Minor Head Injury: Guidelines for the Use of CT—A Multicenter Validation Study[1]

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Purpose: To prospectively and externally validate published national and international guidelines for the indications of computed tomography (CT) in patients with a minor head injury.

Materials and Methods: The study protocol was institutional review board approved. All patients implicitly consented to use of their deidentified data for research purposes. Between February 2002 and August 2004, data were collected in consecutive adult patients with blunt minor head injury (Glasgow Coma Scale score of 13–14 or 15) and a risk factor for neurocranial traumatic complications at presentation at four Dutch university hospitals. Primary outcome was any neurocranial traumatic CT finding. Secondary outcomes were clinically relevant traumatic CT findings and neurosurgical intervention. Sensitivity and specificity of each guideline for all outcomes and the number of patients needed to scan to detect one outcome (ie, the number of patients needed to undergo CT to find one patient with a neurocranial traumatic CT finding, a clinically relevant traumatic CT finding, or a CT finding that required neurosurgical intervention) were estimated.

Results: Data were available for 3181 patients. Only the European Federation of Neurological Societies guidelines reached a sensitivity of 100% for all outcomes. Specificity was 0.0%–0.5%. The Dutch guidelines had the lowest sensitivity (76.5%) for neurosurgical interventions. The best specificities for traumatic CT findings and neurosurgical interventions were reached with the criteria proposed by the United Kingdom National Institute for Clinical Excellence (NICE) (46.1% and 43.6%, respectively), albeit at relatively low sensitivities (82.1% and 94.1%, respectively). The number of patients needed to scan ranged from six to 13 for traumatic CT findings and from 79 to 193 for neurosurgical interventions.

Conclusion: All validated guidelines demonstrated a trade-off between sensitivity and specificity. The lowest number of patients needed to scan for either of the outcomes was reached with the NICE criteria.

Supplemental material:
radiology.rsnajnls.org/cgi/content/full/2452061509/DC1

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In the Western world, the number of patients with a mild head injury treated at a hospital is estimated to be 100–300 per 100 000 persons annually, making it one of the most common injuries seen in emergency departments (1). Minor head injury is usually defined as a blunt injury to the head, after which the patient may briefly lose consciousness, may have short posttraumatic amnesia, or both and may have a normal or minimally altered mental status at presentation (Glasgow Coma Scale [GCS] score of 13–15) (2,3). Intracranial complications of minor head injury occur infrequently. The frequency with which complications occur depends on the population, and, in general, complications occur in 6%–10% of patients; however, these complications are potentially life threatening and may require neurosurgical intervention in a minority (0.4%–1.0%) of cases (3–8). A neurocranial injury that does not require neurosurgical intervention may still cause substantial clinical problems. Patients with these injuries will usually be kept under close clinical observation.

Computed tomography (CT) of the head is commonly considered to be the imaging modality of choice for the rapid and reliable diagnosis of neurocranial traumatic lesions, such as skull fractures, epidural and subdural hematomas, and both hemorrhagic and nonhemorrhagic contusions (6,9–11). Numerous national and international guidelines regarding the use of CT in patients with a minor head injury have been published; some of these guidelines are in part based on published algorithms, such as the New Orleans criteria and the Canadian CT head rule (Table E1, *radiology.rsnajnls.org/cgi/content/full/2452061509/DC1*) (3,7). An important goal of implementing such guidelines is to perform CT in only those patients who are at risk of developing complications. This would reduce costs involved with CT scanning and reduce the strain on emergency, neurology, and radiology departments. In each of the guidelines, a distinction is made between low-, medium-, and high-risk patients. In low-risk patients, CT scanning is deemed unnecessary. In the remaining patients, the clinician is given the choice of scanning all medium- and high-risk patients (lenient criteria) or scanning only high-risk patients (strict criteria).

The published guidelines show considerable overlap. Most guidelines consider a history of loss of consciousness, posttraumatic amnesia, suboptimal GCS score, focal neurologic deficit, posttraumatic seizure, vomiting, or coagulopathy as a risk factor. However, there are substantial differences between the guidelines with respect to the definitions of risk factors, as well as to the number, set, or combinations of risk factors for which CT scanning would be indicated. In some guidelines, a lenient use of CT is recommended, while other guidelines advocate a more restrictive approach. Use of guidelines that recommend the restrictive use of CT in patients with a minor head injury leads to a reduced number of CT scans performed for this indication compared with the number of CT scans performed at the recommendation of lenient guidelines and therefore would be preferable to avoid overuse and reduce radiation dose. While the New Orleans criteria and Canadian CT head rule have recently been externally validated, this is not the case for all

Advances in Knowledge

- All of the validated national and international clinical guidelines for the use of CT in patients with a minor head injury demonstrated a trade-off between sensitivity and specificity, and none of the guidelines was clearly superior.
- A sensitivity of 100% for identifying patients with traumatic findings at CT and those requiring neurosurgical intervention was reached with only those guidelines proposed by the European Federation of Neurological Societies; however, this was associated with an extremely low specificity of 0.0%–0.5%.
- The lowest number of patients needed to scan to detect one patient with traumatic CT findings or the need to undergo neurosurgical intervention was reached with the criteria proposed by the United Kingdom National Institute for Clinical Excellence.

