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Original Article

A Retrospective Observation Study: CT Imaging Scoring Systems as Predictors of Mortality in Adults with Traumatic Brain Injury in the Emergency Department of a Tertiary Care Hospital

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Abstract

Background: Traumatic brain injury (TBI) is a major global health challenge, with high rates of morbidity and mortality. Rapid and accurate prognostication in the emergency department is crucial for triage, clinical decision-making, and allocation of resources. Several computed tomography (CT)-based scoring systems have been developed, yet comparative evaluation in Indian tertiary care settings remains limited. ***Objective:*** To assess and compare the prognostic accuracy of five widely used CT-based scoring systems- Rotterdam, Helsinki, Stockholm, Marshall, and Neuroimaging Radiological Interpretation System (NIRIS)- for predicting in-hospital and 30-day mortality among TBI patients. ***Methods:*** This retrospective observational study included 278 adult TBI patients admitted to the emergency department of a tertiary care center in Ahmedabad, India, during 2024. All underwent non-contrast CT within two hours of arrival. Scans were independently reviewed by neuro-radiologists and scored using the five CT-based systems. Mortality outcomes were analyzed at discharge and 30 days post-injury. Diagnostic performance was assessed using sensitivity, specificity, predictive values, and area under the receiver operating characteristic curve (AUC). ***Results:*** The overall 30-day mortality was 15.1% (n=42). Higher scores in all systems correlated with increased mortality ($p<0.001$). The Stockholm score demonstrated the best performance (specificity 91%, AUC 0.89), followed by the Helsinki score (AUC 0.86). Rotterdam and Marshall scores also showed strong discriminatory ability, while NIRIS was moderately predictive. Diffuse axonal injury, cerebral edema, and midline shift were significant imaging predictors of poor outcome. ***Conclusion:*** All five CT-based scoring systems are valid predictors of mortality in TBI patients. The Stockholm and Helsinki scores demonstrated superior prognostic performance and may be incorporated into early emergency department assessment, particularly when combined with clinical variables such as Glasgow Coma Scale. These findings highlight the importance of structured imaging-based scoring for improving early risk stratification and guiding management.

Keywords: ***traumatic brain injury, CT scoring, mortality prediction, Stockholm score, emergency medicine.***

Introduction

Traumatic brain injury (TBI) is one of the leading causes of morbidity and mortality worldwide, with an annual incidence ranging from 150 to 300 per 100,000 individuals [8]. Severe TBI carries a mortality rate as high as 50%, while moderate TBI accounts for approximately 10% mortality [9]. Beyond mortality, many survivors experience significant long-term physical, cognitive, and psychosocial disabilities, making TBI a major public health and socioeconomic burden. Accurate early prognostication is therefore critical to guide clinical decision-making, optimize resource allocation, and support informed discussions with patients' families.

The etiology of TBI commonly includes road traffic accidents, falls, and assaults. Prognosis is influenced by several clinical and radiological factors, including hypoxia, age, intracranial pressure (ICP), and systemic complications such as sepsis or pneumonia [10]. Preventing secondary brain injury, particularly from raised ICP and subsequent herniation, remains a cornerstone of management, as untreated ICP elevation is strongly linked to poor outcomes and mortality [11].

Among clinical predictors, the Glasgow Coma Scale (GCS) continues to be a widely applied tool, with lower scores correlating with higher mortality [12]. However, neuroimaging- especially computed tomography (CT)- has emerged as indispensable in the acute evaluation of TBI, owing to its rapid acquisition, availability, and ability to detect life-threatening lesions. While magnetic resonance imaging (MRI) offers higher sensitivity for subtle injuries, its limited accessibility and longer acquisition times restrict its use in emergency settings [13].

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Several CT-based scoring systems have been developed to provide structured, objective assessment of TBI severity. These include the Marshall Classification, Rotterdam CT score, Helsinki CT score, Stockholm CT score, and the Neuroimaging Radiological Interpretation System (NIRIS). They evaluate key imaging features such as midline shift, basal cistern compression, intracranial hemorrhage, and diffuse axonal injury, thereby quantifying injury severity and aiding mortality prediction [14]. Comparative studies suggest that such structured radiological scores enhance prognostic accuracy beyond clinical variables alone [15].

