



RESEARCH ARTICLE

Predictors of outcome in patients with traumatic brain injury undergoing neurosurgical intervention

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ABSTRACT

Background: Traumatic brain injury (TBI) is a major cause of mortality and neurological disability, particularly among patients requiring neurosurgical intervention. Early identification of factors associated with poor outcome can assist in prognostication, perioperative management, and counseling of patients and their relatives. This study evaluated clinical, radiological, and treatment-related predictors of outcome in patients with TBI undergoing neurosurgical intervention. **Methods:** A prospective observational study was conducted in 250 patients aged ≥ 18 years with traumatic brain injury who underwent neurosurgical intervention. Demographic characteristics, mechanism of injury, admission Glasgow Coma Scale (GCS), pupillary response, computed tomography (CT) findings, type and timing of surgery, and postoperative complications were recorded. Functional outcome was assessed using the Glasgow Outcome Scale (GOS) at the predefined follow-up. GOS scores 4–5 were considered favorable and scores 1–3 unfavorable. Predictors of outcome were evaluated using univariate analysis followed by multivariable logistic regression. **Results:** The mean age was 41.8 ± 17.6 years, and 78.4% of patients were male. Road traffic accidents were the commonest mechanism of injury (56.8%). Acute subdural hematoma was the most frequent CT finding (35.6%). Overall, 153 (61.2%) patients had a favorable outcome, whereas 97 (38.8%) had an unfavorable outcome. Mortality was **16.8%**. Low admission GCS (≤ 8), bilateral non-reactive pupils, age > 60 years, midline shift > 5 mm, compressed/absent basal cisterns, and postoperative complications were significantly associated with unfavorable outcome. On multivariable analysis, admission GCS ≤ 8 was the strongest independent predictor (adjusted OR 4.86; 95% CI 2.58–9.15; $p < 0.001$). **Conclusion:** Outcome following neurosurgical intervention for TBI is influenced by multiple clinical and radiological factors. Admission GCS, pupillary response, age, CT findings, and postoperative complications are important predictors of unfavorable outcome. Early identification of high-risk patients may facilitate timely intervention and optimized postoperative care.

Keywords: Traumatic brain injury; Neurosurgical intervention; Glasgow Coma Scale; Glasgow Outcome Scale; Pupillary response; Midline shift; Prognostic factors

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INTRODUCTION

Traumatic brain injury (TBI) is a major cause of death and long-term neurological disability worldwide and represents an important emergency encountered in neurosurgical practice. The clinical spectrum ranges from mild injury to severe TBI with intracranial hemorrhage, cerebral edema, mass effect, herniation, and secondary brain injury. Patients requiring neurosurgical intervention constitute a particularly high-risk group because the need for surgery generally reflects the presence of significant structural brain injury or raised intracranial pressure. Despite advances in neuroimaging, intensive care, surgical techniques, and neurocritical care, mortality and unfavorable functional outcomes remain substantial in patients with severe TBI. [1,2] The outcome following TBI is determined by a complex interaction between the

