Validation of the Revised Neuroimaging Radiological Interpretation System For Acute Traumatic Brain Injury in Adult and Pediatric Population

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Indian J Neurotrauma:2021;18:32–37

Abstract

Aim Our study aimed to validate the revised neuroimaging radiological interpretation system (NIRIS), which would standardize the interpretation of noncontrast head CT of acute traumatic brain injury (TBI) patient and consolidate imaging finding into ordinal severity categories that would not only inform specific patient management actions but could also be used as a clinical decision support tool.

Methods We retrospectively studied dispositions and their outcomes of consecutive patients brought to the Sawai Man Singh Hospital Trauma Centre, Jaipur, India, by any means of transport and who underwent a noncontrast CT scan for suspected TBI between April and December 2018.

Results The revised NIRIS correctly predicted disposition and outcome in 62.9% (750/1192) of patients. After excluding patients with OMEI (other major extracranial injuries) and OMII (other major intracranial injuries), a correct prediction was observed in 88.3% (670/758) of patients. After excluding OMEI and OMII, the predictability of revised NIRIS in the adult population is 87.6% (446/509), while predictability in the pediatric population is 92.1% (224/249).

Conclusion Revised NIRIS is a good tool for predicting patient dispositions, to specific management categories, and outcomes in TBI patients after noncontrast CT head.

Keywords
- clinical decision support
- computed tomography (CT)
- outcome
- revised NIRIS
- Traumatic Brain Injury (TBI)

Introduction

Traumatic brain injury (TBI) is a complex multifaceted condition. It is estimated that nearly 1.5 to 2 million persons are injured and 1 million succumb to death every year in India.[1] An estimated 10 million people worldwide are affected every year by new acute TBI events.[2] There are many classifications for triage and prediction of mortality in TBI patients. Glasgow coma scale (GCS), which is based on clinical characteristics, stratifies TBI severity, while Marshall[3] and Rotterdam[4] scoring are based on radiological classification to predict the mortality in moderate-to-severe TBI.[5,6] Patients with identical GCS scores were found to have quite different TBI injuries in several clinical trials, illustrating the limited ability of GCS to stratify TBI patients in terms of the pathophysiology of their injury.[7] Neuroimaging can detect and characterize the presence and extent of brain injury, and plays an important role to stratify and manage TBI patients.[8]

Recently, Wintermark et al[9] proposed the neuroimaging radiological interpretation system (NIRIS) for TBI patients, which would standardize the interpretation of noncontrast head CT and consolidate imaging finding into ordinal severity categories that would not only inform specific patient management actions but could also be used as a clinical decision support tool. The NIRIS is an outcome-based rather than an experience-driven system. According to NIRIS, patients are classified into five mutually exclusive categories: 0–discharge from emergency department; 1–follow-up brain imaging and/or admission; 2–admission to advanced care

published online
February 4, 2021

DOI https://doi.org/10.1055/s-0040-1717210
ISSN 0973-0508.

Thieme Medical and Scientific Publishers Pvt. Ltd. A-12, 2nd Floor, Sector 2, Noida-201301 UP, India

unit; 3–neurosurgical procedure; 4–death up to 6 months after TBI. When compared with Marshall and Rotterdam scoring system, NIRIS performed similarly in terms of death prediction but was superior in terms of predicting specific patient care actions.

Zhou et al[10] successfully validated the NIRIS and proposed the revised NIRIS system (►**Table 1**), which predicted TBI patient disposition and outcome with 91.2% accuracy after excluding patients with other major extracranial traumatic and intracranial nontraumatic injuries.

Recently, Hui Chen et al[11] characterized the demographics, clinical, and imaging findings and outcomes of TBI patients in each of the NIRIS categories. According to Chen at el, there is a significant difference in NIRIS categories that were observed for all imaging, in agreement with the definition of different NIRIS categories.

The goal of our study was to access the performance of the revised NIRIS system in the Indian population and access the predictability of revised NIRIS in pediatric and adult populations separately.

Methods

Study design: We retrospectively included consecutive patients who were brought to the Sawai Man Singh Hospital Trauma Centre, Jaipur, India, by any means of transport and who underwent noncontrast CT scans for suspected TBI between April to December 2018. Patients with penetrating brain injuries and gunshot injuries were excluded from our study.