However, despite their growing adoption internationally, limited research has systematically compared these scoring systems in Indian tertiary care emergency settings. Furthermore, most prior studies have focused on individual scoring systems rather than head-to-head comparisons, leaving uncertainty regarding which systems perform best in specific populations.

Objective: This study aims to evaluate and compare the predictive performance of five major CT-based scoring systems- Marshall, Rotterdam, Helsinki, Stockholm, and NIRIS- in relation to in-hospital and 30-day mortality outcomes among patients presenting with TBI to the emergency department of a tertiary care hospital.

Methods

This retrospective observational study was conducted at the Emergency Department of Sardar Vallabhbhai Patel Institute of Medical Sciences and Research, a tertiary care hospital in Ahmedabad, India. All adult patients (≥18 years) with acute traumatic brain injury (TBI) who presented between 1 January and 31 December 2024 were eligible for inclusion.

Inclusion and Exclusion Criteria

Patients were included if they underwent a non-contrast CT brain scan during their initial emergency evaluation. Exclusion criteria were: (a) patients <18 years, (b) those declared dead on arrival or before undergoing CT, (c) individuals with pre-existing neurological disorders, (d) patients with non-traumatic causes of death, and (e) those who had neurosurgical intervention at an external facility.

Clinical Data Collection

Demographic and clinical parameters recorded included age, sex, mechanism of injury, type of TBI, and Glasgow Coma Scale (GCS) score on admission (mild: 13-15, moderate: 9-12, severe: 3-8) [16]. Data regarding comorbidities, complications (such as sepsis, pneumonia, brain edema, and raised intracranial pressure), associated injuries, neurosurgical procedures, and hospital stay duration were also documented.

Imaging Data

Non-contrast CT scans were performed within two hours of arrival. Scans were independently reviewed by two experienced neuro-radiologists blinded to patient outcomes. Imaging findings included subarachnoid hemorrhage (SAH), epidural hemorrhage (EDH), subdural hemorrhage (SDH), brain contusions, diffuse axonal injury (DAI), midline shift (MLS), cranial fractures, edema, herniation, and parenchymal lacerations. Each patient was scored using five systems:

Marshall CT Classification, Rotterdam CT score [17], Helsinki score, Stockholm score, and NIRIS.

Statistical Analysis

Data were analyzed using SPSS version 16.0 (IBM Corp., Armonk, NY). Continuous variables were summarized with mean, standard deviation, median, and interquartile range, while categorical variables were presented as frequencies and percentages. Group comparisons used the Chi-square test for categorical data and Student's t-test for continuous variables.

Non-parametric tests (e.g., Mann–Whitney U test) were applied where appropriate.

The prognostic accuracy of each CT-based scoring system for predicting in-hospital and 30-day mortality was assessed through sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) and odds ratio. Receiver operating characteristic (ROC) curves were constructed, and discriminative ability was expressed as the area under the curve (AUC) with bootstrapped 95% confidence intervals [18].

Results

1. Clinico-Demographical Data: The average age was 49.53 years, with 192 males and 86 females. however, the Mortality is highest in elderly patients, those with severe GCS (50%), raised ICP, and sepsis. Surgery. Comorbidities and associated injuries were more common among non-survivors.

Table 1: Clinico-demographical data (GCS: Glasgow coma scale, RTA: road traffic accident, ICP – Intracranial Pressure)

Variable	Category	Total Patients (n, %)	Non-survivors (n, %)	Mortality (%)	p-value
Age group	18–30 years	60 (21.6%)	6 (10.0%)	2.6%	0.04
	31–60 years	140 (50.4%)	26 (18.6%)	9.4%	
	>61 years	78 (28.1%)	11 (14.1%)	4.0%	
Sex	Male	192 (69.0%)	32 (16.7%)	11.5%	0.12
	Female	86 (30.9%)	10 (11.6%)	3.6%	
Mechanism of injury	Road traffic accident (RTA)	213 (76.6%)	33 (15.5%)	11.9%	0.035
	Fall from height	36 (12.9%)	6 (16.7%)	2.2%	
	Assault	29 (10.4%)	3 (10.3%)	2.2%	
TBI severity (admission GCS)	Mild (13–15)	167 (60.0%)	8 (4.8%)	2.9%	<0.001
	Moderate (9–12)	50 (18.0%)	20 (40.0%)	7.2%	
	Severe (3–8)	61 (22.0%)	14 (23.0%)	5.0%	
Comorbidities	Present	114 (41.0%)	27 (23.7%)	9.7%	0.006
	Absent	164 (59.0%)	15 (9.1%)	5.4%	
Complications	None	183 (65.8%)	1 (0.5%)	0.4%	<0.001
	Brain edema	28 (10.1%)	14 (50.0%)	5.0%	
	Raised intracranial pressure	8 (2.9%)	6 (75.0%)	2.2%	

