Clinical and Experimental
Health Sciences

Computerized Tomography-Based Scoring Systems (Marshall and Rotterdam Score) versus Physiological Scoring Systems (GCS and APACHE II Score) in Predicting Mortality in Traumatic Brain Injury

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Received: March 23, 2024 **Accepted:** March 6,2025

ABSTRACT

Objective: Since traumatic brain injury (TBI) has high mortality rates, it is essential to identify patients with poor prognosis. In this study, the mortality prediction performances of the Glasgow Coma Scale (GCS), Acute Physiology and Chronic Health Assessment-II (APACHE-II), Marshall, and Rotterdam scores were compared in patients with TBI in the intensive care unit (ICU) of a tertiary center.

Methods: Patients followed up in the ICU due to moderate to severe TBI between January 2020 and January 2022 were retrospectively reviewed. Patients were classified as survivor and nonsurvivor groups. The patient's clinical characteristics and the scoring systems' performance in predicting 28-day mortality were investigated.

Results: A total of 150 patients were included in the study, and 82.4% (n=98) were male. GCS scores were significantly lower in the nonsurvivor group, while APACHE-II, Marshall, and Rotterdam scores were significantly higher ($p < .001$ for all). GCS, APACHE-II, and Rotterdam scores were independent predictors of mortality ($p = .002$, $p = .012$, and $p = .003$, respectively). Receiver operating characteristics curve analysis revealed that GCS cut-off value was ≥6.5, area under the curve (AUC)=0.851, APACHE-II cut-off value was ≥ 21.5, AUC=0.866, Marshall cut-off value was ≥ 3.5, AUC=0.827 and Rotterdam cut-off value was ≥ 3.5, AUC=0.864.

Conclusion: GCS, APACHE-II, Marshall, and Rotterdam scores are valid in predicting mortality in patients with TBI. Their performance in predicting mortality is ranked from highest to lowest as APACHE-II, Rotterdam, GCS, and Marshall.

Keywords: Acute Physiology and Chronic Health Evaluation-II (APACHE-II); Glasgow Coma Scale; in-hospital mortality; scoring system; traumatic brain injury.

1. INTRODUCTION

Traumatic brain injury (TBI) is defined as a disruption in the normal function of the brain due to a blow to the head or a penetrating head injury. It is also called the ''silent epidemic'' due to the increase in its incidence worldwide. Its annual incidence has been reported to be between 27 and 69 million (1). TBI has become a critical health problem that causes economic loss for both the affected individual and society, as well as being a significant cause of morbidity and mortality (2). Early diagnosis and classification in the acute phase of severe TBI cases are essential for better management and predicting outcomes.

TBI is classified as mild (GCS=13-15), moderate (GCS=9-12), and severe (GCS=3-8) using the Glasgow Coma Scale (GCS), a physiological scoring system frequently used in the intensive care unit (ICU) (3). It has been reported that the reliability and accuracy of GCS may be low because the assessment of verbal and motor responses may not be optimal in patients with severe TBI who are orotracheal intubated or under the influence of sedative drugs (4). Another physiological scoring system, Acute Physiology and Chronic Health Assessment-II (APACHE-II) is also used in the ICU for mortality prediction in trauma patients and non-trauma patients (5-8). Another option for early and objective assessment of TBI severity is a morphological classification based on computed tomography (CT) scans, which is the preferred method due to rapid image acquisition. Marshall and Rotterdam scores, which are CT-based scoring systems, have also been reported to help predict mortality in patients with TBI (9-10).

ISSN:2459-1459
https://doi.org/10.33808/clinexphealthsci.1457777

Although the mortality prediction performances of physiological scoring systems and CT-based scoring systems in patients with TBI are compared in the literature, there is no consensus on their superiority. This study aims to compare the prognostic values of GCS, APACHE-II, Marshall, and Rotterdam scores in predicting mortality in patients with TBI who are followed in the ICU of a tertiary center.

2. METHODS

This retrospective observational study was started after the approval of the Istanbul Kanuni Sultan Süleyman Training and Research Hospital Clinical Trials Review Board and Ethics Committee (date: 11.11.2023, KAEK/2023.10.142). The study was conducted following the principles of the Declaration of Helsinki. The data of TBI patients who were followed up and treated in the two years between January 2020 and January 2022 at the ICU of the University of Health Sciences Türkiye, Istanbul Kanuni Sultan Süleyman Training and Research Hospital, were scanned from hospital records and patient files and included in the study.