Demographics and all clinical variables of patients are extracted from our institution's medical record department, including age, sex, mechanism of injury, GCS, status at discharge, other major extracranial injuries (OMEI), and other major intracranial injuries (OMII).

The noncontrast CT imaging finding includes the presence/absence of skull fracture, pneumocephalus, hemorrhage, mass effect, and brain parenchymal injuries. Besides, 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, as they could be seen on multiplying by the slice thickness and dividing 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 3**).

Results

Study population: 1192 patients (age 47.3 ± 18.7 years; 34.8% female), of which 68.3% were adults and 31.7% were of pediatric age (age ≤ 15 years), were studied retrospectively.

Table 1 The revised NIRIS[10]

Category	Definition	Patient management action
NIRIS 0	No abnormal findings	Discharge from the ED
NIRIS 1	• Fracture ± • Pneumocephalus • Epidural hematoma, subdural hematoma, parenchymal hematoma or parenchymal contusion < 0.5 mL ± • Subarachnoid hemorrhage	Follow up brain imaging and /or admit for observation
NIRIS 2	• Epidural hematoma, subdural hematoma, parenchymal hematoma or parenchymal contusion > 0.5 mL ± • Diffuse axonal injury ± • Intraventricular hemorrhage ± • Mild or moderate hydrocephalus ± • Midline shift 0–5 mm	Admit to a more advanced care unit
NIRIS 3	• Epidural hematoma, parenchymal hematoma, parenchymal contusion > 15 mL ± • Subdural hematoma > 50 mL ± • Midline shift > 5 mm ± • Focal herniation	Consider neurosurgical procedure (ventricular drain, burr hole, craniotomy/craniectomy, surgical drainage/evacuation of the hematoma
NIRIS 4	• Epidural hematoma, parenchymal hematoma, parenchymal contusion ≥ 20 mL ± • Subdural hematoma > 200 mL • Severe hydrocephalus ± • Midline shift > 10 mm ± • Diffuse herniation • Duret hemorrhage	High-risk of TBI-related death

Abbreviations: ED, emergency department; NIRIS, neuroimaging radiological interpretation system; TBI, traumatic brain injury.

Table 2 Demographic, clinical and injury severity in this study

Demographics	Overall	Discharge	Follow-up brain imaging/admission	ICU stay	Neurosurgery	Death
Number of patients	1192	320	285	226	199	162
Age, mean ± SD in years	47.3 ± 18.7	39.8 ± 22.8	42.06 ± 27.9	51 ± 20.5	46.4 ± 21.6	59.4 ± 19.1
GCS, median (Q1–Q3)	14 (13–14)	15 (15–15)	15 (13–15)	9.0 (5.5–12.5)	14 (13–14)	8 (3–12)
Female sex, *n* (%)	415 (34.8)	99 (30.8)	98 (34.4)	88 (38.8)	65 (32.5)	65 (40.0)
Mechanism of injury, *n* (%)						
Fall from height	347 (29.1)	27 (8.4)	83 (29.1)	95 (42.0)	83 (41.7)	59 (36.4)
RTA	644 (54.0)	220 (68.7)	145 (50.8)	80 (35.3)	99 (49.7)	100 (61.7)
Assault/violence	171 (14.3)	73 (22.8)	52 (18.9)	32 (14.3)	13 (6.3)	1 (0.6)
Unknown/other	30 (2.5)	0 (0.0)	5 (1.7)	19 (8.6)	4 (2.0)	2 (1.2)
OMII *n* (%)	87 (7.2)	0 (0.0)	42 (14.6)	22 (9.7)	15 (7.3)	8 (4.9)
OMEI *n* (%)	339 (28.4)	126 (39.4)	91 (32.1)	26 (11.3)	73 (36.9)	23 (14.0)
Secondary intracranial complications, *n* (%)	118 (9.8)	0 (0.0)	0 (0.0)	22 (9.6)	36 (18.3)	60 (36.8)
Secondary extracranial complications, *n* (%)	220 (18.4)	0 (0.0)	0 (0.0)	76 (33.6)	57 (28.7)	87 (53.9)
Follow-up brain imaging studies, *n* (%)						
Noncontrast CT head	484 (40.6)	0 (0.0)	117 (41.0)	120 (53.1)	188 (94.3)	59 (36.2)
Contrast-enhanced CT head	19 (1.6)	0 (0.0)	4 (1.4)	8 (3.5)	7 (3.5)	0 (0.0)
Intracranial or cervical CT angiography	105 (8.8)	0 (0.0)	56 (19.6)	30 (13.2)	12 (6.0)	11 (6.7)
Brain MRI	75 (6.3)	0 (0.0)	26 (2.1)	38 (16.8)	9 (4.5)	2 (1.2)
Intracranial or cervical MR angiography	11 (0.9)	0 (0.0)	4 (1.4)	5 (2.2)	2 (1.0)	0 (0.0)

