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MRI VERSUS CT-BASED TRAUMATIC BRAIN INJURY CLASSIFICATION AND ITS ASSOCIATION WITH CLINICAL OUTCOMES: A RETROSPECTIVE COHORT STUDY

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ABSTRACT

Background: Traumatic brain injury (TBI) remains a major cause of morbidity and mortality worldwide. Computed tomography (CT) is the primary imaging modality for initial TBI assessment and is commonly classified using the Marshall scoring system. Magnetic resonance imaging (MRI), however, has greater sensitivity for detecting hemorrhagic and diffuse axonal injuries that may not be fully characterized on CT. While both imaging modalities are frequently performed in moderate-to-severe TBI, limited regional data exist comparing their classification systems in relation to meaningful clinical outcomes. **Objective:** To evaluate the association between CT-based Marshall classification and MRI-detected hemorrhagic lesions with major clinical outcomes in patients with moderate-to-severe TBI. **Methods:** This retrospective cohort study was conducted at King Hussein Medical Center, Royal Medical Services, Jordan. Adult patients with moderate-to-severe TBI who underwent both CT and MRI during the same hospital admission were included. Demographic, clinical, and radiological data were collected from electronic medical records and radiology reports. CT findings were classified according to the Marshall classification system, while MRI findings were assessed for the presence of hemorrhagic lesions. The main outcomes were ICU admission, neurosurgical intervention, and in-hospital mortality. Statistical analysis included chi-square or Fisher's exact tests, Mann–Whitney U tests, and multivariable logistic regression. **Result:** A total of 700 patients were included. MRI-detected hemorrhagic lesions were significantly associated with severe TBI, higher Marshall classification, ICU admission, neurosurgical intervention, in-hospital mortality, and longer hospital stay. In-hospital mortality occurred in 103 patients. Non-survivors were older, had lower admission Glasgow Coma Scale scores, higher rates of hypotension, more advanced Marshall classifications, and more frequent MRI hemorrhagic lesions. In multivariable analysis, older age, male sex, lower admission Glasgow Coma Scale, hypotension, and Marshall Class V–VI were independent predictors of in-hospital mortality. Marshall Class VI independently predicted neurosurgical intervention. However, MRI-detected hemorrhagic lesions were not independently associated with mortality, ICU admission, or neurosurgical intervention after adjustment. **Conclusion:** MRI-detected hemorrhagic lesions were associated with greater TBI severity and worse clinical outcomes, but they did not independently predict outcomes after adjustment for clinical and CT based variables. CT based Marshall classification remained a reliable prognostic tool for early outcome prediction in moderate to severe TBI, while MRI may serve as a complementary modality for detecting additional traumatic brain injury burden.

KEYWORDS: Traumatic brain injury; Computed tomography; Magnetic resonance imaging; Marshall score; Clinical outcomes.

INTRODUCTION

Traumatic brain injury (TBI) continues to be a major cause of morbidity and mortality across the globe, particularly among young adults. It continues to pose a major health and socioeconomic challenge. Despite improvements in the management of TBI, including critical care and neuroimaging, prognostication of TBI patients, particularly those with moderate to severe TBI, continues to be a challenge. Computed tomography (CT) of the head continues to be the first choice of neuroimaging in the acute TBI patient. It is quick, accessible, and sensitive to the detection of potentially life-threatening intracranial abnormalities requiring urgent treatment. The Marshall CT classification system, which was first described in 1991, became the most popular CT-based grading system for TBI. It graded TBI patients according to the severity of the TBI. It stratified patients according to the risk of TBI.[1] Large prognostic models such as the IMPACT study and the CRASH study confirmed the independent prognostic value of CT characteristics for mortality.[2.5]

Nevertheless, CT scans possess limitations, especially for the detection of non-hemorrhagic lesions and subtle TAI, which frequently result in considerable neurologic impairment. In order to overcome the limitations of the CT scan, improvements were made to the prognostic scoring systems, including the Rotterdam score, which has shown better predictive accuracy compared with the Marshall scoring system.[3,4] However, it has been found that the accuracy of the CT scan, including the improved scoring systems, might be limited for the detection of microstructural and hemorrhagic injuries, especially in cases of DAI.