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severity of the initial brain injury, secondary physiological insults, radiological abnormalities, patient characteristics, and the timing and type of treatment. Important established prognostic factors include age, initial Glasgow Coma Scale (GCS) score, pupillary reactivity, systemic hypotension, hypoxia, and computed tomography (CT) findings. Large international prognostic studies have demonstrated that age, GCS motor score, pupillary reactivity, and CT characteristics are among the strongest predictors of mortality and unfavorable functional outcome after TBI. The addition of secondary insults and laboratory abnormalities may further improve prognostic accuracy. [2,3]The initial neurological examination remains one of the most important tools for early prognostication. A lower GCS, particularly a poor motor response, is consistently associated with an increased probability of unfavorable outcome. Similarly, abnormal or absent pupillary responses may indicate severe intracranial injury, mass effect, or brainstem dysfunction and are associated with increased mortality. However, prognostication based on GCS alone may be inadequate, particularly in patients with very severe TBI, and should be interpreted together with other clinical and radiological parameters. [4,5]CT of the brain is essential in the evaluation of patients with significant TBI and plays a central role in determining the need for neurosurgical intervention. Findings such as epidural hematoma, acute subdural hematoma, cerebral contusions, traumatic subarachnoid hemorrhage, intraventricular hemorrhage, compressed or absent basal cisterns, midline shift, and diffuse cerebral injury provide important information regarding the severity of structural brain damage. CT-based classification systems, including the Marshall and Rotterdam CT scores, have demonstrated prognostic value. In particular, higher Rotterdam CT scores have been associated with increased mortality and unfavorable functional outcomes in patients undergoing decompressive craniectomy. Neurosurgical intervention is undertaken when traumatic intracranial lesions produce significant mass effect, neurological deterioration, refractory intracranial hypertension, or other radiological and clinical indications. Surgical procedures may include evacuation of epidural or subdural hematomas, evacuation of traumatic contusions or intracerebral hematomas, decompressive craniectomy, and elevation of depressed skull fractures. Current surgical guidelines emphasize that patients meeting established criteria for evacuation should undergo timely surgical treatment, as neurological deterioration and secondary brain injury can rapidly worsen prognosis. However, the decision to operate does not by itself determine the eventual neurological outcome. Patients undergoing apparently similar neurosurgical procedures may have markedly different outcomes depending on preoperative neurological status, age, pupillary response, type and severity of intracranial lesion, CT characteristics, associated systemic injuries, timing of surgery, and postoperative complications. Therefore, identifying factors associated with favorable and unfavorable outcomes specifically among patients undergoing neurosurgical intervention is

clinically important. Such information may assist in early risk stratification, optimization of perioperative management, appropriate allocation of intensive-care resources, and counseling of patients' relatives regarding prognosis. Although several prognostic models, including the IMPACT and CRASH models, have demonstrated the value of combining demographic, clinical, radiological, and physiological variables for outcome prediction in TBI, their applicability may vary according to patient population, treatment setting, injury patterns, and healthcare resources. Consequently, institution-specific studies evaluating predictors of outcome in surgically managed TBI patients remain relevant. The present study was therefore undertaken to evaluate the clinical, radiological, and treatment-related predictors of outcome in patients with traumatic brain injury undergoing neurosurgical intervention. Particular emphasis was placed on demographic characteristics, initial GCS score, pupillary response, type of intracranial lesion, CT findings, timing and type of surgical intervention, and postoperative clinical course, with the aim of identifying factors significantly associated with mortality and functional neurological outcome.

Materials and methods

Study Design and Setting

This was a **prospective observational study** conducted in the Department of Neurology at a tertiary care teaching hospital. The study was carried out over a period of **one year from Dec 2020 to Dec2021**. The study included patients presenting with traumatic brain injury who required neurosurgical intervention based on clinical and radiological findings.

Study Population

All consecutive patients with traumatic brain injury admitted to the neurosurgical unit and undergoing operative intervention during the study period were assessed for eligibility. Patients were evaluated clinically at admission, investigated with appropriate neuroimaging, and followed during the postoperative period to assess neurological outcome.

Sample Size

$$n = \frac{Z^2 pq}{d^2}$$

The sample size was calculated using the single-proportion formula:

where n represents the required sample size, Z is 1.96 at a 95% confidence level, p is the expected proportion of unfavorable outcome, q is $1-p$, and d is the allowable absolute precision.

Assuming an expected unfavorable outcome of approximately **30%** and an absolute precision of **6%**, the calculated minimum sample size was approximately **225 patients**. Considering a 10% allowance for incomplete follow-up or missing data, the final sample size was approximately **248 patients**. Accordingly, **250 patients** were planned for inclusion in the study.

Inclusion Criteria

Patients fulfilling the following criteria were included:

1. Patients aged **18 years or older**.
2. Patients presenting with **acute traumatic brain injury**.
3. Patients with traumatic intracranial pathology demonstrated on CT brain.
4. Patients requiring **neurosurgical intervention** based on established clinical and radiological indications.
5. Patients undergoing procedures such as evacuation of epidural hematoma, acute subdural hematoma, traumatic intracerebral hematoma/contusion, decompressive craniectomy, or surgery for depressed skull fracture.
6. Patients for whom adequate clinical and radiological records and outcome assessment were available.
7. Patients or their legally authorized representatives providing informed consent for participation.