Implications for Patient Care

- Our results show that only those guidelines proposed by the European Federation of Neurological Societies have 100% sensitivity for the identification of neurocranial complications after a minor head injury.
- A sensitivity of 100% in the identification of neurocranial complications after minor head injury can be reached only by scanning virtually all patients with a minor head injury.
- The criteria for the use of CT in patients with a minor head injury as set forth by the United Kingdom National Institute for Clinical Excellence have the highest potential to reduce the number of CT scans performed while still having reasonable sensitivity for the identification of patients with neurocranial complications or who require neurosurgical intervention after minor head injury.

Published online before print
10.1148/radiol.2452061509

Radiology 2007; 245:831–838

Abbreviations:
EFNS = European Federation of Neurological Societies
GCS = Glasgow Coma Scale
NICE = National Institute for Clinical Excellence
SIGN = Scottish Intercollegiate Guidelines Network
WFNS = World Federation of Neurosurgical Societies

Author contributions:
Guarantors of integrity of entire study, M.S., D.R.K., A.T., M.G.M.H.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; literature research, M.S., D.W.J.D., P.E.V., A.T., M.G.M.H.; clinical studies, M.S., D.W.J.D., G.G.d.H., H.M.D., P.E.V., D.R.K., P.J.N., P.A.M.H., A.T., M.G.M.H.; statistical analysis, M.S., D.W.J.D., M.G.M.H.; and manuscript editing, M.S., D.W.J.D., D.R.K., P.J.N., P.A.M.H., A.T., H.L.J.T., M.G.M.H.

Authors stated no financial relationship to disclose.

guidelines (12,13). It remains unclear whether restrictive guidelines serve to identify at-risk patients as well as do lenient guidelines. Thus, the purpose of our multicenter observational study was to prospectively and externally validate published national and international guidelines for the indications of CT in patients with a minor head injury (12).

Materials and Methods

Study Group

Between February 11, 2002, and August 31, 2004, data were prospectively collected for 3364 consecutive patients at four Dutch university hospitals who met our inclusion criteria (presentation within 24 hours after blunt head injury, aged 16 years or older, and GCS score of 13 or 14 at presentation or GCS score of 15 at presentation with at least one of the following risk factors: history of loss of consciousness, short-term memory deficit, amnesia associated with the traumatic event, posttraumatic seizure, vomiting, headache, clinical evidence of intoxication with alcohol or drugs, anticoagulant treatment or history of coagulopathy, external evidence of injury above the clavicles, or neurologic deficit) (Table 1). Patients were excluded if concurrent injuries precluded head CT within 24 hours of the head injury or if contraindications to CT scanning were present. Although there are no generally acknowledged absolute contraindications to CT scanning, pregnancy is sometimes considered a relative contraindication and was therefore considered an exclusion criterion in our study.

Our study was entirely observational and did not influence patient care or pose any risk to the patients. The systematically collected data solely included information that is routinely documented during the work-up of a patient with a minor head injury. In the centers that participated in this study, it is common practice for any patient meeting the inclusion criteria to be seen in the emergency department by a neurologist or neurologist-in-training under the supervision of a neurologist. According to the policies of most Dutch hospitals, including those of the centers that participated in this study, patients with a minor head injury routinely undergo head CT (14). The study protocol was reviewed and approved by the institutional review board and medical ethics committee at each of the participating centers. All patients included in our study consented to use of their deidentified data for research purposes.

Data Collection

Data were collected digitally with software (OpenSDE; *http://webserver.mi.fgg.eur.nl/opensde*) that was specifically designed for systematic data collection within a clinical setting (Table 1) (15). The software was installed on desktop computers that were easily accessible to the participating physicians. The neurologist or neurologist-in-training who examined the patient systematically collected data on the patient's history, demographics, and general and neurologic examination findings.

All patients who met the inclusion criteria were referred for head CT. The imaging protocol consisted of acquisition of contiguous sections with a maximum thickness of 5 mm infratentorially and 8 mm supratentorially without intravenous contrast material administration. Images were evaluated with brain and bone window settings. The reading neuroradiologist or trauma radiologist added head CT data to the database.

Guideline Selection

We (M.S., D.W.J.D., M.G.M.H.) searched PubMed for national and international guidelines for the use of CT in patients with a minor head injury that were published in English or Dutch since 2000. Guidelines that solely addressed the pediatric population or patients with severe head injury were discarded. Only guidelines that were unambiguous (ie, with clearly defined criteria for indications for CT in a patient with a minor head injury) and either published or freely available on the Internet were considered for evaluation.