Magnetic resonance imaging (MRI) has shown greater sensitivity for the detection of hemorrhagic lesions, microbleeds, and diffuse axonal injuries, especially with the aid of advanced MRI techniques such as diffusion weighted imaging and susceptibility weighted imaging.[9,10] Several studies have demonstrated that MRI lesion burden is associated with neurological impairment and outcome.[11-13] Significantly, MRI findings, particularly those of hemorrhagic lesions, their number, and their location, were independently associated with mortality and disability.[6-8] Recent studies from collaborative studies such as the CENTER TBI study emphasize the potential of multimodal imaging techniques for improved outcome prediction.[17,18]

Both CT scans and MRI scans are often used in patients with moderate to severe TBI, although the majority of previous studies assessed each modality individually rather than comparatively. While the current role of CT scan classifications remains the mainstay for early risk stratification and surgical decision making, there is increasing data to indicate that MRI scans may offer additional prognostic information beyond traditional CT scoring systems.[6,7] However, few studies have directly assessed the association between CT scan based Marshall classification systems and MRI detectable hemorrhagic lesions with clinically significant in hospital outcomes such as the need for neurosurgical intervention, ICU admission, and mortality rates.

Thus, the purpose of this current study is to determine the association of CT based Marshall classification systems with MRI identified hemorrhagic lesions and major clinical outcomes for patients with moderate to severe TBI. This will help us determine the additional prognostic information provided by MRI over established clinical outcome prediction systems based on CT scans and contribute to the growing body of literature regarding regional studies on outcome prediction for TBI patients.

METHODS

Study design

This retrospective cohort study was conducted at a tertiary care center, including patients admitted with traumatic brain injury (TBI). The study reviewed medical records over a defined study period X, following institutional ethical approval.

Study population

Adult patients who were diagnosed with moderate-to-severe TBI and were 18 years or older were the subject of the study. Moderate-to-severe TBI patients were identified based on their clinical assessment, which included the Glasgow Coma Scale. The study included patients who had undergone both non-contrast CT and MRI during the same hospital admission. The study excluded patients who had mild TBI, did not undergo both imaging procedures, had incomplete medical records, and had existing neurological disorders.

Data Collection

Data was retrospectively collected using electronic medical records and radiology reporting systems, employing a data collection tool. Variables collected were demographic factors, such as age and sex, along with clinical data. CT scan results were recorded according to the Marshall classification system, which ranges from Class I to Class VI, according to radiological reports. MRI results were analyzed to determine the presence or absence of hemorrhage, such as microbleeds or signs of diffuse axonal injury, according to radiological reports. Other clinical outcome measures collected were the need to undergo neurosurgical procedures, such as craniotomy or intracranial pressure monitoring, admission to the ICU, or in-hospital mortality.

Statistical Method

Statistical analysis was performed using R program. Mean ± SD or median [IQR] was used to display the continuous variables and compare them through Mann-Whitney U test. Categorical variables were represented in the form of frequencies (%) and were evaluated either through Chi-square or Fisher's exact tests. The multivariate logistic regression models were build to determine independent predictors of in-hospital mortality, ICU admission and neurosurgical intervention considering the age, sex, admission GCS, hypotension, Marshall classification, and MRI results. The findings were given in Odds Ratios (OR) with 95% Confidence Intervals (CI). A significant statistical value would be <0.05.

RESULT

In this cohort of 700 patients, MRI-detected hemorrhagic lesions were significantly associated with severe TBI

(59% vs. 4.1%; p < 0.001) and higher Marshall Classifications (p < 0.001). Lesions in patients were associated with increased mortality (20% vs. 4.5%), neurosurgical intervention (16% vs. 6.9%), and length of stay (p < 0.001) (Table 1).

Older age (46.8 vs. 42.1 years; p = 0.007), severe TBI (74% vs. 34%), and hypotension (28 vs. 8.2; p < 0.001) were significantly related with in-hospital mortality (n = 103). MRI hemorrhagic lesions (89% vs. 61%) and advanced Marshall Classifications (V- VI), significantly more common in non-survivors, had a higher median hemorrhagic foci (p < 0.001, Table 2).
The results of the multivariable logistic regression analysis were the following independent predictors of the outcomes of clinical results. In the case of in-hospital death, older age (OR: 1.02, 95% CI; 1.01-1.04; p=0.001), male sex (OR: 1.82, 95% CI: 1.06-3.26; p=0.035), hypotension (OR: 2.59, 95% CI: 1.41-4.69: p=.002), and the low admission GCS were Marshall Class V and VI were also linked to greater risks of mortality (OR: 6.65 and 7.64, respectively; p<0.05).

Male sex (OR: 1.54; p=0.023), lower GCS (OR: 0.85; p=0.009), hypotension (OR: 2.18; p=0.023), and Marshall Class V/VI independently predicted the ICU admission (Table 3). Neurosurgical intervention was strongly connected with Marshall Class VI (OR: 5.24, 95% CI: 1.31-23.0; p=0.022). It is interesting to note that the occurrence of MRI hemorrhagic lesions was not a significant predictor of mortality (p=0.752), ICU admission (p=0.084) or neurosurgery (p=0.953) in other variable combinations (Table 3).

Table 1: Baseline Demographic, Clinical, and Radiological Characteristics of TBI Patients Stratified by the Presence of MRI-Detected Hemorrhagic Lesions.

