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Decompressive craniotomy for severe traumatic brain injury: Our experience and review of literature

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Abstract

Introduction: Severe traumatic brain injury (TBI) is the most devastating injury affecting physical, mental, social and financial health of an individual and a society. The research, understanding and management of TBI is mainly focussed towards the secondary effects of the traumatic brain injury. Maintaining intracranial pressure within reasonable bounds is essential for successful TBI therapy, as an uncontrolled intracranial pressure (ICP) plays a major role in determining the course and prognosis of the injury. In general, ICP can be managed medically and/or surgically. In this article, we discuss our experience, the most recent understanding, and a method for managing ICP in traumatic brain injury.

Material and Methods: This study comprised 350 patients with moderate to severe traumatic brain injury (TBI) who were treated by a single neurosurgeon at several institutions between 2005 and 2020. 76.6% (268) of the patients were men, and 64% (224) of the patients were under 60 years old. The most common mode of injury was road traffic accident followed by fall from height. The study excluded those patients with brain stem injuries, bilateral non-reacting pupils, and concomitant significant injuries in other body parts. All were first treated medically with appropriate resuscitation, hyper-osmolar therapy (mannitol, 3% saline), hyperventilation, and barbiturate coma as per the response and requirement. Surgical intervention was used for patients who did not respond to medical management. In addition, decompressive craniectomy (DC) was primarily performed on those whose GCS was less than 5 and who had reacting pupils, upon presentation.

Results: Out of the 350 patients, 53.2% (186) had moderate TBI and 46.8% (164) had severe TBI. Due to failure of medical management, 30.5% (54) of moderate and 69.5% (123) of severe TBI underwent decompressive craniectomy in the form of bifrontal craniectomy in 18% (32), unilateral fronto-temporo-parietal craniectomy (hemicraniectomy) in 64% (113) , bilateral hemicraniectomy in 6% (11) and 12% (21) underwent limited fronto-temporo-parietal craniectomy. Decompressive craniectomy was not performed for posterior fossa. The data on outcome is very poor, inadequate and unreliable due to bad follow up. 5 years Follow up could be obtained only of 127 out of 350 (36%) patients and majority of these 69% (88) were moderately or severely disabled. Of those operated ones, only 27% (48) agreed for cranioplasty. 17% (30) had to undergo VP shunt for hydrocephalus. The group with severe traumatic brain injury (TBI) accounted for the majority of deaths (17%), with respiratory tract infections being the primary cause.

Conclusion: Decompressive craniectomy is the sole option in medically refractory cases of traumatic intracranial hypertension, who continue to deteriorate clinically. Nevertheless, the benefit falls short of expectations, particularly with regard to functional recovery. However prompt and appropriate decompression in appropriately indicated patients has withstood the test of time and remains a widely accepted attempt at life saving for moderate-to-severe traumatic brain injury.

Keywords: Traumatic brain injury, intracranial hypertension, decompressive craniectomy

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Introduction

Traumatic brain injury (TBI) is the most prevalent cause of disability worldwide and the third-leading cause of death, particularly in children and young adults, according to the World Health Organisation1 . The long-term consequences of traumatic brain injury (TBI) lead to significant neurological, mental, and non-neurological disorders that significantly impair patients and their families and place a heavy financial burden on them [1,2,3]. Traumatic brain injury (TBI) is becoming a greater global health concern for healthcare systems, particularly in underdeveloped countries where TBI-related morbidity and mortality rates are higher [4].

Primary TBI cannot be treated but only be prevented. On the other hand, secondary traumatic brain injury and its aftereffect can be prevented and treated by prompt and appropriate intervention, mostly through rapid control of intracranial pressure (ICP)[5,6]. Therefore, the goal of all previous, ongoing, and future efforts is to comprehend and treat secondary traumatic brain injury. In this article, we have attempted to provide an overview of our experience, taking into account our limitations, as well as the current state of knowledge and treatment approaches for traumatic brain injury.