Abbreviations: GCS, Glasgow coma scale; OMEI, other major extracranial injuries; OMII, other major intracranial injuries; RTA, road traffic accidents.

Clinical Data

The clinical characteristics of our study patients are reported in ►**Table 2**. Road traffic accidents (RTA) is the leading cause (54%) of TBIs, followed by fall from height (29.1%) and violence (14.3%). As much as 28.4% of these patients had other major extracranial injuries and 7.2% had other major intracranial nontraumatic injuries. The GCS score decreased with increasing revised NIRIS category, and it was significantly lower in patients with revised NIRIS category 4. As much as 40.6% of patients underwent noncontrast CT of head as follow-up imaging, while 1.6% underwent contrast CT of head; 8.8% of these patients had done intracranial/cervical CT angiography and 6.3% had follow-up brain imaging.

Imaging Results

The distribution of imaging common data elements in this study population, stratified by the patient outcome, is depicted in ►**Table 3**. As much as 30.2% patients had a skull fracture, with 22.5% sustaining a calvarial fracture and 8.8% sustaining a skull base fracture, while 70 (5.8%) patients sustained a depressed fracture, of which 30 patients (42.8%) met the criteria for neurosurgery and got operated. A total of 86 (7.2%) patients were admitted with intraventricular hemorrhage, of which eight (9.3%) patients were operated with external ventricular drain (EVD). As much as 26.4% of patients had mass effect, while 14% of patients had brain herniation.

The performance of the revised NIRIS classification in terms of predicting dispositions and outcomes in the retrospective cohort ($n = 1192$) is depicted in ►**Table 4**. The revised NIRIS correctly predicted patient dispositions and outcomes in 62.9% (750/1192) of patients. After excluding patients with OMEI and OMII, a correct prediction was observed in 88.3% (670/758). After excluding OMEI and OMII, the predictability of revised NIRIS in the adult population is 87.6% (446/509), while predictability in the pediatric population is 92.1% (224/249).

Comparison of Revised NIRIS, Marshall and Rotterdam Scoring System for All Five Outcome Categories

The outcome for each score level for revised NIRIS, Marshall, and Rotterdam scoring system is outlined in Supplementary