Characteristic	Overall N = 700	Absent N = 245	Present N = 455	P value
Age (years), Mean ± SD	42.8 ± 17.5	44.7 ± 18.6	41.8 ± 16.8	0.084
Sex, n (%)				0.909
Female	199 (28)	69 (28)	130 (29)	
Male	501 (72)	176 (72)	325 (71)	
Admission Glasgow Coma Scale, Mean ± SD	8.9 ± 2.2	10.8 ± 1.2	7.9 ± 1.9	**<0.001**
TBI Severity Group, n (%)				**<0.001**
Moderate (GCS 9-12)	420 (60)	235 (96)	185 (41)	
Severe (GCS 3-8)	280 (40)	10 (4.1)	270 (59)	
Hypotension, n (%)	78 (11)	15 (6.1)	63 (14)	**0.002**
Marshall Classification, n (%)				**<0.001**
Class I	98 (14)	95 (39)	3 (0.7)	
Class II	126 (18)	100 (41)	26 (5.7)	
Class III	140 (20)	41 (17)	99 (22)	
Class IV	147 (21)	9 (3.7)	138 (30)	
Class V	105 (15)	0 (0)	105 (23)	
Class VI	84 (12)	0 (0)	84 (18)	
Hemorrhagic Foci Count on MRI, Median [Q1, Q3]	0.0 [0.0, 3.0]	0.0 [0.0, 0.0]	2.0 [1.0, 4.0]	**<0.001**
ICU Admission, n (%)	455 (65)	106 (43)	349 (77)	**<0.001**
Neurosurgical Intervention, n (%)	90 (13)	17 (6.9)	73 (16)	**<0.001**
In-Hospital Mortality, n (%)	103 (15)	11 (4.5)	92 (20)	**<0.001**
ICU Length of Stay (days), Median [Q1, Q3]	2.9 [0.0, 4.9]	0.0 [0.0, 3.1]	3.6 [1.8, 5.7]	**<0.001**
Hospital Length of Stay (days), Median [Q1, Q3]	8.3 [6.1, 11.6]	6.5 [4.5, 8.7]	9.7 [7.3, 12.9]	**<0.001**

Table 2: Comparative Analysis of Clinical and Imaging Profiles Between Survivors and Non-Survivors Following Traumatic Brain Injury.

Characteristic	Non-Survivors N = 597	Survivors N = 103	P value
Age (years), Mean ± SD	42.1 ± 17.5	46.8 ± 17.0	**0.007**
Sex, n (%)			0.085
Female	177 (30)	22 (21)	
Male	420 (70)	81 (79)	
Admission Glasgow Coma Scale, Mean ± SD	9.2 ± 2.1	7.2 ± 2.0	**<0.001**
TBI Severity Group, n (%)			**<0.001**
Moderate (GCS 9-12)	393 (66)	27 (26)	
Severe (GCS 3-8)	204 (34)	76 (74)	
Hypotension, n (%)	49 (8.2)	29 (28)	**<0.001**
Marshall Classification, n (%)			**<0.001**

Class I	96 (16)	2 (1.9)	
Class II	117 (20)	9 (8.7)	
Class III	128 (21)	12 (12)	
Class IV	129 (22)	18 (17)	
Class V	77 (13)	28 (27)	
Class VI	50 (8.4)	34 (33)	
MRI Hemorrhagic Lesion, n (%)			**<0.001**
Absent	234 (39)	11 (11)	
Present	363 (61)	92 (89)	
Hemorrhagic Foci Count on MRI, Median [Q1, Q3]	0.0 [0.0, 3.0]	2.0 [0.0, 4.0]	**<0.001**

Table 3: Multivariable Logistic Regression Models Identifying Independent Predictors of In-Hospital Mortality, ICU Admission, and Neurosurgical Intervention.