Outcome Measures

Our primary outcome measure was any traumatic finding in the neurocranium at CT, including any skull or skull base fracture and any intracranial traumatic lesion. A traumatic finding at CT that was considered clinically relevant was considered a secondary outcome measure, as was a traumatic CT finding that subsequently led to neurosurgical intervention. A clinically relevant traumatic

Table 1

Collected Patient Data

History	Symptoms	Physical Examination
Date of birth	Loss of consciousness	External injury (above the clavicles)
Sex	Posttraumatic amnesia	
Time of injury	Posttraumatic seizure	GCS on presentation
Time of presentation	Short-term memory deficit	GCS 1 hour after presentation
Mechanism of injury		Motor deficits
Intoxication	Headache	Sensory deficits
Anticoagulant treatment	Vomiting	Focal neurologic deficits

Note.—High-energy accident was derived from the description of trauma mechanism and defined as a fall from a height of more than 1 m or down more than five stairs), pedestrian or cyclist versus vehicle, driver or passenger ejected from vehicle, or any individual involved in a motorized vehicle accident or high-velocity cycling accident. Presence and severity of intoxication were evaluated clinically and evidenced by slurred speech, alcoholic fetor, or nystagmus. Anticoagulant treatment included coumarine derivatives only and not platelet aggregation inhibitors (eg, aspirin or clopidrogel). No blood coagulation tests were performed, and the presence of coagulopathy was assessed by taking patient history. Loss of consciousness was considered to have occurred when it was reported by a witness or the patient. Posttraumatic amnesia was an inability to recall the traumatic event and subsequent events; the duration (in minutes) was estimated. Posttraumatic seizure was classified as a witnessed or suspected seizure after the head injury. Short-term memory deficit was defined as persistent anterograde amnesia. Headache included both diffuse and localized pain. Vomiting was defined as any episode of emesis after the injury. External evidence of injury was defined as extensive bruising or clinically substantial discontinuity of skin. Focal neurologic deficit was any abnormality at routine clinical neurologic examination indicating a focal cerebral lesion.

finding at CT was defined as any intracranial finding caused by trauma; this included all neurocranial traumatic CT findings (ie, epidural or subdural hematoma, subarachnoid or intraventricular hemorrhage, intraparenchymatous hemorrhagic or nonhemorrhagic contusion, and depressed skull fracture) except isolated linear skull or skull base fractures (3,16). A neurosurgical intervention was defined as any neurosurgical procedure (craniotomy, intracranial pressure monitoring, elevation of depressed skull fracture, or ventricular drainage) performed within 30 days after the traumatic event.

Statistical Analysis

Three authors (M.S., D.W.J.D., M.G.M.H.) working in consensus performed statistical analysis. Missing data were assumed to be missing at random and were imputed on the basis of the available data to avoid bias when data could not be completed by searching patient records (17–21). For categorical data, values that were missing were replaced with the most common value among patients in whom this value was not missing. For continuous data, values that were missing were replaced with the mean value in patients in whom the value was not missing. The percentage of imputed missing data was 3.8% (6425 of 168 593 items), which included items documented as unknown and items that were not documented. Variables that were most frequently imputed were a history of loss of consciousness (18%, 565 of 3181 items) and posttraumatic amnesia (10%, 325 of 3181 items). The reason for imputation for both a history of loss of consciousness and posttraumatic amnesia was that the variables were reported as unknown (15.2% [484 of 3181 items] and 7.2% [230 of 3181 items], respectively) rather than missing (2.5% [81 of 3181 items] and 3.0% [95 of 3181 items], respectively). Owing to the available variable means and consistent with clinical practice, both were imputed as present.

We evaluated the study group for demographic characteristics, mechanism of injury, traumatic findings at CT, and neurosurgical intervention. To validate the guidelines in the study group, we determined the sensitivity and specificity (and their 95% confidence intervals) of all guidelines for each of the outcome measures. A guideline was considered to be positive when a patient fulfilled at least one of the guideline criteria for a CT scan. The sensitivity of each guideline was calculated by dividing the number of patients in whom the outcome measure was present and the guideline was positive by the total number of patients in whom the outcome measure was present. The specificity of each guideline was calculated by dividing the number of patients in whom the outcome measure was absent and the guideline was negative by the total number of patients in whom the outcome measure was absent. We evaluated sensitivity and specificity separately for both the strict criteria (scanning high-risk patients only) and the lenient criteria (scanning both the high- and medium-risk patient groups) of each guideline.

