

Outcome Analysis of Decompressive Craniectomy in Patients with Severe Head Injury

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Abstract:

Background: Severe head trauma is the leading cause of both mortality and morbidity, frequently followed by secondary brain injury and/or intracranial hypertension (ICP). Initial management is medical, but if it fails to treat ICP, decompressive craniectomy (DC) may be the only surgical intervention left to alleviate ICP, salvage the patient and improve cerebral perfusion.

Aim: To review the outcome of DC for patients with severe traumatic brain injury (TBI) and outline predictors of survival and functional recovery.

Methodology: A prospective observational study of 70 patients aged 18 to 65 years with a diagnosis of severe TBI (GCS ≤ 8) and imaging consistent with ICP where DC was performed after optimized medical therapy failed. Patients were monitored and followed in the postoperative neurosurgical intensive care unit (ICU). Outcomes were assessed using the Glasgow Outcome Score Extended (GOSE) at discharge and then at 3- and 6-month follow-up appointments. Analyses were performed with SPSS 25.0 software and $p < 0.05$ was considered significant.

Results: A younger patient age and higher pre-operative GCS were correlated with better functional outcomes and survival (median age 27 years vs 42 years, pre-DC GCS 7 vs 6, continued significance $p < 0.01$). Effective ICP reduction post-surgery is more closely related to good recovery (median decrease in ICP 22 vs 11 mmHg, $p < 0.0001$). Persistent ICP elevation later post-DC implies poor recovery. Acute, early, and delayed complications, including contusion expansion, infections, hydrocephalus, and those related to cranial bone, post-cranioplasty were observed, however, all complications were manageable within a well-defined system of care.

Conclusion: Decompressive craniectomy is an essential intervention for those with severe head injury and refractor intracranial hypertension. A timely surgical intervention, effective ICP reduction, and vigilant perioperative system of care will dramatically improve survival rates and functional outcomes, especially among younger patients with a higher preoperative neurological status.

Keywords: Severe head injury, decompressive craniectomy, intracranial pressure, traumatic brain injury, Glasgow Outcome Score.

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Introduction

Severe head injury is still one of the most catastrophic causes of morbidity and mortality worldwide, especially among young adults and those in their most productive years of life. Traumatic brain injury (TBI) includes all forms of neurological damage that result due to an external force to the head that results in disruption of normal brain function. One of the most common sequelae of TBI is the rapid onset of intracranial hypertension with increased intracranial pressure (ICP), which can influence cerebral perfusion and lead to secondary brain injury [1]. Management of intracranial hypertension is one of the central tenets of modern neurocritical care. However, when medical therapies have failed, surgical interventions such as decompressive craniotomy (DC) can play a role in maintaining life.

Decompressive craniectomy is a surgical technique that entails the resection of a segment of the skull to make room for the enlarged brain to expand outside of the skull and relieve intracranial pressure, with a view to avoiding further neuronal tissue damage caused by compression, ischemia, and herniation. Although the idea of cranial decompression has been around for more than a century, it has received renewed interest in contemporary neurosurgical practice considering improvements in neuroimaging, critical care, and postoperative management [2]. DC is now regarded as a life-saving procedure in selectively treated patients with severe traumatic brain injury, when conventional medical therapies are insufficient.

The pathophysiology of severe head injury includes a complicated cascade of primary and secondary CNS injury. The main damage happens immediately following trauma, and is encompassed by confusion, hemorrhages, and diffuse axonal injuries. The secondary injury, which develops over hours or days, occurs by mechanisms such as cerebral edema, hypoxia, ischemia, and excitotoxicity. Intracranial hypertension is one of the most significant contributors of secondary injury to the brain; it decreases cerebral blood flow and oxygen delivery. If untreated, this may result in irreversible neuronal death and brain herniation. Decompressive craniectomy directly interrupts such a mechanism by providing physical space for the swollen brain and re-establishing cerebral perfusion pressure [3].

