International Journal of Life Sciences, Biotechnology and Pharma Research Vol. 13, No. 11, November 2024 Online ISSN: 2250-3137
Print ISSN: 2977-0122

DOI: 10.69605/ijlbpr_13.11.2024.61

ORIGINAL RESEARCH

Factors Influencing Outcomes after Decompressive Craniectomy in Severe Traumatic Brain Injury

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Received date: 22 September, 2024 Acceptance date: 25 October, 2024

ABSTRACT
Traumatic brain injury (TBI) remains a significant global health burden, associated with high mortality and morbidity, particularly in developing nations. Decompressive craniectomy (DC) has emerged as a crucial surgical intervention for severe TBI cases with refractory intracranial hypertension, aiming to reduce pressure and potentially improve outcomes. This prospective analytical study, conducted at a single tertiary care centre in India, evaluated the outcomes of DC in 52 patients with severe TBI and midline shift. The primary outcomes assessed were mortality and favourable outcomes based on the Glasgow Outcome Scale (GOS) at various follow-up points. Factors such as age, pre-operative GCS, pupillary reactivity, midline shift, and CT scan findings were analysed for their influence on outcomes. The study revealed a mortality rate of 71.1% at 6 months. However, 21.2% of patients achieved a good recovery. Pre-operative GCS, pupillary reactivity, and midline shift were identified as significant predictors of outcomes. These findings underscore the potential of DC to improve outcomes in severe TBI, while also highlighting the need for further research, particularly randomized controlled trials, to establish definitive evidence for its efficacy.

Keywords: Traumatic brain injury, Decompressive craniectomy, Midline shift, Intracranial pressure

INTRODUCTION

Traumatic brain injury (TBI) constitutes a pressing global health challenge, inflicting substantial mortality and morbidity across the world. The socioeconomic ramifications of TBI are particularly pronounced in low- and middle-income countries (LMICs), where it accounts for a disproportionate share of the global burden. These nations grapple with a higher incidence of TBI, often attributed to factors such as road traffic accidents, falls, and occupational hazards(1). The lack of adequate healthcare infrastructure and resources in LMICs further exacerbates the impact of TBI, leading to increased mortality, long-term disability, and significant financial strain on individuals and communities. The World Health Organization estimates that over 60 million people sustain a TBI each year, resulting in approximately 1.5 million deaths and leaving millions more with varying degrees of disability (2). The consequences of TBI extend beyond the immediate physical and cognitive impairments, affecting individuals' quality of life, productivity, and overall well-being.

The pathophysiology of TBI is a cascade of events initiated by the primary injury, leading to secondary insults that significantly impact patient outcomes. The initial trauma disrupts the blood-brain barrier, triggering inflammation and oedema formation within the injured brain tissue. This, coupled with potential vascular damage, compromises cerebral blood flow (CBF) and oxygen delivery (3). The Monro-Kellie doctrine, which states that the intracranial volume is fixed, dictates that any increase in one component (e.g., blood, brain tissue, or cerebrospinal fluid) must be compensated by a decrease in another. In TBI, the expanding oedema and potential hematomas increase intracranial volume, leading to a rise in intracranial pressure (ICP) (4,5).

Elevated ICP, in turn, reduces cerebral perfusion pressure (CPP), further compromising CBF and oxygenation (6). This can create a vicious cycle, as ischemia triggers vasodilation in an attempt to restore

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blood flow, but this further increases ICP(6). Additionally, TBI often disrupts the brain's autoregulatory mechanisms, making it vulnerable to fluctuations in CPP and exacerbating the ischemic insult (7). Sustained ICP elevation has devastating consequences, including brain herniation, tissue necrosis, and ultimately, poor neurological outcomes or death (8).

In the face of intractable intracranial hypertension, decompressive craniectomy (DC) emerges as a surgical lifeline. The essence of this procedure lies in the strategic removal of a segment of the skull, thereby affording the beleaguered brain the space it desperately needs to expand. This calculated expansion serves to directly alleviate the relentless pressure that has built up within the cranial confines (9). By providing an avenue for the brain to swell outward, rather than inward against unyielding bone, DC effectively mitigates the risk of devastating complications such as brain herniation and tissue ischemia (10). The fundamental principle underpinning DC is rooted in the Monro-Kellie doctrine, which posits that the intracranial volume must remain constant (4,5). By augmenting this volume through the removal of a bony constraint, DC facilitates a rapid and substantial reduction in intracranial pressure, offering a critical window of opportunity for the injured brain to recover (10).