To address the trade-off between sensitivity and specificity for each guideline, we calculated the percentage of patients who needed to undergo CT and the number of patients needed to scan to detect one outcome (ie, the number of patients needed to be scanned to find one patient with a neurocranial traumatic CT finding, a clinically relevant traumatic CT finding, or a CT finding that required neurosurgical intervention). The percentage of patients who needed to undergo CT was calculated by dividing the number of patients in whom the guideline was positive by the total number of patients. The number of patients needed to scan was calculated for each outcome measure. This number was calculated for each of the guidelines by dividing the number of patients in whom the guideline was positive by the number of patients in whom the outcome measure was present. Data were analyzed with statistical software (Statistical Package for Social Sciences, version 12.0.1, release 2003; SPSS, Chicago, Ill).

Figure 1

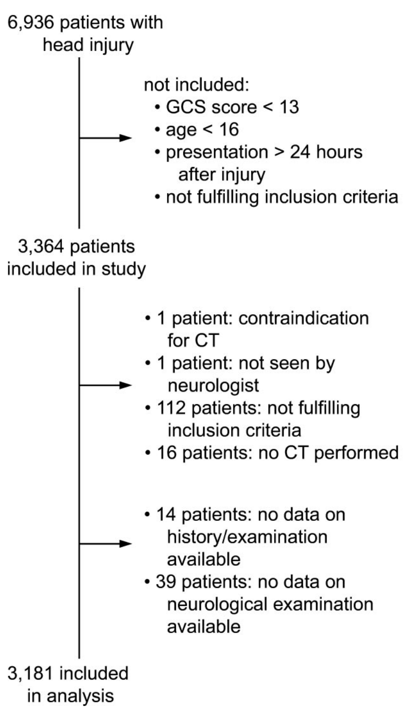

Figure 1: Flowchart of 6936 patients who presented with a head injury. This number is an estimate based on the proportion of patients included in this study from the total number of trauma patients seen by a neurologist or neurologist-in-training in the emergency department of the participating center where the majority of patients were included.

Results

Study Group

Data obtained in 3181 patients were analyzed (Fig 1). The majority (n = 2244, 71%) of patients were male, and the mean age was 41.4 years (range, 16–102 years). The median time between injury and presentation to the emergency department was 60 minutes (mean, 94 minutes; range, 0–23.3 hours). At presentation, most patients (n = 2462, 77.4%) had a GCS score of 15, 568 (17.9%) had a GCS score of 14, and 151 (4.7%) had a GCS score of 13.

Neurocranial traumatic lesions were seen at CT in 312 (9.8%) patients (Table 2), with the highest proportion of traumatic findings seen in patients with a GCS score of 13 (37 patients [24.5%]). Neurosurgical intervention was performed in 17 patients (0.5%) for epidural hematoma ($n = 8$), subdural hematoma ($n = 3$), depressed skull fracture ($n = 3$), and a combination of extra-axial hematoma and depressed skull fracture ($n = 3$) (Table 2). In the majority of patients, more than one risk factor was present (Table 3).

Guideline Selection

Three national and three international guidelines were identified (Table E1, *radiology.rsnajnls.org/cgi/content/full/2452061509/DC1*) (14,22–26). The criteria for the use of CT set forth by the Scottish Intercollegiate Guidelines Network (SIGN) are currently under revision and may be updated in the future; we used the version posted on their Web site at the time of our search (25). The following three guidelines were based on a previously published decision algorithm: the Dutch guidelines on the New Orleans criteria, the criteria proposed by the National Institute for Clinical Excellence (NICE) on the Canadian CT head rule, and the guidelines proposed by the European Federation of Neurological Societies (EFNS) on both the New Orleans criteria and the Canadian CT head rule (3,7).

Guideline Validation

Sensitivity of 100% for both neurocranial and clinically relevant traumatic CT findings, as well as for neurosurgical intervention, was reached with only the EFNS guidelines when either the lenient or the strict criteria were used (Tables E2, E3; *radiology.rsnajnls.org/cgi/content/full/2452061509/DC1*). According to these guidelines, however, all of the patients with minor head injury included in our study would need to undergo CT (Fig 2; Tables E2, E3; *radiology.rsnajnls.org/cgi/content/full/2452061509/DC1*). The lowest sensitivity (76.5%) for identifying patients who underwent neurosurgical intervention was reached with the Dutch guidelines and use of either the lenient or the strict criteria. The highest specificities were achieved with the NICE criteria, which, consequently, indicated that only a relatively small percentage (37.2%–56.6%) of all patients with a minor head injury would need to undergo CT (Fig 2; Tables E2, E3; *radiology.rsnajnls.org/cgi/content/full/2452061509/DC1*).

One patient who required neurosurgical intervention for a subdural hematoma was missed with use of the guidelines proposed by the World Federation of Neurosurgical Societies (WFNS), the NICE criteria, and the SIGN and Scandinavian and Dutch guidelines. This patient did not have a history of loss of consciousness or any other risk factors except for a contusion to the face. Three more patients who required neurosurgical intervention were missed with the Dutch guidelines. All of these patients had several risk factors, including neurologic deficit and clinical evidence of a skull fracture, but no history of loss of consciousness or posttraumatic amnesia.

