Rescue Decompressive Craniectomy in Children with Severe Traumatic Brain Injury

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Abstract

Decompressive craniectomy (DC) is considered a rescue therapy in patients with traumatic brain injury (TBI) with increased intracranial pressure (ICP). In this retrospective study, we examined the impact of craniectomy on ICP in children with severe TBI and their neurological outcome. A total of 14 patients were enrolled. Peak ICP was significantly lower (31 ± 2.9 to 19 ± 4.6 , $p < 0.001$) and minimum cerebral perfusion pressure (CPP) higher (41 ± 10.5 to 58 ± 11.4 , $p < 0.001$) postcraniectomy. The survival rate was 71%. However, 57% of our cohort had a poor neurological outcome at 6 months postinjury. In conclusion, although rescue DC was effective in controlling ICP and CPP, the long-term neurological outcome remained poor.

Keywords

- traumatic brain injury
- pediatric
- craniectomy

Introduction

Traumatic brain injury (TBI) is one of the leading causes of death or severe disability in children.¹ The sophisticated approach to such patients focused on controlling the elevated intracranial pressure (ICP) and decreased cerebral perfusion pressure (CPP), aiming at the prevention of secondary cerebral injuries.² Therefore, numerous medical methods, including sedation, osmotic agents, and barbitol-induced coma have been applied to reduce increased ICP. Surgical techniques such as decompressive craniectomy (DC) have been used in patients with severe TBI when medical therapy fails to lower ICP (rescue craniectomy). Craniectomy is currently considered as a life-saving procedure in such patients, and several authors have described the potential benefits of performing DC in children with severe TBI.^{3–5} On the other hand, craniectomy has been associated with suboptimal outcome and neurological disability.^{6,7} Therefore, current evidence can only support the use of DC as a last-tier therapy for reducing elevated ICP not responding to medical treatment.⁸

The objective of this study was to evaluate the efficacy of craniectomy on controlling the elevated ICP and reduced CPP in pediatric patients with severe TBI. Furthermore, we recorded the survival rates and the neurological outcome in this pediatric cohort at 6 months postinjury.

Methods

Study Population

The medical records of all children with TBI who were admitted to the Pediatric Intensive Care Unit (PICU) of "Aghia Sophia" Children's Hospital, Athens, Greece, during 2009 to 2015 were retrospectively reviewed. This is a medical and surgical PICU with nearly 100 admissions per year. The inclusion criteria of the study consisted of pediatric patients (≤ 14 years of age) who had a DC performed due to a primary closed severe TBI (Glasgow coma scale [GCS] ≤ 8). Patients with mild or moderate TBI (GCS > 8) or those who did not survive for more than 24 hours after PICU admission were excluded from the study. Our study was approved by the ethical committee of our institution.

According to our institutional pediatric TBI guidelines, the medical therapy for patients with severe TBI during the study period consisted of standard supportive measures, including head elevation to 30 degrees, sedation with benzodiazepines and analgesia with opiates, mechanical ventilation with a target of P_{CO_2} to 30 to 35 mm Hg, fluid expansion and/or inotropes and vasopressors to maintain mean arterial pressure > 65 mm Hg and the neurosurgical evacuation of any intracranial mass lesions. The cerebrospinal fluid diversion was not a part of our treatment protocol. For the monitor of

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intracranial hypertension, an ICP intraparenchymal catheter Codman (Johnson & Johnson, Raynham, Massachusetts, United States) was placed into the parietal cerebral parenchyma of the more affected side. Patients who despite standard treatment had elevated ICP (≥ 20 mm Hg for ≥ 15 minutes) were commenced on second line therapy including hyperosmolar agents, such as mannitol and/or hypertonic saline. Those patients whose ICP could not be reduced with medical therapy at least 2 hours postadministration (considering that the effect of hyperosmolar treatment on ICP reduction is usually maintained for 60–120 minutes⁹) underwent an emergency craniectomy with duroplasty as a rescue therapy for controlling intracranial hypertension.