Table 3 Imaging CDE in this study

	Overall	Discharge	Follow-up brain imaging/admission	ICU stay	Neurosurgery	Death
Number of patients	1192	320	285	226	199	162
Skull fracture, n (%)	361 (30.2)	0 (0.0)	98 (34.3)	81 (35.8)	103 (51.7)	79 (48.7)
Calvarial fracture	269 (22.5)	0 (0.0)	89 (31.2)	44 (19.4)	87 (43.7)	49 (30.2)
Skull base fracture	106 (8.8)	0 (0.0)	14 (4.9)	29 (12.8)	24 (12.0)	39 (24.0)
Depressed fracture	70 (5.8)	0 (0.0)	09 (3.1)	18 (7.9)	30 (15.0)	13 (8.0)
Pneumocephalus n (%)	146 (12.2)	0 (0.0)	39 (13.6)	56 (24.7)	33 (16.5)	18 (11.1)
Hemorrhage n (%)	564 (47.3)	0 (0.0)	100 (35.0)	141 (62.3)	180 (90.4)	143 (88.2)
Epidural hematoma	184 (15.4)	0 (0.0)	46 (16.1)	44 (19.4)	66 (33.1)	28 (17.2)
Subdural hematoma	274 (22.9)	0 (0.0)	18 (6.3)	82 (36.2)	72 (36.1)	102 (62.9)
Subarachnoid hemorrhage	186 (15.6)	0 (0.0)	37 (12.9)	84 (37.1)	32 (16.0)	33 (20.3)
Intraventricular hemorrhage	86 (7.2)	0 (0.0)	0 (0.0)	43 (19.0)	8 (4.0)	35 (21.6)
Parenchymal hematoma (including hemorrhagic contusions	398 (33.3)	0 (0.0)	118 (41.4)	126 (55.7)	58 (29.1)	96 (59.2)
Diffuse axonal injury	68 (5.7)	0 (0.0)	6 (2.1)	56 (24.7)	4 (2.0)	2 (1.2)
Mass effect, n (%)	315 (26.4)	0 (0.0)	9 (3.1)	37 (16.3)	171 (85.9)	98 (60.4)
Brain edema/ swelling	279 (23.4)	0 (0.0)	12 (4.2)	76 (33.6)	89 (44.7)	102 (62.9)
Midline shift	406 (34.0)	0 (0.0)	38 (13.3)	89 (39.3)	170 (85.4)	109 (67.2)
Cisternal compression	206 (17.2)	0 (0.0)	14 (4.9)	32 (14.1)	81 (0.40)	79 (48.7)
Brain herniation/Duret hemorrhage	167 (14.0)	0 (0.0)	0 (0.0)	18 (7.9)	66 (0.33)	83 (51.2)
Hydrocephalus	173 (14.5)	0 (0.0)	41 (14.3)	52 (23.0)	41 (20.6)	39 (24.0)
Mild	134 (11.2)	0 (0.0)	40 (14.0)	49 (21.6)	22 (11.0)	23 (14.1)
Moderate	25 (2.0)	0 (0.0)	1 (0.3)	1 (0.4)	11 (5.5)	12 (7.4)
Severe	14 (1.1)	0 (0.0)	0 (0.0)	2 (0.8)	8 (4.0)	4 (2.4)
Non hemorrhagic contusions	67 (5.6)	0 (0.0)	18 (6.3)	24 (10.6)	13 (6.5)	12 (7.4)

Abbreviation: CDE, common data elements.

Table S1. Marshall scores of 1 and 2 were associated with discharge from the emergency department (ED), hospital admission, and intensive care (ICU) monitoring, but it could not differentiate among these outcomes. Marshall scores of 5 and 6 were associated with the neurosurgical procedure and patient death.

In our study, most of the Rotterdam scores were 2 and 3, which did not differentiate among the five outcomes.

Extended Glasgow Outcome Scale (GOSE) and Mortality

Three-month GOSE scores were successfully obtained for 604 patients out of 1192 patients (50.7%) (**Supplementary Tables S2** and **S3**). Among 604 patients, there were 38 dead patients. The GOSE score was significantly higher ($p < 0.0001$) in revised NIRIS 3 and revised NIRIS 4. Mortality progressively increased with increasing revised NIRIS category. Mortality in patients with OMEI and OMII was significantly higher than those patients without OMEI and OMII in revised NIRIS 0.

Discussion

In our study, the revised NIRIS correctly predicted patient dispositions and outcomes in 62.9% (750/1192) of patients. After excluding patients with OMEI and OMII, a correct prediction was observed in 88.3% (670/758) of patients. After excluding OMEI and OMII, the predictability of revised NIRIS in the adult population was 87.6% (446/509), while predictability in the pediatric population (age ≤15 years) was 92.1% (224/249). To date, no study has been conducted to get NIRIS predictability for patient disposition in the pediatric population. In the previous study,[10] revised NIRIS correctly predicted dispositions and outcomes in 60.5% of patients, and after excluding the patients with OMEI and OMII, a corrected prediction was observed in 91.2%.

Still, the revised NIRIS should be considered for revision, as in our study, 30 patients with depressed skull fracture (those who met the criteria for operability) were kept in the revised NIRIS category 1. After the inclusion of depressed fracture patients in revised NIRIS category 3, overall predictability increased from 88.3% to 92.3%, predictability in

Table 4 Distribution of patient dispositions and outcomes in our retrospective study