As expected, the sensitivities for neurocranial and clinically relevant traumatic findings were generally lower when we used the strict criteria rather than the lenient criteria (WFNS guidelines, NICE criteria, SIGN guidelines, and Scandinavian guidelines) (Tables

Table 2

Traumatic Findings at CT

Traumatic Findings at CT	No. of Patients ($n = 312$)
Skull fracture	186 (59.6)
Intraparenchymal lesions	142 (45.5)
Traumatic subarachnoid hemorrhage	86 (27.6)
Subdural hematoma	67 (21.5)
Epidural hematoma	35 (11.2)
Intraventricular hemorrhage	5 (1.6)
Intracranial lesions	233 (74.7)

Note.—Multiple findings may be present in one patient. Data in parentheses are percentages.

Table 3

Presence of Risk Factors in the Entire Study Group and in Patients with a GCS Score of 15 at Presentation

Risk Factor	Entire Study Group ($n = 3181$)	Only Patients with a GCS Score of 15 ($n = 2462$)
Older than 60 years	534 (16.8)	394 (16.0)
Anticoagulant treatment	218 (6.9)	171 (6.9)
High-energy accident	1457 (45.8)	1113 (45.2)
Dangerous mechanism of injury*	679 (21.3)	506 (20.6)
Loss of consciousness	1951 (61.3)	1419 (57.6)
Headache	1910 (60.0)	1454 (59.1)
PTA lasting longer than 30 minutes	916 (28.8)	510 (20.7)
Vomiting	342 (10.8)	213 (8.6)
Short-term memory deficit	475 (14.9)	195 (7.9)
Posttraumatic seizure	23 (0.7)	16 (0.6)
External injury above clavicles	2612 (82.1)	2008 (81.6)
Clinical signs of skull fracture	66 (2.1)	42 (1.7)
Clinical evidence of intoxication	1367 (43.0)	960 (39.0)
GCS score less than 15 1 hour after presentation	506 (15.9)	50 (2.0)
Neurological deficit	304 (9.6)	207 (8.4)
More than one risk factor present	3101 (97.5)	2382 (96.8)

Note.—Data are number of patients. Data in parentheses are percentages. Multiple risk factors may be present in one patient.

* Dangerous mechanism of injury was defined as pedestrian hit by motor vehicle, passenger or driver ejected from motor vehicle, or fall from a height of more than 1 m or down five stairs. PTA = posttraumatic amnesia.

E2, E3; *radiology.rsnajnls.org/cgi/content/full/2452061509/DC1*). The sensitivities for neurosurgical interventions were the same with use of the strict and lenient criteria for all of the guidelines, except the SIGN and NICE criteria, that showed a decrease in sensitivity (ie, one additional patient who required neurosurgical intervention would have been missed with use of strict instead of lenient criteria) (Tables E2, E3; *radiology.rsnajnls.org/cgi/content/full/2452061509/DC1*).

Trade-off between Sensitivity and Specificity

The more restrictive guidelines require scanning only a limited number of patients with a minor head injury; however, the use of these guidelines invariably leads to lower sensitivities than does the use of guidelines that recommend that a large number of patients undergo scanning (Fig 2). This trade-off between sensitivity and the number of patients who need to undergo CT was consistent across outcome measures. The number of patients needed to undergo scanning was highest when the EFNS guidelines were followed; with the NICE criteria, the number of patients needed to undergo scanning to detect one patient with a lesion requiring neurosurgical intervention was lowest (79 and 113 patients for strict and lenient criteria, respectively) (Table E4, *radiology.rsnajnls.org/cgi/content/full/2452061509/DC1*).

