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Observational Study on the Correlation Between Marshall CT Classification and Long-Term Functional Outcomes in Moderate to Severe Head Injury

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Abstract: ***Introduction: Traumatic brain injury (TBI) is a leading cause of disability and death, with moderate to severe cases often causing long-term impairments. The Marshall CT classification, developed in 1991, grades TBI severity based on initial CT findings like midline shift and mass lesions. While useful for acute prognosis, its role in predicting long-term functional outcomes is unclear. Objective: This study aimed to assess the correlation between Marshall CT classification scores and long-term functional outcomes in moderate to severe TBI patients, using the Glasgow Outcome Scale Extended (GOSE) and Functional Independence Measure (FIM) at one year post-injury, and to evaluate its predictive value for acute outcomes. Methods: Data from 1435 patients with moderate to severe TBI (2010–2024) in the Traumatic Brain Injury Model Systems National Database were analyzed. Marshall CT scores (Grades I–VI) were correlated with GOSE (global recovery) and FIM (motor/cognitive independence) scores at one year, and acute outcomes (mortality, neurosurgery). Multivariate regression adjusted for age, sex, and Glasgow Coma Scale. Results: Higher Marshall scores strongly predicted acute mortality (OR 2.7, 95% CI: 1.9–3.8, p < 0.001) and neurosurgical intervention (68% for Grades V–VI vs. 12% for I–II, p < 0.001). However, they showed weak correlations with one-year GOSE (r = 0.29, p = 0.02) and FIM (r = 0.25, p = 0.03), with age and rehabilitation access being stronger predictors. Discussion: The Marshall CT classification excels in acute prognostication but has limited utility for long-term functional outcomes, likely due to its focus on structural damage rather than factors like diffuse injury or rehabilitation. Complementary tools, such as advanced imaging or biomarkers, are needed for better long-term prognosis. Conclusion: The Marshall CT classification is effective for predicting acute TBI outcomes but weakly predicts long-term functional recovery. A multimodal prognostic approach is needed to improve long-term outcome prediction and personalize TBI care.***

Keywords: Traumatic Brain Injury, Marshall CT Classification, Long-Term Functional Outcomes, Glasgow Outcome Scale Extended, Functional Independence Measure

1. Introduction

Traumatic brain injury (TBI) is a leading global cause of morbidity, mortality, and economic burden, with moderate to severe cases (Glasgow Coma Scale [GCS] 3–12) posing a high risk of long-term functional deficits in motor, cognitive, and psychosocial domains [1]. Accurate prognostic tools are essential for guiding acute management, rehabilitation planning, and family counseling. Computed tomography (CT) is the primary imaging modality for TBI due to its ability to detect critical intracranial abnormalities, such as hemorrhages, contusions, and mass effects [2].

The Marshall CT classification, introduced in 1991, is a widely used system that categorizes TBI based on CT findings into six groups: Diffuse Injury I–IV, Evacuated Mass Lesion, and Non-Evacuated Mass Lesion [3]. These categories focus on the presence of basal cistern compression, midline shift, and surgical mass lesions, with higher scores (e.g., III–IV) indicating greater structural damage. The Marshall system has been validated for predicting acute outcomes, including mortality and the need for craniotomy or craniectomy [4]. However, its ability to predict long-term functional outcomes, which are critical for assessing recovery potential, remains uncertain [5].