The efficacy of DC in TBI has been a subject of extensive research and debate. Early studies reported mixed results, with some demonstrating improved survival but not necessarily better functional outcomes (11). However, recent randomized controlled trials (RCTs) like DECRA and RESCUEicp have reignited interest in DC, suggesting potential benefits in reducing mortality and improving functional outcomes in select patients (12). Despite these advances, significant knowledge gaps persist. The optimal timing of DC remains controversial, with conflicting evidence regarding early versus late intervention (13). Additionally, the ideal patient selection criteria for DC are not fully established, and there is a need for better prognostic tools to identify those who would benefit most from the procedure (14).

This study aimed to evaluate the outcomes of decompressive craniectomy in patients with severe traumatic brain injury exhibiting midline shift and mass effect. The primary objective was to assess the impact of DC on mortality and functional outcomes in this specific patient population. The secondary objective was to identify clinical and radiological factors that could predict outcomes after DC, aiding in patient selection and prognostication. By addressing these objectives, this study sought to contribute to the ongoing discourse on the role of DC in the management of severe TBI.

MATERIALS & METHODS

Study Design and Setting

This investigation employed a prospective analytical design, carried out within the confines of a singular tertiary care institution, namely Gandhi Medical College and its affiliated Hamidia Hospital, situated in Bhopal, India. The study unfolded over a span of two years, commencing in August 2022 and culminating in May 2024. This temporal framework allowed for the enrolment and observation of patients presenting with severe traumatic brain injury (TBI) necessitating decompressive craniectomy (DC). The choice of a single-centre setting ensured consistency in patient management protocols and data collection procedures, thereby enhancing the internal validity of the study.

Patient Selection

Stringent inclusion and exclusion criteria were implemented to curate a well-defined cohort for this study. Patients were deemed eligible if they presented with severe head injury, as evidenced by a Glasgow Coma Scale (GCS) score of 12 or lower, necessitating DC as part of their management. The aetiology of the injury was restricted to traumatic causes, excluding non-traumatic conditions such as spontaneous intracranial haemorrhage or stroke. Further, patients exhibiting a post-resuscitation GCS score between 4 and 12 were included, ensuring a degree of neurological responsiveness. Radiological evidence of significant intracranial pathology, including acute subdural hematoma, haemorrhagic contusions with cerebral oedema, and a midline shift exceeding 5mm on CT scan, was also mandatory for inclusion. Conversely, patients with mild TBI, those not requiring surgical intervention, individuals with significant comorbidities or polytrauma, isolated epidural hematoma, non-traumatic aetiologies, a post-resuscitation GCS of 3, absent brainstem reflexes, or those declining consent were excluded from the study. This selection process aimed to create a homogenous study population, thereby minimizing confounding variables and enhancing the study's focus on the specific impact of DC in severe TBI with midline shift.

Data Collection

Upon admission to the emergency department, patients underwent a comprehensive evaluation encompassing vital parameters, airway management, and neurological assessment using the Glasgow Coma Scale (GCS). A computed tomography (CT) scan was promptly performed to assess the extent of intracranial injury. For eligible patients, detailed clinical data was meticulously recorded, including age, sex, mode of injury (road traffic accident, fall, assault), pre- and post-operative GCS scores, pupillary reactivity, and the presence of associated injuries (faciomaxillary, chest, abdominal, spinal, and limb injuries). CT scan findings were also documented, with particular attention to midline shift and the type of intracranial

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lesion (subdural hematoma, haemorrhagic contusion, or a combination). The Glasgow Outcome Scale (GOS), a standardized tool for assessing functional outcomes after TBI, was employed to evaluate patient status at discharge, three months, and six months post-surgery.

Statistical Analysis

Data analysis was conducted using SPSS version 21. The chi-square test was utilized to examine potential associations between various clinical and radiological parameters and patient outcomes, including survival and favourable outcomes as defined by the GOS. A p-value less than 0.05 was considered statistically significant, indicating a non-random association between the variables under investigation. This rigorous statistical approach aimed to identify key factors that could predict outcomes after DC in severe TBI patients, thereby contributing to improved patient selection and prognostication.

RESULTS

Patient Demographics

The study encompassed 52 patients with severe traumatic brain injury (TBI) who underwent decompressive craniectomy. The mean age was 39.8 years (standard deviation 12.24), with the majority (80.8%) being male. The predominant mechanism of injury was road traffic accidents (76.9%), followed by falls (19.2%).