Figure 2

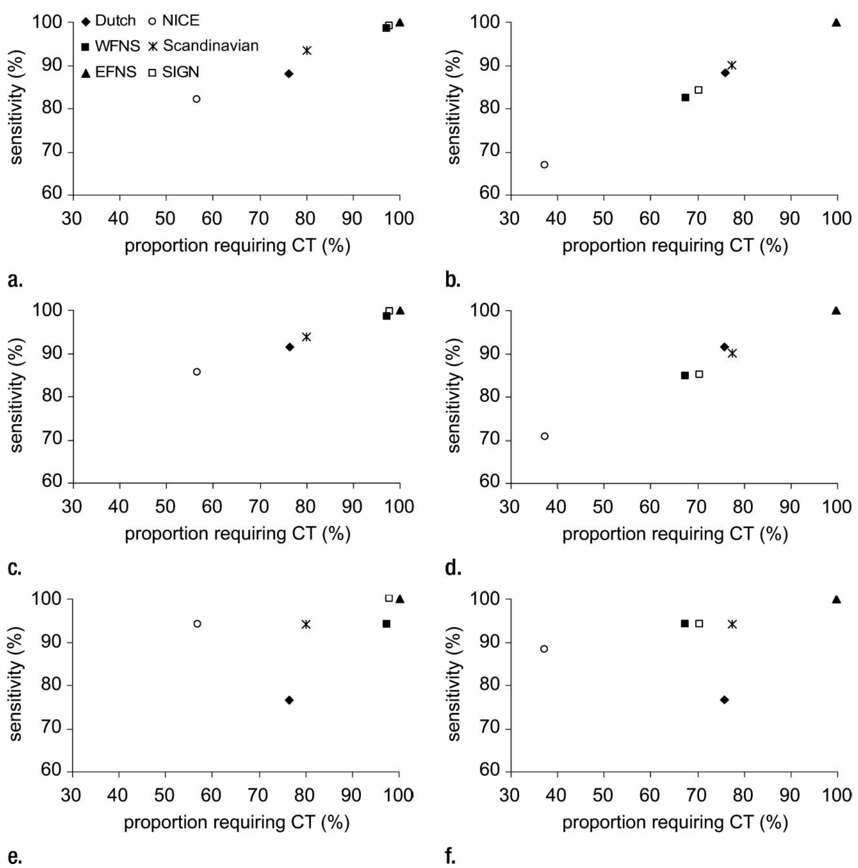

Figure 2: Graphs show the relationship between the proportion of patients in whom CT is required according to each guideline and the sensitivity for **(a, b)** neurocranial traumatic CT findings, **(c, d)** clinically relevant traumatic CT findings, and **(e, f)** neurosurgical intervention for each guideline using lenient **(a, c, e)** and strict **(b, d, f)** criteria.

Discussion

In our study, only the EFNS guidelines reached 100% sensitivity for the identification of patients with either neurocranial or clinically relevant traumatic findings at CT and patients needing neurosurgical intervention. Unfortunately, specificity for these guidelines was low. Guidelines with higher specificities, however, showed lower sensitivities for traumatic findings at CT and for neurosurgical intervention. A sensitivity of 100% may not be required for any neurocranial traumatic CT finding, but it is essential for lesions that require neurosurgical intervention. Only the guidelines proposed by the EFNS and the lenient SIGN criteria reached 100% sensitivity for neurosurgical intervention. Guidelines with the worst performance were the Dutch national guidelines; with use of these guidelines, almost 25% (n = 4) of patients requiring neurosurgery would have been missed.

The low sensitivity of the Dutch guidelines for neurosurgical intervention in our study may be explained by the fact that these guidelines are not clear on whether CT is recommended in patients with a normal level of consciousness and without a history of loss of consciousness or posttraumatic amnesia who have another risk factor, such as vomiting or focal neurologic deficit. If the Dutch guidelines are applied strictly, as they were in our study, these patients are classified as having a minimal head injury and may be sent home without any imaging or observation. Three of the patients that underwent neurosurgery would have been missed this way. This explains the low sensitivity of the Dutch guidelines in our study.

In each of the evaluated guidelines, there is the option of scanning all patients at risk of developing complications (lenient criteria) or scanning only high-risk patients (strict criteria). The strict criteria of the guidelines therefore are expected to enable all high-risk patients (ie, those with CT findings that require neurosurgical intervention) to be identified, while patients with other traumatic findings at CT may be missed. For all but the NICE and SIGN criteria, there was indeed no difference in sensitivity for neurosurgical intervention between the strict and lenient criteria.

Our results largely corroborate findings of the validation study conducted by Ibanez et al (16). In their smaller single-center study, 100% sensitivity for clinically relevant findings at CT was reached with both the WFNS and the EFNS guidelines. Specificities were also low. However, neurosurgical intervention was not considered an outcome measure; therefore, the guidelines were not validated for identification of these high-risk patients. Both the NICE criteria and the WFNS guidelines have also been previously evaluated in a large single-center validation study (5,27). In their study, Fabbri et al (5,27) did not strictly adhere to the guidelines and not all patients underwent CT; these conditions may have undermined the validity of their study. Sensitivity for intracranial CT findings and neurosurgical intervention was high (but not 100%) for the WFNS guidelines and the NICE criteria. The NICE criteria reached a slightly lower sensitivity for both outcome measures; however, in line with our findings, these criteria had much higher specificities than the WFNS guidelines.

In all of the guidelines, a similar trade-off was seen between sensitivity and specificity. There was also a corresponding trade-off between sensitivity and the proportion of patients in whom CT was indicated according to each of the guidelines. The EFNS guidelines had the highest sensitivities, lowest specificities, and highest proportion of patients who required CT, whereas the NICE criteria had the highest specificities and the lowest proportion of patients who required CT but at the cost of lower sensitivities. Overall, this trade-off was consistent across outcome measures and was reflected in the number of CT scans needed to detect any of the outcomes, which was highest for the EFNS guidelines and lowest for the NICE criteria. Thus, none of the guidelines was obviously superior to any of the others.

