CHAPTER 6

External validation of computed tomography decision rules for minor head injury: prospective, multicentre cohort study in the Netherlands

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ABSTRACT

Objective

To externally validate four commonly used computed tomography (CT) decision rules for minor head injury (MHI).

Design and Setting

Prospective multicenter cohort study in three university and six non-university hospitals in the Netherlands.

Participants

Consecutive adult patients aged 16 years and over who presented with MHI at the emergency department with a Glasgow Coma Scale score of 13-15 between March 2015 and December 2016.

Main outcome measures

The primary outcome was any intracranial traumatic finding on CT; the secondary outcome was a potential neurosurgical lesion on CT. We compared the sensitivity, specificity and clinical usefulness, (defined as net benefit, a weighted sum of true positive classifications) of four CT decision rules: CT in Head Injury Patients (CHIP) rule; New Orleans Criteria (NOC); Canadian CT Head Rule (CCHR); and National Institute for Health and Care Excellence (NICE) guideline for head injury.

Results

For the primary analysis, only six centers that included patients with and without CT were selected. Of 4557 eligible patients who presented with minor head injury, 3742 (82%) received a CT scan; 384 (8%) had a intracranial traumatic finding on CT, and 74 (2%) had a potential neurosurgical lesion. The sensitivity for any intracranial traumatic finding on CT ranged from 73% (NICE) to 99% (NOC); specificity ranged from 4% (NOC) to 61% (NICE). Sensitivity for a potential neurosurgical lesion ranged between 85% (NICE) and 100% (NOC); specificity from 4% (NOC) to 59% (NICE). Clinical usefulness depended on thresholds for performing CT scanning: the NOC rule was preferable at a low threshold, the NICE rule was preferable at a higher threshold, whereas the CHIP rule was preferable for an intermediate threshold.

Conclusions

Application of the CHIP, NOC, CCHR, or NICE decision rules can lead to a wide variation in CT scanning among patients with minor head injury, resulting in many unnecessary CT scans and some missed intracranial traumatic findings. Until an existing decision rule has been updated, any of the four rules can be used for patients presenting minor head injuries at the emergency department. Use of the CHIP rule is recommended because it leads to a substantial reduction in CT scans while missing few potential neurosurgical lesions.

Introduction

Minor head injury (MHI) or mild traumatic brain injury is a common injury increasingly seen in emergency departments.[1,2] Possible causes for this increase are ageing of the population and increased awareness of the potential intracranial complications of MHI among general practitioners and paramedics.[3,4] Although the risk of intracranial complications after MHI is low, the consequences are important as these patients require close observation and sometimes even neurosurgical intervention.[5] Several clinical decision rules exist that aim to identify those patients with MHI who are at high risk for intracranial complications and need computed tomography (CT) of the head. Examples of frequently used decision rules are: the New Orleans Criteria (NOC); Canadian CT Head Rule (CCHR); and the National Institute for Clinical Excellence (NICE) guideline for Head injury (Supplementary Table 1).[6-8]

The purpose of these rules is to detect all relevant intracranial traumatic lesions while minimizing the number of unnecessary CT scans. Relevant lesions are those that need neurosurgical intervention or prolonged clinical observation because of a risk of neurological deterioration. Although the number of patients that present at the emergency departments with MHI has increased substantially, the overall incidence of disease specific mortality after head injury has remained fairly stable.[9] An increased number of patients leads to more CT scans, longer waiting times at the emergency department, burden for the patients, radiation risks, and higher costs.[10] The need for reliable CT decision rules for MHI to reduce unnecessary CT scans is therefore even more apparent.

Two of the decision rules have been developed for patients who had had blunt trauma to the head, have a Glasgow Coma Scale (GCS) of 13-15 at presentation, and have experienced loss of consciousness (LOC) and/or posttraumatic amnesia (PTA).[6,7] However, these rules cannot be applied to patients without LOC or PTA.[11,12] Therefore a new decision rule was developed, the CT in Head Injury Patients (CHIP) rule, which includes patients with and without LOC or PTA.[13] The potential reduction of CT scans by use of the CHIP rule was estimated at 23% compared to scanning of all patients.[13]

The NOC, CCHR and NICE guideline were externally validated in previous studies, but there has been no external validation of the CHIP rule, even though this is necessary to determine whether the rule is generally applicable.[14-21] Our aim was to perform an external validation of frequently used CT decision rules for MHI (CHIP, NOC, CCHR, NICE) and compare their performance in a multicenter study in the Netherlands in university and non-university hospitals.

Methods

Study design

We conducted a prospective, multicenter cohort study between March 2015 and December 2016 in the Netherlands. Three university emergency departments (all level 1 trauma centers) and six non-university emergency departments (trauma level 1 (two centers), trauma level 2 (two centers) and trauma level 3 (two centers)) participated in this study. The emergency departments were all situated at an urban location. Institutional ethics and research board approval was obtained and informed consent was waived.

Inclusion criteria were age 16 years and over, presentation within 24 hours after blunt trauma to the head and a GCS score of 13-15 at presentation at the emergency department. Patients with and without LOC or PTA were included. We excluded all patients with a GCS score less than 13, patients younger than 16 years, transferred from other hospitals or with any contra-indication for CT.

Definition of risk factors

Clinical data concerning risk factors for intracranial complications used in the CCHR, NOC, NICE and CHIP decision rules were collected.[6-8,13] These clinical risk factors were: age, history of coagulopathy, use of anticoagulants, dangerous trauma mechanism (pedestrian/cyclist versus vehicle, ejected from vehicle, fall from elevation (more than 1 meter or 5 stairs) or an equivalent mechanism), fall from any elevation, loss of consciousness reported by patient or witness (presence and duration), retrograde amnesia (presence and duration), posttraumatic amnesia (presence and duration), headache, vomiting (frequency), intoxication with drugs or alcohol (history or suggestive findings on examination), posttraumatic seizure, GCS score on presentation, significant injury above clavicles, suspected open or depressed skull fracture, contusion of skull, clinical signs of skull base fracture (for example: raccoon eyes, battle sign, hemotympanum, CSF otorrhea, CSF rhinorrhea, palpable discontinuity, bleeding from ear), neurological deficit (paresis, dysphasia or other such as cranial nerve damage including diplopia, changes in sensibility, asymmetrical reflexes or pathological reflexes, coordination problems and ataxia), GCS deterioration 1 hour after presentation.

Main outcome measures

The primary outcome was any intracranial traumatic finding on CT, defined as a subdural hematoma, epidural hematoma, subarachnoid hemorrhage, cerebral lesions (hemorrhagic contusion, non-hemorrhagic contusion, diffuse axonal injury), intraventricular hemorrhage, and skull fracture. The secondary outcome was any potential neurosurgical lesion, which was defined as an intracranial traumatic finding on CT which could lead to a neurosurgical intervention or death. Examples of potential neurosurgical lesions are an epidural hematoma, large acute subdural hematoma (mass), large contusion(s) (mass), depressed skull fracture, and any lesion with a midline shift or herniation. To compare our findings with previous studies we also assessed the performance of decision rules for detecting neurosurgical interventions. All outcome measures were chosen a priori.

Study procedures

During patient inclusion in the study, neurologists (in training) and emergency physicians (in training) followed their local guideline for CT scanning in patients with MHI. Most participating centers used the same national guideline based on the CHIP rule, two centers followed a slightly adapted guideline (Supplementary Table 2).

Eligible patients were consecutively included by trained researcher physicians, who did not personally interview the patients. Clinical data were collected before diagnostic tests as far as possible by using forms the clinicians could fill in for each patient. The head CT scans were performed according to a routine trauma protocol at each hospital. The CT scans were interpreted by (neuro)radiologists who were aware of the patient's history and clinical findings, but they were not aware of the actual score of the CT decision rules.