Mortality and Favourable Outcomes

The overall mortality rate at 6 months post-surgery was 71.1%. At the time of discharge, 5.8% of patients demonstrated a good recovery (GOS 5), and 15.4% showed mild disability (GOS 4). At the 3-month follow-up, these figures shifted to 11.5% for good recovery and 5.7% for mild disability. By the 6-month mark, good recovery was seen in 15.4% and mild disability in only 1.9% of patients. Notably, no patients remained in a persistent vegetative state throughout the follow-up period.

Table 1 - Distribution of patients according to age group – survival and outcome

Age Group	Status and outcome of the patient				
	Survival			Death GOS(1)	Total
	Favourable GOS (5 and 4)	Unfavourable GOS (3 & 2)	Total		
13-20	0	0	0	0	0
21-30	4 (30.8)	4 (30.8)	8 (61.5)	5 (38.4)	13 (100.0)
31-40	3 (18.8)	1 (6.2)	4 (25)	12 (75)	16 (100.0)
41-50	2 (15.4)	2 (15.4)	4 (30.8)	9 (69.2)	13 (100.0)
51-60	2 (33.3)	0	2 (33.3)	4 (66.7)	6 (100.0)
≥61	0	0	0	4 (100.0)	4 (100.0)
Total	11 (21.1)	7 (13.5)	18 (34.6)	34 (65.4)	52 (100.0)

Predictive Factors and Outcomes

Several factors were found to be significantly associated with outcomes after DC.

Age: Although not statistically significant, a trend towards decreased survival was observed with increasing age. The survival rate was highest in the youngest age group (≤30 years) at 61.5%, and decreased progressively with each subsequent age group, reaching 0% in the oldest group (≥61 years).

Pre-operative GCS: A strong association was found between pre-operative GCS scores and both survival and favourable outcomes ($p < 0.001$). Patients with moderate TBI (GCS 9-12) exhibited a significantly higher survival rate (73.3%) and a greater proportion of favourable outcomes (60%) compared to those with severe TBI (GCS 6-8; survival 18.9%, favourable outcomes 5.4%) or very severe TBI (GCS 3-5; survival 0%, favourable outcomes 0%).

Pupillary Reactivity: Pupillary reactivity was significantly associated with both survival and favourable outcomes ($p < 0.001$). Patients with reactive pupils had a notably higher survival rate (63%) and a greater likelihood of favourable outcomes (40.7%) compared to those with abnormal pupillary reactions (survival 4%, favourable outcomes 0%).

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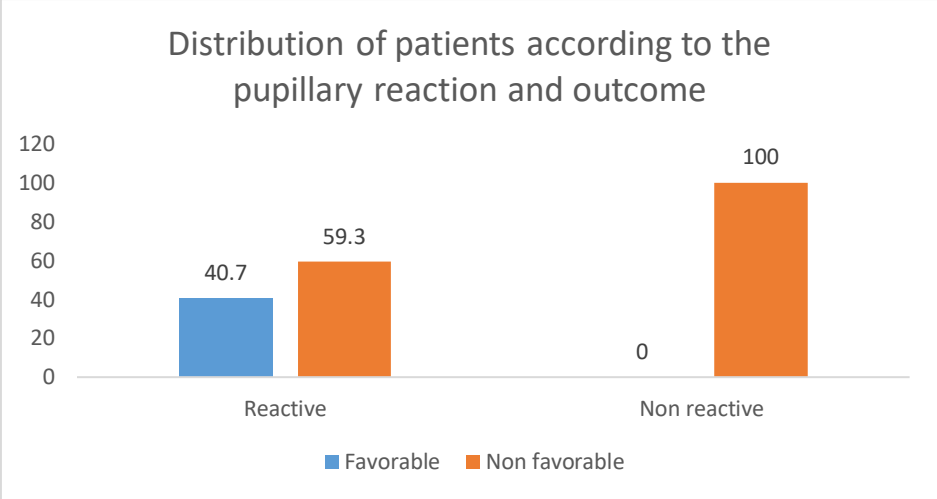

Figure 1 – Distribution of patients according to the pupillary reaction and outcome

Midline Shift: Pre-operative midline shift also demonstrated a significant association with survival and outcomes ($p < 0.05$ and $p < 0.001$, respectively). As the degree of midline shift increased, survival rates and the proportion of favourable outcomes decreased. Patients with a midline shift greater than 11 mm had the lowest survival rate (13.3%) and no favourable outcomes.

