & Hall; 1997.
28. **Nagelkerke N.** A note on a general definition of the coefficient of determination. Biometrika. 1991;78:691-692.
29. **Harrell FE, Jr., Lee KL, Pollock BG.** Regression models in clinical studies: determining relationships between predictors and response. J Natl Cancer Inst. 1988;80:1198-202.
30. **Harrell FE Jr.** Regression Modeling Strategies. New York: Springer-Verlag; 2001.
31. **Steyerberg EW, Eijkemans MJ, Harrell FE, Jr., Habbema JD.** Prognostic modelling with logistic regression analysis: a comparison of selection and estimation methods in small data sets. Stat Med. 2000;19:1059-79.
32. **Berry CC.** A tutorial on confidence intervals for proportions in diagnostic radiology. AJR Am J Roentgenol. 1990;154:477-80.
33. **Steyerberg EW, Harrell FE, Jr., Borsboom GJ, Eijkemans MJ, Vergouwe Y, Habbema JD.** Internal validation of predictive models: efficiency of some procedures for logistic regression analysis. J Clin Epidemiol. 2001;54:774-81.
34. **Teasdale GM, Murray G, Anderson E, Mendelow AD, MacMillan R, Jennett B, et al.** Risks of acute traumatic intracranial haematoma in children and adults: implications for managing head injuries. BMJ. 1990;300:363-7.
35. **Hunink MG.** Decision making in the face of uncertainty and resource constraints: examples from trauma imaging. Radiology. 2005;235:375-83.
36. **Reilly BM, Evans AT.** Translating clinical research into clinical practice: impact of using prediction rules to make decisions. Ann Intern Med. 2006;144:201-9.
37. **Haydel MJ.** Clinical decision instruments for CT scanning in minor head injury. JAMA. 2005;294:1551-3.

Current Author Addresses: Drs. Smits and Tanghe: Department of Radiology, Erasmus MC–University Medical Center Rotterdam, PO Box 2040, 3000 CA Rotterdam, the Netherlands.
Dr. Dippel: Department of Neurology, Erasmus MC–University Medical Center Rotterdam, PO Box 2040, 3000 CA Rotterdam, the Netherlands.
Dr. Steyerberg: Department of Public Health, Erasmus MC–University Medical Center Rotterdam, PO Box 2040, 3000 CA Rotterdam, the Netherlands.
Dr. de Haan: Department of Medical Informatics, Erasmus MC–University Medical Center Rotterdam, PO Box 2040, 3000 CA Rotterdam, the Netherlands.
Drs. Dekker and Kool: Department of Radiology, University Medical Center, Nÿmeger St., Radboud, Geert Grooteplein 10, 6525 GA Nijmegen, the Netherlands.
Dr. Vos: Department of Neurology, University Medical Center, Nÿmeger St., Radboud, Geert Grooteplein 10, 6525 GA Nijmegen, the Netherlands.
Dr. Nederkoorn: Department of Neurology, Academic Medical Center, Meibergdreef 9, 1105 AZ Amsterdam, the Netherlands.
Dr. Hofman: Department of Radiology, University Hospital Maastricht, PO Box 5800, 6200 AZ Maastricht, the Netherlands.
Dr. Twijnstra: Department of Neurology, University Hospital Maastricht, PO Box 5800, 6200 AZ Maastricht, the Netherlands.
Dr. Hunink: Department of Epidemiology and Biostatistics and Department of Radiology, Erasmus MC–University Medical Center Rotterdam, PO Box 2040, 3000 CA Rotterdam, the Netherlands.

Author Contributions: Conception and design: M. Smits, D.W.J. Dippel, M.G.M. Hunink.
Analysis and interpretation of the data: M. Smits, D.W.J. Dippel, E.W. Steyerberg, M.G.M. Hunink.
Drafting of the article: M. Smits, D.W.J. Dippel, M.G.M. Hunink.
Critical revision of the article for important intellectual content: M. Smits, D.W.J. Dippel, E.W. Steyerberg, G.G. de Haan, H.M. Dekker, P.E. Vos, D.R. Kool, P.J. Nederkoorn, P.A.M. Hofman, A. Twijnstra, H.L.J. Tanghe, M.G.M. Hunink.
Final approval of the article: M. Smits, D.W.J. Dippel, E.W. Steyerberg, G.G. de Haan, H.M. Dekker, P.E. Vos, D.R. Kool, P.J. Nederkoorn, P.A.M. Hofman, A. Twijnstra, H.L.J. Tanghe, M.G.M. Hunink.
Provision of study materials or patients: D.W.J. Dippel, H.M. Dekker, P.E. Vos, D.R. Kool, P.J. Nederkoorn, P.A.M. Hofman, A. Twijnstra, H.L.J. Tanghe.
Statistical expertise: E.W. Steyerberg.
Obtaining of funding: M.G.M. Hunink.
Administrative, technical, or logistic support: M. Smits, D.W.J. Dippel, G.G. de Haan, H.M. Dekker, P.E. Vos, D.R. Kool, P.J. Nederkoorn, P.A.M. Hofman, A. Twijnstra, H.L.J. Tanghe, M.G.M. Hunink.
Collection and assembly of data: M. Smits, D.W.J. Dippel, H.M. Dekker, P.E. Vos, D.R. Kool, P.J. Nederkoorn, P.A.M. Hofman, A. Twijnstra.