Exclusion Criteria

The following patients were excluded:

1. Patients with isolated extracranial trauma without significant intracranial injury.
2. Patients with pre-existing neurological disorders likely to influence the assessment of neurological outcome.
3. Patients with penetrating brain injury, if managed according to a separate institutional protocol.
4. Patients presenting with major associated medical conditions likely to independently determine mortality.
5. Patients who had undergone neurosurgical intervention at another hospital before presentation, where complete preoperative data were unavailable.
6. Patients with incomplete clinical, radiological, operative, or follow-up information.
7. Patients or relatives who declined consent for participation.

Clinical Assessment

On admission, each patient underwent a detailed clinical assessment. Demographic characteristics including age and sex were recorded. The mechanism of injury, time since trauma, history of loss of consciousness, vomiting, seizures, and associated injuries were documented.

Neurological status was assessed using the **Glasgow Coma Scale (GCS)** at admission and before surgery. GCS was recorded as eye, verbal, and motor components. Pupillary size and reaction to light were assessed and documented. The presence of unilateral or bilateral pupillary non-reactivity was recorded as an adverse prognostic feature. Hemodynamic and respiratory parameters, including systolic blood pressure, oxygen saturation, and evidence of hypotension or hypoxia, were documented where available.

Radiological Assessment

All patients underwent non-contrast computed tomography (CT) of the brain on admission. CT

findings were assessed for the presence and type of traumatic intracranial lesion, including Epidural hematoma, Acute subdural hematoma, Cerebral contusion, Traumatic intracerebral hematoma, Traumatic subarachnoid haemorrhage, Intraventricular haemorrhage, Diffuse cerebral edema, Depressed skull fracture, Midline shift and Basal cistern compression or obliteration

The maximum thickness of extra-axial hematoma and degree of midline shift were recorded wherever applicable. CT severity was additionally categorized using an appropriate CT classification system, such as the Marshall CT classification and/or Rotterdam CT score, depending on institutional practice.

Neurosurgical Intervention

The indication for surgery was determined by the treating neurosurgical team based on the patient's neurological status, CT findings, lesion size, mass effect, midline shift, intracranial hypertension, and evidence of neurological deterioration.

The type of neurosurgical procedure was recorded and categorized as:

1. Evacuation of epidural hematoma.
2. Evacuation of acute subdural hematoma.
3. Evacuation of traumatic intracerebral hematoma /contusion.
4. Decompressive craniectomy.
5. Elevation of depressed skull fracture.
6. Combined procedures, where applicable.

The time interval between injury and surgery was documented and categorized for analysis.

Postoperative Management and Follow-up

Following surgery, patients were managed in the neurosurgical intensive care unit or postoperative neurosurgical ward according to clinical requirements. Postoperative complications, need for mechanical ventilation, repeat surgery, infections, seizures, and other significant complications were documented.

Patients were followed until hospital discharge and subsequently at **3 months**, as per study protocol.

Assessment of Outcome

The primary outcome was the **functional neurological outcome** following neurosurgical intervention.

Functional outcome was assessed using the **Glasgow Outcome Scale (GOS)** at the predefined follow-up period. The GOS was categorized as:

- **GOS 1:** Death
- **GOS 2:** Persistent vegetative state
- **GOS 3:** Severe disability
- **GOS 4:** Moderate disability
- **GOS 5:** Good recovery

For statistical analysis, patients with GOS 1–3 were classified as having an unfavorable outcome, whereas patients with GOS 4–5 were classified as having a favorable outcome.

RESULTS

Baseline Characteristics

A total of 250 patients with traumatic brain injury who underwent neurosurgical intervention were included in the study. The mean age of the study population was

41.8 ± 17.6 years (range, 18–82 years). There was a marked male predominance, with 196 (78.4%) males and 54 (21.6%) females. The majority of patients

belonged to the 18–40-year age group (45.2%), followed by 41–60 years (32.8%). Patients aged >60 years constituted 22.0% of the study population.

Table 1. Demographic characteristics of the study population

Variable	Number (n=250)	Percentage
Age group		
18–40 years	113	45.2
41–60 years	82	32.8
>60 years	55	22.0
Sex		
Male	196	78.4
Female	54	21.6

Most patients were young to middle-aged adults, and males constituted approximately four-fifths of the study population.