The question is, what do we need to aim for? It is desirable for a guideline to enable the identification of all patients with CT findings who require neurosurgical intervention. The importance of identifying other traumatic lesions at CT, however, depends on the effect of management decisions on the patient's clinical outcome. CT scanning is the only reliable way to rule out serious intracranial complications, while observation performs badly as a diagnostic tool and may lead to a less-than-optimal outcome since intervention subsequent to deterioration is delayed (28,29). CT findings generally affect clinical management (eg, the decision between discharge or clinical observation); however, since a patient's condition only occasionally deteriorates during observation, it is difficult—if not impossible—to assess whether observation, and therefore CT scanning, really affected the patient's clinical outcome. This would imply that a sensitivity of 100% for traumatic findings at CT may not be necessary, but then the question of what sensitivity would be desirable would remain. The number of patients needed to scan to detect one outcome may be used as a first approximation of the trade-off between sensitivity and specificity, and it is useful in the identification of poorly performing guidelines. One way to further deal with this dilemma is to perform a cost-effectiveness analysis (30). A cost-effectiveness analysis will enable one to take into account the effect of the guidelines' sensitivities and specificities and their influence on patient care, offering a combined measure of a guideline's validity and utility. We intend to perform this analysis for each of the evaluated guidelines in a follow-up study to determine whether any guideline is superior in terms of both cost and effectiveness.

Our study had a number of limitations. First, our inclusion criteria coincided with the criteria proposed in the EFNS guidelines. This is evident from the extremely low specificity we found. A further limitation of our study was that some of the criteria from the guidelines were not exactly the same as the data we collected in our study; however, this was inherent to the observational nature of our study. The risk factor of high-energy accident was not separately defined, and we determined its presence by using the description of trauma mechanism. Since we then defined high-energy accident to include various broad categories, this lack of specification probably did not have a large effect on the sensitivities of the guidelines, but it may have had some negative influence on the reported specificities. Previous neurosurgery and shunt placement were not formally recorded, nor was altered behavior; therefore, these risk factors could not be used as criteria for one of the guidelines. The same was true for pretraumatic seizure, although this risk factor was again derived from the trauma mechanism description. Furthermore, only the presence and duration of posttraumatic amnesia (but not retrograde amnesia) were assessed at the participating centers. We find that retrograde amnesia is difficult to assess clinically; therefore, it is not a reliable parameter in daily clinical practice, as opposed to posttraumatic amnesia, which is easier to evaluate. Thus, in the evaluation of guidelines that propose retrograde amnesia as a risk factor, we used posttraumatic amnesia as a risk factor instead. Since the relative risks of retrograde and posttraumatic amnesia have been shown to be similar, it does not seem likely that this had a substantial influence on our results (3,31).

Another limitation is that we validated only those guidelines that were published in English (because they are widely accessible) or Dutch (because our study was performed in the Netherlands). A final limitation of our study is the theoretical possibility that we may have missed patients with clinically important traumatic CT findings or who required neurosurgical intervention who were not (initially) referred to a neurologist and consequently did not undergo CT scanning. Although we acknowledge this possibility, we believe this is unlikely to have happened in many cases because the centers that participated in this study were primary regional trauma and neurosurgical centers in which a neurologist or neurologist-in-training was always present and the threshold for referral was low. To our knowledge, only one of more than 3000 patients in our study group had not been seen by a neurologist. Consequently, this patient was not included in the data analysis.

In conclusion, all of the validated guidelines show a trade-off between sensitivity and specificity and a corresponding trade-off between sensitivity and the proportion of patients who require CT scanning according to the guideline in the identification of patients with traumatic findings at CT, as well as in the identification of patients who require neurosurgical intervention for a complication after a minor head injury. The choice of which guideline to use will depend largely on the objective of implementing a guideline. If the objective is to not miss any patients with a traumatic finding at CT, basically all patients with minor head injury will need to undergo CT, as recommended in the EFNS guidelines. If, however, the objective is to reduce the number of CT scans performed to evaluate minor head injuries (eg, to reduce workload or because of limited availability) and one is willing to accept the risk of misdiagnosing the occasional patient who presents with minor symptoms, the NICE criteria have a high potential to reduce the number of CT scans performed while still having a reasonable sensitivity for the identification of patients with traumatic brain injury and those who require neurosurgical intervention. The final choice of a guideline and its implementation depend on the objective and on cost and effectiveness considerations of the consequences of implementation.

Acknowledgments: We thank J. Brauer, who is a research nurse in the department of neurology at University Medical Center Nijmegen St Radboud, and the research nurses in the department of radiology at Erasmus MC (W. J. van Leeuwen, C. H. van Bavel-van Hamburg, and B. Tara-Prins) for their invaluable contribution to patient data collection.