Inclusion criteria are as follows: (1) age ≥18 years; (2) isolated head trauma; (3) admitted to ICU within 24 hours after trauma; (4) abbreviated injury score (AIS) ≥ 3; (5) patients with moderate to severe TBI (GCS<13). Exclusion criteria included: (1) performing cardiopulmonary resuscitation within the first 24 hours after trauma; (2) staying in the ICU for less than 24 hours or death of the patient within the first 24 hours; (3) absence of brain tomography imaging; (4) COVID-19 suspected or positive; (5) missing data.

Demographic data, primary diagnoses, trauma type and etiology, operation status, ICU, mechanical ventilator (Mv) and hospital stay, discharge location, GCS and APACHE-II, Marshall and Rotterdam scores at ICU admission, and 28-day mortality of the patients were obtained from the hospital information system and patient files. The diagnoses of all patients with moderate to severe TBI were based on their histories and cranial tomography findings performed in the emergency department. The same radiologist calculated Marshall and Rotterdam scores by examining the cranial tomography.

2.1 Physiological Scoring Systems in TBI

GCS was defined in 1974 to determine the severity of trauma. It is frequently used as a significant predictor of prognosis in patients with head trauma. It is a popular, simple, reliable, and repeatable method for assessing trauma patients' consciousness levels. GCS scores range between 3 and 15 points, depending on patients' eye opening, verbal responses, and motor movements. Low scores indicate poor prognosis (11). The APACHE-II score evaluates 12 physiological parameters, as well as the patient's age and previous health status. The highest score is 71; high scores indicate poor prognosis (12). APACHE-II is not a trauma-specific scoring system like GCS. Only GCS is evaluated for trauma patients. However, it has been stated that APACHE-II is superior to GCS in trauma patients due to the evaluation of increasing age and chronic health problems.

2.2 Radiological Scoring Systems in TBI

Cranial CT scanning, the preferred method in the acute evaluation after severe TBI, objectively assesses structural damage. Its objectivity provides diagnostic information for operative intervention decisions and objective prognosis data. The Marshall and Rotterdam classifications, the two most common radiographic TBI classifications, are strongly associated with outcome. The Marshal and Rotterdam scoring systems, which score between 1 and 6 points based on cranial tomography findings, further underscore the objectivity of this diagnostic tool. The three main findings evaluated in the Marshall score are the status and amount of midline shift, the status of the basal cisternae, and high or mixed-density lesions, which depend on the lesion volume. In the Rotterdam score, in addition to the condition of the basal cisterns, the presence and amount of midline shift, as in the Marshal score, epidural mass lesion, intraventricular hemorrhage, or traumatic subarachnoid hemorrhage are evaluated (13-15).

The study's primary outcome was 28-day mortality in patients with moderate to severe TBI. It compared the mortality prediction performance of physiologic scoring systems (GCS and APACHE II score) and CT-based scoring systems (Marshal and Rotterdam score) at ICU admission. In this context, G* Power 3.1 program was used to determine the sample size. For t-tests, when $p < .05$, effect size = 0.5, and the power of the study was determined as 80%, it was calculated that 140 patients should be included in the study.

2.3. Statistical analysis

Statistical analysis was performed using the SPSS 25.0 (SPSS Inc., Chicago, USA) program. Data were expressed as number of patients, percentage, median (range), mean, and standard deviation. The normality of the data was evaluated with the Shapiro-Wilks test and histogram. Mann-Whitney U test was used to evaluate quantitative data that did not show normal distribution. Qualitative data were analyzed using Chi-square and Fisher exact tests. Multivariate regression analysis was used to determine whether GCS, APACHE-II, Marshal and Rotterdam score differed significantly between the groups and were independent predictors of mortality. Receiver operating characteristics (ROC) curve analysis was performed to determine the prognostic value of GCS, APACHE-II, Marshall and Rotterdam scores. Youden index (sensitivity+specificity-1) was used to determine the cut-off values in ROC analysis. The significance level was accepted as $p < .05$.