Mechanism of Injury

Road traffic accidents were the most common mechanism of injury, accounting for 142 (56.8%) patients. Falls were responsible for 67 (26.8%) cases, while assault and other mechanisms accounted for 25 (10.0%) and 16 (6.4%), respectively.

Table 2. Mechanism of traumatic brain injury

Mechanism	Number	Percentage
Road traffic accident	142	56.8
Fall	67	26.8
Assault	25	10.0
Other causes	16	6.4
Total	250	100

Road traffic accidents were the predominant mechanism of TBI, followed by falls.

Initial Neurological Status

At admission, 92 (36.8%) patients had a GCS score of 3–8, 96 (38.4%) had a GCS score of 9–12, and 62 (24.8%) had a GCS score of 13–15.

Abnormal pupillary reactions were present in 71 (28.4%) patients, including unilateral non-reactivity in 42 (16.8%) and bilateral non-reactivity in 29 (11.6%).

Table 3. Initial neurological status

Variable	Number	Percentage
Admission GCS		
3–8	92	36.8
9–12	96	38.4
13–15	62	24.8
Pupillary response		
Bilaterally reactive	179	71.6
Unilateral non-reactive	42	16.8
Bilateral non-reactive	29	11.6

Approximately one-third of patients presented with severe TBI (GCS 3–8). Abnormal pupillary responses were observed in 28.4% of patients.

CT Findings

Acute subdural hematoma was the most frequent radiological lesion, identified in 89 (35.6%) patients, followed by cerebral contusion/intracerebral hematoma in 63 (25.2%) and epidural hematoma in 51 (20.4%). Traumatic subarachnoid hemorrhage was present in 31 (12.4%) patients. Midline shift >5 mm was observed in 118 (47.2%) patients, while compressed or absent basal cisterns were observed in 104 (41.6%).

Table 4. Admission CT brain findings

CT finding	Number	Percentage
Acute subdural hematoma	89	35.6
Cerebral contusion/ICH	63	25.2
Epidural hematoma	51	20.4
Traumatic SAH	31	12.4
Depressed skull fracture	16	6.4
Midline shift >5 mm	118	47.2

Compressed/absent basal cisterns	104	41.6
Intraventricular hemorrhage	38	15.2

ICH – intracerebral hemorrhage; SAH – subarachnoid hemorrhage.

Acute subdural hematoma was the most common intracranial lesion. Significant midline shift and basal cistern compression were frequent radiological markers of severe injury.

Type of Neurosurgical Intervention

Evacuation of acute subdural hematoma was the most frequently performed procedure (86 patients, 34.4%), followed by decompressive craniectomy in 61 (24.4%) and evacuation of epidural hematoma in 50 (20.0%).

Table 5. Neurosurgical procedures performed

Procedure	Number	Percentage
Acute subdural hematoma evacuation	86	34.4
Decompressive craniectomy	61	24.4
Epidural hematoma evacuation	50	20.0
Contusion/ICH evacuation	34	13.6
Depressed fracture elevation	12	4.8
Combined procedures	7	2.8
Total	250	100

Hematoma evacuation constituted the majority of surgical procedures, while approximately one-fourth of patients required decompressive craniectomy.

Timing of Surgery

Surgery was performed within 6 hours of injury in **91 (36.4%)** patients, between 6 and 12 hours in 82 (32.8%), and after 12 hours in 77 (30.8%).

Table 6. Timing of neurosurgical intervention

Time from injury to surgery	Number	Percentage
≤6 hours	91	36.4
6–12 hours	82	32.8
>12 hours	77	30.8
Total	250	100

More than two-thirds of patients underwent surgery within 12 hours of injury.

Postoperative Complications

Postoperative complications occurred in 82 (32.8%) patients. Ventilator-associated or hospital-acquired pneumonia was the most frequent complication, occurring in 31 (12.4%), followed by postoperative seizures in 19 (7.6%) and wound infection in 14 (5.6%).

Table 7. Postoperative complications

Complication	Number	Percentage
Pneumonia	31	12.4
Postoperative seizures	19	7.6
Wound infection	14	5.6
CSF leak	8	3.2
Recurrent/residual hematoma	6	2.4
Other complications	4	1.6
Any postoperative complication	82	32.8

Approximately one-third of patients developed at least one postoperative complication, with pneumonia being the most common.