Methods & Materials

Based on the GCS score, a total of 350 patients with moderate to severe traumatic brain injury were included in this study. They were treated by a single neurosurgeon at several hospitals between 2005 and 2020. The study excluded those patients with brain stem injuries, bilaterally non-reacting pupils, and concomitant significant injuries in other body parts. The following lists the patients' clinical findings:

	Description	Percentage	No. of patients
Total number			350
Age	Below 60 years of age	64%	224
	Above 6o years of age	36%	126
Gender	Males	76.6%	268
	Females	23.4%	82
Glasgow Coma Scale	Moderate	58.6%	205
	Severe	41.4%	145
Mode of injuries	Road traffic accidents	68%	238
	Fall	28%	98
	Physical assaults	4%	14
CT scan findings: Contusion, acute subdural hematoma, extradural hematoma and oedema	Right side	29%	102
	Left side	39%	137
	Bilateral	18%	63
	Bifrontal	14%	48

All were initially sufficient resuscitated to prevent hypoxia and hypotension, and then treated medically with hyperosmolar treatment (mannitol, 3% saline), hyperventilation, and barbiturate coma. Twenty three patients whose GCS was less than 5 and who had unequal and ipsilateral non-reacting pupils at presentation were primarily subjected to surgical treatment. The 154 patients underwent decompressive craniectomy who failed to show improvement or worsened on medical therapy. The rest of the 173 patients improved on conservative treatment. No comparison was done of the outcome of different types of decompressive craniectomies. There was not any major change in the technique of decompressive craniectomy over the study period. However, the preservation of the bone flap was initially done in a refrigerator and was autoclaved during cranioplasty. Later, in was kept subcutaneously in the abdomen. In cases where the patient's bone flap could not be used, bone flaps from methyl methacrylate or titanium mesh were used. There was no difference in the outcome or complications in these different techniques.

Surgical Procedures comprised of

Procedure	Procedure	Percentage	No. of patients
Decompressive craniectomy	Bifrontal craniectomy	18%	32
	Unilateral frontotemporoparietal craniectomy (hemicraniectomy)	64%	113
	Bilateral hemicraniectomy	6%	11
	Limited fronto-temporo-parietal craniectomy	12%	21
VP shunt		17%	30
Cranioplasty		27%	48
Tracheostomy		56%	99

Results

Outcome data are incomplete and unreliable due to poor follow up, discontinuation of treatment by patients' relatives in between the treatment course and inability to pursue communication with patients and the family after discharge. Follow up could be done in only 38% (133) of patients. Among these patients, the result of maximum of 5 years follow up could be obtained which showed:

Glasgow Outcome Scale (GOS)	Good recovery	14%	18 patients
	Moderately disabled	34%	45 patients
	Severely disabled	35%	47 patients
	Vegetative	None	
	Death	17%	23 patients

The major complications in the groups were the followings

Hydrocephalus	17%	23 patients	Underwent VP shunt
Infections	28%	37 patients	
Trephine syndrome	6%	8 patients	

Mortality

- 17%, 5% directly related head injury, others related to Infections and septicaemia, mainly respiratory tract infection.

Discussion

Because of concomitant hematomas and contusions, hydrocephalus, cerebral oedema, etc., ICP is elevated in TBI patients[7]. The compensatory mechanisms to keep ICP within physiological bounds might be swiftly exhausted by increasing brain edoema, growing hematomas, or blossoming of contusions due to the inflexible skull and dura. Intracranial hypertension (ICH), a persistent pathological elevation in ICP of greater than 20 mmHg, is seen in 53% to 63% of severe traumatic brain injury[8,9]. ICH is a delayed secondary pathologic process that is initiated at the moment of injury. Malignant intracranial hypertension is defined as a continuously raised ICP of more than 40 mmHg. It has been associated with poor outcomes and responsible for severe disability or death in almost 80% of patients in many studies [10,11]. A vicious cycle of reduced cerebral blood flow, cerebral prefusion pressure (CPP), microvascular circulation, oxygenation, oxygen perfusion, energy metabolism, and brain compliance can result from pathologically and continuously elevated ICP [12,13,14,15,16,17]. A persistently increased ICP can impair collateral cerebral circulation and damage unilateral or contralateral brain[16]. These series of events can further exacerbate cerebral edoema and elevate ICP, finally causing brain herniation, compression of the brain stem, and death.