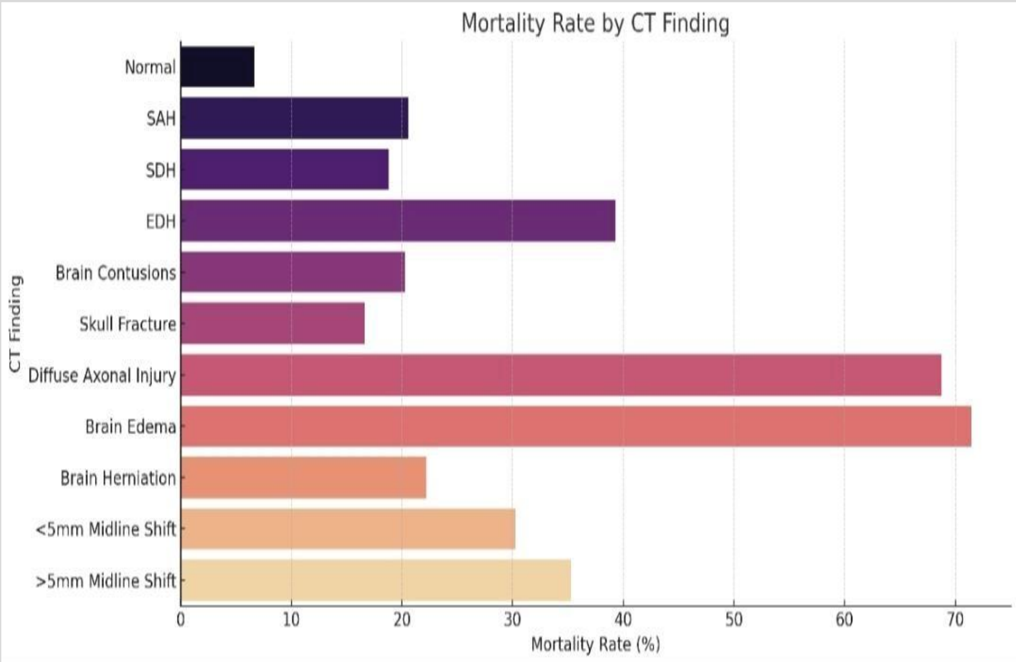
	Aspiration pneumonitis	18 (6.5%)	2 (11.1%)	0.7%	
	Sepsis	27 (9.7%)	14 (51.9%)	5.0%	
	Shock	14 (5.0%)	7 (50.0%)	2.5%	
	Herniation	9 (3.2%)	2 (22.2%)	0.7%	
Associated injuries	Present	94 (33.8%)	25 (26.6%)	9.0%	0.23
	Absent	184 (66.2%)	17 (9.2%)	22.7%	
Surgery performed	Yes	44 (15.8%)	14 (31.8%)	5.0%	0.04
	No	234 (84.2%)	28 (11.8%)	10.0%	

2. Radiological Profile: Normal CT findings strongly correlate with survival ($p = 0.001$) Statistically significant ($p < 0.05$) findings associated with higher mortality in Diffuse Axonal Injury, Brain Herniation, Midline Shift EDH despite being an intracranial bleed. Brain Edema and Diffuse Axonal Injury are strongly associated with increased mortality ($p < 0.001$). Skull fracture and EDH showed trends toward significance but didn't meet the 0.05 threshold due to patients with EDH are operated quickly and hence have less mortality.