The clinical risk factors were collected by taking the patient's history or information from a witness or family member. Characteristics such as injury severity score were also collected. All patients' details about hospital admission, neurosurgical intervention, and moment of discharge were collected. If the patient was scanned, details about CT findings were recorded. The electronic health records were reviewed 30 days after the injury to assess follow-up information about a neurosurgical intervention. All data were entered by researcher physicians in the case report forms of the web based data management system OpenClinica (LCC, version 3.12.2).

Data management

After patient inclusion and data entering, two authors (KAF and CLvdB) checked the database for correct patient inclusion and completeness of data using IBM statistical package for social sciences (SPSS) version 21. Missing data were assumed to be missing at random; so to avoid bias, missing data were imputed on the basis of all the risk factors mentioned above, using multiple imputation (n=5) with the "multivariate imputation by chained equations" function in R, version 3.3.2 (R foundation for statistical computing).

Data analysis

The study population was described in terms of demographic characteristics, risk factors, admission to the hospital, and neurosurgical intervention. In patients with a CT scan, we also evaluated any intracranial traumatic findings and potential neurosurgical lesions on CT. Continuous variables were described as mean and interquartile range, categorical variables as frequencies and percentages.

The diagnostic performance of the CHIP, NOC, CCHR, and NICE decision rules for detecting intracranial traumatic findings and potential neurosurgical lesions were compared. Because the NOC and CCHR rules were developed in a specific patient population, we performed the analysis in our entire study population, as well as in a subset of the study population (based on the inclusion/exclusion criteria of the development studies of the NOC and CCHR; referred to as original NOC and original CCHR), and in our entire study population with adjustment of the rules. In the adjusted rules, the exclusion criteria of the NOC and CCHR rules were added as additional risk factors (referred to as adjusted NOC and adjusted CCHR). For the NOC rule, a Glasgow coma scale score of 13 or 14 and presence of neurological deficit were added. Finally, for the CCHR rule, use of anticoagulation, post-traumatic seizure, and presence of neurological deficit were added. All patients who had a risk factor according to the NOC or CCHR rules scored positive on these rules, indicating that they needed a CT scan.

The sensitivity, specificity, and proportion of patients needing a CT scan (with 95% confidence intervals) were assessed for each of the four decision rules. Sensitivity was calculated by dividing the number of patients in whom the outcome measure was present and the decision rule was positive, by the total number of patients in whom the outcome measure was present. Specificity was calculated by dividing the number of patients in whom the outcome measure was absent and the decision rule was negative, by the total number of patients in whom the outcome measure was absent. The Cochran's Q test was used to directly compare the sensitivities and specificities between the four decision rules, but it should be noted that results of this test do not automatically imply that any one rule is better than the other.[22] The proportion of patients needing a CT scan was calculated by dividing the number of patients in whom the decision rule was positive by the total number of patients. Confidence intervals were calculated by a bootstrapping method in R, which analyses the performance for each rule 500 times and derived the confidence intervals from the results.

In patients without a CT scan the outcomes could not be observed. In these patients the expected outcomes (any intracranial traumatic finding and potential neurosurgical lesion) were imputed based on their risk factors with multiple imputation, in order to avoid selection bias and thus yield unbiased estimates of sensitivity and specificity.[23] This imputation was possible for patients from six of the nine centers, because the other three centers had not included patients without a CT scan. The patients with and without CT scans (with imputed outcomes) from these six centers were used for the primary analysis. In addition, we analyzed all patients with a CT scan from all the centers in a secondary (sensitivity) analysis, which in theory would lead to an overestimation of sensitivity and underestimation of specificity of all the rules.

In this decision problem, avoiding false negatives was more important than avoiding false positives: a false negative result leads to not performing a CT scan and thus potentially misses a lesion, whereas a false positive result leads to performing an unnecessary CT scan. The decision rule should identify all patients with potential neurosurgical lesions and most with intracranial traumatic findings, because of the severe clinical consequences (intracranial surgery, neurological sequelae, death).

Net proportional benefit has been proposed to incorporate such weighting in calculation of clinical usefulness of decision rules.[24,25] For each rule, we expressed the net proportional benefit using the formula: (true positives/total number) - weight×(false positives/total number). Over a range of different weights, the net proportional benefit was calculated and compared with the scanning of all patients. The weight in this formula expresses the ratio of harmful consequences due to a false positive divided by the harmful consequences of a false negative, and it is equivalent to the odds of a lesion above which one would perform a CT scan. At a low threshold for performing CT, we would avoid false negatives of the decision rule (that is, maximize true positives) at the cost of performing many CT scans: if the threshold is 1%, this level implies performing 100 CT scans to avoid one missed lesion. At a higher threshold for performing CT, we would avoid false positives of the decision rule: if the threshold is 10%, this level implies performing 10 CT scans to avoid one missed lesion. We considered an intermediate range of thresholds (4-6% for any traumatic finding and 0.5%-1% for potential neurosurgical lesion) acceptable from a clinical point of view.[24,26] Net proportional benefit expresses the true positives and the decision rule with the highest net benefit at the intermediate thresholds has the highest clinical value.[24] All statistical analyses were performed using R software, version 3.3.2 (R foundation for statistical computing, Vienna, Austria).

Patient involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in developing plans for design or implementation of the study. No patients were asked to advise on interpretation or writing up of results. There are plans to disseminate the results of the research to the relevant patient community.

Results

Between March 2015 and December 2016, 5839 consecutive patients with MHI were entered in the database in the participating centers (Figure 1). After checking the in- and exclusion criteria 322 patients were excluded from the study (GCS score < 13, age < 16 years or no blunt head injury). In three out of nine centers only patients with a CT were included (n=960). The remaining six centers included patients with and without a CT (n=4557).

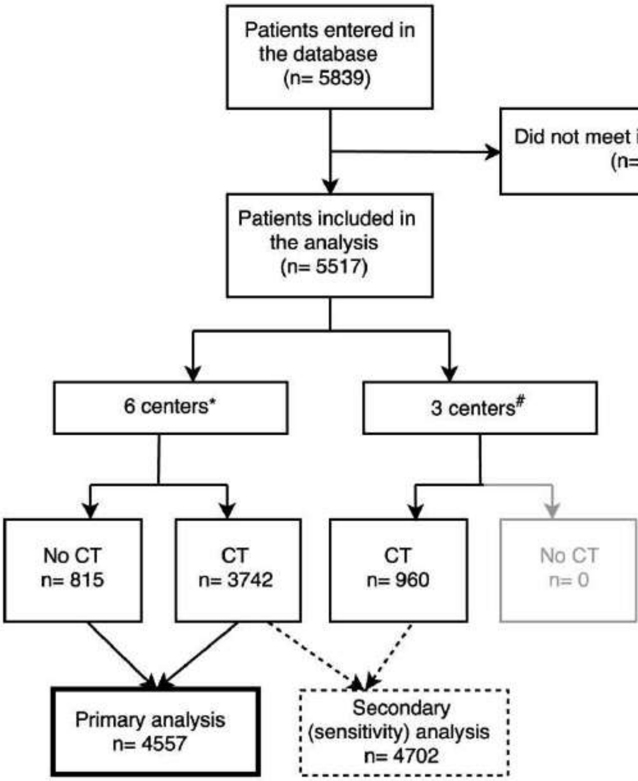

Figure 1. Study flow diagram.

*Six centers=one university center (trauma level 1) and five non-university centers (trauma levels 1 (two centers), 2 (one), 3 (two)), including patients with and without CT scans; three centers=two university centers (both trauma level 1) and one non-university center (trauma level 2), including only patients with a CT scan. CT=computed tomography

For the primary analysis 4557 patients from six centers were included; 3742 patients (82.1%) received a CT scan and 815 (17.9%) did not. Compared with patients who received a CT scan, more patients without a scan had a Glasgow coma scale score of 15 (n=3109 (83.1%) v n=805 (98.8%)), and fewer patients experienced loss of consciousness (n=1136 (30.3%) v n=56 (6.8%)) or post-traumatic amnesia (n=1075 (28.7%) v n=29 (3.5%); Table 1). Some data were unknown to the including physician, which was most frequently the case for retrograde amnesia (n=675, 14.8%), loss of consciousness (n=651, 14.3%), post-traumatic amnesia (n=502, 11%), and headache (n=630, 13.8%; Table 1).

