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PRIMARY DECOMPRESSIVE CRANIECTOMY IN TRAUMATIC BRAIN INJURY: CLINICAL OUTCOMES AND A PRELIMINARY RISK-SCORING SYSTEM FOR PATIENT SELECTION

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ABSTRACT

Background: Traumatic brain injury (TBI) is a leading global cause of mortality and neurological disability. Decompressive craniectomy (DC) addresses refractory intracranial hypertension, but the optimal selection of patients for this procedure remains a critical and unresolved clinical challenge, particularly in resource-limited settings.
Methods: A prospective observational study was conducted at a tertiary hospital in Meerut, India (July 2024–November 2025). Patient enrollment was stopped in November 2025 to allow 3-month follow-up completion for all cases by February 2026. Fifteen patients aged 18–65 years who underwent primary unilateral DC for TBI were enrolled. Clinical (GCS, pupillary response, fall in GCS, anticipated prolonged ventilation), radiological (Modified Rotterdam CT score with sulcal effacement in higher fronto-parietal cuts), and intraoperative (brain bulge) variables were recorded. Serial CT evaluation was performed to guide surgical intervention. Three-month functional outcome was assessed using the Glasgow Outcome Scale (GOS), dichotomised as favorable (GOS 4–5) or unfavorable (GOS 1–3).
Results: The cohort comprised predominantly young adult males (mean age 34.7 ± 14.6 years; 73.3% male) injured in road traffic accidents (73.3%). Favorable outcomes were achieved in 33.3% of patients; mortality was 33.3%. Age was the only variable significantly associated with mortality: survivors were substantially younger than non-survivors (mean 26.1 vs. 51.8 years; $p = 0.003$). GCS improved significantly from admission (mean 8.07) to 3-month follow-up (mean 12.18; $p = 0.047$). A six-variable preliminary risk score — incorporating age, GCS, anticipated prolonged ventilation, radiological severity, intraoperative brain bulge, and in-hospital fall in GCS — demonstrated a progressive increase in unfavorable outcomes with higher scores.
Conclusion: Primary DC reduces mortality in severe TBI, though functional recovery is strongly age-dependent. The proposed risk-scoring model offers a simple, resource-independent tool for patient selection pending prospective multicentric validation.

KEYWORDS: Traumatic brain injury; decompressive craniectomy; intracranial hypertension; Glasgow Outcome Scale; scoring system; India.

1. INTRODUCTION

Traumatic brain injury (TBI) represents a foremost global public health crisis, contributing to an estimated 69 million injuries annually and accounting for a disproportionate share of trauma-related deaths and permanent neurological disability worldwide. In India, the epidemic is magnified by rapidly expanding motorisation, inadequate road safety infrastructure, heterogeneous emergency medical services, and a historical paucity of population-based injury surveillance — collectively generating a disease burden that is likely the highest in any single nation.[1][2][3]

The neurobiological basis of severe TBI (GCS ≤8 at presentation) involves two temporally overlapping injury cascades. The primary injury reflects immediate, irreversible mechanical disruption of neural tissue, axons, and cerebral vasculature at the moment of impact. This is followed by a self-amplifying wave of secondary injury — intracranial hypertension, malignant cerebral edema, excitotoxicity, mitochondrial dysfunction, and diffuse microvascular compromise — that determines the ultimate extent of neurological devastation. Sustained elevation of intracranial pressure (ICP) beyond 20 mmHg compresses cerebral perfusion pressure (CPP) below the critical threshold of 60 mmHg, propagating ischemia, uncal herniation, and death.[4][5]