Data Collection

The demographic (age, gender, mechanism of injury) and clinical data (GCS, size and reaction of pupils, computed tomography [CT] findings, the requirement for inotropes support, the duration of sedation, ventilation, and overall hospitalization) were collected. The physiology-based Pediatric Risk of Mortality (PRISM) III score was used for the estimation of the PICU trait mortality risk, based on variables, such as vital signs, blood gas analysis, and laboratory data on the first 24 hours of PICU stay¹⁰ and the Injury Severity Score, an anatomical score of six body regions (head, face, chest, abdomen, extremities, and external) for the estimation of severity of illness in trauma patients.¹¹ Furthermore, the classification of the Rotterdam score on admission including the degree of basal cistern compression, the midline shift, the epidural hematomas, and the intraventricular/subarachnoid blood utilized for the prognostic evaluation of our patients.¹²

The data regarding the craniectomy were reviewed, including the surgical technique (unilateral or bilateral craniectomy), the size of bone flap, time of surgery, and the presence of complications, such as hydrocephalus, infection of the surgical wound, and subdural effusion.¹³ Also, we reviewed the timing and the surgical details of cranioplasty.

ICP and CPP data were extracted from the nursing flow sheet. The peak ICP and minimum CPP values of each day were recorded, and the mean daily ICP and CPP were calculated as the average of the hourly measurements per day (mean daily ICP = Summary of hourly ICP values/hours of measurements, and mean daily CPP = Summary of hourly CPP/hours of measurements). The ICP and CPP at the time when the intracranial catheter was placed (open pressures) were also recorded.

Outcomes

The primary outcome of the study was the evaluation of the DC impact on lowering ICP and elevating CPP. Secondary outcomes were the neurological outcome and the overall mortality. The neurological outcome was assessed either by reviewing each patient's record on the follow-up appointment or, if those data were not available, by telephone interview with the patient's caregiver. The Pediatric Glasgow Outcome Scale Extended (GOS-E Peds) was evaluated at 6 months after the injury (score 1 and 2 refers to upper

and lower good recovery, respectively, 3 and 4 recovery with moderate upper and lower disability, 5 and 6 to severe impairment with upper or lower severe disability, 7 to vegetative state, and 8 to death).¹⁴

Statistical Analysis

Continuous variables were expressed as mean $\pm$ standard deviation or median (interquartile range), as appropriate. The normality of the distributions of continuous variables was assessed by the Kolmogorov-Smirnov test. Comparisons of continuous variables were performed utilizing Student's unpaired *t*-test or the nonparametric Mann-Whitney test. Categorical variables were expressed as *n* (%). Repeated measures *t*-test was used for the estimation of the significance of changes of ICP and CPP before and after DC. All tests performed were two-sided and a *p* value less than 0.05 was considered statistically significant ($\alpha = 0.05$). The data were analyzed using SPSS Statistics Version 20.0 (IBM Inc., Chicago, Illinois, United States).

Results

A total of 14 patients with a rescue DC were identified out of a total of 55 patients with severe TBI who had been admitted to our PICU during the study period (►Fig. 1); five males (36%) and nine females (64%). Age ranged from 8 months to 14 years old (mean: 7.7 ± 5.0 years). The leading causes of injury were road traffic accident (57%) followed by falling from a height (36%). The median admission GCS was 6 (range: 4–7) and the mean PRISM III score 15.8 ± 9.1 . CT findings on admission revealed diffuse edema in 13 patients (93%), while 7 patients (50%) suffered from an injury in multiple body regions. The demographic, clinical, and laboratory data of the study population are presented in ►Table 1.

Craniectomy Data and Effects on Intracranial Pressure

The procedure of craniectomy was performed at a median of 19 (range: 5–50) hours after the injury. Half of the patients underwent unilateral frontoparietal bone removal with a mean diameter of bone flap removal 8.7 ± 1.2 cm, whereas the other half had broad bilateral bifrontoparietal craniectomy (mean bone flap diameter: 12.8 ± 2.4 cm). Duroplasty was performed in all cases. The commonest complications following the procedure were the subdural effusion (21%) (►Table 2). One patient also developed hydrocephalus, and he was treated with placement of external cerebrospinal fluid drainage.

Patients who required DC presented significantly abnormal open ICP and low open CPP. Craniectomy led to significant reduction of peak ICP and elevation of minimum CPP resulting in significantly lower postoperative peak ICP ($p < 0.001$) and higher postoperative minimum CPP ($p < 0.001$) (►Table 3). The mean daily ICP and CPP of the study population in the first week postinjury is presented in ►Fig. 2.