Table 1. Baseline characteristics of 4557 study patients from six centers*.

	All patients (n=4557)	Missing	Patients with CT (n=3742)	Patients without CT (n=815)
Age mean in years (range)	53.1 (16-101)	-	56.9 (16-101)	35.7 (16-96)
Sex, n male (%)	2656 (58.3%)	-	2145 (57.3%)	511 (62.7%)
GCS score at presentation		-		
• GCS 13	143 (3.1%)		141 (3.8%)	2 (0.2%)
• GCS 14	500 (11.0%)		492 (13.1%)	8 (1.0%)
• GCS 15	3914 (85.9%)		3109 (83.1%)	805 (98.8%)
Use of anticoagulation		29 (0.6%)		
• None	4045 (88.8%)		3233 (86.4%)	812 (99.6%)
• Coumarin	418 (9.2%)		418 (11.2%)	-
• Direct oral anticoagulants	54 (1.2%)		53 (1.4%)	1 (0.1%)
Use of thrombocyte aggregation inhibitors	615 (13.5%)	33 (0.7%)	577 (15.4%)	38 (4.7%)
Bleeding disorder	44 (1%)	33 (0.7%)	41 (1.1%)	3 (0.4%)
Mechanism of injury		47(1.0%)		
• Road traffic accident pedestrian	64 (1.4%)		57 (1.5%)	7 (0.9%)
• Road traffic accident cyclist	162 (3.6%)		152 (4.1%)	10 (1.2%)
• Fall from height	574 (12.6%)		532 (14.2%)	42 (5.2%)
• Other†	3710 (81.4%)		2955 (79.0%)	755 (92.6%)
Ejected from vehicle	150 (3.3%)	56 (1.2%)	135 (3.6%)	15 (1.8%)
Loss of consciousness		651 (14.3%)		
• None	2714 (59.6%)		1968 (52.6%)	746 (91.5%)
• 15 minutes or less	1160 (25.5%)		1105 (29.5%)	55 (6.7%)
• More than 15 minutes	32 (0.7%)		31 (0.8%)	1 (0.1%)

Table 1. Continued

	All patients (n=4557)	Missing	Patients with CT (n=3742)	Patients without CT (n=815)
Retrograde amnesia		675 (14.8%)		
• None	3425 (75.2%)		2637 (70.5%)	788 (96.7%)
• 30 minutes or less	312 (6.8%)		303 (8.1%)	9 (1.1%)
• More than 30 minutes	145 (3.2%)		144 (3.8%)	1 (0.1%)
Posttraumatic amnesia		502 (11%)		
• None	2951 (64.8%)		2185 (58.4%)	766 (94.0%)
• Up to 2 hours	976 (21.4%)		948 (25.3%)	28 (3.4%)
• 2-4 hours	69 (1.5%)		68 (1.8%)	1 (0.1%)
• More than 4 hours	59 (1.3%)		59 (1.6%)	-
Intoxication with drugs or alcohol	1031 (22.6%)	85 (1.9%)	922 (24.6%)	109 (13.4%)
Posttraumatic seizure	36 (0.8%)	68 (1.5%)	33 (0.9%)	3 (0.4%)
Headache	1410 (30.9%)	630 (13.8%)	1208 (32.3%)	202 (24.8%)
Vomiting		50 (1.1%)		
• Once	158 (3.5%)		148 (4.0%)	10 (1.2%)
• Twice or more	144 (3.2%)		142 (3.8%)	2 (0.2%)
GCS deterioration (after 1 hr)		23 (0.5%)		
• 1 point	38 (0.8%)		38 (1.0%)	-
• 2 or more points	12 (0.3%)		12 (0.3%)	-
Neurological deficit‡	130 (2.9%)	141 (3.1%)	128 (3.4%)	2 (0.2%)
Signs of skull base fracture	144 (3.2%)	25 (0.5%)	139 (3.7%)	5 (0.6%)
Visible injury of the head	2564 (56.3%)	19 (0.4%)	2208 (59%)	356 (43.7%)
Visible injury of the face	1631 (35.8%)	22 (0.5%)	1315 (35.1%)	316 (38.8%)
Suspicion of open fracture	11 (0.2%)	40 (0.9%)	11 (0.3%)	-
Injury Severity Score, mean (range)	6.5 (0-75)	-	7.1 (0-75)	3.5 (0-29)

Data are number (%) of patients unless stated otherwise. CT=computed tomography.
*These centers refer to those on the left-hand side of figure 1, for the primary analysis.
†Includes patients with mild head injury such as a bumped head against an object.
‡History or suggestive findings on examination (eg, nystagmus, abnormal walking).

In 384 patients (8.4%), CT showed an intracranial traumatic finding, mostly consisting of traumatic subarachnoid hemorrhages (n=182; 4.0%) and skull fractures (n=150; 3.3%; Table 2). Of 74 (1.6%) patients with a potential neurosurgical lesion, 18 (0.4%) underwent a neurosurgical intervention for head injury within 30 days after the injury.

In 116 of 3742 patients without LOC and in 117 of 3742 patients without PTA an intracranial traumatic finding was found (Table 3). In total 20 patients without LOC had a potential neurosurgical lesion and four patients underwent a neurosurgical intervention. In patients without PTA, 14 had a potential neurosurgical lesion and three patients underwent a neurosurgical intervention.

Table 2. Traumatic CT findings in 3742 patients with a CT scan from six centers*

CT finding	N (%)
CT finding†	384 (8.4%)
Skull fracture	150 (3.3%)
• Depressed fracture	19 (0.5%)
• Linear fracture	66 1.4%)
• Skull base fracture	68 (1.5%)
Subarachnoid hemorrhage	182 (4.0%)
Contusion	
• Small	115 (2.5%)
• Large (mass)	10 (0.2%)
Subdural hematoma	
• Small	126 (2.8%)
• Large (mass)	22 (0.5%)
Epidural hematoma	
• Small	30 (0.7%)
• Large (mass)	5 (0.1%)
Suspicion of DAI on CT	13 (0.3%)
Basal cisterns compressed or obliterated	11 (0.2%)
CT shift	
• 0-4mm	16 (0.4%)
• 5mm or more	9 (0.2%)

CT = computed tomography, DAI = diffuse axonal injury
*These centers refer to those on the left-hand side of figure 1, for the primary analysis.
†some patients had more than 1 CT finding

In a subgroup analysis of the 3914 patients with a Glasgow coma scale score of 15, more than half the patients (n=2465, 63%) had no loss of consciousness and no post-traumatic amnesia. Ninety-three (3.8%) patients had any intracranial traumatic finding, seven (0.3%) had a potential neurosurgical lesion, and one underwent a neurosurgical intervention.