Table 2: Radiological data

CT Finding	Total Patients (n, %)	With Complications (n, %)	Non-survivors (n, %)	Mortality (%)
Normal scan	75 (27.0%)	8 (10.7%)	5 (6.7%)	1.8%
Subarachnoid hemorrhage (SAH)	107 (38.5%)	47 (43.9%)	22 (20.6%)	7.9%
Subdural hematoma (SDH)	69 (24.8%)	34 (49.3%)	13 (18.8%)	4.7%
Epidural hematoma (EDH)	28 (10.1%)	19 (67.9%)	11 (39.3%)	6.8%
Brain contusions	69 (24.8%)	35 (50.7%)	14 (20.3%)	5.0%
Skull fractures	108 (38.8%)	45 (40.7%)	18 (16.7%)	6.5%
Diffuse axonal injury (DAI)	16 (5.8%)	13 (81.3%)	11 (68.8%)	4.0%
Brain edema	28 (10.1%)	8 (28.6%)	20 (71.4%)	7.2%
Brain herniation	9 (3.2%)	4 (44.4%)	2 (22.2%)	0.7%
Midline shift <5 mm	76 (27.3%)	20 (26.3%)	23 (30.3%)	8.3%
Midline shift >5 mm	34 (12.2%)	14 (41.2%)	12 (35.3%)	4.3%

(SAH: Subarachnoid Haemorrhage: Subdural Hematoma, CT: Computed Tomography, DAI: Diffuse Axonal Injury, EDH: Epidural Hematoma)



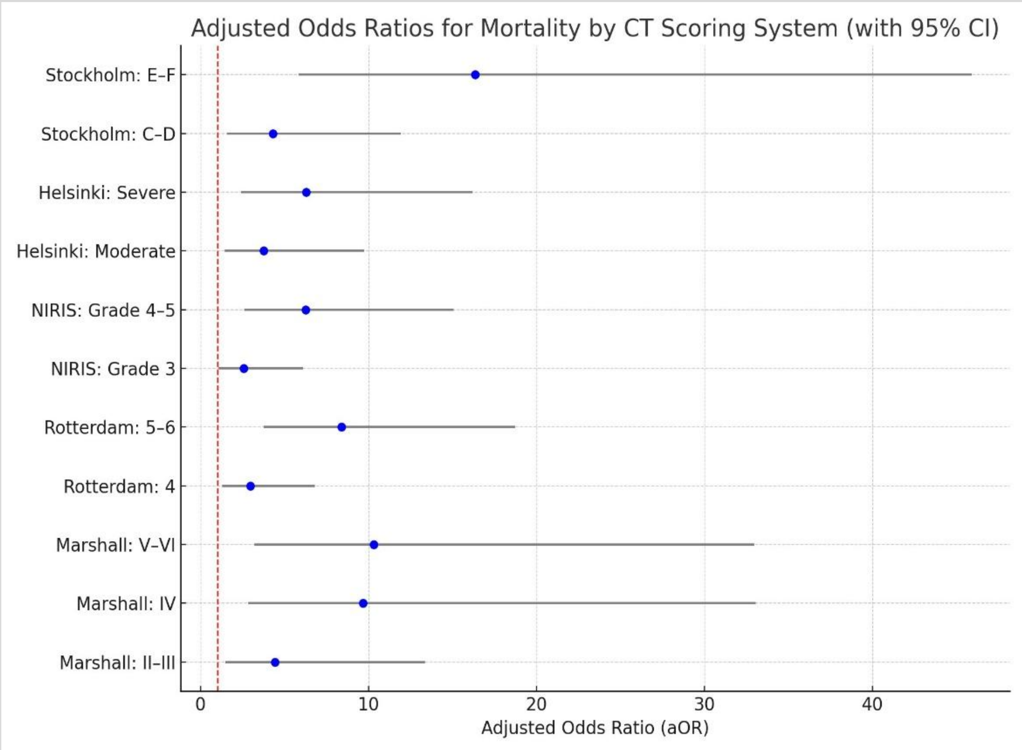
Graph 1: Above given horizontal bar chart visually compares categorical variables (in this case, CT findings) against a quantitative outcome (mortality rate as a percentage). Each horizontal bar represents a different CT finding, and its length reflects the associated mortality rate.

Table 3: SCORING SYSTEMS: Mortality increases with higher scores in all scoring systems expect in the Marshall – II-III has 8.6 % mortality and IV has 4.3%. All scoring systems show statistically significant differences in mortality across their categories ($p < 0.001$).