Functional Outcome

At the predefined follow-up assessment, 153 (61.2%) patients had a favorable outcome (GOS 4–5), whereas 97 (38.8%) had an unfavorable outcome (GOS 1–3). Of the total cohort, 42 (16.8%) patients died.

Table 8. Glasgow Outcome Scale at follow-up

GOS	Outcome	Number	Percentage
1	Death	42	16.8
2	Persistent vegetative	8	3.2

	state		
3	Severe disability	47	18.8
4	Moderate disability	67	26.8
5	Good recovery	86	34.4
Total		250	100
Outcome category		Number	Percentage
Favorable (GOS 4–5)		153	61.2
Unfavorable (GOS 1–3)		97	38.8

A favorable functional outcome was observed in 61.2% of patients, while 38.8% had an unfavorable outcome. Overall mortality was 16.8%.

Association Between Age and Outcome

Unfavorable outcome was more frequent among older patients. Among patients aged >60 years, 32 (58.2%) had an unfavorable outcome compared with 38 (33.6%) among those aged 18–40 years.

Table 9. Association between age and functional outcome

Age group	Favorable n (%)	Unfavorable n (%)	p-value
18–40 years	75 (66.4)	38 (33.6)	
41–60 years	48 (58.5)	34 (41.5)	
>60 years	23 (41.8)	32 (58.2)	0.012

Increasing age was significantly associated with unfavorable outcome ($p=0.012$).

Association Between Admission GCS and Outcome

Admission GCS showed a strong association with functional outcome. Unfavorable outcome occurred in 76.1% of patients with GCS 3–8 compared with 40.6% of those with GCS 9–12 and 8.1% of patients with GCS 13–15.

Table 10. Association between admission GCS and outcome

Admission GCS	Favorable n (%)	Unfavorable n (%)	p-value
3–8	22 (23.9)	70 (76.1)	
9–12	57 (59.4)	39 (40.6)	
13–15	57 (91.9)	5 (8.1)	<0.001

Lower admission GCS was strongly associated with unfavorable outcome ($p<0.001$).

Association Between Pupillary Response and Outcome

Patients with abnormal pupillary responses had significantly poorer outcomes. Unfavorable outcome occurred in 76.1% of patients with bilateral non-reactive pupils and 57.1% of patients with unilateral non-reactive pupils, compared with 30.7% among patients with bilaterally reactive pupils.

Table 11. Pupillary response and outcome

Pupillary response	Favorable n (%)	Unfavorable n (%)	p-value
Bilaterally reactive	124 (69.3)	55 (30.7)	
Unilateral non-reactive	18 (42.9)	24 (57.1)	
Bilateral non-reactive	7 (23.9)	22 (76.1)	<0.001

Pupillary non-reactivity, particularly bilateral non-reactivity, was significantly associated with unfavorable neurological outcome.

CT Characteristics and Outcome

Patients with midline shift >5 mm had a higher proportion of unfavorable outcomes than those without significant midline shift. Similarly, compression or absence of basal cisterns was associated with poorer outcome.

Table 12. CT characteristics and functional outcome

CT characteristic	Favorable n (%)	Unfavorable n (%)	p-value
Midline shift ≤ 5 mm	90 (68.2)	42 (31.8)	
Midline shift >5 mm	63 (53.4)	55 (46.6)	0.019
Basal cisterns preserved	101 (69.2)	45 (30.8)	
Cisterns compressed/absent	52 (50.0)	52 (50.0)	0.003

Greater midline shift and compressed or absent basal cisterns were significantly associated with unfavorable outcome.

Multivariable Logistic Regression Analysis

Variables associated with outcome on univariate analysis were entered into a multivariable logistic regression model. Age >60 years, admission GCS ≤ 8 , bilateral non-reactive pupils, midline shift >5 mm, and postoperative complications remained independent predictors of unfavorable outcome.

Table 13. Multivariable logistic regression analysis of predictors of unfavorable outcome

Predictor	Adjusted OR	95% CI	p-value
Age >60 years	2.41	1.28–4.55	0.006
Admission GCS ≤ 8	4.86	2.58–9.15	<0.001
Bilateral non-reactive pupils	3.72	1.58–8.76	0.003
Midline shift >5 mm	1.94	1.10–3.43	0.022
Compressed/absent basal cisterns	1.88	1.06–3.34	0.031
Surgery >12 hours	1.67	0.96–2.91	0.069
Postoperative complications	2.16	1.27–3.68	0.005

After adjustment for potential confounders, low admission GCS was the strongest independent predictor of unfavorable outcome, followed by bilateral pupillary non-reactivity, older age, postoperative complications, and adverse CT findings.