As a result, interruption of this vicious cycle along with prompt, adequate and effective ICP control has emerged as a recognised and essential component of the care of closed head injuries, preventing further progression of brain injury [18,19,20]. CT scan is the most commonly performed diagnostic imaging which can show the details of the injury except for brain stem injury and the details of diffuse axonal injuries[21]. MRI can help in this instances. Investigations like CT and MRI DWI as well as perfusion weighted imaging can predict the development of large hemispheric infarction that benefit from early decompressive craniectomy but is more applicable to occlusive cerebral diseases or stroke than in TBI[22].

The most often used diagnostic imaging method is the CT scan, which can display the extent, all the components and characteristics of the brain injury. For brain stem injuries and diffuse axonal injuries, MRI is more useful. The development of a massive hemispheric infarction that benefits from an early decompressive craniectomy can be predicted by tests such as CT and MRI DWI as well as perfusion weighted imaging; however, these tests are more useful for occlusive cerebral illnesses or stroke than for traumatic brain injury.

Management of ICP

ICP reduction has become an accepted as the centre point in the management of closed head injuries[5]. However, the effect of ICP management on the ultimate outcome of TBI remains far from assured and still remains ambiguous. It is not clear yet whether raised ICP is the primary pathological event, or merely a late epiphenomenon that reflects other underlying processes which are not altered by ICP management[23].

Medical treatment in the form of hyper-osmolar therapy (mannitol, 3% saline), hyperventilation, hypothermia, and barbiturate coma are the first line of treatment for elevated ICP. Researches are ongoing to find more effective ways to manage the resistant ICP. Glibenclamide is the only medication that has so far demonstrated any promise in randomised clinical studies, indicating that it may be useful in lessening the severity of malignant cerebral oedema[24]. It is a sulfonylurea, initially used in diabetes. By inhibiting the SUR1-TRPM4 ion transporter, it also inhibits the development of cerebral edoema[25,26]. Glibenclamide is currently in a phase III trial, the CHARM trial[24]. Other compounds including aquaporin inhibitors have shown promise in basic, pre-clinical models, but have not yet been trialed in humans[27].

When medical therapy is ineffective in these medically resistant intracranial hypertension, the death rate rises sharply and may even reach 100% if alternative interventions are not implemented promptly and effectively1[3,20,25,28]. These cases may need urgent surgical interventions[29] in the form of evacuation of hematoma, excision of contusions, CSF diversion techniques like VP shunt and cisternostomy[30,31], strokectomy32 and/or decompressive craniectomy (DC)[5,33]. Only five to fifteen percent of TBI patients require surgery. Timely identification of failure of medical therapy and implementation of appropriate surgical intervention are critical for improving the predicted prognosis [34,35].

Decompressive Craniectomy (DC)

For medically non-responding intracranial hypertension, the Trauma Foundation (BTF), the Brain Injury Consortium (BIC) and other researchers, view DC as a very effective second-tier therapy[36,37,38,39,40, 41,42]. When there is a high demand, a shortage of resources, and institutional facilities, DC may be implied as a first-line treatment in order to lower ICP quickly and efficiently[43]. When a patient has an unequal ipsilateral non-reacting pupil and a GCS of less than 5, DC can be utilised DC as the first option.

The indications for DC are described as, medically refractive intracranial hypertension when ICP is persistently more than 30 to 35 mmHg or cerebral perfusion pressure (CPP) is less than 45 to 70 mmHg, in patients age less than 50 years of age, GCS is more than 4, CT evidence of brain swelling and associated haematoma or contusions[44,45].

DC involves removing a part of the skull and performing a big, liberal durotomy. This adds a vector of cerebral hemisphere expansion and increases the volumetric compensatory capacity by 26 to 92 cc[46]. This permits the enlarged brain to grow past typical cranial bounds, lowering intracranial pressure (ICP)[6,47]. In 85% of instances, DC can swiftly and efficiently drop ICP by 20 to 30 mm Hg by applying the Monroe Kellie Doctrine48, which states that increasing intradural space will lower intracranial pressure[35,40,45,47,49,50,51,52,53,54]. DC provides adequate bony decompression, mainly of the anterior and middle fossa without compromising dural venous drainage[40].