Table:3 CT scoring system (NIRIS: Neuroimaging Radiological Interpretation System)

Scoring System	Category / Score	Total Patients (n)	Non-survivors (n, %)	Mortality (%)	p-valu
Marshall	Grade I (Normal)	75	4 (5.3%)	1.4%	<0.001

	Grades II–III (Diffuse injury)	120	24 (20.0%)	8.6%	
	Grade IV (Shift >5 mm)	34	12 (35.3%)	4.3%	
	Grades V–VI (Mass lesions)	49	18 (36.7%)	6.5%	
Rotterdam	Score 2–3	122	10 (8.2%)	3.6%	<0.001
	Score 4	86	18 (20.9%)	6.5%	
	Score 5–6	70	30 (42.9%)	10.8%	
NIRIS	Grades 1–2	100	8 (8.0%)	2.9%	<0.001
	Grade 3	110	20 (18.2%)	7.2%	
	Grades 4–5	68	24 (35.3%)	8.6%	
Helsinki	Mild	90	6 (6.7%)	2.2%	<0.001
	Moderate	104	22 (21.2%)	7.9%	
	Severe	84	26 (30.9%)	9.4%	
Stockholm	Low risk	105	5 (4.8%)	1.8%	<0.001
	Moderate	113	20 (17.7%)	7.2%	
	High risk	60	27 (45.0%)	9.7%	



Graph 2: Above given forest plot for 278 patients showing the adjusted odds ratios (aORs) for mortality associated with different CT-based scoring systems used in traumatic brain injury (TBI), along with their 95% confidence intervals (CIs).

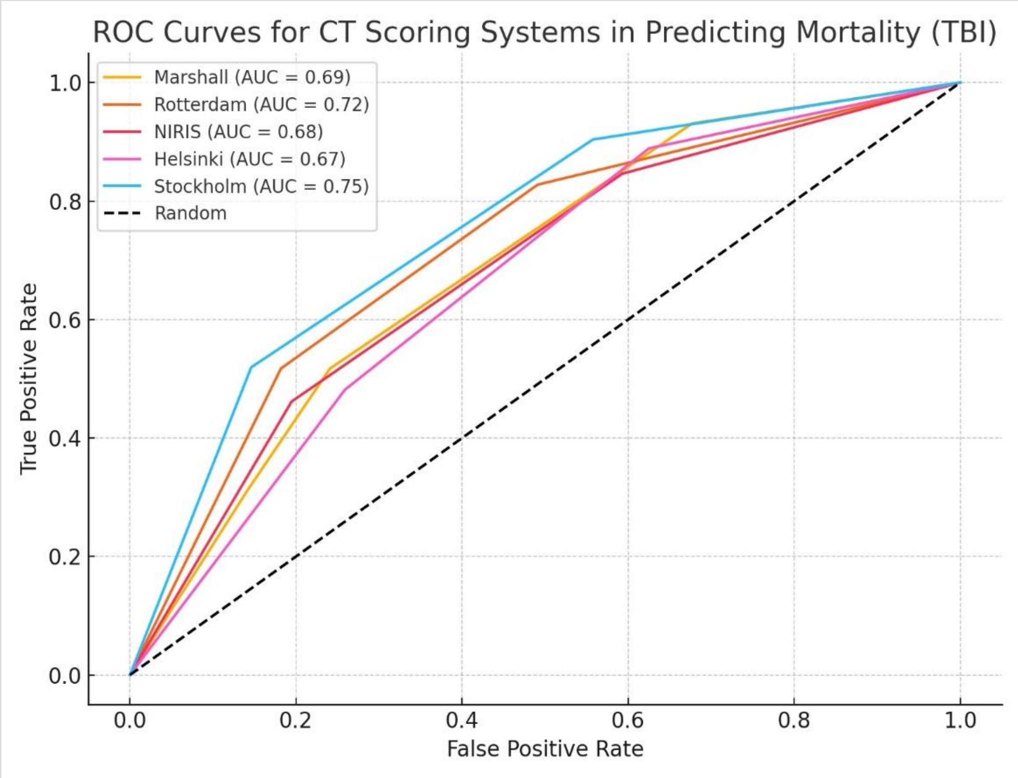
4. Diagnostic performance metrics of CT scoring systems in predicting mortality: The Marshall score demonstrated the highest sensitivity (93%), but its specificity was comparatively low (32%), resulting in moderate overall accuracy (45%). The Rotterdam score showed sensitivity of 83% and specificity of 51%, achieving the highest accuracy among the systems evaluated (58%). The Stockholm score showed sensitivity of 90%, specificity of 44%, and accuracy of 53%, alongside the largest AUC (0.86). The NIRIS and Helsinki scores yielded intermediate values, both maintaining good sensitivity (>85%) but lower specificity (<42%), corresponding to accuracies of 49% and 47%, respectively.

