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Neuroimaging Radiological Interpretation System for Acute Traumatic Brain Injury

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Abstract

The purpose of the study was to develop an outcome-based NeuroImaging Radiological Interpretation System (NIRIS) for patients with acute traumatic brain injury (TBI) that would standardize the interpretation of noncontrast head computer tomography (CT) scans and consolidate imaging findings into ordinal severity categories that would inform specific patient management actions and that could be used as a clinical decision support tool. We retrospectively identified all patients transported to our emergency department by ambulance or helicopter for whom a trauma alert was triggered per established criteria and who underwent a noncontrast head CT because of suspicion of TBI, between November 2015 and April 2016. Two neuroradiologists reviewed the noncontrast head CTs and assessed the TBI imaging common data elements (CDEs), as defined by the National Institutes of Health (NIH). Using descriptive statistics and receiver operating characteristic curve analyses to identify imaging characteristics and associated thresholds that best distinguished among outcomes, we classified patients into five mutually exclusive categories: 0-discharge from the emergency department; 1-follow-up brain imaging and/or admission; 2-admission to an advanced care unit; 3-neurosurgical procedure; 4-death up to 6 months after TBI. Sensitivity of NIRIS with respect to each patient's true outcome was then evaluated and compared with that of the Marshall and Rotterdam scoring systems for TBI. In our cohort of 542 patients with TBI, NIRIS was developed to predict discharge (182 patients), follow-up brain imaging/admission (187 patients), need for advanced care unit (151 patients), neurosurgical procedures (10 patients), and death (12 patients). NIRIS performed similarly to the Marshall and Rotterdam scoring systems in terms of predicting death. We developed an interpretation system for neuroimaging using the CDEs that informs specific patient management actions and could be used as a clinical decision support tool for patients with TBI. Our NIRIS classification, with evidence-based grouping of the CDEs into actionable categories, will need to be validated in different TBI populations.

Keywords: clinical decision support; common data elements; CT; outcome; TBI

Introduction

Traumatic brain injury (TBI) is a complex, multi-faceted condition. Each year more than 2.5 million persons in the United States seek medical care for TBI. According to the U.S. Centers for Disease Control and Prevention, an estimated 2% of the United States population now lives with TBI-caused disabilities, at an annual cost of about $77 billion.[1,2]

Imaging is critical in the identification and treatment of these patients. The goals of imaging include (1) detecting injuries that may require immediate surgical or procedural intervention, (2) detecting injuries that may benefit from early medical therapy or vigilant neurologic supervision, and (3) determining the prognosis of patients to tailor rehabilitative therapy or discharge planning. There is inconsistent use of terminology in radiology reporting, however, thus leading to variations in clinical practice.[3–6] Thus, the challenge remains for physicians to understand the inconsistent terminology among radiologists to guide appropriate management and treatment decisions.[3–6]

The common data elements (CDEs) were developed for TBI to promote the use of consistent terminology and definitions in characterizing intracranial injuries across all imaging studies, as

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well as all clinical aspects of TBI.[7,8] The CDEs include an extensive list of the injuries that can be identified with definitions of terms used to describe these injuries on the images. To date, CDEs are not commonly adopted in radiology reporting unlike other imaging classification schemes such as the Breast Imaging and Reporting Data System (BI-RADS), perhaps because CDEs are not associated with specific patient care or treatment decisions.

The existing classification schemes, such as the Marshall score[9] and the Rotterdam score[10] were developed to predict mortality rather than guide TBI patient care, and therefore have poor predictive validity for more granular outcomes such as the need for follow-up imaging, intensive care unit (ICU), or neurosurgical procedures. This may in part be related to the lack of a uniform language in the radiology reports referred to above. There is a need for a classification system for the imaging obtained in patients with TBI, leveraging the TBI CDEs, and with a validated predictive value in terms of TBI patient outcome and management.[11]

Breast imaging is a field of radiology in which the interpretation of imaging studied is highly codified and standardized through BI-RADS.[12–14] BI-RADS is a lexicon that discriminates the findings from mammogram screening (for breast cancer diagnosis) into a small number of well-defined categories. Although BI-RADS started out for use with breast screening mammography, it was later adapted for use with magnetic resonance imaging (MRI)[15] and breast Ultrasonography (US)[16] as well. BI-RADS was meant to transform breast imaging language to a universal one by defining the related descriptive terms that previously had been shown in the literature to be predictive of benign and malignant disease.