Appendix Table 1. **Univariable Analysis of Variables That Were Entered into the Multivariable Logistic Regression Analysis***

Variable	Patients with an Intracranial Traumatic Finding on CT (n = 243)	Odds Ratio (95% CI)	*P* Value	Nagelkerke R^2
Age, *y*	48.2	1.2 (1.1–1.3)†	0.000	0.025
Trauma mechanism, *n (%)*			0.000	0.022
Other	102 (5)	1.0 (reference)		
Pedestrian or cyclist versus vehicle	51 (15)	3.2 (2.2–4.5)		
Fall from any elevation	82 (10)	2.2 (1.6–2.9)		
Ejected from vehicle	8 (12)	2.6 (1.2–5.6)		
Symptoms				
Persistent anterograde amnesia, *n (%)*	72 (15)	2.7 (2.0–3.6)	0.000	0.028
Vomiting, *n (%)*	55 (16)	2.7 (2.0–3.7)	0.000	0.023
PTA duration, *min*	75	1.7 (1.4–2.0)‡	0.000	0.032
Loss of consciousness, *n (%)*	182 (9)	2.0 (1.5–2.7)	0.000	0.016
Headache, *n (%)*			0.058	0.004
No	84 (6)	1.0 (reference)		
Diffuse	120 (9)	1.4 (1.1–1.9)		
Localized	39 (7)	1.1 (0.7–1.7)		
Posttraumatic seizure, *n (%)*	5 (22)	3.4 (1.3–9.3)	0.001	0.003
External evidence of injury, *n (%)*				
Signs of skull fracture	36 (49)	14 (8.4–22)	0.000	0.070
Contusion of the skull	140 (12)	2.4 (1.8–3.1)	0.000	0.030
Signs of facial fracture	24 (10)	1.3 (0.9–2.1)	0.193	0.001
Contusion of the face	118 (7)	0.8 (0.7–1.1)	0.194	0.001
Neurologic examination				
Mean number of patients with GCS score of 15 (SD)	0.57	2.3 (1.9–2.7)	0.000	0.048
Neurologic deficit, *n (%)*	42 (14)	2.1 (1.5–3.1)	0.000	0.012
Change in GCS score at 1 h	−0.04	0.8 (0.7–1.0)	0.009	0.004
Use of anticoagulant therapy, *n (%)*	13 (16)	2.3 (1.3–4.3)	0.005	0.005
Intoxication, *n (%)*			0.002	0.002
No	164 (9)	1.0 (reference)		
Mild	18 (6)	0.7 (0.4–1.2)		
Moderate	22 (4)	0.4 (0.3–0.7)		
Severe	39 (9)	1.1 (0.7–1.5)		

* For continuous variables, the mean for patients with an intracranial finding on CT is shown. CT = computed tomography; GCS = Glasgow Coma Scale; PTA = posttraumatic amnesia.
† Per 10 y.
‡ Per 60 min of PTA.

Appendix Table 2. **Performance of the Detailed and Simple Prediction Model***

Model	Score ≥1.1	Score <1.1	Risk Factor Present†	Risk Factors Absent‡	Sensitivity (95% CI), %	Specificity (95% CI), %	CT Reduction (95% CI), %
Detailed prediction model							30 (29–32)
Neurosurgical intervention required	17	0			100 (82–100)	30 (28–33)	
No neurosurgical intervention required	2207	957					
Intracranial traumatic CT findings present	229	14			94 (91–97)	32 (30–35)	
Intracranial traumatic CT findings not present	1995	943					
Simple prediction model							23 (22–25)
Neurosurgical intervention required			17	0	100 (82–100)	23 (21–26)	
No neurosurgical intervention required			2422	742			
Intracranial traumatic CT findings present			234	9	96 (93–98)	25 (23–27)	
Intracranial traumatic CT findings not present			2205	733			

* CT = computed tomography.
† A minimum of 1 major or 2 minor risk factors are present.
‡ No major risk factors and ≤1 minor risk factor are present.