The main management goal in severe head injury is to maintain good cerebral perfusion and oxygenation, while preventing secondary brain injury. Management starts largely as a medical effort to achieve this, using sedation, osmotic therapy (either mannitol or hypertonic saline), controlled ventilation, and draining cerebrospinal fluid to treat elevated intracranial pressure (ICP) [4]. At times though, this may not be enough, and therefore decompressive craniectomy becomes necessary. Decompressive craniectomy may be seen as both a preventive measure and a treatment when neurosurgeons are faced with clinically significant ICP; it will reduce the immediate risk of brain herniation and may positively affect outcomes, particularly among select populations of head-injured patients.

The criteria for decompressive craniectomy in patients with severe head trauma are generally established based on clinical and radiological assessments. Historically, the procedure was most often performed on patients with diffuse cerebral swelling, large confusions, or refractory intracranial hypertension that did not respond to maximal medical management. The timing of surgery is also critical, since early decompression can prevent further irreversible brain injury, while delayed surgical intervention will eliminate any potential for benefit [5]. Moreover, the choice to proceed with decompressive craniectomy and the decision to provide care in the intensive care & neuro critical care unit must involve navigating a multiplicity of opinions among experienced neurosurgeons, neuro intensivists, and a critical care team to select the appropriate patient and provide effective postoperative care.

Many powerful randomized clinical trials have influenced the way the practice of decompressive craniectomy was conducted in TBI. For example, the DECRA (Decompressive Craniectomy in Diffuse Traumatic Brain Injury) and RESCUE (Randomized Evaluation of Surgery with Craniectomy for Uncontrolled Elevation of Intracranial Pressure) trial outcomes, have provided us with critical evidence regarding the advantages and disadvantages of

decompressing craniectomy. It is true that DC had a significant reduction in rates of intracranial pressure and mortality; however, the potential for the rate of severe disability and with poor functional outcome remains a concern in the survivors [6]. These findings highlight the importance of the consideration of individual factors in patients and opportunity for guidelines and standardization in treatment protocols.

Despite the controversies, decompressive craniectomy will always be an important intervention to reduce pressure from severe head injury, particularly in parts of the world where access to advanced neurocritical care is not that prevalent. In these cases, timely surgical decompression could mean the difference between life and death. Moreover, the surgical procedure will evolve from decompression by bifrontal, unilateral front temporoparietal, and hemi-craniectomy patterns and pathologies that are common, it is also important to mention that improvement in surgical outcomes in patients has evolved as cardinal in the realm of subacute postoperative patient care; regarding gradual bone flap replacement (cranioplasty) rehabilitation, and neuro-monitoring [7].

An ethical and social dimension will be present when the clinician ultimately decides to perform a decompressive craniectomy. The decompressive craniectomy may be lifesaving. However, patients who survive a craniectomy likely, will survive with significant neurological impairment and a poor quality of life. Families and clinicians go through a complex decision-making process about the odds of survival compared to the reality of living long-term with a disability [8]. Thus, the ethical aspects of severe head trauma will require a transparent conversation, informed consent, and an interprofessional process.

Over the past several years, research has begun to refine the indications, timing, and techniques of decompressive craniectomy to improve therapeutic outcomes. Developments such as individualized decompressive strategies, dural expansion techniques, and new multidimensional neuro-monitoring technologies all lend themselves to a more individualized surgical approach [9]. In addition, the combination of decompressive craniectomy with neuroprotective adjuncts, protocolized rehabilitation interventions, and a robust approach to post-acute care allows for a more from-a-whole-context approach to improve outcomes for severely brain injured patients.

In conclusion, decompressive craniectomy is the treatment of choice for reducing the chance of death from severe head injury, particularly when intracranial hypertension complicates things despite maximal medical therapy. The objectives of decompressive craniectomy are to relieve pressure within the

cranial cavity, provide adequate reperfusion to the brain, and prevent lethal brain herniation. There will remain some level of controversy regarding decompressive craniectomy; nevertheless, the procedure saves many lives in the scope of injury management as part of the complete neurotrauma supportive care pathway. As we expand our research in future science, technique development, and critical care innovations, we will redefine and enhance the function of decompressive craniectomy in safeguarding patients with brain injuries. Decompressive craniectomy is not only about the act of the surgical technique or surgical procedure to restore the normal characteristics of the skull, but also to have the proper indications for surgery, the multidisciplinary team approach, and patient centered quality care, beyond the surgical intervention.