When escalating tiers of medical management — osmotherapy, controlled hyperventilation, sedation, barbiturate coma, and CSF drainage — fail to normalise ICP, decompressive craniectomy (DC) provides a definitive surgical rescue strategy. By removing a large calvarial segment, DC creates additional intracranial volume, abruptly lowering ICP and restoring CPP. Yet the evidence base for DC is sharply contested. The landmark DECRA trial demonstrated that early bilateral DC significantly reduced ICP and shortened ICU duration but counterintuitively increased the proportion of unfavorable neurological outcomes at 6 months. The RESCUEicp trial subsequently confirmed a clear mortality benefit of DC over continued medical management in patients with refractory ICP, albeit at the cost of more survivors with severe disability or in a vegetative state. These divergent findings make patient selection — not operative technique — the central determinant of DC benefit.[6][7][8]

Currently, surgical decision-making integrates clinical severity (GCS, pupillary response), CT morphology, and institutional experience. However, no validated, regionally adapted scoring instrument synthesises clinical, radiological, and intraoperative parameters into an objective pre-surgical recommendation tailored to the Indian demographic context — primarily young males injured in road traffic accidents, often after protracted prehospital transfer. This study was designed to fill that gap.[9]

The present study aimed to: (i) evaluate outcomes following primary DC for TBI at a tertiary Northern Indian centre; (ii) identify clinical, radiological, and intraoperative predictors of 3-month functional outcome; and (iii) develop a preliminary, resource-independent risk-scoring model to support objective patient selection for this high-stakes procedure.

2. MATERIALS AND METHODS

2.1 Study Design and Setting

This prospective, single-centre, observational cohort study was conducted in the Department of General Surgery, N.S.C.B. Subharti Medical College and Associated Chhatrapati Shivaji Subharti Hospital, Meerut (Uttar Pradesh), India — a 1,400-bed tertiary-care teaching hospital serving a large Northern Indian catchment. The study period ran from July 2024 to November 2025. Enrollment was stopped in November 2025 to ensure 3-month follow-up completion for all patients by February 2026. Institutional Ethics Committee approval was obtained (Ref: IEC/SMC/2024/XX) and written informed consent was secured from each patient or their legally authorised representative prior to enrolment.

2.2 Patient Selection

Consecutive patients aged 18–65 years admitted with closed-head TBI requiring primary unilateral DC were eligible. Fifteen patients fulfilled the inclusion criteria over the study period.

Inclusion criteria: (i) age 18–65 years; (ii) closed-head TBI confirmed on non-contrast computed tomography (NCCT) brain; (iii) primary or escalation-to-surgery DC after failure of initial conservative management.

Exclusion criteria: (i) haemodynamic instability from diffuse secondary brain injury; (ii) prior surgery at a referring facility; (iii) known coagulopathy; (iv) previous cranial surgery; (v) compound comminuted depressed skull fracture; (vi) therapeutic anticoagulation or dual antiplatelet therapy.

2.3 Clinical and Radiological Assessment

At admission: age, GCS (total and motor component), bilateral pupillary status (reactive / sluggishly reactive / non-reactive), documented in-hospital fall in GCS (≥2 points), and anticipated prolonged ventilation (defined as expected post-operative ventilatory requirement >5 days due to significant comorbidities including uncontrolled diabetes mellitus, chronic kidney disease, COPD, or aspiration pneumonitis) were recorded. All patients underwent emergency NCCT brain. Serial CT evaluation was performed to guide surgical intervention. CT morphology was graded using a Modified Rotterdam CT Score that incorporates basal cistern status, midline shift, presence of subarachnoid haemorrhage, epidural mass lesion, and sulcal effacement in higher fronto-parietal cuts.

2.4 Surgical Procedure

Primary DC was performed as a standardised large hemicraniectomy with bone flap ≥12 cm in maximal diameter encompassing the frontal, temporal, and parietal regions. Timing of surgery was decided based on CT findings or neurological deterioration, with the period extending from within 6 hours to 5 days post-injury. Persistent brain bulge following dural opening — defined as brain tissue herniating beyond the inner table after complete hematoma evacuation — was documented as a marker of malignant cerebral edema. The excised bone flap was preserved in a right paraumbilical subcutaneous pouch for subsequent cranioplasty.