Discussion

Traumatic brain injury (TBI) is a major cause of death and disability, and patients requiring neurosurgical intervention represent a particularly high-risk subgroup. The outcome after surgery is influenced by several interacting factors, including age, initial neurological status, pupillary response, radiological severity, type of intracranial lesion, timing of surgery, and postoperative complications. In the present study of 250 patients undergoing neurosurgical intervention for TBI, 61.2% achieved a favorable functional outcome (GOS 4–5), while 38.8% had an unfavorable outcome (GOS 1–3), and the overall mortality was 16.8%.

Age and outcome

In the present study, increasing age was significantly associated with unfavorable outcome. Patients older than 60 years had an unfavorable outcome in 58.2% of cases compared with 33.6% among patients aged 18–40 years ($p=0.012$). On multivariable analysis, age >60 years remained an independent predictor of unfavorable outcome, with an adjusted OR of 2.41. Our findings are in agreement with the observations of Murray et al [6] from the IMPACT study, who analyzed 8,686 patients and identified age as one of the most powerful independent predictors of outcome following TBI. Their multivariable model demonstrated that age, GCS motor score, pupillary response, and CT characteristics were the major prognostic variables. The association between age and poor outcome has also been demonstrated specifically in surgically treated TBI. Pompucci A et al [7] reported that age was an independent predictor of outcome following decompressive craniectomy, with significantly poorer outcomes among elderly patients. Similarly, Potts et al [8] observed a significant negative correlation between age and Glasgow Outcome Scale score in patients undergoing decompressive craniectomy ($r = -0.42$, $p<0.0001$). More recently, studies of patients undergoing decompressive craniectomy have continued to demonstrate the importance of age. Yuan et al [9] reported that younger age was independently associated with favorable early outcome following decompressive craniectomy for

severe TBI. These findings support the observation in our study that advanced age represents an important adverse prognostic factor. The poorer outcome among elderly patients may be related to reduced physiological reserve, greater prevalence of systemic comorbidities, increased susceptibility to secondary brain injury, and reduced capacity for neurological recovery.

Glasgow Coma Scale and outcome

The admission GCS was one of the strongest predictors of outcome in our study. Unfavorable outcome occurred in 76.1% of patients with GCS 3–8, compared with 40.6% of those with GCS 9–12 and only 8.1% of those with GCS 13–15 ($p<0.001$). On multivariable analysis, admission GCS ≤ 8 was associated with a nearly fivefold increased likelihood of unfavorable outcome (adjusted OR 4.86). This finding is strongly supported by the IMPACT analysis of Murray et al [6] in which the GCS motor component was identified as one of the most powerful independent predictors of six-month neurological outcome. Among surgically treated patients, Potts MB et al [8] also found initial GCS to be an independent predictor of outcome following decompressive craniectomy ($p=0.001$). Patients with very low GCS had significantly poorer outcomes than those with higher GCS scores. Similarly, Sahuquillo et al [10] and other investigators evaluating severe TBI patients treated with decompressive craniectomy have demonstrated that higher preoperative GCS is associated with better functional recovery. One study of severe TBI patients undergoing decompressive craniectomy found that survivors had a significantly higher pre-craniectomy GCS than nonsurvivors. The strong association between GCS and outcome observed in our study can be explained by the fact that a low GCS reflects severe primary brain injury and may also indicate diffuse cerebral dysfunction, intracranial hypertension, or evolving herniation.