Methodology

Study Design: This research was designed as a prospective observational study that aimed to investigate the effects of decompressive craniectomy (DC) on patients with severe head injury. We looked at clinical factors, surgeries, and post-operative outcomes to assess the effect of DC on mortality and neurological recovery.

Study Area: The study was performed at the Department of Neurosurgery, Malda Medical College and Hospital in Malda, West Bengal, India from December 2022 to November 2023

Study Participants

Inclusion Criteria:

- Individuals aged 18 to 65 with a severe traumatic brain injury (TBI) with a Glasgow Coma Scale (GCS) score of ≤ 8 upon admission.
- Patients with radiographic signs of elevated intracranial pressure (ICP) because of cerebral edema, an acute subdural hematoma or contusion.
- Patients undergoing decompressive craniectomy after a period of optimal medical management has failed.

Exclusion Criteria:

- Patients with bilaterally fixed, dilated pupils at admission.
- Those with polytrauma non-survivable or brain-survivable injuries.
- Patients who died before the operative indication or did not consent.
- Patients who suffered penetrating head injuries or previous cranial surgery.

Sample Size: The study enrolled 70 patients who met criteria for inclusion to participate.

Procedure: All patients with severe head injury were initially stabilized in the emergency department based on ATLS (Advanced Trauma Life

Support) protocols. After the initial resuscitation, neurological assessment was performed with the GCS (Glasgow Coma Scale), and baseline investigations such as CT scan of the brain were evaluated. Only patients with evidence of raised intracranial pressure that was refractory to maximal medical management (mannitol, hypertonic saline, head elevation, sedation, and controlled ventilation) were recruited for decompressive craniectomy.

Surgical techniques involved performing a large fronto-temporo-parietal craniectomy using duality to provide adequate decompression of the swollen brain. The operative note documented intraoperative data including brain swelling, hematoma type, and contusions. Patients who were managed after surgery in neurosurgical intensive care unit (ICU) care for an additional postoperative phase, with continuous ICP, GCS, and vital monitoring. Records of complications such as rebleeding, infections, hydrocephalus and persistent intracranial hypertension. When assessing recovery and functional independence, neurological outcomes were evaluated at discharge and follow-up at 3 and 6 months using the Glasgow Outcome Score Extended (GOSE).

Statistical Analysis: Data was collected and analyzed utilizing SPSS version 25.0 (IBM Corp., Armonk, NY). Continuous variables were expressed as mean $\pm$ standard deviation (SD) and analyzed using either the student's t-test or the Mann-Whitney U test, contingent upon data distribution. Categorical variables were represented as frequencies and percentages and analyzed using the Chi-square test. A p-value < 0.05 was considered statistically significant. Outcomes were classified as good (GOSE 5–8) or poor (GOSE 1–4, including death) to evaluate the prognostic impact of decompressive craniectomy in severe head injury.

Result

Table 1 illustrates the clinical and demographic variables correlated with long-term functional outcomes in 70 individuals who underwent decompressive craniectomy (DC). Gender distribution was similar between groups and not statistically significant. Patients with a good outcome were significantly younger (median age 27 vs. 42 years, $p = 0.003$) and had higher pre-DC Glasgow Coma Scale (GCS) scores (7 vs. 6, $p < 0.0001$). Preoperative maximum intracranial pressure (ICP) did not differ significantly between groups, but a higher proportion of patients with poor outcomes had unchanged ICP after surgery (65% vs. 33%, $p = 0.003$). Additionally, the median decrease in ICP was significantly greater in patients with good outcomes compared to those with poor outcomes (22 vs. 11 mmHg, $p < 0.0001$), indicating that age, initial neurological status, and effective ICP reduction are key predictors of long-term functional recovery after DC.