While BI-RADS cannot replace personal experience, good knowledge of the literature, and continuous medical education, it has proven to be a useful tool for quality assurance[17,18] and for communication between physicians of different specialties who deal with breast diseases and breast cancer screening. Since the first edition of the BI-RADS lexicon was published in 1992, it has been accepted and is being used by all official breast cancer organizations and by virtually all radiologists in the United States.[19] Because it allows for a clearer communication of the imaging results and of the required next steps in patient treatment, BI-RADS provides opportunities for improved patient care.[20]

In the current study, we leveraged the CDEs to develop an outcome-based (not experience driven) NeuroImaging Radiological Interpretation System (NIRIS) that could standardize the interpretation of noncontrast head CTs and consolidate imaging findings into ordinal severity categories that would be associated with specific management actions. We compared the classification performance of our NIRIS system with that of the Marshall[9] and Rotterdam[10] scoring systems, which use different noncontrast head CT imaging features to predict the risk of fatal outcome in patients with TBI. Of note, while the Marshall and Rotterdam scoring systems were developed to predict death (as mentioned above), NIRIS was developed with the intent of being more granular in terms of predicting TBI patient care based on the initial imaging.

Table 1. National Institutes of Health Common Data Elements for Traumatic Brain Injury Imaging Identified in our Study Population

	Discharged	*Follow-up neuroimaging/ admission*	*Advanced care unit stay*	*Neuro-surgery*	*Death*	*Total*
Number of patients	182	187	151	10	12	542
	N (%)	*N (%)*	*N (%)*	*N (%)*	*N (%)*	*N (%)*
Skull fracture	0 (0)	3 (1.6)	17 (11.3)	6 (60.0)	5 (41.7)	31 (5.7)
Calvarial fracture	0 (0)	2 (1.1)	16 (10.6)	6 (60.0)	5 (41.7)	29 (5.4)
Skull base fracture	0 (0)	1 (0.5)	4 (2.6)	3 (30.0)	1 (8.3)	9 (1.7)
Pneumocephalus	0 (0)	2 (1.0)	6 (4.0)	3 (30.0)	1 (8.3)	12 (2.2)
Hemorrhage	0 (0)	7 (3.7)	50 (33.1)	10 (100.0)	6 (50.0)	73 (13.5)
Epidural hematoma	0 (0)	0 (0)	9 (6.0)	2 (20.0)	0 (0)	11 (2.0)
Volume in cc (mean ± SD)	0 ± 0	0 ± 0	0.04 ± 0.3	2.8 ± 2.3	0 ± 0	0.03 ± 0.4
Subdural hematoma	0 (0)	3 (1.6)	22 (14.6)	5 (50.0)	4 (33.3)	34 (6.3)
Volume in cc (mean ± SD)	0 ± 0	0.1 ± 1.4	2.7 ± 9.7	5.7 ± 9.5	25.5 ± 46.8	1.5 ± 9.4
Subarachnoid hemorrhage	0 (0)	3 (1.6)	30 (19.9)	6 (60.0)	6 (50.0)	45 (8.3)
Intraventricular hemorrhage	0 (0)	2 (1.1)	10 (6.6)	1 (10.0)	3 (25.0)	16 (3.0)
Parenchymal hematoma (including hemorrhagic contusions)	0 (0)	0 (0)	7 (4.6)	2 (20.0)	1 (8.3)	10 (1.8)
Volume in cc (mean ± SD)	0 ± 0	0 ± 0	0.03 ± 0.2	2.7 ± 1.8	0.2 ± 0.6	0.02 ± 0.3
Diffuse axonal injury	0 (0)	0 (0)	1 (0.7)	2 (20.0)	1 (8.3)	4 (0.7)
Mass effect	0 (0)	0 (0)	7 (4.6)	4 (40.0)	2 (16.7)	13 (2.4)
Brain edema/swelling	0 (0)	0 (0)	0 (0)	0 (0)	1 (8.3)	1 (0.2)
Midline shift	0 (0)	0 (0)	7 (4.6)	4 (40.0)	2 (16.7)	13 (2.4)
In mm (mean ± SD)	0 ± 0	0 ± 0	0.2 ± 0.8	2.1 ± 3.3	1.4 ± 3.5	0.1 ± 0.9
Cisternal compression	0 (0)	0 (0)	0 (0)	0 (0)	2 (16.7)	2 (0.4)
Brain herniation/Duret hemorrhages	0 (0)	0 (0)	0 (0)	2 (20.0)	3 (25.0)	5 (0.9)
Hydrocephalus	0 (0)	3 (1.6)	30 (19.9)	6 (60.0)	6 (50.0)	45 (8.3)
Focal	0 (0)	2 (1.1)	22 (14.6)	4 (40.0)	2 (16.7)	30 (5.5)
Diffuse	0 (0)	1 (0.5)	8 (5.3)	2 (20.0)	4 (33.3)	15 (2.8)
Brain parenchymal injuries	0 (0)	3 (1.6)	19 (12.6)	5 (50.0)	2 (16.7)	29 (5.4)
Nonhemorrhagic contusions	0 (0)	3 (1.6)	19 (12.6)	5 (50.0)	2 (16.7)	29 (5.4)