3. RESULTS

The study included 150 TBI patients who were followed up and treated in the ICU (Figure 1). The majority of the patients were male (81.6% n=124). No significant difference was observed between the groups in terms of gender (p = .640). The mean age was significantly higher in the nonsurvivor group (55.1±23.7 vs. 44.5±20.2 years, p = .024). Blunt trauma was detected in 97.4% of the patients (n=148), and 55.3% (n=84) underwent surgery. The surgical status did not affect mortality (p = .274). The mean GCS score was significantly lower in the nonsurvivor group (4.2±1.9 vs. 8.7±3.3, p < .001), while APACHE-II (29.7±6.9 vs.18.4±7.9, p < .001), Marshall (4.7±1.0 vs. 2.8±1.3, p < .001) and Rotterdam (4.4±1.1 vs. 2.5±1.2, p < .001) scores were significantly higher. The revised trauma score was significantly lower in the nonsurvivor group (1.2±0.4 vs. 2.5±0.7, p < .001). Percutaneous tracheostomy was performed in the ICU for 10.5% of the total population (n=15). The tracheostomy procedure did not differ significantly between the groups (p = .096). In the nonsurvivor group, ICU and mechanical ventilation length of stay were significantly lower (p < .001 for both). However, hospital length of stay did not differ significantly between the groups (18.8±18.9 vs. 17.8±8.8 days, p =.187). After their treatment, patients were discharged to the ward (69.1%), palliative care (3.9%), external center (3.3%), and home (2%) in order of frequency. Brain death was diagnosed in 1.3% (n=2) of the entire population. The 28-day mortality rate was 20.7% (n=31) (Table 1).

When Marshall and Rotterdam CT scores were examined, Marshall class 2 (42.1%) and Rotterdam class 2 (34.9%) were detected most frequently in the entire population. Marshall class 5 (64.5%) and Rotterdam class 4 (29%) were observed most frequently in the nonsurvivor group (Table 2).

When trauma etiologies were evaluated, falls from the same level or heights (44.7%, n=68) and traffic accidents (38.2%, n=58) were the most common causes of TBI (Table 3).

The most common primary diagnoses in patients with TBI were acute subdural hematoma (30.9%, n=47) and subarachnoid hemorrhage (24.3%, n=37). Primary diagnoses did not differ significantly between the groups (p = .276) (Table 4).

Table 1. *Clinical characteristics of patients*

Variable	Overall (n=150)	Survivor (n=119)	Nonsurvivor (n=31)	p-value
Age (years)	46.8±21.4 (18-90)	44.5±20.2 (18-90)	55.1±23.7 (18-89)	**.024**
Gender, n (%)				.640
Female	28 (18.4)	21 (17.6)	7 (21.2)	
Male	124 (81.6)	98 (82.4)	26 (78.8)	
Trauma severity, n (%)				**< .001**
Moderate	68 (44.7)	66 (55.5)	2 (6.1)	
Severe	84 (55.3)	53 (44.5)	31 (93.9)	
Trauma type, n (%)				.206
Blunt	148 (97.4)	117 (98.3)	31 (93.9)	
Penetrating	4 (2.6)	2 (1.7)	2 (6.1)	
RTS score	2.2±0.8 (1-4)	2.5±0.7 (1-4)	1.2 ±0.4 (1-2)	**< .001**
GCS score	7.7 ±3.5 (3-12)	8.7 ±3.3 (3-12)	4.2 ±1.9 (3-10)	**< .001**
APACHE-II: score	20.8 ±9.0 (6-52)	18.4 ±7.9 (6-45)	29.7 ±6.9 (15-52)	**< .001**
Marshall score	3.2 ±1.5 (1-6)	2.8 ±1.3 (1-6)	4.7 ±1.0 (2-6)	**< .001**
Rotterdam score	2.9 ±1.4 (1-6)	2.5 ±1.2 (1-6)	4.4 ±1.1 (2-6)	**< .001**
Neurosurgery, n (%)	84 (55.3)	63 (52.9)	21 (63.6)	.274
Tracheostomy, n (%)	15 (10.5)	9 (7.6)	6 (18.2)	.096
Duration of ICU (days)	11.3±13 (2-95)	9.3±9.9 (2-60)	18.8±18.9 (2-95)	**< .001**
Duration of Mv (days)	6.5±11.2 (0-75)	3.6±8.1 (0-50)	16.7±14.6 (2-75)	**< .001**
Duration of hospital (days)	18±11.7 (2-95)	17.8±8.8 (4-60)	18.8±18.9 (2-95)	.187
Discharge				-
Ward	105 (69.1)			
Palliative care	6 (3.9)			
Transfer to outer center	5 (3.3)			
Home	3 (2)			
Brain death, n (%)	2 (1.3)			**-**
Mortality (28-day)	31 (20.7)			**-**