NIRIS CT	Discharge	Admission	ICU	Neurosurgery	Death	Total
0	320	103	54	0	45	522
1	0	182	40	32	24	278
2	0	0	80	10	17	107
3	0	0	42	133	41	216
4	0	0	10	24	35	69
Total	320	285	226	199	162	1192
Study population minus patients with OMEI AND OMII (*n* = 758)						
0	320	03	0	0	0	323
1	0	130	20	30	0	180
2	0	0	64	6	5	75
3	0	0	6	121	8	135
4	0	0	4	6	35	45
Total	320	133	94	163	48	758
Distribution of adult patient dispositions and outcomes in our retrospective study (*n* = 815)						
0	203	62	30	0	34	329
1	0	135	32	24	20	211
2	0	0	37	8	7	52
3	0	0	32	107	31	170
4	0	0	10	22	21	53
Total	203	197	141	161	113	815
Adult population minus patients with OMEI AND OMII (*n* = 509)						
0	203	03	0	0	0	206
1	0	87	12	24	0	123
2	0	0	34	6	3	43
3	0	0	2	95	5	102
4	0	0	4	4	27	35
Total	203	90	52	129	35	509
Distribution of pediatric patient dispositions and outcomes in our retrospective study (*n* = 377)						
0	117	41	24	0	11	193
1	0	47	8	8	04	67
2	0	0	43	2	10	55
3	0	0	10	26	10	46
4	0	0	0	2	14	16
Total	117	88	85	38	49	377
Pediatric population minus patients with OMEI AND OMII (*n* = 249)						
0	117	0	0	0	0	117
1	0	43	8	6	0	57
2	0	0	30	0	2	32
3	0	0	4	26	3	33
4	0	0	0	2	8	10
Total	117	43	42	34	13	249

Abbreviations: NIRIS, neuroimaging radiological interpretation system; OMEI, other major extracranial injuries; OMII, other major intracranial injuries.
Note: The gray shaded cells are presenting the exact number of disposed of patients in the respective revised NIRIS category.

the adult age group increased from 87.6% to 92.3%, and predictability increased from 92.1% to 92.3% in the pediatric age group. After keeping depressed fracture (those who met the criteria for operability) in revised NIRIS category 3, the predictability of revised NIRIS is similar in the pediatric and adult population.

TBI is a major cause of morbidity and mortality. Road traffic accidents (RTA), which is a leading cause of TBI in many parts of the world, is expected to become the third-largest cause of global disease burden by 2020.[12]

Some studies focused on clinical characteristics that predict the outcome in TBI patients, including the IMPACT[13] and TRACT-TBI studies.[14] These studies have verified the prognostic value of many known predictors associated with worse GOS scores (e.g., age, GCS,[15] pupil response,[15] CT findings,[16] pre-existing psychiatric conditions, and lower education).

In our study, the most common cause of TBI is RTA and it involves mostly the young population. We found that patients within the category revised NIRIS 0 registered good GCS and GOSE scores at 3 months, and as the grading of revised NIRIS category increases, there is a decrease in the GCS and GOSE scoring of patients. Patients within a higher revised NIRIS category have major intracranial or extracranial injuries with a longer hospital stay, need ICU monitoring, and may die from their injury. In our study, the cause of longer hospital stays, ICU monitoring and mortality is determined not only by severity of TBI but also by other intracranial and extracranial injuries. The extracranial injury explains the high morbidity and mortality in lower revised NIRIS categories like revised NIRIS 0 and revised NIRIS 1.

In a previous study,[9] as well as our study, revised NIRIS was found to perform similarly to the Rotterdam scale and the Marshall scoring system in terms of predicting survival/death, while revised NIRIS performed better than the Rotterdam and Marshall scoring systems in terms of predicting discharge, admission, follow-up neuroimaging, advanced care unit stay, and neurosurgical procedures.

Our study has several limitations. One of the main limitations is that it is a retrospective study, causing selection and information bias. With retrospective studies, the temporal relationship is frequently difficult to assess. Our study is based on a CT scan only. Our study did not include those patients with TBI who do not fulfill the criteria for CT of head, which may be a cause of selection bias. MRI is done in only a few patients who are suspected of diffuse axonal injury (DAI) and not on ventilatory support. Our institute is a high-volume center and many cases of TBI are categorized as brought dead and those cases are not included in our study.

Conclusion

CT findings in combination with GCS scoring is likely to provide the best outcome in TBI patient management. We successfully validated the revised NIRIS in the Indian population with adult and pediatric subpopulations. Revised NIRIS is a good tool for predicting patient dispositions, to specific management categories, and outcomes. Still, revised NIRIS requires some correction to improve predictability, and multicentre cross-validation with the help of a prospective study is still required.

Conflict of Interest
None declared.

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