The cryopreserved autologous bone flap was reimplanted in 10 children (71%) who survived, with a mean time to cranioplasty 3 ± 1 month. There was no difference in the

Fig. 1 Study population. DC, decompressive craniectomy; ICP, intracranial pressure; TBI, traumatic brain injury.

time to cranioplasty whether there had been a unilateral or bilateral craniectomy initially (2.7 ± 0.9 vs. 3.2 ± 1 months, respectively, $p = 0.477$). Three of our patients developed aseptic bone resorption that required surgical revision and one developed infection of the surgical site.

Secondary Outcomes

The majority of the patients survived (71%), whereas four patients (29%) did not respond to any treatment and died. The neurological assessment, however, at 6 months post-injury revealed significant disability in the majority of our study group, as six patients (43%) were in vegetative state and another two (14%) suffered by severe lower or upper impairment.

Discussion

In the current study, we reviewed the impact of craniectomy on the ICP and CPP control. As such, patients underwent DC

Table 1 Demographic and clinical characteristics

Patients' characteristics	Study population (n = 14)
Age, y	7.7 ± 5.0
Gender, male	5 (36)
Mechanism of injury	
Road traffic accident	8 (57)
Fall	5 (36)
Compression	1 (7)
Pediatric risk of mortality III score	15.8 ± 9.1
Injury severity score	32.1 ± 12.8
Glasgow coma scale on admission	6 (4–7)
Pupils on admission	
Both miosis	6 (43)
Anisocoria	7 (50)
Both dilated (with present light reflex)	1 (7)
Injury of multiple body regions	7 (50)
Computed tomography findings	
Brain contusion	10 (71)
Skull fracture	10 (71)
Edema	13 (93)
Subarachnoid hemorrhage	5 (36)
Subdural hematoma	8 (57)
Epidural hematoma	6 (43)
Intracerebral hemorrhage	5 (36)
Axonal injuries	2 (14)
Midline shift	3 (21)
Rotterdam score	3 (3–4)
Inotropic support	9 (64)
Sedation duration, d ^a	10.7 ± 5.9
Ventilation duration, d ^a	14.5 ± 7.0
Intensive care unit stay duration, d ^a	18.5 ± 9.7

Abbreviations: IQR, interquartile range; SD, standard deviation.

Note: Continuous variables expressed as mean $\pm$ SD or median (IQR). Categorical variables expressed as n (%).

^aInotropic support, sedation, and ventilation support refer to intensive care unit stay.

had an effective decrease in ICP and an increase in CPP postoperatively. Regarding the neurological outcome at 6 months postinjury, we recorded high rates of survival in a vegetative state or with severe disability.

The current strategies for the treatment of patients with severe TBI are mainly ICP-targeted and are focused on lowering elevated ICP, to avoid the development of cerebral edema and the formation of secondary injuries. Thus, craniectomy can be applied as a rescue therapy when all medical measures have failed to control intracranial hypertension, and several studies have shown a favorable outcome after DC regarding the ICP

Table 2 Craniectomy data and complications

Data/complications	Overall DC (n = 14)	Unilateral (n = 7)	Bilateral (n = 7)	p-Value ^a
Craniectomy, h	19 (5–50)	8 (4–48)	30 (6–51)	0.383
Bone flap diameter, cm	10.7 ± 2.8	8.7 ± 1.2	12.8 ± 2.4	0.002
Hydrocephalus	1 (7)	0	1 (14)	1.000
Infection	2 (14)	0	2 (29)	0.462
Subdural effusion	3 (21)	1 (14)	2 (29)	1.000

Abbreviations: DC, decompressive craniectomy; IQR, interquartile range; SD, standard deviation.

Note: Continuous variables expressed as mean ± SD or median (IQR). Categorical variables expressed as n (%).

^ap-Value of Student's t-test or Mann-Whitney test.

Table 3 Pressure data

Pressure	Open pressure	Before DC	After DC	p-Value ^a
ICPmax, mm Hg	28 ± 12.3	31 ± 2.9	19 ± 4.6	
ICPmax difference, mm Hg			–12 ± 5.4	<0.001
CPPmin, mm Hg	35 ± 14.9	41 ± 10.5	58 ± 11.4	
CPPmin difference, mm Hg			16 ± 7.9	<0.001

Abbreviations: CPP, cerebral perfusion pressure; DC, decompressive craniectomy; ICP, intracranial pressure; SD, standard deviation.

Note: Variables expressed as mean ± SD.