Table 3. Baseline characteristics of 3742 patients with a CT scan from six centers*, according to status of CT findings

	Normal CT (n=3358)	**Abnormal CT (n=384)**	**All patients with CT (n=3742)**
Age mean in years (range)	56.6 (16-101)	59.1 (17-98)	56.9 (16-101)
Sex, n male (%)	1901 (56.6)	244 (63.5%)	2145 (57.3%)
GCS score at presentation			
• GCS 13	94 (2.8%)	47 (12.2%)	141 (3.8%)
• GCS 14	401 (11.9%)	91 (23.7%)	492 (13.1%)
• GCS 15	2863 (85.3%)	246 (64.1%)	3109 (83.1%)
Use of anticoagulation			
• None	2886 (85.9%)	347 (90.4%)	3233 (86.4%)
• Coumarin	387 (11.5%)	31 (8.1%)	418 (11.2%)
• Direct oral anticoagulants	50 (1.5%)	3 (0.8%)	53 (1.4%)
Use of thrombocyte aggregation inhibitors	502 (15.0%)	75 (19.5%)	577 (15.4%)
Bleeding disorder	39 (1.2%)	2 (0.5%)	41 (1.1%)
Mechanism of injury			
• Road traffic accident Pedestrian	48 (1.4%)	9 (2.3%)	57 (1.5%)
• Road traffic accident cyclist	127 (3.8%)	25 (6.5%)	152 (4.1%)
• Fall from height	451 (13.4%)	81 (21.1%)	532 (14.2%)
• Other†	2691 (80.1%)	264 (68.8%)	2955 (79%)
Ejected from vehicle	120 (3.6%)	15 (3.9%)	135 (3.6%)
Loss of consciousness			
• None	1852 (55.2%)	116 (30.2%)	1968 (52.6%)
• 15 minutes or less	943 (28.1%)	162 (42.2%)	1105 (29.5%)
• More than 15 minutes	21 (0.6%)	10 (2.6%)	31 (0.8%)
Retrograde amnesia			
• None	2443 (72.8%)	194 (50.5%)	2637 (70.5%)
• 30 minutes or less	251 (7.5%)	52 (13.5%)	303 (8.1%)
• More than 30 minutes	102 (3.0%)	42 (10.9%)	144 (3.8%)
Posttraumatic amnesia			
• None	2068 (61.6%)	117 (30.5%)	2185 (58.4%)
• Up to 2 hours	776 (23.1%)	172 (44.8%)	948 (25.3%)
• 2-4 hours	54 (1.6%)	14 (3.6%)	68 (1.8%)
• More than 4 hours	38 (1.1%)	21 (5.5%)	59 (1.6%)
Intoxication *	836 (24.9%)	86 (22.4%)	922 (24.6%)
Posttraumatic seizure	26 (0.8%)	7 (1.8%)	33 (0.9%)
Headache	1086 (32.3%)	122 (31.8%)	1208 (32.3%)

Table 3. Continued

	Normal CT (n=3358)	Abnormal CT (n=384)	All patients with CT (n=3742)
Vomiting			
• Once	131 (3.9%)	17 (4.4%)	148 (4.0%)
• Twice or more	119 (3.5%)	23 (6.0%)	142 (3.8%)
GCS deterioration (after 1 hr)			
• 1 point	33 (1.0%)	5 (1.3%)	38 (1.0%)
• 2 or more points	6 (0.2%)	6 (1.6%)	12 (0.3%)
Neurological deficit ‡	100 (3.0%)	28 (7.3%)	128 (3.4%)
Signs of skull base fracture	89 (2.7%)	50 (13.0%)	139 (3.7%)
Visible injury of the head	1945 (57.9%)	263 (68.5%)	2208 (59%)
Visible injury of the face	1181 (35.2%)	134 (34.9%)	1315 (35.1%)
Suspicion of open fracture	6 (0.2%)	5 (1.3%)	11 (0.3%)
Injury Severity Score, mean (range)	6.2 (0-54)	15.2 (1-75)	7.1 (0-75)

Data are number (%) of patients unless stated otherwise. CT=computed tomography.
*These centers refer to those on the left-hand side of figure 1, for the primary analysis.
†Includes patients with mild head injury such as a bumped head against an object.
‡History or suggestive findings on examination (eg, nystagmus, abnormal walking).

Of all 4557 patients, 1511 (33.2%) were admitted to the hospital for head injury and other reasons. Of the admitted patients, 226 (5.0%) were admitted for two nights or longer because of head injury; 52 (1.1%) had neurological deterioration during admission, and six (0.1%) were intubated for longer than 24 h. Eleven (0.2%) patients died as a result of head injury, and 21 (0.5%) died as a result of a different illness or trauma.

Performance of the decision rules

After imputation of outcomes in patients without a CT scan, 23 of 815 patients had any intracranial traumatic finding and no patient had a potential neurosurgical lesion. None of these 815 patients without a CT scan had undergone a neurosurgical intervention in 30 days after injury. The sensitivity for identifying patients with any intracranial traumatic finding on CT ranged from 72.5% for the NICE criteria to 98.8% for the NOC (Table 4; Supplementary Figure 1).

Table 4. Performance of the four decision rules* used for CT in 4557 patients with minor head injury presenting at six centers†

	Positive n	**Negative** n
CHIP n=4557		
Any traumatic finding on CT		
CHIP - Positive	383	3253
CHIP - Negative	24	897
Potential neurosurgical lesion		
CHIP - Positive	72	3564
CHIP - Negative	2	919
NICE n=4557		
Any traumatic finding on CT		
NICE - Positive	295	1624
NICE - Negative	112	2526
Potential neurosurgical lesion		
NICE - Positive	63	1856
NICE - Negative	11	2627
NOC n=4557		
Any traumatic finding on CT		
NOC - Positive	402	3966
NOC - Negative	5	184
Potential neurosurgical lesion		
NOC - Positive	74	4294
NOC - Negative	0	189
CCHR n=4557		
Any traumatic finding on CT		
CCHR - Positive	327	2314
CCHR - Negative	80	1836
Potential neurosurgical lesion		
CCHR - Positive	65	2576
CCHR - Negative	9	1907

*CHIP=CT in head injury patient rule; NICE=National Institute for Health and Care Excellence guideline for head injury; NOC=New Orleans criteria; CCHR=Canadian CT head rule. †These centers refer to those on the left-hand side of figure 1, for the primary analysis.

Sensitivity % (CI)	Specificity % (CI)	Positive likelihood ratio (CI)	Negative likelihood ratio (CI)
94.1 (91.5 to 96.3)	21.6 (20.4 to 22.9)	1.20 (1.16 to 1.23)	0.27 (0.17 to 0.40)
97.3 (93.1 to 100)	20.5 (19.4 to 21.7)	1.22 (1.17 to 1.26)	0.13 (0 to 0.34)
72.5 (67.8 to 77.2)	60.9 (59.3 to 62.5)	1.85 (1.72 to 2.0)	0.45 (0.37 to 0.53)
85.1 (76.4 to 92.9)	58.6 (57.1 to 60.1)	2.06 (1.84 to 2.27)	0.25 (0.12 to 0.40)
98.8 (97.6 to 99.8)	4.4 (3.8 to 5.1)	1.03 (1.02 to 1.05)	0.28 (0.06 to 0.53)
100 (100 to 100)	4.2 (3.6 to 4.8)	1.04 (1.04 to 1.05)	0 (0 to 0)
80.3 (76.1 to 84.2)	44.2 (42.7 to 45.9)	1.44 (1.35 to 1.52)	0.44 (0.36 to 0.55)
87.8 (79.7 to 94.9)	42.5 (41.0 to 44.1)	1.53 (1.40 to 1.66)	0.29 (0.12 to 0.47)

6

The sensitivity for identifying patients with potential neurosurgical lesions was 100% for NOC, the NICE criteria had the lowest sensitivity (85.1%) for identifying potential neurosurgical lesions (Table 4). The NICE criteria would have missed 11/74 patients with potential neurosurgical lesions (Supplementary Table 3). The CHIP criteria would have missed two patients with potential neurosurgical lesions, these patients both had a small epidural hematoma, which did not need neurosurgical treatment and one of them had surgery to repair a depressed skull fracture (Supplementary Table 3).