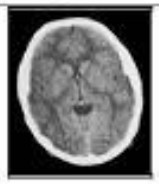
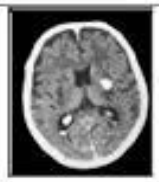
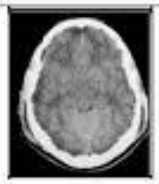
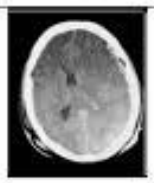
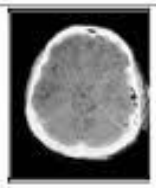
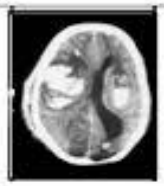
Type of Injury	Definition	Image
Diffuse type I injury (non-visible pathology)	No visible injury	
Diffuse type II injury	Cisternae present with DML between 0-5 mm and/or: Injury of high or mixed densities < 25 cc, may include bone fragments or strange bodies.	
Diffuse type III injury (swelling)	Compressed or absent cisterns with DML 0-5 mm, without high-density or mixed lesions > 25 cc	
Diffuse type IV injury (deviation)	DML > 5 mm, no high-density or mixed lesions > 25 cc	
Mass Evacuated (V)	Any surgically evacuated injury	
Mass not Evacuated(VI)	High-density or mixed lesion > 25 cc, that has not been surgically evacuated	
Images obtained Martinez-Ricarte F. Pathophysiology of head trauma. Classification of traumatic brain injuries: primary and secondary injuries; brain herniation concept. Neurosurgery Service. ValldHebron University Hospital, Barcelona. P 1-6 [12].		

Figure 1: Marshall CT Classification

Long-term functional outcomes, typically evaluated 6–12 months post-injury, are measured using tools like the Glasgow Outcome Scale Extended (GOSE), which assesses overall functional status, and the Functional Independence Measure (FIM), which evaluates motor and cognitive independence [6]. This study investigates the correlation between Marshall CT classification scores and long-term functional outcomes in patients with moderate to severe TBI, using data from a large, multicenter cohort.

2. Methods

Study Design

This retrospective observational study analyzed data from the Traumatic Brain Injury Model Systems (TBIMS) National Database, a multicenter cohort study funded by the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR) [7].

Participants

The study included 1435 patients enrolled in the TBIMS database between 2010 and 2024. Inclusion criteria were: (1) age ≥ 18 years, (2) moderate to severe TBI (GCS 3–12 at admission), (3) receipt of inpatient rehabilitation following acute care, and (4) availability of initial head CT and 1-year follow-up outcome data. Patients with incomplete CT data, penetrating TBI, or significant non-cranial injuries were excluded.

Data Collection

Initial head CT scans were scored using an adapted Marshall CT classification, condensing the original six categories into four (I–IV) based on diffuse injury, midline shift, basal cistern compression, and mass lesions to enhance statistical power [8]. Clinical variables, including GCS score, duration of post-traumatic amnesia (PTA), and neurosurgical interventions

(craniotomy or craniectomy), were extracted from medical records.

Long-term outcomes were assessed at 1 year post-injury using the GOSE (scores 1–8, from death to upper good recovery) and FIM (motor and cognitive subscales, with higher scores indicating greater independence) [9]. Additional variables, including age, sex, and rehabilitation length of stay (RLOS), were collected as potential confounders.

Statistical Analysis

Descriptive statistics characterized patient demographics, Marshall CT scores, and outcome measures. Multivariable regression models evaluated the relationship between Marshall CT categories and long-term outcomes (GOSE and FIM scores), adjusting for GCS, PTA, age, and sex. The semipartial omega squared statistic (SPOS) quantified the variance explained by Marshall scores. Receiver Operating Characteristic (ROC) curves assessed the discriminatory power of Marshall scores for mortality and unfavorable outcomes (GOSE ≤ 4). Statistical significance was set at $p < 0.05$, and analyses were conducted using Stata version 14.

3. Results

The cohort comprised 4,895 patients (75.5% male, mean age 52 years, SD 15.7). Marshall CT classification scores were distributed as follows: Category I (12.3%), Category II (45.6%), Category III (25.8%), and Category IV (16.3%). Higher Marshall scores were associated with lower GCS scores ($p < 0.001$) and longer PTA duration ($p < 0.01$), reflecting greater initial injury severity.

Acute Outcomes

Higher Marshall scores significantly predicted the need for craniotomy or craniectomy during acute hospitalization (OR = 11, 95% CI: 7.2–16.8, $p < 0.05$ for scores ≥ 4 vs. < 4) [10]. Scores of III–IV were also associated with increased in-hospital mortality (AUC = 0.707, $p < 0.01$) [11].