Table 4: Diagnostic performance metrics of CT scoring systems in predicting mortality.

Scoring System	Sensitivity (%)	Specificity y (%)	Positive Predictive Value (PPV, %)	Negative Predictive Value (NPV, %)	AUC	Overall Accuracy
Marshall	93	32	27	95	0.79	0.45
Rotterdam	83	51	31	92	0.83	0.58
NIRIS	85	41	25	92	0.78	0.49
Helsinki	89	38	26	93	0.75	0.47
Stockholm	90	44	27	95	0.86	0.53

(NIRIS – Neuroimaging Radiological Interpretation System, NPV – Negative Predictive Value, PPV – Positive Predictive Value, AUC- Area Under the Receiver Operating Characteristic Curve)

5.The Receiver-Operating Characteristic (ROC) Curve analysis for the five CT scoring systems, illustrating their ability to discriminate between survival and mortality in TBI patients:



Graph 3: Each curve plots the True Positive Rate (Sensitivity) against the False Positive Rate (1 - Specificity). Stockholm and Rotterdam scores had the highest AUCs, suggesting stronger predictive accuracy. Marshall, NIRIS, and Helsinki followed with moderately strong AUCs.

6. Mortality: The mortality patterns and causes in a patient population, indicating an early mortality rate of 3.58% within the first 3 days due to severe presentation and primary brain injury. The majority of deaths, 35.72%, occur by day 7, with late mortality between 7 days and 1 month primarily caused by complications like infections, diffuse axonal injury, or poor neurological recovery, leading to a total 1-month mortality of 15.1% (42 patients).

Table 5: mortality of patients

Time Point	Deaths (n, % of total)	Interval Mortality Rate (%)	Cumulative Deaths (n)	Cumulative Mortality Rate (%)
On admission	7 (16.7%)	2.5%	7	2.5%
1 day	3 (7.1%)	1.1%	10	3.6%
3 days	8 (19.0%)	2.9%	18	6.5%
7 days	15 (35.7%)	5.5%	33	11.9%
1 month	9 (21.4%)	3.2%	42	15.1%

Discussion

In this study of 278 patients with traumatic brain injury (TBI), the overall 30-day mortality was 15.1%, with the majority of deaths occurring within the first week of admission. These findings are consistent with prior literature, which emphasizes the critical period of early mortality in TBI patients [23]. Early deaths were largely attributable to primary brain injury and severe clinical presentation, whereas late deaths were more commonly related to secondary complications such as sepsis and raised intracranial pressure.

Clinico-demographic Predictors

Age and comorbidities emerged as significant predictors of poor outcome. Patients aged over 60 years and those with pre-existing conditions such as hypertension and diabetes experienced higher mortality rates. This aligns with international data from the IMPACT and CRASH studies, which demonstrated that increasing age and comorbid burden independently worsen prognosis [24]. Interestingly, although males constituted the majority of cases, females demonstrated proportionally higher mortality, a trend reported in earlier observational studies suggesting sex-specific physiological and hormonal influences on TBI response [25].

Glasgow Coma Scale and Clinical Parameters

Admission Glasgow Coma Scale (GCS) score was strongly associated with mortality, reaffirming its role as a cornerstone of TBI severity assessment. In our cohort, patients with moderate TBI (GCS 9–12) had unexpectedly high mortality compared to severe TBI cases, a pattern that may reflect under-recognition of risk in this group and supports closer monitoring [26]. Complications such as raised ICP, sepsis, and brain edema were strongly correlated with mortality, underscoring the importance of aggressive prevention and timely management of secondary brain injury [27].