SD, standard deviation.

Methods

Study design

With the approval of our Institutional Review Board, we retrospectively identified all the patients transported to our emergency department by ambulance or helicopter for whom a trauma alert was triggered per established criteria (http://stan.md/2nw7pfD) and who underwent a noncontrast head CT because of suspicion of TBI, between November 2015 and April 2016.

Imaging review

Two neuroradiologists reviewed the noncontrast head CTs and assessed the TBI imaging CDEs as defined by the National Institutes of Health (NIH)[7] (Table 1). These include presence/absence of skull fracture, pneumocephalus, hemorrhage, mass effect, and brain parenchymal injuries. In addition, we quantified the volume of epidural, subdural, and parenchymal hematomas and contusions, as well as the amount of midline shift. The volumes of these hematomas and contusions were calculated as their maximal length multiplied by their maximal width multiplied by the number of slices they could be seen on multiplied by the slice thickness and divided by 2. If a patient presented with several hematomas or contusions, we summed up their volumes to come up with a total volume of hematomas and contusions. We quantified the amount of subarachnoid hemorrhage, intraventricular hemorrhage, brain edema/swelling, cisternal compression, and hydrocephalus using ordinal scales (Table 1). The two neuroradiologists each reviewed the imaging and resolved their disagreements by consensus review of the images. They were blinded to each subject's outcome.

Finally, based on the CDE review, we determined the Marshall score[9] (Supplementary Table 1; see online supplementary material at ftp.liebertpub.com) and the Rotterdam score[10] (Supplementary Table 2; see online supplementary material at ftp.liebertpub.com) for each noncontrast head CT.

Clinical data collection

We reviewed the study patients' electronic medical records for the demographic and clinical variables listed in Table 2. We recorded the worst Glasgow Coma Scale (GCS) score from the field and the admission before intubation, if any. We used our medical records, as well as a Social Security death index to assess whether our study patients were deceased. The determination of whether death was TBI-related was performed through a review of the medical records, and an assessment of whether the brain injuries or the other bodily injuries, if any, were responsible for the patient's death.

Statistical analyses

We defined mutually exclusive outcome categories, ordered by severity, based on documented patient disposition from the emergency department. Patients who were sent home without services, left against medical advice, or placed under police custody were considered to be discharged (level 0). Level 1 patients included those who were admitted to a floor bed, received mental health or pediatric care, were sent to an observation unit, transferred to another hospital, and/or underwent follow-up neuroimaging. Level 2 patients included admittance to an advanced care unit (for instance, telemetry/stepdown unit or ICU). Neurosurgical procedures (level 3) included external ventricular drain, burr hole, craniotomy/craniectomy, and/or surgical evacuation or drainage of a hematoma. Finally, we ascertained death up to six months after TBI (level 4) and cause of death from a review of the electronic medical records. Patients were categorized according to their worst outcome, (e.g., a patient who had an ICU stay and then died would be categorized as level 4 - death).