The specificity for identifying any intracranial traumatic finding was lowest for the NOC (4.4%) and highest for the NICE criteria (60.9%). The specificity for potential neurosurgical lesions ranged from 4.2% (NOC) to 58.6% (NICE criteria). The sensitivity and specificity differed significantly between all the rules (Cochran's Q $P < 0.001$). Sensitivity and specificity for the original CCHR and NOC were slightly different from the adjusted versions (see the methods section for definition of the original and adjusted groups; (Supplementary Table 4A, 4B). For the outcome of neurosurgical intervention, the NOC rule had the highest sensitivity (100%) and the NICE criteria the highest specificity (58.1%; (Supplementary Table 5).

Clinical usefulness

The decision curve of the NOC rule was almost identical to CT scanning all patients in both study outcomes (Figure 2). When using a low threshold for performing CT (to avoid false negatives of the decision rule), we found that the NOC rule and the scanning of all patients had the highest net proportional benefit. When using a high threshold for performing CT (to avoid false positives), we found that the NICE criteria had the highest net proportional benefit (Figure 2). Over a narrow range of intermediate thresholds, the CHIP criteria had the highest net proportional benefit (0.038-0.054 for intracranial traumatic findings and 0.008-0.012 for potential neurosurgical lesions). For the neurosurgical intervention outcome, the differences in net proportional benefit were small (Supplementary Figure 2).

Proportion of patients needing CT

According to the different decision rules the proportion of the study population needing CT was 95.9% (95% confidence interval 95.3% to 96.5%) with the NOC; 79.8% (78.6% to 80.9%) with the CHIP criteria; 58.0% (56.4% to 59.4%) with the CCHR and 42.1% (40.6% to 43.6%) with the NICE criteria. To increase the sensitivity of the CHIP criteria to the level of the NOC, 733 more CTs would have been needed to identify 19 more patients with intracranial traumatic findings and two more patients with a potential neurosurgical lesion.

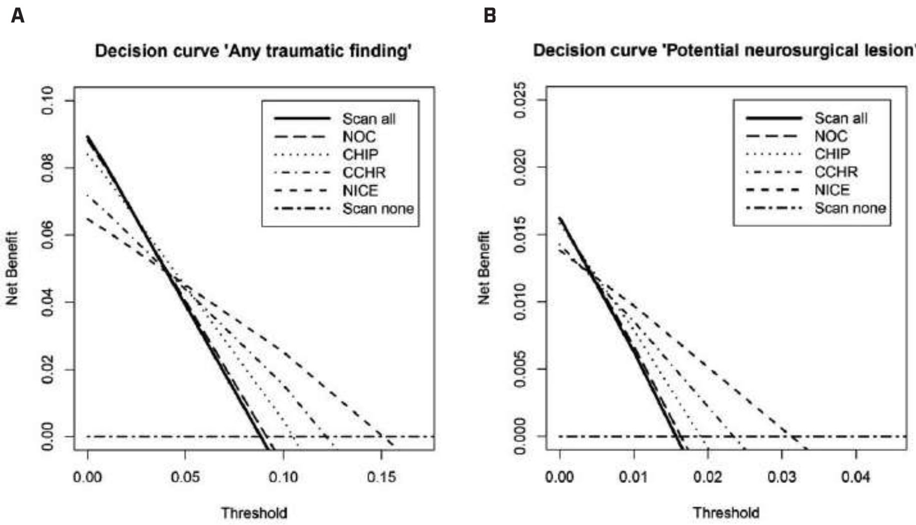

Figure 2.

Decision curves for study outcomes showing net proportional benefit per CT decision rule

CT=computed tomography; CHIP=CT in head injury patient rule; NICE=National Institute for Health and Care Excellence guideline for head injury; NOC=New Orleans criteria; CCHR=Canadian CT head rule; scan all=scanning of all patients; scan none=scanning no patients. For each rule, the net proportional benefit was calculated with the formula: (true positives/total number) - weight×(false positives/total number)

Secondary (sensitivity) analysis in all patients receiving CT scans

In all included centers, 4702 patients received a CT scan (Figure 1). Most of these patients had a Glasgow coma scale score of 15 at presentation (n=3798; 80.8%), 1511 (32.1%) experienced loss of consciousness, and 1480 (31.5%) had post-traumatic amnesia (Supplementary Table 6A). We found that 528 (11.2%) patients had an intracranial traumatic finding on CT (Supplementary Table 6B). Although the sensitivity of all rules was higher and the specificity lower, their ordering was the same. The NOC rule had the highest sensitivity (99.1%) and lowest specificity (3.1%) for any intracranial traumatic finding, whereas the NICE guideline had the highest specificity (50.3%) and lowest sensitivity (77.5%; Supplementary Figure 3). Net proportional benefit analysis showed the same pattern as in the primary analysis (Supplementary Figure 3).

Discussion

Principal findings

In this large, multicenter, external validation study of CT decision rules for MHI patients, the NOC had the highest sensitivity and was the only rule with a 100% sensitivity for potential neurosurgical lesions. Nevertheless, the high sensitivity of the NOC comes at the cost of an extremely low specificity with as consequence that practically all patients require a CT scan. The NICE guideline had the highest specificity and the lowest proportion that required a CT but at the cost of a low sensitivity. The sensitivity of the CHIP criteria was high (97% for potential neurosurgical lesions) with an acceptable specificity and a substantial reduction in the proportion requiring CT. Of note, the sensitivity for identifying patients with any intracranial traumatic finding on CT was less than 100% for all decision rules.

Which decision rule is the best for the situation depends on several factors. It depends not only on its characteristics but also on how many CT scans the physician is willing to perform to identify one patient with an intracranial traumatic finding or potential neurosurgical lesion. Because a potential neurosurgical lesion could have serious consequences, such as a neurosurgical intervention or even death, most professionals would agree that the sensitivity of the decision rule should be 100%.[27] However, it is less easy to agree on the desired sensitivity for finding any intracranial traumatic lesion, because not all small intracranial traumatic findings have clinical consequences. If a CT decision rule gives a false positive result, the patient receives an unnecessary CT and will be discharged after spending a few hours in the emergency department. If the rule gives a false negative result, the patient will be discharged without a CT and an intracranial traumatic finding will be missed. If this intracranial traumatic finding was a potential neurosurgical lesion and adequate therapy was omitted or was given too late, this could have serious consequences.[27]

The net proportional benefit analysis may help in finding the best decision rule for different thresholds, but the interpretation of the curves may be challenging.[24] If a low threshold is chosen, the best rule to use in order to identify all patients with any lesion is the NOC, but this would imply that practically all patients undergo CT. At a high threshold, using the NICE criteria avoids unnecessary scans and has the highest net proportional benefit, but important lesions may be missed. For the outcome potential neurosurgical lesion a very low net proportional benefit threshold and 100% sensitivity is desired. For intermediate thresholds, using the CHIP criteria makes a trade-off between avoiding missed lesions while achieving a substantial reduction in CTs of 21%. For the outcome intracranial traumatic finding the threshold can be higher, because it is not necessary that all findings are identified. From a societal perspective, not only clinical usefulness but also cost-effectiveness is important. A cost-effectiveness study showed that a prediction rule needs a sensitivity of at least 97% for identifying potential neurosurgical lesions in order to be cost-effective, otherwise performing CT in all patients with MHI is more cost-effective.[26] In our study, only the NOC and the CHIP criteria fulfilled this criterion.

Comparison with other studies

Several other studies have validated and compared the sensitivity and specificity of CT decision rules for adult MHI patients, but only the NOC, CCHR and NICE decision rules have been externally validated.[13-17,28] Our study adds the CHIP rule to externally validated decision rules and compares it head-to-head with the other rules. Validation studies vary in design and in outcome measures (eg, clinically significant findings on CT are not uniformly defined), and are therefore difficult to compare. In addition, the case mix of our study is different from previous validation studies because we included all patients with blunt traumatic minor head injury, including those without risk factors. Our study is in line with earlier findings that the NOC rule has a high sensitivity but leads to a high scan rate, whereas the CCHR rule and NICE guideline can reduce the number of CT scans substantially, but at the cost of a lower sensitivity. However, the potential reduction in CT scans has not been proved in clinical practice yet. In terms of sensitivity and specificity, the CHIP rule lies between the NOC and CCHR rules.