Table 2 – Distribution of patients according to the Pre-Op Mid Line Shift and survival

Pre-Op Mid Line Shift	Status of the patient		Total	Chi square value P value
	Survival	Death		
	N (%)	N (%)	N (%)	10.860
<5 mm	1 (100.0)	0 (0.0)	1 (100.0)	
5-8 mm	9 (64.3)	5 (35.7)	14 (100.0)	0.013
8-11 mm	6 (27.3)	16 (72.7)	22 (100.0)	
>11 mm	2 (13.3)	13 (86.7)	15 (100.0)	
Total	18 (34.6)	34 (65.4)	52 100.0)	

CT Scan Findings: The type of intracranial lesion on CT scan was significantly associated with both survival and favourable outcomes ($p < 0.01$). Patients with isolated subdural hematoma (SDH) exhibited the highest survival rate (83.3%) and the greatest proportion of favourable outcomes (83.3%). In contrast, patients with isolated haemorrhagic contusion (HC) had the lowest survival rate (8.3%) and the lowest proportion of favourable outcomes (8.3%). Patients with a combination of SDH, HC, and other findings had intermediate outcomes.

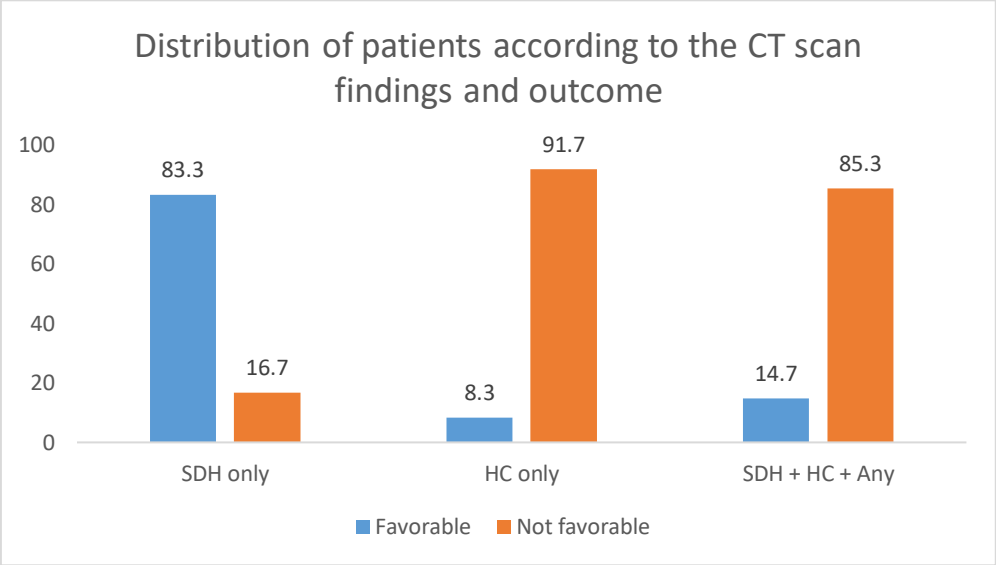

Figure 2 – Distribution of patients according to the CT scan findings and outcome

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Complications

The majority of patients (76.9%) did not experience any complications. Among those who did, pulmonary complications were the most prevalent (9.5%), followed by surgical site infections (5.8%) and other wound infections (3.8%). Less frequent complications included diabetic ketoacidosis with acute renal failure and shock, each occurring in 1.9% of patients.

DISCUSSION

Interpretation of Findings

The present study, conducted at Gandhi Medical College and Hamidia Hospital, revealed a 6-month mortality rate of 71.1% following DC for severe TBI with midline shift. While this figure underscores the gravity of such injuries, it is essential to recognize that 21.2% of patients achieved a good recovery (GOS 5) at the final follow-up. This observation aligns with recent literature, suggesting that DC can lead to meaningful functional outcomes in a subset of patients, even in the context of high mortality rates (12).

The study identified several factors significantly associated with outcomes after DC. The strong correlation between pre-operative GCS and both survival and favourable outcomes echoes findings from numerous other studies (1,14–16). This reinforces the critical role of pre-operative neurological status in predicting outcomes and underscores the importance of early and aggressive management of severe TBI. Similarly, the significant association between pupillary reactivity and outcomes aligns with previous research, highlighting its value as a prognostic indicator(1,14–17).

The observation that increasing midline shift is linked to poorer outcomes is consistent with the understanding that greater midline shift reflects more severe brain injury and increased intracranial pressure (1). This finding supports the use of midline shift as a key factor in patient selection for DC and prognostication. The study also found that isolated subdural hematoma (SDH) was associated with better outcomes compared to isolated haemorrhagic contusion (HC) or combined lesions. This suggests that the type of intracranial pathology may influence the efficacy of DC, potentially guiding surgical decision-making.