^ap-Value of repeated measures t-test.

control.^{3–5,15–19} A retrospective study of 23 pediatric patients who had a DC performed demonstrated an optimal control of ICP in 83% of them postoperatively,³ while in another case series of 6 children with severe TBI who underwent DC, 5 of them had postcraniectomy ICP readings of less than 20 mm Hg.⁴ Furthermore, retrospective studies in adult patients have also shown that patients had lower ICP and higher CPP post-craniectomy.^{20,21} The two largest randomized controlled trials (RCTs) DECRA and Rescue-ICP concluded that DC could be effective for the management of intracranial hypertension in patients with severe TBI, performed either early in the course of the treatment or as a rescue therapy in patients with refractory to medical treatment ICP.^{22,23} In accordance with the previous studies, our findings have shown that rescue craniectomy has led to significant reduction of ICP and increase of CPP in pediatric patients who had a suboptimal response to medical treatment.

Although the control of ICP is the main aim of the current management of severe TBI, the evidence regarding the long-term outcome of such patients remains scarce. Of note, as it has been recently clarified, the optimal control of ICP cannot exclude the presence of undergoing cerebral injuries and cannot guarantee a good neurological outcome.^{24,25} Some pediatric and adult studies have demonstrated that craniectomy was associated with optimal neurological outcome,^{3,4,26–30} while, on the contrary, there are studies that have shown that patients underwent DC had poor outcome compared with medical treatment.^{31,32} In both recent RCTs, craniectomy patients presented significantly less favorable outcome at six months postinjury.^{22,23} The performance of early DC in DECRA study resulted in comparable rates of mortality between DC and non-DC group, but a worse rating

on GOS-E at 6 months. Furthermore, the performance of craniectomy as a last-tier therapy in patients with refractory ICP in Rescue-ICP trial was associated with lower mortality, but higher rates of vegetative state, lower and upper severe disability. Our study was not designed to evaluate the effect of DC in the neurological outcome; however, similarly to previous studies, our findings revealed that craniectomy patients had an unfavorable outcome at 6 months postinjury with the majority of them surviving in a vegetative state.

With regard to the surgical technique of craniectomy, the latest adult Brain Trauma Foundation guidelines recommend a large frontotempoparietal bone flap removal for reduced mortality and improved neurological outcomes.³³ The performance of a DC as large as possible has been suggested to minimize the risk of complications such as subdural effusions that are reported at rates up to 21%.³⁴ A similar rate of effusion or other complication was recorded in our study as well.

Cranioplasty is related to significant complications such as aseptic bone resorption and infection of the surgical site. The method of craniectomy segment storage, the material of reimplantation (autologous or synthetic), the bone flap size or the timing of surgery (early [<6 weeks] vs. late [>6 weeks] cranioplasty³⁵) have been associated with such complication.^{6,36,37} However, the overall data from large systematic reviews and meta-analysis cannot make any clear recommendation regarding the technique or the timing of the surgery.^{38,39} Our cohort underwent a cryopreserved autologous reimplantation at a mean of 3 ± 1 months postinjury. Although it can be considered a late procedure, we recorded a 30% incidence of bone flap resorption, similarly to previous studies.^{13,40}

Fig. 2 (A) Mean daily ICP in the study population. (B) Mean daily CPP in the study population. CPP, cerebral perfusion pressure; ICP, intracranial pressure.

The current study has several limitations that should be addressed. First, it was a retrospective single center analysis of data, and therefore it was not powered by the highest level of benefit analysis; however, there was a consistent, systematic data collection. Second, the decision to perform a craniectomy was based on the failure of the medical treatment to control ICP and as such, patients who eventually had a DC could be those that had undergone the severest form of injury. Of note, there were two patients who underwent craniectomy and presented with fixed dilated pupils and did not survive more than 24 hours; as per the study protocol, those patients were excluded from the analysis. Therefore, a possible bias regarding the long-term neurological outcome cannot be excluded, and future randomized studies are needed to counteract such bias. Third, our study was designed for the evaluation of the impact of DC in the ICP reduction only. As it was not a case-control study, it was not designed for the evaluation of the impact of DC in the neurological outcome. Our data can only support that DC was effective in reducing ICP in children with severe TBI; as our study included a small sample of patients, any regression analysis of risk factors of poor

outcome as well as an exclusion of possible confounders could not be performed.

Conclusion

In our study, rescue DC in pediatric patients with severe TBI can be effective in reducing elevated ICP and improving decreased CPP. However, despite the performance of craniectomy and the subsequent optimal control of cerebral pressure, our patients had a poor long-term neurological outcome.

Conflict of Interest

None.

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