All the decision rules in this study have been designed for an emergency department population. Although only the NICE and CHIP criteria have been designed to apply to all patients with minor head injury, in daily practice the NOC and CCHR rules probably apply to these patients as well. Therefore, we also investigated adjusted versions of the NOC and CCHR rules, which are applicable to all patients with minor head injury. The sensitivity and specificity of these two adjusted rules were comparable to the sensitivity and specificity of their original versions.

Our study population had a mean age of 53.1 years; by comparison, patients in the development studies for the NOC, CCHR, and CHIP rules had a mean age of 36-41 years. This difference is probably indicative of ageing of the population, but other factors such as changed referral patterns or increasing incidence fall accidents might contribute as well.[9] The percentage of patients with any intracranial traumatic finding (8.4%) was comparable with most other studies (6.9%-12.1%).[6,7,13] The percentage of patients who underwent a neurosurgical intervention within 30 days after injury in our study (0.4%) was low compared to most other studies (0.4%-1.5%). This difference might be because the indication for neurosurgery not only depends on clinical factors, but also differs from country to country and from neurosurgeon to neurosurgeon and could have changed over time.[29] We therefore believe that instead of actual neurosurgical interventions, it is better to use 'potential neurosurgical lesions' as outcome measure. The confidence intervals for neurosurgical intervention were wide (sensitivity 71%-100%) because of the low prevalence of this outcome.

Patients with MHI presenting at the emergency department not only reflect the ageing of the population but also the result of the decision rules themselves. In the Netherlands, use of anticoagulants (coumarines or direct oral anticoagulants) is considered a risk factor for intracranial complications and a reason for referral to the emergency department in both the ambulance and general practitioner protocols.[30] The percentage of patients using anticoagulants in our study was higher than in the CHIP rule development study (9.2% vs 12.7%).[15]

Limitations

A limitation of our study was that not all consecutive patients with minor head injury were scanned. Following the guidelines for CT scanning at the participating centers resulted in patients with 0-1 minor criteria who did not undergo a CT scan. Therefore, patients who did not receive a CT scan but had intracranial traumatic findings (that is, those with false negative results) could have been missed. To detect this patient subgroup and precisely estimate their relative frequency among unscreened patients would need many thousands of individuals, which was not feasible. Missing patients without a CT scan could have led to a slight overestimation of the sensitivity and an underestimation of the specificity. We therefore performed the primary analysis on data from six centers which also collected data for patients without a CT scan. For all the rules, the new calculated sensitivities were a little lower and the specificities higher, as expected. The fact that most centers in our study used CT guidelines based on the CHIP rule could have introduced a bias in favor of the CHIP rule, owing to possible missed lesions (because the patient was not scanned according to the local guideline) that would have been detected by the other rules. However, by imputing the outcomes of the patients without a CT scan, we were able to keep this bias to a minimum.

Because most physicians used the CHIP rule on a regular basis, they were more likely to apply it correctly. However, many risk factors are the same for all rules and the validation was performed based on the scored risk factors, not on the physicians' judgment of a rule being positive or negative. In addition, in our centers, it is clinical practice to assess not only risk factors from the CHIP rule, but also other risk factors such as headache and retrograde amnesia. In our study, it was unclear how quickly patients proceeded to CT and whether lesions appeared after this time. However, af Geijerstam et al. concluded in a literature review that the risk for developing an intracranial lesion after an early normal CT is very low.[31]

Another limitation was the possibility that we missed patients undergoing a neurosurgical intervention in a different hospital. However, because the participating centers were all the primary neurosurgery centers of the area, this potential bias is highly unlikely. Furthermore, because we used potential neurosurgical lesions as a secondary outcome instead of neurosurgical intervention, our main findings would not have been affected. In the development studies of the four decision rules, potential neurosurgical lesions were not used as an outcome measure.

Conclusions and policy implications

Application of the CHIP, NOC, CCHR, or NICE decision rules leads to a wide variation in CT scanning among patients with minor head injury, resulting in unnecessary CT scans and missed intracranial traumatic findings. Only the NOC rule did not miss potential neurosurgical lesions, but this was at the cost of having to scan nearly all patients. Although the NICE guideline had the highest reduction of CT scans (58%), missing 15% of patients with potential neurosurgical lesions would be unacceptable to most physicians in the emergency department, because it would mean that for every 200 patients not be scanned according to the NICE criteria, one patient would turn out to have a potential neurosurgical lesion.

Of the four investigated rules, the CHIP rule performed the best with an acceptable sensitivity of 97% for potential neurosurgical lesions according to previous cost effectiveness analysis, the highest net proportional benefit at intermediate thresholds, and a substantial reduction of CT scans of 21% compared with the scanning of all patients. Updating an existing decision rule might increase the sensitivity and specificity for detecting potential neurosurgical lesions. Until this update is conducted, it is justified to use any of the four rules for patients with minor head injury presenting at the emergency department. We recommend use of the CHIP rule because it leads to a substantial reduction of CT scans and misses very few potential neurosurgical lesions.

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Supplementary Material

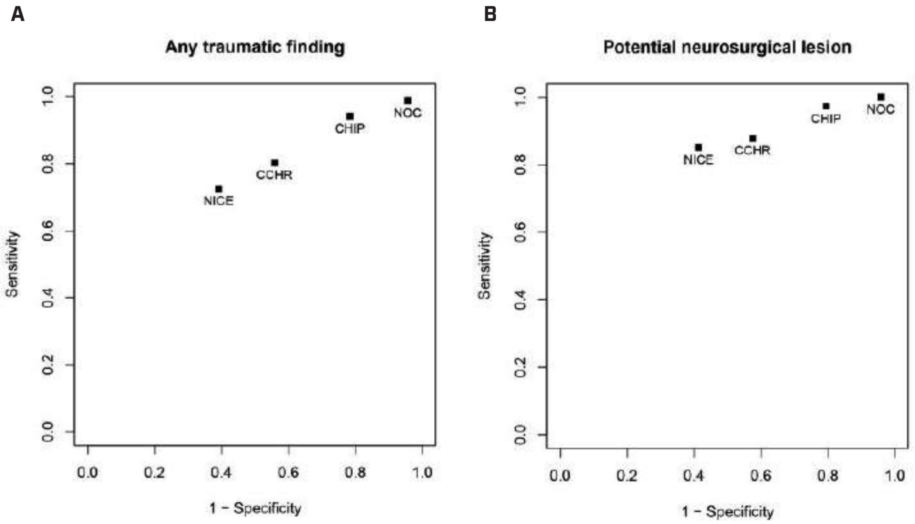
Supplementary Table 1. Overview of decision rules CCHR, NOC, CHIP and NICE

Study	Patient population	Indications for CT
NOC: New Orleans Criteria Haydel et al, 2000	GCS score of 15, loss of consciousness, normal findings on brief neurological examination, >3y	Clinical findings: • Headache (diffuse or local) • Vomiting • Age > 60 years • Drug or alcohol intoxication • Deficits in short-term memory (persistent anterograde amnesia in patient with otherwise normal GCS) • Physical evidence of trauma above clavicles • Seizure
CCHR: Canadian CT Head Rule Stiell et al, 2001	GCS score 13-15, witnessed LOC, definite amnesia or witnessed disorientation, age > 16y Exclusion: use of anticoagulation or obvious open skull fracture	High risk for intervention: • GCS < 15 at 2 hours after injury • Suspected open or depressed skull fracture • Any sign of basal skull fracture • Vomiting 2 or more episodes • Age 65 years or older Medium risk for brain injury on CT: • Amnesia before impact 30 min or more • Dangerous mechanism (pedestrian vs vehicle, ejected from vehicle, fall from elevation ≥ 3 feet, or 5 stairs)
CHIP: CT in Head Injury Patients Smits et al, 2007	GCS 13-14 or GCS of 15 and 1 risk factor, age ≥16	CT indicated if ≥ 1 major criterion: • Pedestrian or cyclist vs vehicle • Ejected from vehicle • Vomiting • PTA of 4 hours or more • Clinical sign of skull fracture • GCS < 15 • GCS deterioration ≥ 2 points (1 hour after presentation) • Use of anticoagulant therapy • Posttraumatic seizure • Age 60 years or older CT indicated if ≥ 2 minor criteria: • Fall from any elevation • Persistent anterograde amnesia • PTA of 2-4 hours • Contusion of skull • Neurologic deficit • LOC • GCS deterioration of 1 point (1 hour after presentation) • Age 40-60 years