2.5 Outcome Assessment

Primary outcome: three-month functional status assessed using the Glasgow Outcome Scale (GOS): 1 = death; 2 = vegetative; 3 = severe disability; 4 = moderate disability; 5 = good recovery. Outcomes were dichotomised as favorable (GOS 4–5) and unfavorable (GOS 1–3). Secondary outcome: GCS trajectory from admission through 3-month follow-up.

2.6 Scoring Model Development

Variables with established independent prognostic significance in the published literature and consistent directional trends in this cohort were selected. Each qualifying variable was assigned a binary score of 1 (criterion met) or 0 (absent); total scores were summed (maximum 6) and compared with 3-month GOS grouping.

2.7 Statistical Analysis

Data were analysed using IBM SPSS v20.0. Continuous variables are reported as mean ± SD and median (range). Comparisons used Mann–Whitney U (between-group) and Wilcoxon signed-rank (paired within-group) tests. Categorical associations were assessed by Fisher's exact test. Spearman rank correlation (ρ) quantified ordinal associations. Two-tailed $p < 0.05$ was considered statistically significant.

3. RESULTS

3.1 Demographic and Clinical Profile

Fifteen patients were enrolled over 17 months. The cohort comprised 11 males (73.3%) and 4 females (26.7%), with a mean age of 34.7 ± 14.6 years (median 30 years; range 18–65). The majority were young adults aged 18–37 years. Road traffic accidents accounted for 73.3% (n = 11) of injuries, and falls from height for 26.7% (n = 4). Demographic data are illustrated in Figure 1.

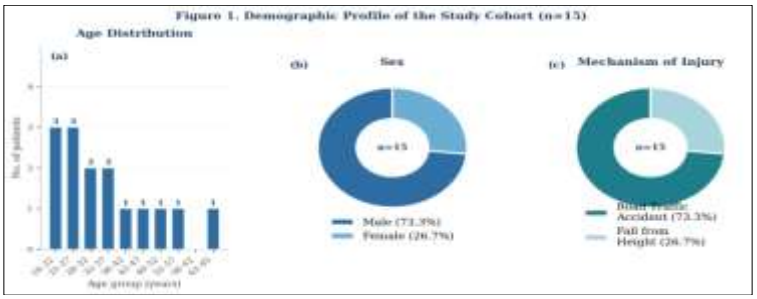

Figure 1. Demographic profile. (a) Age distribution indicating the majority population is young adults (18-37 years). (b) Sex distribution-73.3% males. (c) Mechanism of injury: 73.3% road traffic accidents.

3.2 Clinical Variables and Mortality

Overall mortality was 33.3% (n = 5). Age was the sole variable to demonstrate a statistically significant association with mortality. Survivors (n = 10) were substantially younger than non-survivors (mean age 26.1 ± 6.0 vs. 51.8 ± 10.8 years; p = 0.003, Mann–Whitney U). No other admission variable — including GCS, pupillary status, mechanism of injury, or Modified Rotterdam score — reached statistical significance for mortality, likely due to limited sample size. Directional trends were nonetheless consistent with established prognostic literature (Table 1).

Table 1. Comparison of Admission Variables Between Survivors and Non-Survivors

Variable	Survivors (n=10)	Non-Survivors (n=5)	p value
Age;Mean ± SD (yrs)	26.1 ± 6.0	51.8 ± 10.8	**0.003 ***
Male sex; n (%)	8 (80%)	3 (60%)	0.560
Road traffic accident; n (%)	7 (70%)	4 (80%)	0.560
Admission GCS;Median (range)	7.5 (3–13)	10.0 (3–14)	0.757
Bilateral reactive pupils;n (%)	4 (40%)	2 (40%)	1.000
Fall in GCS during admission;n (%)	6 (60%)	4 (80%)	0.119
Modified Rotterdam Score with sulcal effacement; Median	6.0	7.0	0.367
Intraoperative brain bulge; n (%)	9 (90%)	5 (100%)	1.000

* Statistically significant ($p < 0.05$). p values calculated by Mann–Whitney U test (continuous variables) and Fisher's exact test (categorical variables).