Descriptive statistics were used to first characterize the cohort, with categorical characteristics summarized as counts/percentages and continuous characteristics summarized as means with standard deviation. Differences among categorical imaging outcomes were assessed with Fisher exact tests. Continuous outcomes were

Table 2. Demographic, Clinical and Injury Severity Characteristics in Our Study Population

	Discharged	*Follow-up neuroimaging/ admission*	*Advanced care unit stay*	*Neurosurgery*	*Death*	*Total*
Number of patients	182 *N (%)*	187 *N (%)*	151 *N (%)*	10 *N (%)*	12 *N (%)*	542 *N (%)*
Demographics						
Age, years (mean ± SD)	43.4 ± 21.8	51.6 ± 25.7	52.2 ± 24.8	49.2 ± 19.4	72.5 ± 23.9	49.4 ± 24.5
Female sex	68 (37.4)	67 (35.8)	39 (25.8)	1 (10.0)	5 (41.7)	180 (33.2)
Glasgow Coma Scale (median, Q1–Q3)	15, 15-15	15, 14-15	15, 14-15	13, 6-15	6, 3.5-13.5	15, 14-15
Mechanism of injury						
Fall from height	13 (7.1)	15 (8.0)	25 (16.6)	2 (20.0)	3 (25.0)	58 (10.7)
Motor vehicular collision	114 (62.6)	111 (59.4)	81 (53.6)	6 (60.0)	5 (41.7)	317 (58.5)
Unknown	55 (30.2)	61 (32.6)	45 (29.8)	2 (20.0)	4 (33.3)	167 (30.8)
Other major intracranial nontraumatic injury	0 (0)	1 (0.5)	2 (1.3)	1 (10.0)	1 (8.3)	5 (0.9)
Other major extracranial traumatic injury	6 (3.3)	71 (38.0)	85 (56.3)	5 (50.0)	6 (50.0)	173 (31.9)
Secondary intracranial complications	0 (0)	1 (0.5)	3 (2.0)	4 (40.0)	5 (41.7)	13 (2.4)
Secondary extracranial complications	0 (0)	6 (3.2)	16 (10.6)	5 (50.0)	6 (50.0)	33 (6.1)
Follow-up brain imaging studies						
Patients with any non-contrast head CTs	182 (100.)	169 (90.4)	140 (92.7)	10 (100.)	10 (83.3)	511 (94.3)
Patients with any contrast-enhanced head CTs	0 (0)	0 (0)	2 (1.3)	0 (0)	0 (0)	2 (0.4)
Patients with any intracranial and/or cervical CTAs	0 (0)	6 (3.2)	14 (9.3)	4 (40.0)	1 (8.3)	25 (4.6)
Patients with any brain MRIs	0 (0)	6 (3.2)	13 (8.6)	6 (60.0)	2 (16.7)	27 (5.0)
Patients with any intracranial and/or cervical MRAs	0 (0)	0 (0)	5 (3.3)	0 (0)	1 (8.3)	6 (1.1)

CT, computed tomography; CTA, computed tomography angiography; MRI, magnetic resonance imaging; MRA, magnetic resonance angiography. Percentages calculated out of N = 542.

Table 3. NeuroImaging Radiological Interpretation System

Category	*Definition*	*Patient management actions*
NIRIS 0	No abnormal finding	Discharge from the ED
NIRIS 1	Fracture ± Extra-axial hematoma, parenchymal hematoma or parenchymal contusion <0.5 cc ± Subarachnoid hemorrhage	Follow-up neuroimaging and/or admit for observation
NIRIS 2	Extra-axial hematoma, parenchymal hematoma or parenchymal contusion >0.5 cc ± Diffuse axonal injury ± Intraventricular hemorrhage ± Mild hydrocephalus ± Midline shift 0–5mm	Admit to a more advanced care unit
NIRIS 3	Extra-axial hematoma, parenchymal hematoma or parenchymal contusion >5 cc ± Moderate hydrocephalus ± Midline shift >5 mm ± Focal herniation	Consider neurosurgical procedure (ventricular drain, burr hole, craniotomy/craniectomy, surgical drainage/evacuation of hematoma)
NIRIS 4	Extra-axial hematoma, parenchymal hematoma or parenchymal contusion >25 cc ± Severe hydrocephalus ± Diffuse herniation / Duret hemorrhage	High risk of TBI-related death

NIRIS, NeuroImaging Radiological Interpretation System; ED, emergency department.

dichotomized (e.g., hemorrhage, no hemorrhage) so that differences could be assessed using Fisher exact tests. For instance, one analysis compared patients who were admitted and/or underwent follow-up neuroimaging (level 1) to all patients who had more severe outcomes (levels 2–4). These results were used to provide the categorical classification system for NIRIS and then the thresholds of continuous characteristics were determined with receiver operating characteristic (ROC) curves, analyzed univariately. We chose the threshold that yielded the highest sensitivity and specificity for discriminating between each outcome and outcome(s) of greater severity. For instance, after identifying hematomas as CDEs differentiating between NIRIS levels, we conducted ROC analysis to identify the threshold values for the volume of hematomas that best discriminated between NIRIS levels. The result of the analysis plan described above was the classification of each patient into one of five mutually exclusive outcome categories based on a specific set of imaging characteristics.