Supplementary Table 1. Continued

Study	Patient population	Indications for CT
NICE: National Institute for Health and Care Excellence guideline: Head injury	Adults with head injury	<u>Perform CT within 1 hour:</u> • GCS < 13 • GCS < 15 at 2 hours after injury • Suspected open or depressed skull fracture • Any sign of basal skull fracture • Posttraumatic seizure • Focal neurologic deficit • More than one episode of vomiting since head injury <u>Perform CT within 8 hours:</u> • Current warfarin treatment <u>LOC and/or PTA and:</u> • Age > 65 years • History bleeding or clotting disorder • Dangerous mechanism of injury • More than 30minutes retrograde amnesia of events before head injury

CT = computed tomography, GCS = Glasgow Coma Scale, PTA = posttraumatic amnesia, LOC = loss of consciousness



Supplementary Figure 1. Performance of the CT decision rules (6 centers, n=4557).

CT = computed tomography, CHIP = CT in head Injury Patient rule, NICE = National Institute for Health and Care Excellence, NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule

Supplementary Table 2. Overview CT guidelines used in participating centers

	National guideline
Number of centers	7
1 or more major criteria	• GCS < 15 (including persisting PTA) • 2 or more points deterioration in GCS (1 hour after presentation) • Vomiting • Posttraumatic seizure • Signs of skull fracture • Pedestrian or cyclist versus vehicle • Ejected from motor vehicle • PTA ≥ 4 hours • Use of anticoagulants • Focal neurologic deficit • Suspicion of intracranial injury after focal "high impact" injury
2 or more minor criteria	• Fall from any elevation • LOC • Posttraumatic amnesia 2-4 hours • Visible injury to the head, excluding the face (without signs of fracture) • 1 point deterioration in GCS (1 hour post presentation) • Age > 40 years

CT = computed tomography, GCS = Glasgow Coma Scale, PTA = posttraumatic amnesia, LOC =loss of consciousness, INR = international normalized ratio, NOACS = novel oral anticoagulants

Local guideline 1	Local guideline 2
1	1
• GCS < 15 • 2 or more points deterioration in GCS (1 hour after presentation) • Vomiting • Posttraumatic seizure • Age ≥60 years • Signs of skull fracture • Dangerous mechanism (Pedestrian or cyclist versus vehicle; Ejected from motor vehicle; Fall from more than 1m or 5 stairs; Or equivalent mechanism) • Post traumatic amnesia ≥ 4 hours • Coagulopathy, e.g. use of coumarin derivate (INR >1.7), NOACs, or chronic alcohol abuse • Focal neurologic deficit • Intoxication that impairs neurological examination	• GCS < 15 (including persisting PTA) • Deterioration in GCS • Vomiting > 1 time • Posttraumatic seizure • Signs of skull fracture • Dangerous mechanism (Pedestrian or cyclist versus vehicle; Ejected from motor vehicle; Fall from high elevation) • Post traumatic amnesia > 1 hour • Use of anticoagulants/coagulopathy • Focal neurologic deficit
• Fall from < 1 m • LOC • PTA 2-4 hours • Persisting PTA (recall deficit) • Traumatic injury above the clavicles • 1 point deterioration in GCS (1 hour post presentation) • Age 40-60 years	• Fall from any elevation • LOC • Unclear trauma mechanism • Visible injury to the head, excluding the face (without signs of fracture) • Violence • Age > 65 years

Supplementary Table 3. Overview of missed neurosurgical lesions

	Patient characteristics	CT result	Missed by rule
1	32y, assault blunt instrument, intoxication, significant injury to the head, focal high impact injury	Small EDH, skull fracture	CHIP, NICE, CCHR
2	21y, scooter vs motor vehicle, high energy trauma, significant injury to face and head	Small EDH, small ASDH, skull fracture	CHIP, NICE, CCHR
3	69y, fall from scooter, headache, significant injury to the head	Small EDH	NICE
4	52y, fall from standing height, LOC, PTA, significant injury to the head	Small EDH, tSAH	NICE, CCHR
5	37y, fall from scooter, intoxication, LOC, retrograde amnesia < 30 min, PTA 2-4hrs	Small EDH, tSAH, small ASDH	NICE, CCHR
6	26y, forklift against head, LOC, PTA, headache, significant injury to the head, focal high impact injury	Small EDH, tSAH, small ASDH, contusion (small), skull fracture	NICE, CCHR
7	22y, fall from standing height, LOC, retrograde amnesia <30min	Small EDH	NICE, CCHR
8	36y, assault blunt instrument, LOC, PTA, significant injury to the head, focal high impact injury	Small EDH, skull fracture (depressed)	NICE, CCHR
9	88y, scooter vs truck, high energy trauma, significant injury to the head	Small EDH, skull fracture	NICE
10	24y, bicycle vs motor vehicle, high energy trauma, significant injury to the face, LOC, PTA, headache	Small EDH, contusion (small), skull fracture	CCHR
11	40y, bicycle vs bicycle, significant injury to the head, PTA, headache	Small EDH, contusion (small), skull fracture	NICE, CCHR
12	89y, fall from standing height, significant injury to the face	Large ASDH	NICE

CT = computed tomography, EDH = epidural hematoma, CHIP = CT in head Injury Patient rule, NICE = National Institute for Health and Care Excellence, CCHR = Canadian CT Head Rule ASDH = acute subdural hematoma, LOC = loss of consciousness, PTA = posttraumatic amnesia, tSAH = traumatic subarachnoid hemorrhage

Supplementary Table 4A. NOC and CCHR validation in population with in- and exclusion criteria as in development cohort (6 centers)

	Positive n	Negative n	Sensitivity % (CI)	Specificity % (CI)
Original NOC n=1147 (subset of population with in- and exclusion criteria of original NOC study)				
Any traumatic finding on CT			98.6 (96.4 to 100)	3.5 (2.4 to 4.5)
NOC - Positive	137	973		
NOC - Negative	2	35		
Potential neurosurgical lesion			100 (100 to 100)	3.3 (2.3 to 4.2)
NOC - Positive	20	1090		
NOC - Negative	0	37		
Original CCHR n= 1683 (subset of population with in- and exclusion criteria of original CCHR study)				
Any traumatic finding on CT			81.6 (76.8 to 86.2)	42.5 (39.9 to 45.1)
CCHR - Positive	209	821		
CCHR - Negative	47	606		
Potential neurosurgical lesion			85.1 (74.0 to 94.2)	39.5 (37.2 to 41.9)
CCHR - Positive	40	990		
CCHR - Negative	7	646		

CI = 95% confidence interval, NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule, CT= computed tomography

Supplementary Table 4B. Adjusted NOC and adjusted CCHR validation in entire study population (6 centers)