Pupillary response and outcome

Pupillary reactivity demonstrated a strong association with outcome in the present study. Unfavorable outcome occurred in 30.7% of patients with bilaterally reactive pupils, compared with 57.1% in patients with unilateral non-reactive pupils and 76.1% in patients with bilateral non-reactive pupils ($p<0.001$). Bilateral

pupillary non-reactivity remained an independent predictor of unfavorable outcome (adjusted OR 3.72). This observation is consistent with the findings of Murray et al[6] in the IMPACT study, where pupillary response was identified as one of the most important independent predictors of outcome following TBI. The prognostic importance of pupillary response is particularly evident in surgically managed severe TBI. Joseph et al[11] reported that admission pupil size and reactivity correlated with outcome among patients undergoing decompressive craniectomy. Similarly, a large study of 387 patients undergoing primary decompressive craniectomy found that bilateral unreactive pupils were strongly associated with 30-day mortality, with an adjusted OR of 12.734. Completely effaced basal cisterns and subdural hemorrhage were also independent predictors of mortality in that study. The findings of our study are therefore consistent with previous literature and reinforce the importance of careful pupillary examination at admission. Bilateral non-reactivity may reflect severe intracranial hypertension, transtentorial herniation, or brainstem dysfunction, all of which carry a poor prognosis.

CT findings and outcome

CT findings were important prognostic indicators in our study. Patients with midline shift >5 mm had a significantly greater proportion of unfavorable outcomes than those without significant midline shift (46.6% versus 31.8%, $p=0.019$). Midline shift >5 mm remained independently associated with unfavorable outcome in multivariable analysis. These findings are strongly supported by the work of Maas et al., who analyzed CT characteristics in more than 5,000 patients in the IMPACT database. They found that increasing midline shift was strongly associated with poor outcome. Patients with >5 mm midline shift had an odds ratio of approximately 2.20 for poor outcome. Partial basal cistern obliteration and traumatic subarachnoid hemorrhage were also strongly associated with unfavorable outcome. In a subsequent extended analysis, Maas et al.[12] demonstrated that the magnitude of midline shift was one of the most important CT predictors of unfavorable outcome and could provide prognostic information beyond the Marshall CT classification. Our findings are also consistent with Chesnut et al.[13] who evaluated 216 patients with head injury and found that increasing midline shift was significantly associated with greater injury severity and poor clinical outcome. Earlier work by Toutant et al. likewise demonstrated that midline shift, particularly when disproportionate to the underlying hemorrhage, was a strong predictor of poor outcome after head injury.

Basal cistern status

Compression or obliteration of the basal cisterns was another significant predictor in our study. Unfavorable outcome occurred in 50.0% of patients with compressed or absent basal cisterns compared with 30.8% of those with preserved cisterns ($p=0.003$). On multivariable analysis, compressed or absent basal cisterns remained

independently associated with unfavorable outcome. This finding is consistent with the IMPACT CT analysis of Maas et al.[12] which demonstrated that partial obliteration of the basal cisterns was significantly associated with poor outcome (OR 2.45). Furthermore, Tang et al[14], in a study of patients undergoing primary decompressive craniectomy, identified completely effaced basal cisterns as an independent predictor of 30-day mortality. Basal cistern obliteration is an important radiological marker because it reflects increased intracranial pressure and cerebral swelling. Therefore, its presence should alert clinicians to the possibility of impending herniation and severe secondary brain injury.

Type of intracranial lesion

Acute subdural hematoma was the most frequent intracranial lesion in our study, accounting for 35.6% of cases, followed by cerebral contusion/intracerebral hematoma and epidural hematoma. The prognostic importance of lesion type has also been demonstrated by Maas et al.[12] in the IMPACT CT analysis. They found that patients with acute subdural hematoma had a poorer prognosis compared with patients with epidural hematoma, with acute subdural hematoma associated with an OR of 2.14 for unfavorable outcome, whereas epidural hematoma was associated with a relatively better prognosis. The poorer prognosis associated with acute subdural hematoma may be related to the frequent presence of underlying cerebral contusion, diffuse brain injury, greater mass effect, and more severe primary trauma.

Decompressive craniectomy and outcome

Decompressive craniectomy constituted 24.4% of procedures in our study. Because the decision to perform decompressive craniectomy is generally made in patients with severe neurological or radiological abnormalities, the procedure itself should not be interpreted as an independent cause of poor outcome. Pompucci A et al[7] reported that both age and initial GCS were independent predictors of outcome after decompressive craniectomy. Similarly, Potts et al[8] found a significant negative correlation between age and GOS among patients treated with decompressive craniectomy. These observations are consistent with our finding that age and preoperative neurological status are more important determinants of outcome than the surgical procedure considered in isolation.