Table 1: Clinical and demographic variables correlated with prospective functional outcomes following decompressive craniectomy (n = 70)

Factors	Poor Outcome (n = 34)	Good Outcome (n = 36)	p-value
Gender (M/F)	28 (82%) / 6 (18%)	28 (78%) / 8 (22%)	0.41
Age (years)	42	27	0.003
Pre-DC ICP (max)	35	31	0.14
Pre-DC GCS	6	7	<0.0001
Median decrease in ICP	11	22	<0.0001
Unchanged ICP	22 (65%)	12 (33%)	0.003

Table 2 shows outcomes of survival after decompressive craniectomy in a sample of 70 patients and predictors of mortality. Overall, survivors (n = 40) were younger, having a median age of 27 compared to 42 in non-survivors; this difference was statistically significant (p = 0.023). Preoperative Glasgow Coma Scale (GCS) scores were better in survivors (median 7) compared to non-survivors (median 5, p < 0.0001) which suggests that survivors were neurologically better prior to their surgery. Maximum pre-decompression intracranial pressure (ICP) was also

less in survivors (29 mmHg) than in non-survivors (41 mmHg, p = 0.009) and the proportion of patients that had elevated ICP after surgery was greater for non-survivors (57% vs. 43%, p = 0.002). Finally, the median change in ICP from the preoperative measurement to the postoperative measurement was better for the survivors (21 mmHg) compared to the non-survivors (11 mmHg, p = 0.0003). Therefore, both baseline physiological status and the degree of ICP reduction are important predictors of survival.

Table 2: Survival outcomes and associated factors after decompressive craniectomy (n = 70)

Factors	Non-Survivors (n = 30)	survivors (n = 40)	p-value
Age	42	27	0.023
Pre-DC GCS	5	7	<0.0001
Pre-DC ICP (max) (mmHg)	41	29	0.009
Unchanged ICP (%)	57%	43%	0.002
Median decrease in ICP (mmHg)	11	21	0.0003

Table 3 presented acute and late complications following decompressive craniectomy (DC). These acute complications, fully associated with the DC itself, can be divided by timing: ultraearly complications, which occur immediately to within the first few hours postoperatively include contusion expansion, epidural hematoma, external cerebral herniation, infection or fever episodes, seizures, leakage of cerebrospinal fluid (CSF), and wound complications; Early complications arising within months post-decompressive craniectomy (DC) encompass

subdural effusions or hygromas, exacerbation of contralateral mass lesions, paradoxical herniation, and infections. Delayed complications manifest after 30 days or more, including the sinking skin flap syndrome (SSFS), Trephined syndrome, and hydrocephalus. Late complications are almost always associated with subsequent cranioplasty and may include, but are not limited to, bone resorption, osteomyelitis, and hypo vascular bone necrosis that demonstrates the range of complication risk over time following DC.

Table 3: categories of problems following decompressive craniectomy (DC)

Complications	Different types of complications
Acute complications (directly associated with DC)	Delayed occurrences (beyond 30 days from decompression): Syndrome of the sinking skin flap (SSFS) or Trephined syndrome with hydrocephalus
	Early (in the first months): Evolution of contralateral mass lesions, Subdural effusions or hygromas, infection and paradoxical herniation
	Ultra-early: Epidural hematoma, blossoming of contusion, intracranial infection, epilepsy, external cerebral herniation, wound problems and CSF leakage
Delayed complications (associated with cranioplasty)	Osteomyelitis, hypo vascular bone necrosis and bone resorption

Discussion

This research examined 70 patients who had decompressive craniectomy (DC) and explored clinical, demographic and physiological factors to functional recovery and death outcomes over the long-term. Age and our premise neurological status as assessed by the Glasgow Coma Scale (GCS) were significant predictors of functional recovery and death outcomes. Patients who experienced good functional recovery were significantly younger (median age 27 vs 42 years) and had a higher pre-DC GCS score (7 vs 6) than patients who experienced poor recovery. These findings highlight the role that baseline factors regarding the patient impact patient recovery potential. The findings are like earlier literature that found younger patients generally had greater neuroplasticity and resilience as compared to older patients following a severe brain injury. Cooper et al., (1976) [10] reported a case series of 50 patients who underwent hemispheric craniectomy for acute subdural haematoma, with a mortality rate of 90%.

Intracranial blood pressure (ICP) was established as a potential decisive factor of outcomes. Although the maximal preoperative ICP values did not differ significantly between patients with good and patients with poorer function outcomes, the change in ICP after DC seems to be well correlated with recovery. Patients with good outcomes had a higher median ICP decrement than patients with poorer outcomes (22 mmHg vs. 11 mmHg). This may demonstrate that ICP decompression and control of intracranial hypertension may enhance neurological recovery. Furthermore, those patients who had continued elevations of ICP after surgery appeared to be more likely to experience poor outcomes. Overall, this suggests that there needs to be close monitoring of ICP after decompressive craniectomy as interventions that enhance CP can improve outcomes. Periera et al., (1977) [11] documented a cohort of 12 patients who underwent decompressive craniectomy for intractable cerebral hypertension, resulting in a death rate of 50%.