Values are expressed as number of patients, percentage, mean ± standard deviation (min-max). RTS: Revised trauma score, GCS: Glasgow Coma Scale, APACHE-II: Acute Physiology and Chronic Health Assessment-II, ICU: Intensive care unit, Mv: Mechanical ventilation

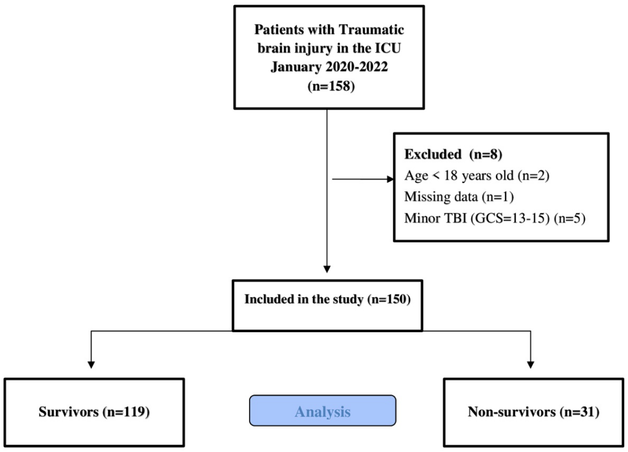

Figure 1. *Flow chart of the study*

Table 2. *Marshall and Rotterdam scores by groups*

Variable	Overall (n=150)	Survivor (n=119)	Nonsurvivor (n=31)
Marshall CT score			
I	10 (6.6)	10 (8.4)	0
II	64 (42.1)	62 (52.1)	2 (6.4)
III	14 (9.2)	11 (9.2)	3 (9.6)
IV	10 (6.6)	7 (5.8)	3 (9.6)
V	48 (31.6)	28 (23.5)	20 (64.5)
V	6 (3.9)	1 (0.8)	5 (16.1)
Rotterdam CT score			
I	21 (13.8)	21 (17.6)	0
II	53 (34.9)	51 (42.8)	2 (6.4)
III	31 (20.4)	27 (22.6)	4 (12.9)
IV	15 (9.9)	6 (5)	9 (29)
V	24 (15.8)	12 (10)	12 (3.9)
V	8 (5.3)	2 (1.6)	6 (19.3)

Values are expressed as the number of patients and percentage.

Table 3. *Trauma etiologies of patients with traumatic brain injury*

	Overall (n=150)	Survivor (n=119)	Nonsurvivor (n=31)
Falls	68 (44.7)	44 (37)	24 (72.7)
Traffic accidents	58 (38.2)	51 (42.9)	7 (21.2)
Fight/Battering	16 (10.5)	16 (13.4)	0
Work accidents, crush	6 (3.9)	6 (3.9)	0
Gunshot wounds/explosions	4 (2.6)	2 (1.7)	2 (6.1)

Values are expressed as the number of patients and percentage.

In multivariate regression analysis, GCS, APACHE-II, and Rotterdam scores were independent predictors of mortality ($p = .002$, $p = .012$, and $p = .003$, respectively) (Table 5).

In the ROC analysis of the prognostic values of the scoring systems in mortality prediction, the cut-off value for the GCS score was 6.5, and the area under the curve (AUC)=0.851 (95%CI, 0.788-0.914). The cut-off value for the APACHE-II score was 21.5, and the AUC=0.866 (0.806-0.926). The cut-off value for the Marshall score was 3.5, and the AUC=0.827 (0.755-0.899). The cut-off value for the Rotterdam score was 3.5, and the AUC=0.864 (0.799-0.929) (Table 6).

Table 4. *Primary diagnoses in traumatic brain injuries*

	Overall (n=150)	Survivor (n=119)	Nonsurvivor (n=31)	p-value
Primary diagnosis				.276
Acute subdural hematoma	47 (30.9)	34 (28.6)	13 (27.7)	
Subarachnoid hemorrhage	37 (24.3)	27 (22.7)	10 (30.3)	
Epidural hematoma	30 (19.7)	26 (21.8)	4 (12.1)	
İntraserebral hematoma	19 (12.5)	14 (11.8)	5 (15.2)	
Contusio cerebri	11 (7.2)	10 (8.4)	1 (3)	
Brain edema	8 (5.3)	8 (6.7)	0	

Values are expressed as the number of patients and percentage.