Imaging Predictors

Radiological features, particularly diffuse axonal injury (DAI), cerebral edema, and midline shift, were significantly associated with mortality in this study. These findings are consistent with neuropathological evidence that axonal disruption and extensive edema are major determinants of poor outcome [28]. Normal CT findings, conversely, strongly predicted survival, supporting the value of CT in risk stratification at presentation. While epidural hematoma (EDH) demonstrated relatively high mortality, it did not reach statistical significance-possibly due to the small sample size and the fact that timely surgical evacuation can improve outcomes [29].

CT-Based Scoring Systems

All five scoring systems–Marshall, Rotterdam, Helsinki, Stockholm, and NIRIS–showed statistically significant correlations with mortality. Mortality increased progressively with higher scores, validating their prognostic reliability. Among them, the Stockholm score demonstrated the highest discriminatory power (AUC 0.89), followed by Helsinki and Rotterdam. These results are comparable with European studies that identified Stockholm and Helsinki as robust predictors of outcome in TBI [30]. Marshall and NIRIS systems, while valuable, showed slightly lower predictive accuracy, which may be attributed to their more limited scoring granularity.

Clinical Implications

Our findings suggest that structured CT scoring systems should be integrated into emergency department protocols for early prognostication. Specifically, the Stockholm and Helsinki scores may be most suitable for rapid risk stratification in Indian tertiary care settings, where timely triage decisions are critical. When combined with clinical parameters such as GCS and comorbidity assessment, these scores can enhance decision-making regarding intensive monitoring, neurosurgical intervention, and family counseling [31].

Limitations

This study has several limitations. Its retrospective design introduces potential biases in data collection and interpretation. Being a single-center study, generalizability is limited, and the sample size of non-survivors (n=42) restricts subgroup analyses. Biomarkers and advanced imaging modalities, such as MRI, were not included, which might have improved prognostic accuracy. Moreover, long-term functional outcomes were not assessed, and mortality alone may not fully capture the burden of TBI [32].

Future Directions

Future research should focus on prospective multicenter validation of CT-based scoring systems in diverse populations. Integrating radiological scores with clinical variables, pupillary reactivity, and emerging biomarkers could lead to development of multimodal prognostic models. Advances in machine learning may further refine predictive accuracy and allow for individualized patient trajectories. Early application of such models in emergency departments has the potential to improve survival and optimize resource utilization [33].

Conclusion

This study demonstrates that CT-based scoring systems are reliable tools for predicting mortality in patients with traumatic brain injury. Mortality was strongly associated with advanced age, comorbidities, low Glasgow Coma Scale scores, and complications such as raised intracranial pressure and sepsis. Radiological indicators including diffuse axonal injury, cerebral edema, and midline shift were significant predictors of poor outcomes.

Among the five evaluated CT-based systems, the Stockholm and Helsinki scores exhibited the highest predictive accuracy, supported by their strong area under the curve (AUC) values and odds ratios. The Rotterdam and Marshall systems also performed well, while NIRIS offered moderate prognostic utility. These findings underscore the value of structured radiological scoring in complementing clinical parameters to enhance early risk stratification.

In resource-constrained emergency settings, incorporation of these scores into routine assessment can aid in timely triage, guide neurosurgical decision-making, and provide families with realistic prognostic information [34]. Moving forward, multicenter prospective studies integrating CT scores with biomarkers and clinical data are warranted to develop multimodal predictive models that could further refine individualized care pathways [35].

List of Abbreviations

RTA: Road Traffic Accident
SAH: Subarachnoid Haemorrhage
SD: Standard Deviation
SDH: Subdural Hematoma
TBI: Traumatic Brain Injury
AUC: Area Under the Receiver Operating Characteristic Curve
aOR: Adjusted Odds Ratio
CI: Confidence Interval
CT: Computed Tomography
DAI: Diffuse Axonal Injury
EDH: Epidural Hematoma
GCS: Glasgow Coma Scale
ICP: Intracranial Pressure
IQR: Interquartile Range
MLS: Midline Shift
MRI: Magnetic Resonance Imaging
NCCT: Non-Contrast Computed Tomography
NIRIS: Neuroimaging Radiological Interpretation System
NPV: Negative Predictive Value
PPV: Positive Predictive Value
ROC: Receiver Operating Characteristic

Declarations

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Considerations

The study was approved by the Institutional Ethics Committee of Sardar Vallabhbhai Patel Institute of Medical Sciences and Research. As it was retrospective, informed consent was waived. All patient data were anonymized to protect confidentiality.

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