Survival analysis of survivors demonstrated similar patterns to the functional outcomes. Survivors were statistically significantly younger than non-survivors and had a statistically significant higher preoperative GCS, suggesting that the effects of initial physiological reserve on recovery outcomes likely affected both recovery and survival after decompression. Survivors also demonstrated a lower preoperative ICP, and lower levels of ICP after decompression, in comparison to non-survivors. It appears that the initial intracranial environment and effective decompression may contribute to prognosis after decompression. It was also more common for the non-survivor group to have persistently elevated ICP status beyond the postoperative period further emphasizing the consequence of complications causing

secondary brain injury. Ucar et al., (2005) [12] suggested that only 16% of the 100 patients studied attained a satisfactory outcome with DC, as evaluated by the GOS.

The complication profile after DC illustrated the range of potential risks associated with the intervention. Acute complications were noted, some of which were categorized as ultra-early complications, such as contusion expansion, extradural haematoma, extra-cerebral herniation, seizures, CSF leaks and infections, followed by early complications such as subdural effusions, paradoxical herniation and progression of contralateral lesions. Delayed complications were also mentioned; sinking skin flap syndrome (SSFS) and hydrocephalus are two long-term complications after cranial decompression. Furthermore, long-term complications after cranioplasty, such as bone resorption and osteomyelitis, demonstrate the importance of proper follow-up and management of patients to avoid complications. Timofeev and Hutchinson (2006) [13] demonstrated a cohort of 49 patients, of which 61% had a decent outcome.

This research emphasizes that the results of decompressive craniectomy (DC) are determined by multiple factors. Age, preoperative neurological condition, and good ICP control, seem to be the best visible predictors of functional recovery and survival. The evidence indicates that (1) younger patients with good GCS scores constitute the best intervention when action is taken early, (2) monitoring ICP and controlling ICP in an intense fashion is an important method for optimizing outcomes in all patients, and (3) because of the commonality of complications, acute and delayed, organized perioperative protocols, and ongoing follow up, needs to be implemented to properly identify and manage sequelae. Howard et al., (2008) [14] concluded that 30% of patients (n=40) experienced favourable outcomes following decompressive craniectomy, whereas 55% succumbed to death.

In summary, decompressive craniectomy continues to be important intervention for severe intracranial hypertension in younger patients who are neurologically intact at the time of surgery. Successful outcomes hinge on a timely surgical intervention, intraoperative control of ICP, and vigilant postoperative monitoring for complications. Our experience reaffirms a reliance on patient centered assessment and tailored management plans for the best perioperative outcomes and enhance survival and meaningful recovery after DC.

Conclusion

This research shows that decompressive craniectomy is an important, and maybe lifesaving, treatment approach to offering surgical intervention for patients with severe head injury who suffer from

ongoing neurological deficits secondary to residual refractory intracranial hypertension. Age and pre-operative GCS neurological status were identified as predictors of functional recovery and survival rate, with younger age and higher GCS being the most favorable predictors. The most important predictor of favorable outcomes was the postoperative successful reduction in ICP, which warrants the timing of intervention and the ongoing perioperative management of ICP. Decompressive craniectomy offers the risk of acute, early, and delayed surgical complications, yet with appropriate postoperative follow up and monitoring, morbidity and long-term rehabilitation can be improved. Ultimately the outcomes from this study suggest that when decompressive craniectomy is performed by surgeons with proper training and education, and the patient is under close monitoring and ongoing vigilance is planned post-operatively to help rehabilitation from morbidity and mortality post-injury, there is reduced risk of life from decompressive craniectomy overall, the likelihood of negative neurological outcome, with surgical intervention addressing intracranial hypertension and reversible neurological deficits may offer the most efficacious outcome, and surgical intervention is essentially important for managing 21st century neurotrauma practice.

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