Table 5. *The multivariate logistic regression analysis results*

Variables	Odds Ratio	95% CI (min-max)	p-value
GCS score	1.475	1.154-1.885	**.002**
APACHE-II score	0.901	0.830-0.977	**.012**
Marshall score	0.669	0.386-1.160	.152
Rotterdam score	0.447	0.265-0.755	**.003**
Constant	388.6		.001

CI: Confidence interval (minimum-maximum), GCS: Glasgow Coma Scale, APACHE-II: Acute Physiology and Chronic Health Assessment-II

Table 6. *Prognostic performance of GCS, APACHE-II, Marshall and Rotterdam score for predicting mortality*

	Cut-off	Sensitivity	Specificity	AUC (95% CI)
GCS	6.5	0.909	0.731	0.851 (0.788-0.914)
APACHE-II	21.5	0.970	0.672	0.866 (0.806-0.926)
Marshall	3.5	0.848	0.697	0.827 (0.755-0.899)
Rotterdam	3.5	0.818	0.832	0.864 (0.799-0.929)

AUC: Area under curve, CI: Confidence interval (minimum-maximum), GCS: Glasgow coma scale, APACHE-II: Acute Physiology and Chronic Health Assessment-II

4. DISCUSSION

In this study, the values of physiological scoring systems and CT-based scoring systems in predicting mortality in patients with TBI followed in the ICU were investigated. It was determined that GCS, APACHE-II, Marshall, and Rotterdam scores helped predict mortality. In addition, GCS, APACHE-II, and Rotterdam scores were independent predictors of mortality. In the ROC analysis of the scores' prognostic values, the areas under the curve were close to each other and ranked from largest to smallest as APACHE-II (0.866), Rotterdam (0.864), GCS (0.851), and Marshall (0.827).

TBI affects people of all ages and genders in both developed and developing countries and is the leading cause of death and disability (16). Mortality rates as high as 30-40% have been reported in patients with severe TBI (17, 18). Gursoy et al. (19) from Turkiye reported that 57% of patients with

TBI were male, the mean age was 47±17 years, and the most common diagnoses were subarachnoid hemorrhage and subdural hematoma. The authors reported that the mortality rate was 34.6%. Goswami et al. (10) from India reported that 85% of patients with TBI were male and that gender did not have a significant effect on mortality. The authors reported that severe TBI was detected in 65% of patients, traffic accidents were the cause in 84% of patients, and the mortality rate was 32.3%. In our study, in line with the literature, the mean age in the entire population was 46±21 years, and 82.4% of the patients were male. Although the mean age was significantly higher in the nonsurvivor group, gender did not significantly affect mortality. The most common causes of TBI were falls (44.7%) and traffic accidents (38.2%). The most common primary diagnoses were acute subdural hematoma (30.9%) and subarachnoid hemorrhage (24.3%). Our 28-day mortality rate was found to be 20.7%. Our mortality rate, being lower than Gürsoy (19) and Goswami (10), may be affected by many parameters, such as the type of trauma, the presence of accompanying polytrauma, and the status of the operation, as well as the lower rate of serious TBI (55%) detected in our study. Although operations are frequently performed in TBI, it has been reported that the mortality of patients who undergo surgical procedures increases compared to patients who receive conservative treatment (20). In our study, although the rate of neurosurgery was high in the nonsurvivor group, no significant difference was observed (63% vs. 52%, p = .274). Intracranial hemorrhages and other traumatic brain injuries are the most important causes of brain death (21). In the current study, brain death was detected in 1.3% of the patients (n=2). We believe that early diagnosis and prediction of prognosis in patients with TBI are also crucial for organ transplantation.

Accurate and reliable scores are essential in assessing disease severity, predicting prognosis, and managing healthcare resources in critically ill TBI patients. Physiological scoring systems such as GCS and APACHE-II are frequently used in ICUs (5,11,12). Dalgiç et al. (20) reported that APACHE-II and GCS scores have sufficient sensitivity and specificity in predicting mortality in patients with head trauma accompanied by systemic trauma and that the APACHE-II (AUC=0.94) score is superior to GCS (0.87) in predicting mortality. Nik et al. (22) reported no significant difference between GCS and APACHE-II scores in predicting mortality in ICU patients with TBI. The authors stated that both scores had acceptable positive predictive value, but the APACHE-II (AUC=0.83) score performed better than the GCS (AUC=0.81). Gürsoy et al. (19) investigated the prognostic value of APACHE-II and INCNS (Infection, Nutrition, Consciousness, Neurological function, Systemic Condition) scores in patients with TBI. The authors reported that INCNS and APACHE-II scores had good prognostic performance, and the INCNS score was superior to APACHE-II in predicting TBI mortality. In our study, in line with the literature, the APACHE-II score was more successful in predicting mortality than GCS in patients with TBI (AUC=0.866 vs. 0.851). However, both GCS and APACHE-II scores were independent predictors of mortality. We believe that the APACHE-II score is superior to the GCS in predicting mortality because many factors can affect the GCS (use of sedatives and neuromuscular drugs, inability to assess verbal responses due to endotracheal intubation), and the 12 parameters evaluated in the APACHE-II score, as well as age and chronic health status, are effective.