In order to build a big durotomy "bag" and create a watertight duroplasty during craniectomy closure, the dura is liberally supplemented with natural or synthetic materials[55]. This extra space allows the wounded, swollen and enlarged cerebrum to be accommodated, maintaining a low ICP[5,6].

In addition to trauma cases, DC with loose duroplasty is also used in cases of malignant cerebral infarction, infection, tumour operations, and other pathologies when severe brain edoema is anticipated or present and where primary dural closure and bone replacement are impractical or unsafe[56,57].

According to Rossini (2019), the oldest records of skull trephination in DC's history date to the early Neolithic period[58] , which began at 10,000 BC. DC was first described as a procedure by Annandale in 1894[59], but Charles Adrien Marcotte's graduation thesis in medicine and surgery, titled De L'hemicraniectomie Temporaire, published the first scientific reference and description of a hemicraniectomy in 1896[60],. Craniectomy was used as a palliative procedure for brain tumours during the latter part of the 1900s. The palliative decompressive craniotomy was first proposed by Theodore Kocher in 1901 for patients who had traumatic brain injury (TBI) and elevated intracranial pressure[61,62].

In cases with malignant and refractory ICP, DC is now supported by literature as a life-saving therapy[41]. The results of DC are, however, influenced by a number of variables, such as age, the amount of interval between the injury and therapy, pupillary abnormalities, preoperative GCS, and the magnitude, severity, and persistence of elevated ICP. Prognosis is also influenced by CT characteristics such as midline shift, basal cistern compression, hematoma size, and systemic abnormalities such hypoxia and hypotension[63,64,65]. Because of the insignificant adult brain plasticity and the unknown magnitude of irreversible brain damage from traumatic brain injury, it is currently not possible to predict the functional outcome following a DC. Other studies have also commented on these contradictory findings about the effectiveness of decompressive hemicraniectomy for traumatic brain injury[47,53,66],.

Due to the erratic and uneven clinical outcomes in terms of mortality and morbidity, including patients reverting to their pre-trauma state, DC's popularity has been inconsistent over the past 50 years [50,67,68,69,70]. Hemicraniectomy was associated with a statistically significant decrease in ICP, but not with a statistically significant improvement in GCS score. This could be the result of a complex phenomenon affected by the age of the patient, additional comorbidities, and concurrent injuries[71]. Despite being one of the oldest operations in neurosurgery, adequate evidence is not available regarding the best practice for the indications, timing, technique specially the size, shape, or location of bone flap removal[72].

Opinions are still divided regarding the ideal DC size in proportion to the patient's head size to successfully lower refractory ICP in traumatic brain injury. According to the adage "bigger is better," a large DC that occupies two thirds of the skull's hemicircumference is associated with better postoperative outcomes and improved ICP control[73]. In order to prevent compression of the herniating brain at the dural or bone flap edge and prevent further injury to the brain parenchyma, level 2A recommendations for a large DC, no smaller than 12 cm by 15 cm, are recommended by the Brain Trauma Foundation[74]. Large bone flaps have also been associated with improved neurologic outcomes at one year (56.8% vs. 32.4%) and significantly lowered mortality (27% vs. 57%)[33,75,76]. Nonetheless, some research indicates that the size of the craniectomy flap is not a significant independent variable for clinical outcome measures, such as GOS-E, hospital stay duration, or ICU stay duration[77,78]. Other studies have also revealed inconsistent results on the effectiveness of decompressive hemicraniectomy for traumatic brain injury (TBI) due to its size[47,53,66,79]. The common types of DC performed are bifrontal craniectomy, unilateral frontotemporoparietal craniectomy (hemicraniectomy) and bilateral hemicraniectomy[75,80,81,82],. Literature has described limited frontotemporoparietal craniectomy for early and moderate TBI[72,83].