3.3 GCS Trajectory

Serial GCS assessment revealed a characteristic and clinically meaningful postoperative trajectory. Mean GCS at admission was 8.07 (±2.6; median 8). Immediately post-surgery (day 0), GCS fell to 3.07 (±1.3; median 3), reflecting pharmacological sedation and perioperative physiology ($p < 0.001$ vs. admission). By postoperative day 7, GCS had recovered to a mean of 7.64, no longer significantly different from admission ($p = 0.968$). At 3-month follow-up, mean GCS was 12.18 (±3.0; median 13) — a statistically significant improvement over admission values ($p = 0.047$, Wilcoxon signed-rank test), demonstrating meaningful neurological recovery in the surviving cohort (Figure 2).

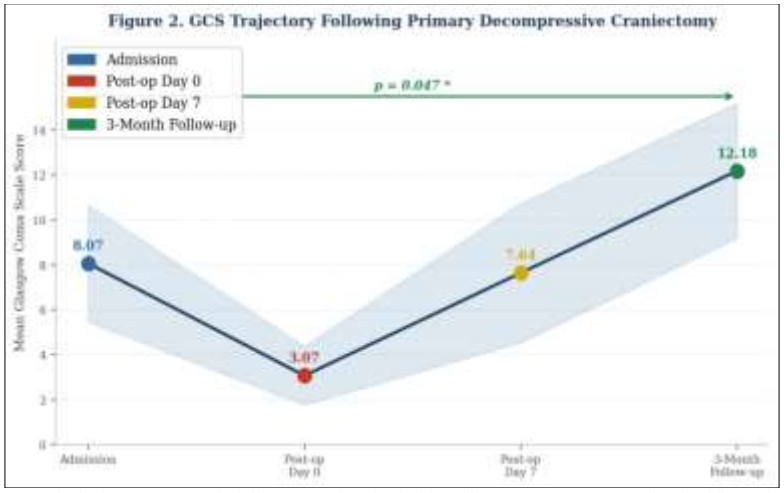

Figure 2. GCS trajectory on admission to 3-month follow up. The shaded band is ±1 SD. At 3 months significant improvement was noticed ($p = 0.047$). The fact that the day 0 drop is transient is indicative of perioperative sedation.

3.4 Three-Month Functional Outcome

At 3-month review, 5 patients (33.3%) achieved a favorable outcome (GOS 4–5) and 10 patients (66.7%) had unfavorable outcomes (GOS 1–3). Five patients (33.3%) died (GOS 1); 1 patient remained in a vegetative state (GOS 2); 4 had severe disability (GOS 3); 3 moderate disability (GOS 4); and 2 made a good recovery (GOS 5). Full GOS distribution is presented in Table 2 and Figure 3.

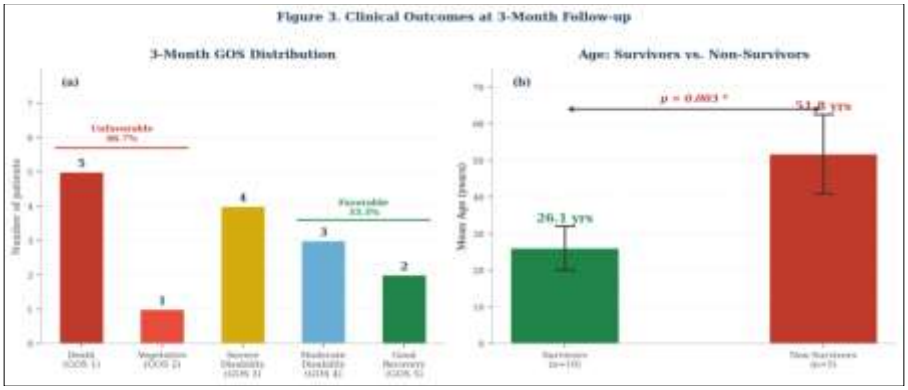

Figure 3. Clinical outcomes at 3-month follow-up. (a) GOS distribution by category. (b) Mean age comparison between survivors and non-survivors; age was the only significant mortality predictor ($p = 0.003$).