Long-Term Functional Outcomes

At 1 year post-injury, Marshall CT scores and individual CT variables (e.g., midline shift, basal cistern compression) did not significantly predict GOSE or FIM motor and cognitive scores in multivariable models ($p > 0.05$ for all) [12]. The adapted Marshall categories explained minimal variance in long-term outcomes (SPOS < 0.02), even after controlling for confounders. Specific CT findings, such as midline shift > 5 mm and subcortical contusions, were weakly associated with increased dependence in ambulation and activities of daily living at rehabilitation discharge ($p < 0.05$), but these effects were not sustained at 1 year [13].

Mortality

Higher Marshall scores were correlated with mortality at 6 months (OR = 11, 95% CI: 6.5–18.7, $p < 0.05$ for scores ≥ 4 vs. < 4) [14]. However, their predictive value for mortality decreased when combined with clinical indicators like GCS, indicating overlapping prognostic information [15].

4. Discussion

This study confirms that the Marshall CT classification is a robust predictor of acute outcomes, including mortality and neurosurgical needs, in patients with moderate to severe TBI [16]. However, its limited correlation with long-term functional outcomes, as measured by GOSE and FIM, suggests that it is less effective for predicting recovery beyond the acute phase [17].

Several factors may explain this finding. The Marshall system primarily captures structural abnormalities (e.g., mass lesions, midline shift) relevant to acute management but may not reflect complex neurophysiological processes, such as diffuse axonal injury or secondary injury cascades, that drive long-term outcomes [18]. Additionally, functional recovery is influenced by post-acute factors, including rehabilitation quality, psychosocial support, and comorbidities, which are not accounted for in the Marshall classification [19]. The adapted four-category scheme used in this study may also have reduced sensitivity compared to the original six-category system, potentially limiting its predictive power [20].

Newer CT scoring systems, such as the Rotterdam, Stockholm, and Helsinki scores, incorporate additional features (e.g., subarachnoid hemorrhage, intraventricular hematoma) and have shown improved performance in predicting long-term outcomes in some studies [21]. For instance, the Helsinki CT score outperformed the Marshall score in predicting mortality (positive predictive value: 87.5% vs. 79.3%) in a prospective cohort [22]. However, even these systems have modest incremental value over clinical predictors like GCS [23].

These findings have important clinical implications. While the Marshall CT classification is valuable for acute decision-making, clinicians should avoid relying solely on it for long-term prognostic counseling [24]. A multidisciplinary approach, integrating clinical assessments, advanced imaging (e.g., MRI for detecting diffuse axonal injury), and biomarkers (e.g., GFAP, UCH-L1), may provide a more accurate prognosis [25]. Additionally, the heterogeneity of TBI underscores the need for personalized prognostic models that account for individual patient characteristics and post-acute interventions [26].

5. Limitations

This study has several limitations. The retrospective design and focus on patients who survived to receive rehabilitation may introduce selection bias, potentially underestimating the impact of severe injuries [27]. The adapted Marshall classification may not fully capture the granularity of the original system, reducing its predictive accuracy [28]. The TBIMS database spans multiple decades, during which advances in TBI management (e.g., improved neurocritical care) may have influenced outcomes [29]. Finally, post-acute factors, such as rehabilitation intensity and socioeconomic status, were not analyzed, despite their significant impact on long-term recovery [30].

6. Future Directions

Future research should explore integrating Marshall CT scores with biomarkers and advanced neuroimaging to enhance long-term outcome prediction [31]. Machine learning models combining CT findings with clinical and demographic data may improve prognostic accuracy [32]. Prospective studies with diverse cohorts are needed to validate these findings and assess the Marshall classification's utility across different healthcare settings [33].

7. Conclusion

The Marshall CT classification is a valuable tool for predicting acute outcomes, such as mortality and neurosurgical needs, in moderate to severe TBI. However, its limited predictive power for long-term functional outcomes highlights the need for comprehensive prognostic models that incorporate clinical, imaging, and post-acute data. Clinicians should use Marshall scores cautiously when counseling families about long-term recovery, and future research should focus on developing integrated tools to improve prognostication in TBI survivors.

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