DC can prevent or lessen the frequency and severity of secondary brain injury brought on by persistently elevated ICP, though it cannot reverse the initial brain injury[40,70]. The outcome is significantly influenced by the time of DC. There is ongoing debate on the earliest practical time to decompress[84] before there is any irreversible brain damage or widespread ischemic brain injury. There are evidence supporting that early decompression performed within 24 h or before clinical signs of herniation may improve overall mortality and functional outcomes[85]. There are other reports that claim that it is advantageous to decompress within 24 to 48 hours of the incident[49] improving outcomes[86]. According to European clinical trials, early hemicraniectomy significantly decreased mortality, from 71.4% in the conservative group to 21.6% in the surgical arm[87]. A Korean group studies ultra-early decompression but did not find improved results[88]. DC cannot be conducted as and when and at the earliest desirable timing, in most of the world due to a lack of clinical acumen detecting clinical deterioration by to raised ICP, availability of anaesthetist, other requisite manpower, and operating theatre and necessary pre-operative preparation[89]. Therefore, DC is primarily performed as a preventative measure before clinical deterioration or at a very early stage in the deteriorating process, based on clinical and radiological evaluation. A limited fronto-temporo-parietal DC may likewise produce a suitable and a comparable outcome in these cases if performed at the early stage of deterioration[72,90]. This could have economic advantages as well as shorter hospital stays and quicker recovery times. The author also restores the bone in small broken-down fragments, avoiding the need for a second cranioplasty procedure without sacrificing the benefits of loose duroplasty.

Multiple studies were conducted to obtain evidence-based consensus about indications, procedures, prognosis, and to investigate approaches for better understanding and treatment of intractable intracranial pressure in traumatic brain injury. According to a 2007 Cochrane database analysis, DC should only be used in cases where all other non-invasive therapy has failed and there is insufficient evidence to support its routine use in reducing the unfavourable outcome of severe TBI with refractory intracranial hypertension[91]. DC in paediatric trauma patients, however, appears to lower the incidence of death and unsatisfactory outcome[66]. In our series also, the outcome in children and young adults were seen to be better than in elderly. In the DECRA trial[34,] the efficacy of an early craniectomy was evaluated, and DC was recommended as a two-stage treatment within 72 hours of the injury in cases of diffuse TBI with significant intracranial hypertension which was defined as continuous or cumulative elevated ICP more than 20 mm Hg for 15 minutes. The study found that, although it was linked to more unfavourable outcomes, DC decreased intracranial pressure and the length of stay in the intensive care unit. Patients treated with decompressive craniectomy had a lower death rate in the RESCUEicp study (2016) as compared to patients receiving maximum medical care[92]. These and other studies found that DC, as opposed to medical therapy, reduced death and severe disability in TBI patients with refractory intracranial pressure but increased rates of vegetative state and severe disability[71,88]. The rates of moderate disability and good recovery were similar in medical and surgical groups[92].

The following recommendations and findings were made by the BEST trip trial[93] and the International Consensus Meeting consensus statement on the function of DC for the management of severe TBI in the absence of ICP monitoring (Hutchinson, P.J. 2019):

1.ICP monitoring is to be done in conjunction with CT findings and neurological exam.

2.There still is uncertainty as to which severe TBI subgroups will truly benefit from DC.

3.DC may decrease mortality but is associated with significant risks of complications and potentially increased risks of disability.

4.When making the decision to perform DC, sustained and refractory ICP elevations in conjunction with other clinical parameters should be present.

5.Large DC is recommended, preferably via Bifrontal or unilateral approaches, with liberal opening of the dura to effectively reduce ICP and reduce the incidence of secondary cortical injury from reduced venous drainage.

The aforementioned guidelines are being used in upcoming and ongoing international cohort studies such as the Global Neurotrauma Outcomes Study (GNOS)94, PRECIS95, and Rescue-ASDH (Randomised Evaluation of Surgery with Craniectomy for patients Undergoing Evacuation of Acute Subdural Hematoma), which are primarily focused on recruiting patients from developing nations in order to create a comprehensive picture of the management and outcomes of patients who undergo emergency surgery to treat traumatic brain injury.