Table 2. Three-Month Glasgow Outcome Scale (GOS) Distribution (n=15)

GOS Category	n	% (n=15)
GOS 5: Good recovery	2	13.3
GOS 4: Moderate disability	3	20.0
GOS 3: Severe disability	4	26.7

GOS 2: Vegetative state	1	6.7
GOS 1: Death	5	33.3
Favorable outcome (GOS 4–5)	**5**	**33.3**
Unfavorable outcome (GOS 1–3)	**10**	**66.7**

GOS = Glasgow Outcome Scale.

Spearman correlation revealed no statistically significant relationship between admission GCS and GOS ($\rho = 0.120$; $p = 0.670$), nor between Modified Rotterdam score and GOS ($\rho = -0.207$; $p = 0.459$). The negative direction of the latter correlation is nonetheless consistent with the established prognostic role of CT severity grading in TBI.

3.5 Fall in GCS and Mortality

In-hospital fall in GCS (≥2 points from admission) was observed in 8 of 15 patients (53.3%). Among patients with GCS decline, 3 of 8 (37.5%) died, compared with 2 of 7 (28.6%) among those without GCS decline. A non-significant trend toward higher mortality was seen with GCS decline (37.5% vs 28.6%; $p = 0.714$; Fisher's exact test $p = 1.000$), most likely owing to the limited sample size. The observed trend nonetheless supports the biological plausibility of GCS decline as an indicator of secondary neurological deterioration and its inclusion as a variable in the risk-scoring model (Table 5).

Table 5. Fall in GCS vs. Mortality Status (Contingency Table, n=15)

Fall in GCS	Alive (n=10)	Dead (n=5)	Total
No	5 (50.0%)	2 (40.0%)	7 (46.7%)
Yes	5 (50.0%)	3 (60.0%)	8 (53.3%)
Total	10 (100%)	5 (100%)	15 (100%)

$\chi^2 = 0.134$; df = 1; $p = 0.714$. Fisher's exact test $p = 1.000$. Trend observed but not statistically significant.

3.6 Preliminary Risk-Scoring Model

A six-variable scoring model was derived from variables with established prognostic significance in the literature and clinically consistent trends in this cohort: age ≥50 years, admission GCS ≤12, anticipated prolonged ventilation, Modified Rotterdam score ≥5 with sulcal effacement in higher fronto-parietal cuts, intraoperative brain bulge, and in-hospital fall in GCS. Each fulfilled criterion was scored 1 (Table 3, maximum total score = 6). No patient had a risk score <3, reflecting the high baseline severity of this DC cohort. Table 4 presents risk score distribution against 3-month outcome, demonstrating a progressive increase in unfavorable outcomes with rising score. The model is illustrated graphically in Figure 4.

Table 3. Variables, Criteria, and Rationale for the Six-Variable Preliminary Risk-Scoring Model Subharti Neurosurgery Meerut Composite -SNMC Clinical Radiological Scoring System

Variable	Criterion	Clinical Rationale	Score
Age	≥50 yrs	Age is an advanced age = less recovery capacity, neuroplasticity and physiological reserve.	1
Admission GCS	≤ 12	GCS ≤ 12 Indicates moderate to severe neurological depression at presentation	1
Anticipated prolonged ventilation	> 5 days	Significant co-morbidities including uncontrolled diabetes mellitus,chronic kidney disease,COPD, aspiration pneumonitis independently complicate clinical condition and may warrant ventilation > 5 days	1