While the study did not find a statistically significant association between age and outcomes, a trend towards decreased survival with increasing age was observed. This aligns with the notion that the brain's plasticity and capacity for recovery diminish with age (1). However, the lack of statistical significance may be attributed to the relatively small sample size and the limited age range of the study population.

In contrast to some previous studies (18,19), this study did not identify sex as a significant predictor of outcomes after DC. This discrepancy may be due to variations in study populations, injury patterns, or other confounding factors. Further research is needed to elucidate the potential role of sex in influencing outcomes after DC.

Finally, the study's findings regarding the most common complications after DC, particularly pulmonary complications, are consistent with previous reports (20). This emphasizes the need for vigilant post-operative care and proactive management of potential complications to optimize patient outcomes.

Clinical Implications

The identification of pre-operative GCS, pupillary reactivity, and midline shift as significant predictors of outcomes after DC carries substantial clinical implications. These factors can serve as valuable tools in guiding patient selection for DC, enabling clinicians to identify individuals who are most likely to benefit from the procedure. For instance, patients with a low pre-operative GCS, abnormal pupillary reactions, or a large midline shift may have a poorer prognosis, and alternative treatment strategies might be considered. Conversely, patients with a higher GCS, reactive pupils, and minimal midline shift may be more likely to experience favourable outcomes after DC, supporting the decision to proceed with surgery.

Furthermore, these predictive factors can aid in prognostication, allowing clinicians to provide more accurate and realistic expectations to patients and their families regarding potential outcomes after DC. This can facilitate informed decision-making and shared goal setting, ensuring that treatment plans align with individual patient needs and preferences.

In the broader context of severe TBI management, these findings underscore the importance of early and aggressive intervention to mitigate secondary brain injury and optimize outcomes. Rapid identification and treatment of intracranial hypertension, along with careful consideration of factors such as GCS and pupillary reactivity, can help guide timely decision-making regarding the need for DC. Additionally, the study's results highlight the potential influence of the type of intracranial lesion on outcomes, suggesting that further research is warranted to explore the role of lesion characteristics in predicting response to DC.

Overall, the identification of these predictive factors has the potential to refine patient selection, improve prognostication, and inform decision-making in the management of severe TBI, ultimately leading to more personalized and effective treatment strategies.

Study Limitations

The present study, while offering valuable insights into the outcomes of DC in severe TBI, is not without its limitations. The relatively small sample size of 52 patients may limit the statistical power and generalizability of the findings. Additionally, the single-centre design restricts the applicability of the results to other settings and populations, as variations in patient demographics, injury patterns, and

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treatment protocols may exist. The lack of intracranial pressure (ICP) monitoring is another notable limitation, as it precludes a direct assessment of the impact of DC on ICP reduction and its correlation with outcomes. Future research should aim to address these limitations by conducting larger, multicentre studies with standardized ICP monitoring protocols.

Future Research Directions

Several avenues for future research emerge from this study. Larger, multicentre studies with diverse patient populations and standardized ICP monitoring are needed to validate the findings and enhance their generalizability. Additionally, future research should explore the impact of different surgical techniques (e.g., unilateral vs. bifrontal craniectomy) and the timing of DC (early vs. late) on outcomes. Investigating long-term functional outcomes, quality of life, and neurocognitive function after DC is also crucial to gain a more comprehensive understanding of its impact on patients' lives. Finally, the development and validation of prognostic models incorporating the identified predictive factors could further refine patient selection and optimize the use of DC in severe TBI management.

CONCLUSION

In this single-centre prospective study evaluating decompressive craniectomy (DC) in severe traumatic brain injury (TBI) with midline shift, we observed a mortality rate of 71.1% at 6 months. However, a significant proportion of patients (21.2%) achieved good recovery. Pre-operative Glasgow Coma Scale (GCS), pupillary reactivity, and midline shift emerged as strong predictors of survival and favourable outcomes. These findings highlight the potential of DC to improve outcomes in select patients.

Our study underscores the importance of considering pre-operative GCS, pupillary reactivity, and midline shift when making decisions about DC in severe TBI. These factors can aid in identifying patients who are most likely to benefit from the procedure, facilitating informed decision-making and prognostication. The potential for good recovery in a subset of patients, even in the context of high mortality, emphasizes the value of DC as a life-saving and potentially function-preserving intervention.

While our study provides valuable insights, further research, particularly well-designed randomized controlled trials, is necessary to definitively establish the efficacy of DC in TBI management. Future studies should also focus on long-term functional and quality-of-life outcomes, as well as the impact of different surgical techniques and timing of DC.

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