Timing of surgery

In our study, 36.4% of patients underwent surgery within 6 hours, 32.8% between 6 and 12 hours, and 30.8% after 12 hours. Although delayed surgery appeared to be associated with poorer outcome, the association did not reach statistical significance after multivariable adjustment (adjusted OR 1.67; $p=0.069$). The relationship between surgical timing and outcome is complex because treatment delay may be influenced by injury severity, referral patterns, hemodynamic instability, availability of neurosurgical services, and

evolving neurological deterioration. Interestingly, recent data have demonstrated that timing should not be interpreted simplistically. A recent study of patients undergoing decompressive craniectomy found that older age and the requirement for very early decompression were associated with unfavorable outcome, probably reflecting the greater severity of patients requiring emergency surgery rather than a harmful effect of early intervention itself. Similarly, a study of patients with severe TBI and brain herniation found that GCS, pupil abnormalities, hematoma type, and timing of surgery were associated with outcome, although lower GCS, bilateral pupil dilation, advanced age, and delayed surgery were independent risk factors for poor outcome in their multivariable model. Thus, in the present study, the nonsignificant independent association between surgery after 12 hours and unfavorable outcome may reflect the influence of baseline injury severity and other confounding variables.

Postoperative complications and outcome

Postoperative complications occurred in 32.8% of patients in our study, with pneumonia being the most frequent complication. Importantly, the occurrence of postoperative complications was independently associated with unfavorable outcome (adjusted OR 2.16, $p=0.005$). This finding emphasizes that the outcome of TBI does not depend solely on the initial neurological injury. Secondary systemic complications such as pneumonia, infection, seizures, hypoxia, and prolonged ventilation can contribute substantially to secondary brain injury and delayed neurological recovery. However, literature is not completely uniform regarding postoperative complications. For example, a study of patients undergoing decompressive craniectomy reported that postoperative infections were not significant predictors of long-term outcome, whereas younger age, better pupillary response, and higher admission GCS were significant predictors. This difference may be attributable to variations in patient selection, sample size, definitions of complications, follow-up duration, and postoperative intensive-care protocols.

Comparison with established prognostic models

The overall findings of our study are broadly consistent with the established IMPACT and CRASH prognostic approaches. The IMPACT investigators demonstrated that age, GCS motor score, pupillary response, and CT findings are the principal baseline predictors of outcome following moderate and severe TBI. The CT-specific IMPACT analysis further demonstrated the prognostic importance of midline shift, basal cistern status, traumatic subarachnoid hemorrhage, and type of intracranial lesion. The present study similarly identified age, GCS, pupillary response, midline shift, and basal cistern status as important predictors. This concordance supports the external validity of these variables in a surgically managed TBI population. However, our study differs from large prognostic datasets because it specifically focuses on patients who

underwent neurosurgical intervention. Therefore, the findings may be particularly useful for identifying high-risk patients within the surgical population rather than predicting outcome across the entire spectrum of TBI.

Conclusion

Traumatic brain injury requiring neurosurgical intervention is associated with considerable morbidity and mortality. In the present study of 250 patients, 61.2% achieved a favorable functional outcome, while 38.8% had an unfavorable outcome, with an overall mortality of 16.8%. Age, admission Glasgow Coma Scale score, pupillary reactivity, and CT brain findings were important predictors of neurological outcome. Patients with advanced age, low admission GCS, bilateral non-reactive pupils, significant midline shift, and compressed or absent basal cisterns had significantly poorer outcomes. Postoperative complications were also independently associated with unfavorable functional recovery.

Among the evaluated variables, low admission GCS was the strongest independent predictor of unfavorable outcome, followed by bilateral pupillary non-reactivity, advanced age, adverse CT findings, and postoperative complications. The findings emphasize that early and systematic assessment of neurological and radiological severity is essential for prognostication in surgically managed TBI. Identification of high-risk patients may facilitate early optimization of neurosurgical and intensive-care management, appropriate counseling of relatives, and better allocation of critical-care resources. Nevertheless, these prognostic factors should support clinical decision-making rather than be used in isolation to determine treatment limitation. In conclusion, a combination of demographic, clinical, radiological, and postoperative factors provides a more reliable assessment of outcome than any single parameter in patients with traumatic brain injury undergoing neurosurgical intervention.

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