Modified Rotterdam Score With b/l Sulcal Effacement	≥5	with sulcal effacement in higher fronto-parietal cuts Quantifies radiological severity: cistern compression, midline shift, haemorrhage burden, and cortical sulcal effacement	1
Intraoperative brain bulge	Present	Marker of malignant cerebral edema and persistently elevated ICP refractory to decompression	1
Fall in GCS	Present	Decrease in GCS in hospital > 2 → Sign of secondary neurological deterioration .	1
		Maximum Total Score	**6**

ICP = intracranial pressure, GCS = Glasgow Coma Scale. GCS in the fall as a trend variable (p = 0.714); not independently significant but in the same direction with respect to secondary neurological deterioration.

Table 4. Total Risk Score vs. 3-Month Functional Outcome (Six-Variable Model, max score = 6)

Risk Score	Favorable (GOS 4–5)	Unfavorable (GOS 1–3)	Total patients
0–2	—	—	0
3	1 (33.3%)	2 (66.7%)	3
4	3 (37.5%)	5 (62.5%)	8
5	1 (25.0%)	3 (75.0%)	4

Data are given numerically (n (%)). Green shading - favorable outcome, red shading - unfavorable outcome.

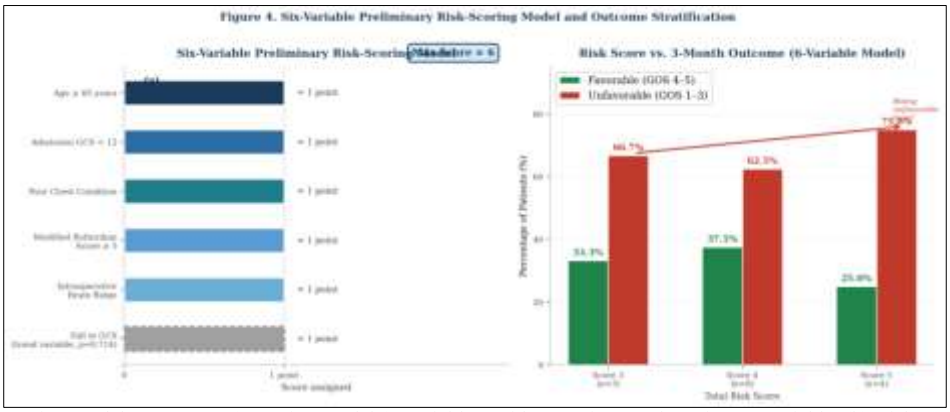

Figure 4. Risk-scoring model summary. (a) Scoring model (6-variables) with a maximum of 1 point per variable. (b) Risk score according to outcome at 3 months with increasing numbers of unfavorable outcomes indicated along the gradient.

4. DISCUSSION

This prospective study evaluated primary DC in 15 TBI patients at a Northern Indian tertiary centre, yielding a 3-month mortality of 33.3% and a favorable outcome rate of 33.3%. These figures align with published Indian and international series, where mortality following DC for severe TBI ranges from 20–50% and favorable neurological recovery from 20–40%.

4.1 Age as the Principal Determinant of Survival

The most compelling finding was the strong, statistically significant influence of age on survival. Survivors were on average 25 years younger than non-survivors (26.1 vs. 51.8 years; p = 0.003). This age gradient is biologically plausible: younger individuals retain greater neuroplasticity, more robust cerebral autoregulatory capacity, and superior physiological reserve to sustain the metabolic demands of severe TBI and the physiological stress of major cranial surgery. The prognostic centrality of age in DC outcomes has been consistently documented: Nambiar et al. reported superior functional recovery in younger DC recipients in an Australian series, and Moussa et al. identified age as an independent determinant of poor neurological recovery.