References

1. Cassidy JD, Carroll LJ, Peloso PM, 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;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):113–125.
3. Stiell IG, Wells GA, Vandemheen K, et al. The Canadian CT head rule for patients with minor head injury. Lancet 2001;357:1391–1396.
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;145:843–850.
5. Fabbri A, Servadei F, Marchesini G, et al. Prospective validation of a proposal for diagnosis and management of patients attending the emergency department for mild head injury. J Neurol Neurosurg Psychiatry 2004;75:410–416.
6. Borg J, Holm L, Cassidy JD, et al. Diagnostic procedures in mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. J Rehabil Med 2004; 43(suppl):61–75.
7. 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;343:100–105.
8. Miller EC, Holmes JF, Derlet RW. Utilizing clinical factors to reduce head CT scan ordering for minor head trauma patients. J Emerg Med 1997; 15:453–457.
9. Glauser J. Head injury: which patients need imaging? which test is best? Cleve Clin J Med 2004;71: 353–357.
10. Stein SC, Ross SE. The value of computed tomographic scans in patients with low-risk head injuries. Neurosurgery 1990;26:638–640.
11. Stein SC, Ross SE. Mild head injury: a plea for routine early CT scanning. J Trauma 1992;33:11–13.
12. Smits M, Dippel DW, de Haan GG, et al. External validation of the Canadian CT head rule and the New Orleans criteria for CT scanning in patients with minor head injury. JAMA 2005;294:1519–1525.
13. Stiell IG, Clement CM, Rowe BH, et al. Comparison of the Canadian CT head rule and the New Orleans criteria in patients with minor head injury. JAMA 2005;294:1511–1518.
14. Vos PE, Battistin L, Birbamer G, et al. EFNS guideline on mild traumatic brain injury: report of an EFNS task force. Eur J Neurol 2002;9:207–219.
15. 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;11:162–165.
16. Ibanez J, Arikan F, Pedraza S, et al. Reliability of clinical guidelines in the detection of patients at risk following mild head injury: results of a prospective study. J Neurosurg 2004;100:825–834.
17. Little RJ. Regression with missing X's: a review. J Am Stat Assoc 1992;87:1227–1237.
18. Donders AR, van der Heijden GJ, Stijnen T, Moons KG. Review: a gentle introduction to imputation of missing values. J Clin Epidemiol 2006;59: 1087–1091.
19. Little RJ, Rubin DB. Quick methods for multivariate data with missing values. In: Statistical analysis with missing data. New York, NY: Wiley, 1987; 39–49.
20. Kline R. Principles and practice of structural equation modeling. In: Methodology in the social sciences. 2nd ed. New York, NY: Guildford, 1998; 74–77.
21. 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;59:1102–1109.
22. Twijnstra A, Brouwer O, Keyser A, et al. Richtlijnen voor diagnostiek en behandeling van patiënten met een licht schedel-hersenletsel [Guidelines for diagnosis and management of patients with minor head injury]. Dutch Association of Neurology. Published 2001. Accessed December 15, 2006.
23. Servadei F, Teasdale G, Merry G. Defining acute mild head injury in adults: a proposal based on prognostic factors, diagnosis, and management. J Neurotrauma 2001;18:657–664.
24. Yates D, Breen K, Brennan P, et al; for the Guideline Development Group. Head injury: triage, assessment, investigation and early management of head injury in infants, children and adults. National Institute for Health and Clinical Excellence Web site. http://www.nice.org.uk/. Published June 25, 2003. Accessed March 17, 2005.
25. Teasdale G, Gentleman D, Andrews P, et al; for the Guideline Development Group. Early management of patients with head injury. Scottish Intercollegiate Guidelines Network. http://www.sign.ac.uk/guidelines/fulltext/46/index.html; http://www.sign.ac.uk/guidelines/published/index.html. Published August 2000. Updated December 11, 2001. Accessed April 17, 2005.
26. Ingebrigtsen T, Romner B, Kock-Jensen C. Scandinavian guidelines for initial management of minimal, mild, and moderate head injuries. J Trauma 2000;48:760–766.
27. Fabbri A, Servadei F, Marchesini G, et al. Clinical performance of NICE recommendations versus NCWFNS proposal in patients with mild head injury. J Neurotrauma 2005;22:1419–1427.
28. Dunning J, Lecky F. The NICE guidelines in the real world: a practical perspective. Emerg Med J 2004;21:404–407.
29. af Geijerstam JL, Britton M. Mild head injury: reliability of early computed tomographic findings in triage for admission. Emerg Med J 2005;22: 103–107.
30. Hunink MG. Decision making in the face of uncertainty and resource constraints: examples from trauma imaging. Radiology 2005;235:375–383.
31. Dunning J, Stratford-Smith P, Lecky F, et al. A meta-analysis of clinical correlates that predict significant intracranial injury in adults with minor head trauma. J Neurotrauma 2004;21:877–885.

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