In patients with head trauma, computed tomography provides a rapid and practical assessment of TBI severity using morphological characterization and diagnosis. For this purpose, CT-based scoring systems developed by Marshall (1995) and Rotterdam (2005) allow early prediction of clinical outcomes and prognosis in TBI patients (21). These CT-based scoring systems are repeatable, show minimal variability between evaluators, and are easy to use. Goswami et al. (10) reported that the Rotterdam and Marshall scores at the time of initial presentation of patients with TBI were significantly higher in the mortality group. The authors stated that the cut-off value of the Rotterdam score was >4, and the AUC was 0.827, and the cut-off value of the Marshall score was >3, and the AUC was 0.833. Asim et al. (23) stated that both scoring systems were independent predictors of mortality in patients with TBI. The authors stated that the Rotterdam score was superior to the Marshall score in predicting mortality. In another study, it was reported that both the Rotterdam and Marshall scores helped predict mortality in patients with TBI, and the AUC value was determined to be 0.85 (24). In our study, both scores were significantly higher in the mortality group, which aligns with the literature. However, while the Rotterdam score was an independent predictor of mortality, the Marshall score was not. While the cut-off value for both the Marshall and Rotterdam scores was determined as 3.5, the Rotterdam score was superior in predicting mortality (0.864 vs. 0.827). We compared the performance of physiologically based scoring systems and CT-based scoring systems in predicting mortality in patients with TBI, realizing that the literature lacks sufficient data to compare these scoring systems. We found that physiological scoring systems such as GCS and APACHE-II and CT-based scoring systems such as Rotterdam and Marshall scores have similar and acceptable prognostic values in critically ill patients with TBI.

Our study has some limitations. The main limitation is that it is retrospective and single-centered. In addition, Rotterdam and Marshall scores were obtained from cranial CT findings at the time of first admission to the emergency department, and CT findings during patient follow-up were not considered.

5. CONCLUSION

In conclusion, GCS, APACHE-II, Marshall, and Rotterdam scores are scoring systems with high sensitivity and specificity for predicting mortality in patients with TBI in the ICU. When the performances of physiological and CT-based scoring systems in predicting mortality were compared, it was determined that they were ranked as APACHE-II, Rotterdam, GCS, and Marshall, although they were similar. Using physiological and CT-based scores in patients with TBI will be helpful in the early detection of patients with poor prognosis and in planning aggressive treatment.

Acknowledgements: *None.*

Funding: *The author(s) received no financial support for the research.*

Conflicts of interest: *The authors declare that they have no conflict of interest.*

Ethics Committee Approval: *This study was approved by the Ethics Committee of the University of Health Sciences, Istanbul Kanuni Sultan Süleyman Training and Research Hospital Clinical Research Ethics Committee (Approval date: 11.11.2023; Number: KAEK/2023.10.142)*

Peer-review: *Externally peer-reviewed.*

Author Contributions:

Research idea: KA, ÜT

Design of the study: KA, ÜT, ASŞ

Acquisition of data for the study: KA, ÜT

Analysis of data for the study: KA, ÜT

Interpretation of data for the study: KA, ÜT, ASŞ

Drafting the manuscript: KA, ÜT, ASŞ

Revising it critically for important intellectual content: KA, ÜT, ASŞ

Final approval of the version to be published: KA, ÜT, ASŞ

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How to cite this article: Arslan K, Topal Ü, Şahin AS. Computerized Tomography-Based Scoring Systems (Marshall and Rotterdam score) versus Physiological Scoring Systems (GCS and APACHE II score) in Predicting Mortality in Traumatic Brain Injury. Clin Exp Health Sci 2025; 15: 83-89. DOI: 10.33808/clinexphealthsci.1457777