To assess classification performance with respect to established scoring systems for patients with TBI, we compared the sensitivity of NIRIS to that of the Marshall and Rotterdam scoring systems, with sensitivity defined as the proportion of patients with a particular outcome that were correctly classified by the scoring system. All analyses were performed using R software, version 3.3.[21]

Results

Study population

We identified 542 adult patients (mean age: 49.4 ± 24.5 years; 180 females [33%] and 362 males (67%]) who met our inclusion criteria.

Imaging results

The distribution of the NIH TBI imaging CDEs in our study population stratified by patient outcome is reported in Table 1.

Clinical data

The clinical characteristics of our study patients are reported in Table 2. Nearly 60% of the patients were admitted to the emergency department because of motor vehicle collisions. Nearly a third of the patients had major extracranial traumatic injuries. Most follow-up imaging consisted of follow-up noncontrast head CT scans. Nine (1.7%) patients had an external ventricular drain placed, and seven (1.3%) patients underwent a craniotomy or craniectomy.

NIRIS

Based on the Fisher exact tests of categorical characteristics (Supplementary Table 3; see online supplementary material at ftp.liebertpub.com) and ROC analyses (Supplementary Table 4; see online supplementary material at ftp.liebertpub.com), we identified the relevant imaging variables and thresholds of continuous characteristics that best discriminated patients into the mutually exclusive patient disposition categories to form NIRIS. The imaging characteristics described in the NIRIS score (Table 3, Fig. 1) are those characteristics that best discriminate between a lower score and a more severe score.

Comparison of NIRIS, Marshall, and Rotterdam Scores for prediction of survival/death

The mortality rate for each score level for the NIRIS, Marshall, and Rotterdam scoring systems is reported in Table 4; the proportion of deceased patients among those classified into each level generally increased with incremented score. Of note, the five patients with NIRIS 1 and the one patient with NIRIS 3 who died, died from non-TBI related causes, while the six patients with NIRIS 4 died from their TBI (Supplementary Table 5; see online supplementary material at ftp.liebertpub.com). Similar observations were made for the patients with low Marshall and Rotterdam scores who died (Supplementary Table 5).

Sensitivity of NIRIS for DEATH prediction among patients who died from TBI was 100% for NIRIS (six of six). In comparison, the Marshall (with a cutoff value of 2 or more) and Rotterdam (with a cutoff value of 3 or more) scoring systems correctly identified five of six (83.3%) and six of six (100.0%) TBI-related

Table 4. Mortality Rates According to the NeuroImaging Radiological Interpretation System, Marshall and Rotterdam Scoring Systems

Score	*No. of patients*	*Mortality (%)*
NIRIS 0	182	0/182 (0.0%)
NIRIS 1	287	5/287 (1.7%)
NIRIS 2	31	0/31 (0.0%)
NIRIS 3	28	1/28 (3.6%)
NIRIS 4	14	6/14 (42.9%)
Score	*No. of patients*	*Mortality (%)*
Marshall 1	492	7/492 (1.4%)
Marshall 2	35	1/35 (2.9%)
Marshall 3	0	0/0 (0.0%)
Marshall 4	0	0/0 (0.0%)
Marshall 5	7	2/7 (28.6%)
Marshall 6	8	2/8 (25.0%)
Score	*No. of patients*	*Mortality no. (%)*
Rotterdam 1	5	0/5 (0.0%)
Rotterdam 2	493	5/493 (1.0%)
Rotterdam 3	37	4/37 (10.8%)
Rotterdam 4	6	2/6 (33.3%)
Rotterdam 5	1	1/1 (100.0%)
Rotterdam 6	0	0/0 (0.0%)

NIRIS, NeuroImaging Radiological Interpretation System.