4.2 GCS and Radiological Predictors

Neither admission GCS nor Modified Rotterdam score reached statistical significance in this study. This almost certainly reflects the constraints of a small sample (n = 15) rather than a true absence of prognostic value for these well-validated indices. The weak negative Spearman correlation between Rotterdam score and GOS ($\rho = -0.207$) and the marginally higher median Rotterdam scores in non-survivors (7 vs. 6) are directionally consistent with the established literature.

4.3 Neurological Recovery and GCS Trajectory

The statistically significant improvement in GCS from admission to 3 months (8.07 to 12.18; $p = 0.047$) is a clinically meaningful finding that underscores the brain's capacity for neurological recovery over time following surgical decompression. This trajectory mirrors the recovery patterns described in the RESCUEicp cohort and subsequent observational studies. It also has an important clinical implication: early postoperative GCS in the immediate post-surgical period should not, in isolation, guide withdrawal-of-care decisions.[8]

4.4 Fall in GCS as a Prognostic Trend Variable

In-hospital GCS decline was observed in 53.3% of patients and was associated with a higher proportion of deaths (37.5% vs. 28.6%), although this did not reach statistical significance ($p = 0.714$). GCS decline is a well-recognised clinical indicator of secondary neurological deterioration and has been associated with worse prognosis in multiple TBI series.[4][8]

4.5 Proposed Six-Variable Scoring Model

The six-variable risk score demonstrated a consistent gradient of increasing unfavorable outcomes with rising score. The model's principal advantage is its exclusive use of universally obtainable bedside and intraoperative variables requiring no specialised monitoring equipment — a critical consideration in Indian district hospitals and smaller trauma centres without continuous ICP monitoring capability. The adoption of age ≥50 years as a cutoff improves clinical applicability in this young cohort while maintaining biological plausibility. The inclusion of sulcal effacement in higher fronto-parietal cuts in the Modified Rotterdam Score aligns with emerging literature on cortical compression as a predictor of malignant edema. Future iterations should explore weighted scoring and validate the model prospectively in a multicentre Indian TBI registry.[9]

4.6 Limitations

Several limitations must be acknowledged. The single-centre design and small sample (n = 15) limit statistical power and generalisability. Absence of continuous ICP monitoring precluded correlation of ICP trajectories with surgical timing and outcome. The 3-month follow-up horizon may underestimate late neurological recovery, which can continue for 12–24 months post-TBI. The scoring model is preliminary and requires prospective validation before clinical implementation.

5. CONCLUSION

Primary decompressive craniectomy provides a meaningful survival benefit in severe TBI and facilitates significant neurological recovery over the ensuing months. In this Northern Indian cohort, age emerged as the dominant predictor of survival — an actionable finding with direct implications for pre-surgical counselling and prognostic discussions with families.

The proposed six-variable preliminary risk score — incorporating age ≥50 years, GCS, anticipated prolonged ventilation (>5 days due to significant comorbidities), radiological severity with sulcal effacement in higher fronto-parietal cuts, intraoperative brain bulge, and in-hospital fall in GCS — offers a transparent, resource-independent framework for stratifying patients before committing to this high-stakes intervention. Prospective multicentric validation in larger Indian TBI cohorts is the essential next step toward embedding objective, data-driven patient selection into routine neurotrauma practice.

DECLARATIONS

Ethical Approval: The study has obtained ethical approval from the Institutional Ethics Committee (IEC) of Subharti Medical College, Meerut, India (Ref: IEC/SMC/2024/XX), before the study was started.
Informed Consent: All patients (or legally authorised representatives) were able to give written informed consent.
Conflict of Interest: There are no conflict of interest to declare.
Funding: NO external funding was received. This research was done as part of postgraduation study.
Data Availability: Yes, de-identified data can be made available upon reasonable request.
Author contribution: M.A.: study conceptualisation and patient enrolment, data collection, surgical participation, statistical analysis, and manuscript preparation. D.K.: supervision of study, surgical advice, critical intellectual review

and revision of manuscript. D.C.: intellectual content, intellectual revision, validation of CT grading. All the authors have seen and approved the final manuscript.

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