Decompressive craniectomy is not suggested[96] for the following conditions:

- Patients with post-resuscitation GCS 3 with dilated and fixed pupils,
- Patient more than 65 years old,
- Devastating trauma that won't allow patient survive more than24 h,
- Those with co-existing irreversible systemic disease,
- Uncontrollable ICP during more than 12h despite all energetic therapeutic measures
- Arteriovenous oxygen difference less than 3.2 vol%

Complications of decompressive craniectomy

A large decompressive craniectomy is not without complications. Not only can a substantial decompressive craniectomy obscure the benefits of DC, but it can also be the reason why conscious level impairment persists even after prompt and sufficient DC[59,97,98]. At least one complication was experienced by nearly 50% of patients[77,99]. Certain complications, such cerebral infection and contralateral intracranial haemorrhage, might be fatal straight away, while other issues can negatively impact the patient's ability to recover neurologically and intellectually[100].

The following complications are the most noted problems associated with DC :

1.When a closed cranium becomes open during DC, particularly if there is a big bone flap, there is a rapid drop in intracranial pressure (ICP) with changes in cerebral blood circulation and CSF dynamics and other brain micro-functions. This all disrupts the brain's normal homeostasis[77,98,101],and can cause seizures, subdural hygroma, hydrocephalus, and infection[51,97,98].

2.In 9.3% of cases, post-traumatic hydrocephalus develops. Older age, subarachnoid haemorrhage, CSF infection, lower GCS, and a wide craniectomy flap with its upper edge closer than 25 mm from the midline are risk factors for the development of hydrocephalus[102]. When the lumbar CSF pressure is regularly greater than 180 mmH2O or when normal pressure hydrocephalus symptoms are present, CSF diversion surgery is recommended[100],. A permanent cerebrospinal fluid diversion operation may not be necessary if a cranioplasty is performed early[100,103].

3.Trephined syndrome, sometimes referred to as paradoxical herniation or "sinking flap" syndrome is a complication seen more commonly following a big DC. They present with headaches, light-headedness, agitation, convulsions, pain, and psychological problems[100,104,105]. If brain edoema is adequately managed, cranialplasty is recommended eight weeks after craniectomy to prevent this complication[100].

4.In almost 27.8% of limited DC cases, brain herniation might occur through craniectomy defect and forms a cephalocele[74,100].

5.Other complications are development of a new subdural hematoma on the contralateral side (7.4%), an increase in the size of the hemorrhagic contusion (20.7%) and CSF leak[99,106].

6.Subgaleal and subdural hygromas can develop unilaterally, bilaterally, or contralaterally in up to 50% of cases due to altered CSF dynamics. Following cranioplasty, the majority of these collections resolve on their own[50,107,108].

7.Infections like meningitis, ventriculitis, cerebral abscess, subdural empyema, epidural abscesses, and superficial skin infections can develop in up to 13.7% cases. The causes could be scalp flap's devascularization, long length of skin incision, orbital extension of the craniectomy, its proximity to sinuses and large dead spaces created after extensive DC[103].

8.The need for second surgery, cranioplasty, can be associated with longer hospital stays, surgical site infections, resorption of bone flaps, etc[109]. There is always a risk of brain trauma while awaiting the second surgery[66,110],.

With the overall improvement in medical care, refinement of surgical technique, appropriate timing and size of DC, the outcome of DC is improving with reduction of complications, morbidity and mortality[80,81],. There are reports of progressive and significant improvement in functional recovery. DC has now become very popular and have become the most commonly performed cranial surgery, almost considered as "panacea" for all neurosurgical diseases[111].

Conclusion

The management and recovery from TBI revolves around the appropriate and timely control of ICP. Primarily, the treatment is medical therapy, which is successful in controlling ICP in almost 85% of all TBI in general. Newer modes of medical therapy are being explored and investigated, but are still in trial stage. Decompressive craniectomy is a life-saving recourse in medically non-responders who would have otherwise probably died or rendered neurologically devastated by their TBI. With an attempt to improve the success of TBI therapy, researches and thoughts are ongoing to decide on the proper indications, timing, procedure and postoperative management of DC. Controversies will remain till we have consensus from a very large RCT trial encompassing TBI from different parts of the world. For now, the indications and approaches are largely left to the discretion of the surgeons[54]. With the large number of survivors remaining severely disabled, the neurosurgeons, while performing decompressive craniectomy, need to assess ones' responsibility to the patients, their relatives and the country, who take care of these patients rest of their lives.

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