Table 5. Outcome Distribution According to the NeuroImaging Radiological Interpretation System, Marshall and Rotterdam Scoring Systems

Score	*Discharged*	*Admitted/ follow-up neuroimaging*	*ICU stay*	*Neuro-surgery*	*Death*	*Total*
NIRIS 0	182	0	0	0	0	*182*
NIRIS 1	0	180	101	1	5	*287*
NIRIS 2	0	5	25	1	0	*31*
NIRIS 3	0	2	19	6	1	*28*
NIRIS 4	0	0	6	2	6	*14*
Total	182	187	151	10	12	542

Score	*Discharged*	*Admitted/ follow-up neuroimaging*	*ICU stay*	*Neuro-surgery*	*Death*	*Total*
Marshall 1	182	183	118	2	7	*492*
Marshall 2	0	4	27	3	1	*35*
Marshall 3	0	0	0	0	0	*0*
Marshall 4	0	0	0	0	0	*0*
Marshall 5	0	0	0	5	2	*7*
Marshall 6	0	0	6	0	2	*8*
Total	182	187	151	10	12	542

Score	*Discharged*	*Admitted/ follow-up neuroimaging*	*ICU stay*	*Neuro-surgery*	*Death*	*Total*
Rotterdam 1	0	1	3	1	0	*5*
Rotterdam 2	182	183	119	4	5	*493*
Rotterdam 3	0	3	27	3	4	*37*
Rotterdam 4	0	0	2	2	2	*6*
Rotterdam 5	0	0	0	0	1	*1*
Rotterdam 6	0	0	0	0	0	*0*
Total	*182*	*187*	*151*	*10*	*12*	*542*

ICU, intensive care unit; NIRIS, NeuroImaging Radiological Interpretation System.

The gray shading indicates the optimal score for the corresponding disposition.

deaths, respectively. When all causes of death were considered, NIRIS achieved 50.0% (six of 12) sensitivity; the Marshall scoring system, 41.7% (five of 12) sensitivity; and the Rotterdam scoring system, 58.3% (seven of 12) sensitivity.

Comparison of NIRIS, Marshall, and Rotterdam scores for prediction of all five outcome categories

The outcomes for each score level for the NIRIS, Marshall, and Rotterdam scoring systems are reported in Table 5. For each scoring system and by patient disposition, we identified the score that yielded the highest sensitivity (best score) and reported the associated sensitivity (true positives/[true positives+false negatives]) in Supplementary Table 6; see online supplementary material at ftp.liebertpub.com.

For patients discharged from the emergency department, the NIRIS score that best identified these patients was 0, correctly classifying all 182 patients. The Marshall and Rotterdam scoring systems also correctly identified these patients at scores of 1 and 2, respectively.

Marshall 1, however, was also shown to be the best score for identifying admitted and advanced care patients, as well as for overall fatal outcome. Similarly, Rotterdam 2 was shown to be the best score for identifying all outcomes except for TBI-related death. Therefore, despite achieving equal or higher sensitivity than NIRIS for advanced care stay and neurosurgery outcomes, there is no intuitive progression in Marshall and Rotterdam thresholds to predict outcomes of increasing severity.

As shown in Table 5, the Marshall and Rotterdam scoring systems were not able to distinguish well the patients who were discharged, admitted, or staying in an advanced care unit from each other. Similarly, the Marshall and Rotterdam scoring systems were not able to distinguish well the patients who underwent neurosurgery and who died. NIRIS, on the other hand, allowed for a more nuanced stratification of the patients. In fact, there is a one-to-one correspondence between NIRIS scores 0–4 and outcomes, as highlighted in the diagonal cells of Table 5.

Of note, there were 107 patients with NIRIS 1 who experienced more severe outcomes (i.e., advanced care unit stay, required a neurosurgery procedure, or died) than expected for a NIRIS score of 1 (expected to just have follow-up brain imaging or be admitted). These patients with a NIRIS score of 1 who experienced more severe outcomes (i.e., advanced care unit stay, required a neurosurgery procedure, or died) were not typical of NIRIS 1 because they had other complicating factors influencing their care. Major extracranial traumatic injuries were present in 68.2% (compared with 23% in NIRIS 1 patients who just had follow-up brain imaging or were admitted) of these patients, and major intracranial nontraumatic injury was present in 28.0% (compared with 0.5%) of cases. In addition, there were secondary extracranial complications in 15.9% (compared with 3.7%) of these patients and secondary intracranial complications in 1.9% of these patients (compared with