Characteristic	**In-Hospital Mortality**				**ICU Admission**				**Neurosurgical Intervention**			
	OR	**95% CI**		**p value**	**OR**	**95%CI**		**p value**	**OR**	**95%CI**		**P value**
		Lower	**Upper**			**Lower**	**Upper**			**Lower**	**Upper**	
Age (years), Mean ± SD	1.02	1.01	1.04	**0.001**	1.00	0.99	1.01	0.448	1.01	1.00	1.03	0.058
Sex, n (%)												
Female												
Male	1.82	1.06	3.26	**0.035**	1.54	1.06	2.24	**0.023**	1.22	0.73	2.08	0.460
Admission Glasgow Coma Scale, Mean ± SD	0.78	0.66	0.91	**0.002**	0.85	0.74	0.96	**0.009**	0.95	0.82	1.11	0.535
Hypotension												
No												
Yes	2.59	1.41	4.69	**0.002**	2.18	1.15	4.43	**0.023**	1.39	0.72	2.56	0.314
Marshall Classification, n (%)												
Class I												
Class II	2.77	0.66	18.8	0.209	1.45	0.83	2.55	0.192	1.21	0.39	4.19	0.743
Class III	2.41	0.51	17.5	0.309	1.23	0.64	2.34	0.532	2.19	0.68	7.77	0.199
Class IV	2.97	0.60	22.4	0.219	2.01	0.96	4.22	0.064	3.01	0.87	11.6	0.091
Class V	6.65	1.33	51.1	**0.035**	2.99	1.27	7.18	**0.013**	3.22	0.86	13.3	0.092
Class VI	7.64	1.43	61.0	**0.028**	3.30	1.20	9.60	**0.024**	5.24	1.31	23.0	**0.022**
MRI Hemorrhagic Lesion, n (%)												
Absent												
Present	1.18	0.44	3.37	0.752	1.65	0.94	2.92	0.084	0.97	0.40	2.43	0.953

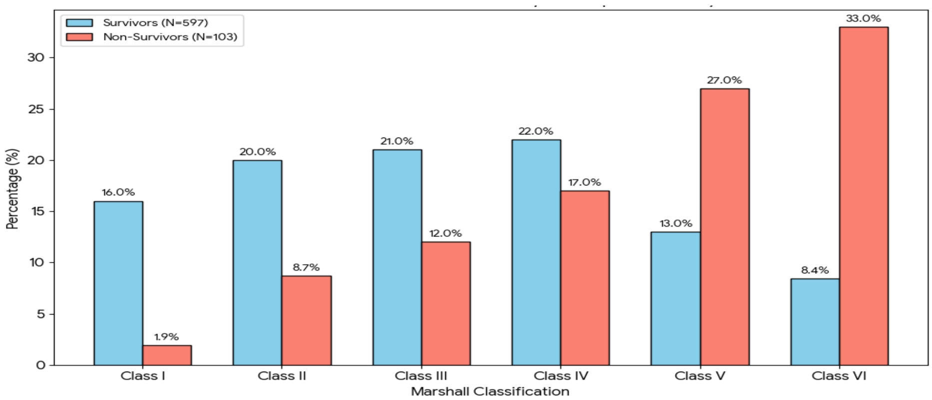

Figure 1: Distribution of Marshall Classification Categories Stratified by In-Hospital Mortality Status ($p < 0.001$).

DISCUSSION

Our study, which included 700 patients with moderate and severe traumatic brain injury, showed a strong association of hemorrhagic lesions on MRI with injury severity and clinical outcomes, although this association was lost after adjusting for other variables, whereas CT-based Marshall classification showed a consistent and strong prognostic association for all clinical outcomes.

The association of MRI hemorrhagic lesions with severe traumatic brain injury, increased mortality, and increased interventions is in line with the previously published literature, which has shown a higher sensitivity of MRI in detecting hemorrhagic lesions and diffuse axonal injury, which are often not detectable on CT scans.[9,11] The literature has shown that MRI lesion burden has a positive association with poor outcomes and neurological impairment.[12,13,20], especially in patients with injury to critical structures such as the brainstem.[19] Despite this, MRI appears to be a marker of injury severity rather than having prognostic value, as shown in this study, which is in line with the previously published literature, which has shown that the prognostic value of MRI may not be significant after adjusting for clinical variables.[6-8]

In contrast, the Marshall classification system remained a powerful predictor of mortality, ICU admission, and neurosurgical intervention. Advanced Marshall classification systems, such as Marshall V and VI, were independently associated with poorer outcomes, supporting the original classification system[1] and the validation in large prognostic models such as IMPACT and CRASH.[2,5]

Moreover, previously established clinical predictors, such as older age, hypotension, and lower GCS, were independently associated with poorer outcomes, consistent with previous studies.[3,5] Hypotension is a well-recognized contributor to secondary brain injury and poorer outcomes.

Although MRI did not independently predict outcome in this study, it has a complementary role, especially in detecting subtle injury, which is associated with long-term cognitive impairment.[10,11] Recent large-scale studies, including CENTER-TBI, suggest the use of multimodal imaging in improving prognostic accuracy.[16-18]

This study has a number of limitations, including its retrospective nature, which may be subject to selection bias, and the lack of long-term outcome measures, as well as the timing of MRI and reliance on radiology reports.

CONCLUSION

MRI-detected hemorrhagic lesions correlate with the severity of TBI and poor outcome, although they are not independent predictors of outcome after adjusting for clinical and CT-based variables. The Marshall classification of CT scans remains a reliable prognostic tool in the early management of patients with TBI, and MRI has a supplementary role in the assessment of patients with TBI.

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