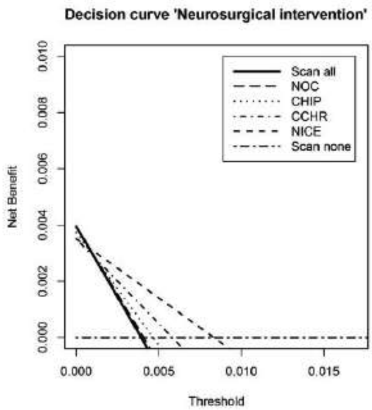
	Positive n	Negative n	Sensitivity % (CI)	Specificity % (CI)
Adjusted NOC n=4557 (including in- and exclusion criteria of original study as risk factors)				
Any traumatic finding on CT			98.8 (97.6 to 99.8)	4.0 (3.4 to 4.5)
NOC - Positive	402	3984		
NOC - Negative	5	166		
Potential neurosurgical lesion			100 (100 to 100)	3.8 (3.2 to 4.3)
NOC - Positive	74	4312		
NOC - Negative	0	171		
Adjusted CCHR n=4557 (including in- and exclusion criteria of original study as risk factors)				
Any traumatic finding on CT			81.8 (77.6 to 85.7)	42.0 (40.4 to 43.6)
CCHR - Positive	333	2409		
CCHR - Negative	74	1741		
Potential neurosurgical lesion			87.8 (79.7 to 94.9)	40.3 (38.9 to 41.7)
CCHR - Positive	65	2677		
CCHR - Negative	9	1806		

CI = 95% confidence interval, NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule, CT= computed tomography

Supplementary Table 5. Performance of rules with outcome neurosurgical intervention (6 centers)

	Positive n	Negative n	Sensitivity % (CI)	Specificity % (CI)
CHIP n=4557				
Neurosurgical intervention			94.4 (81.8 to 100)	20.3 (19.2 to 21.4)
CHIP – Positive	17	3619		
CHIP – Negative	1	920		
NICE n=4557				
Neurosurgical intervention			88.9 (71.4 to 100)	58.1 (56.6 to 59.6)
NICE – Positive	16	1903		
NICE – Negative	2	2636		
NOC n=4557				
Neurosurgical intervention			100 (100 to 100)	4.2 (3.6 to 4.7)
NOC – Positive	18	4350		
NOC – Negative	0	189		
CCHR n=4557				
Neurosurgical intervention			88.9 (71.4 to 100)	42.2 (40.7 to 43.8)
CCHR – Positive	16	2625		
CCHR – Negative	2	1914		

CI = 95% confidence interval, CHIP = CT in head Injury Patient rule, NICE = National Institute for Health and Care Excellence, NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule



Supplementary Figure 2. Decision curves showing net benefit for the outcome neurosurgical intervention.

CT = computed tomography, CHIP = CT in head Injury Patient rule, NICE = National Institute for Health and Care Excellence, NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule. Per rule net benefit was calculated using the formula: (true positives/n) – weight*(false positives/n).

Supplementary Table 6A. Baseline characteristics all patients with a CT scan (9 centers, n =4702)

	Normal CT (n=4174)	Abnormal CT (n=528)	All patients with CT (n=4702)
Age mean in years (range)	55.5 (16-101)	58.6 (16-98)	55.9 (16-101)
Sex, n male (%)	2372 (56.8%)	337 (63.8%)	2709 (57.6%)
GCS score at presentation			
• 13	138 (3.3%)	69 (13.1%)	207 (4.4%)
• 14	557 (13.3%)	140 (26.5%)	697 (14.8%)
• 15	3479 (83.3%)	319 (60.4%)	3798 (80.8%)
Use of anticoagulation			
• None	3581 (85.8%)	474 (89.8%)	4055 (86.2%)
• Coumarin	490 (11.7%)	45 (8.5%)	535 (11.4%)
• NOACS	56 (1.3%)	3 (0.6%)	59 (1.3%)
Bleeding disorder	47 (1.1%)	3 (0.6%)	50 (1.1%)
Mechanism of injury			
• RTA pedestrian	60 (1.4%)	12 (2.3%)	72 (1.5%)
• RTA cyclist	164 (3.9%)	36 (6.8%)	200 (4.3%)
• Fall from height	574 (13.8%)	124 (23.5%)	698 (14.8%)
• Other	3325 (79.7%)	348 (65.9%)	3673 (78.1%)
Ejected from vehicle	183 (4.4%)	32 (6.1%)	215 (4.6%)
LOC			
• None	2192 (52.5%)	153 (29.0%)	2345 (49.9%)
• 15 minutes or less	1238 (29.7%)	225 (42.6%)	1463 (31.1%)
• More than 15 minutes	30 (0.7%)	18 (3.4%)	48 (1.0%)
Retrograde amnesia			
• None	2819 (67.5%)	227 (43.0%)	3046 (64.8%)
• 30 minutes or less	445 (10.7%)	96 (18.2%)	541 (11.5%)
• More than 30 minutes	142 (3.4%)	58 (11.0%)	200 (4.3%)
PTA			
• None	2456 (58.8%)	154 (29.2%)	2610 (55.5%)
• Up to 2 hours	970 (23.2%)	200 (37.9%)	1170 (24.9%)
• 2-4 hours	80 (1.9%)	22 (4.2%)	102 (2.2%)
• More than 4 hours	144 (3.4%)	64 (12.1%)	208 (4.4%)
Intoxication *	1075 (25.8%)	117 (22.2%)	1192 (25.4%)
Post-traumatic seizure	31 (0.7%)	11 (2.1%)	42 (0.9%)
Headache	1358 (32.5%)	184 (34.8%)	1542 (32.8%)
Vomiting			
• Once	173 (4.1%)	27 (5.1%)	200 (4.3%)
• Twice or more	161 (3.9%)	35 (6.6%)	196 (4.2%)

Supplementary Table 6A. Continued

	Normal CT (n=4174)	Abnormal CT (n=528)	All patients with CT (n=4702)
GCS deterioration			
• 1 point	35 (0.8%)	6 (1.1%)	41 (0.9%)
• 2 or more points	9 (0.2%)	9 (1.7%)	18 (0.4%)
Neurological deficit	104 (2.5%)	29 (5.5%)	133 (2.8%)
Signs of skull base fracture	109 (2.6%)	77 (14.6%)	186 (4.0%)
Visible injury of the head	2237 (53.6%)	338 (64.0%)	2575 (54.8%)
Visible injury of the face	1420 (34.0%)	178 (33.7%)	1598 (34.0%)
Suspicion of open fracture	8 (0.2%)	17 (3.2%)	25 (0.5%)
ISS, mean (range)	6.5 (0-54)	15.3 (1-75)	7.5 (0-75)

CT = computed tomography, GCS = Glasgow Coma Scale, NOACS = novel oral anticoagulants, RTA= road traffic accident, LOC = loss of consciousness, PTA = posttraumatic amnesia, ISS = Injury Severity Score

*history or suggestive findings on examination (for example nystagmus, abnormal walking, etc.)

**GCS deterioration 2 hrs after presentation

Supplementary Table 6B. Traumatic CT findings all patients with a CT scan (9 centers, n=4702)

CT finding	N (%)
CT finding	528 (11.2%)
Skull fracture	213 (4.5%)
• Depressed fracture	25 (0.5%)
• Linear fracture	103 (2.2%)
• Skull base fracture	89 (1.8%)
Subarachnoid hemorrhage	266 (5.7%)
Contusion	
• Small	154 (3.3%)
• Large (mass)	14 (0.3%)
Subdural hematoma	
• Small	173 (3.7%)
• Large (mass)	27 (0.6%)
Epidural hematoma	
• Small	47 (1.0%)
• Large (mass)	5 (0.1%)
Suspicion of DAI on CT	14 (0.3%)
Basal cisterns compressed or obliterated	13 (0.3%)
CT shift	
• 0-4mm	22 (0.5%)
• 5mm or more	13 (0.3%)

CT = computed tomography, DAI = diffuse axonal injury
*some patients had more than 1 CT finding