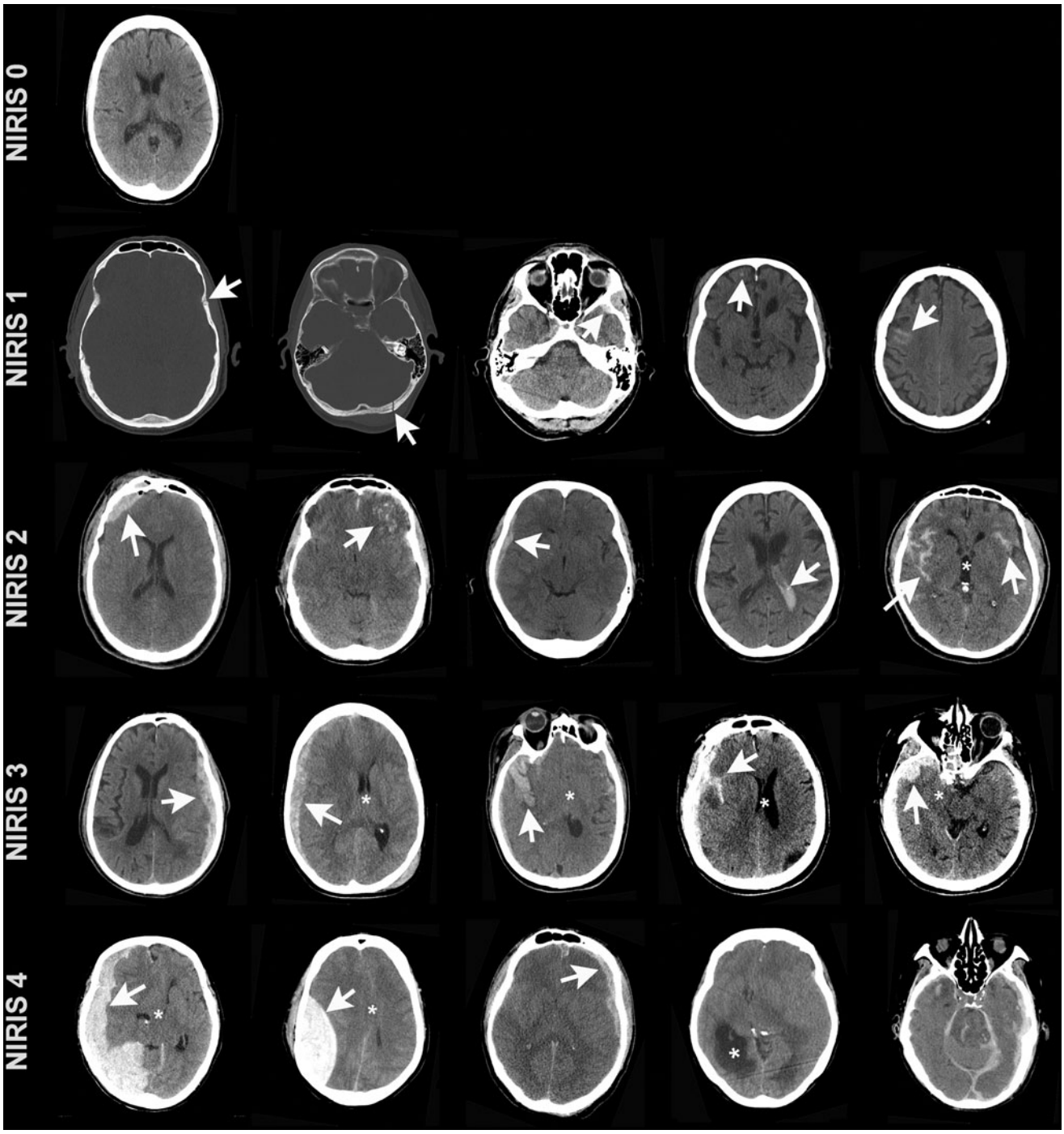

FIG. 1. Illustration of imaging features of the different NeuroImaging Radiological Interpretation System (NIRIS) levels. *NIRIS 0*: normal noncontrast head computed tomography. *NIRIS 1*, from left to right: left sphenoid fracture, left occipital fracture; epidural hematoma <0.5 cc; hemorrhagic contusion <0.5 cc; subarachnoid hemorrhage without hydrocephalus. *NIRIS 2*, from left to right: epidural hematoma >0.5 cc; hemorrhagic contusion >0.5 cc; subdural hematoma >0.5 cc; intraventricular hemorrhage, but midline shift less then 5 mm in all cases; subarachnoid hemorrhage with mild hydrocephalus. *NIRIS 3*, from left to right: subdural hematoma >5 cc (times 2), hemorrhagic contusion >5 cc, subarachnoid hemorrhage and extraaxial hematoma >5 cc, all with midline shift >5 mm; extraaxial hematoma and hemorrhagic contusion with right uncal herniation. *NIRIS 4*, from left to right: subdural hematoma >25 cc, epidural hematoma >25 cc, both with diffuse herniation and obstruction hydrocephalus; subdural hematoma >25 cc with diffuse brain edema; midline shift with entrapment and severe obstructive hydrocephalus of the right lateral ventricle; extraaxial hematomas, hemorrhagic contusions and transtentorial herniation with Duret hemorrhages.

2.5%). Similar observations could be made for the Marshall and Rotterdam scores.

Discussion

The goal of our study was to develop an outcome-based (not experience driven) NIRIS that would use a similar approach to BI-RADS, but would be applied to brain imaging, with an initial focus on TBI. We were successful at deriving a categorization system for the NIH CDEs based on clinical outcomes, with each category associated with specific management actions. NIRIS includes five categories; NIRIS 0 - patients are typically discharged, NIRIS 1 - patients undergo follow-up neuroimaging and/or admitted, NIRIS 2 - patients require admission to an advanced care unit, NIRIS 3 - patients require neurosurgical intervention (ventricular drain, burr hole, craniotomy/craniectomy, surgical drainage/evacuation of hematoma), and NIRIS 4 - patients who have a high likelihood of a fatal outcome from their TBI. Of course, patients with TBI can also have trauma involving other organs than the brain, and such non-neuro trauma will affect patient hospital course independently of the TBI findings.

NIRIS performed similarly to the Rotterdam scale and the Marshall scoring system in terms of predicting survival/death. NIRIS performed much better than the Rotterdam and Marshall scoring systems in terms of predicting discharge, admission, follow-up neuroimaging, advanced care unit stay, and neurosurgical procedures. This is by design because the Rotterdam and Marshall scoring systems were developed to allow more accurate predictive statements at the time of the TBI patient's initial evaluation regarding the likelihood of a fatal or nonfatal outcome. On the other hand, NIRIS was developed with the intent of being more granular in terms of guiding TBI patient care based on the initial noncontrast head CT findings and its subsequent outcomes.

The Marshall scoring system could not distinguish between patients being discharged, admitted, or going to advanced care units; they all had low Marshall scores (Table 5). On the other hand, all patients in our cohort who had a fatal outcome, underwent a neurosurgical procedure, or a stay in the ICU had indistinguishable high Marshall scores; there were very few patients with intermediary Marshall scores. Patients in our cohort with low Rotterdam scores were similarly indistinguishable; a Rotterdam score of 2 was given to the majority of patients that were discharged, admitted, or had a stay in an advanced care unit (Table 5). There were few patients with high Rotterdam scores.

We acknowledge several limitations in our study. It is a retrospective study, which may introduce selection or information bias. It focused exclusively on CT. MRI was not included in this initial study, although NIRIS could be translated to MRI in future investigations, similar to the extended implementation with BI-RADS. Given the single cohort in this study population, we were not able to test and validate the NIRIS classification; however, future investigations will be aimed at validating NIRIS in other TBI populations to assess its accuracy in guiding management and treatment decisions in the TBI population.

As mentioned above, we used our medical records, as well as a Social Security death index to assess whether our study patients were deceased. Despite this precaution, there is still a chance that we missed a small number of patients who died at a different facility. The sample sizes across the outcome categories were unequal; for instance, only 10 patients underwent neurosurgical procedures, and there were only 12 deaths in our study population, which limits the generalizability of our classification, especially for the higher NIRIS scores. In addition, patients who died were older than the rest of the cohort, and this may represent a confounding factor.

Conclusion

We successfully applied the concept of the BI-RADS to neuroimaging with an initial focus on acute TBI. Our NIRIS classification, with evidence-based grouping of the CDEs into actionable categories, will need to be validated in different TBI populations. Our vision for the NIRIS classification once validated is that it will be included in all radiology reports for head CTs in patients with TBI to standardize and streamline the communication of the radiology results to the clinical teams taking care of these patients.

Author Disclosure Statement

No competing financial interests exist.

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