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Original Article

Early Cranioplasty after Decompressive Craniectomy in Patients with Severe Traumatic Brain Injury

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BACKGROUND: Cranioplasty is performed after decompressive craniectomy (DC) mainly for protection of the brain and cosmetic purposes. Furthermore, cranioplasty may also improve neuronal and cognitive functions. Despite cranioplasty after DC is a common procedure, the proper timing for cranioplasty is still debatable.
OBJECTIVE: This study aims at evaluating the impact of timing of cranioplasty after DC on functional and surgical outcomes in patients with severe traumatic brain injury.

METHODS: This retrospective study included patients who underwent cranioplasty after DC for severe traumatic brain injury. Patients were divided into two groups based on the time to cranioplasty, either within 2 months (early group) or after 2 months from the initial DC (late group). Patients' demographics, clinical and radiological data, operative details, postoperative complications, and neurological status at the final visit were collected. Glasgow coma scale (GCS) was used to evaluate the initial neurological status; initial radiological findings at time of trauma were classified according to Marshall Classification Score of traumatic brain injury. Disability rating scale (DRS) and Glasgow outcome score (GOS) were used to evaluate the functional outcome.

RESULTS: Sixty-two patients were included in this study ,44 males and 18 females, and the mean age was (33.2±15.1). Thirty six patients (58.1%) were included in the late group, while 26 patients (41.9%) were in the early group. There was no statistically significant difference in patients' characteristics, operative details or mean follow up time between the two groups. The mean GOS was higher in the early group but was not statistically significant (3.85 ±0.35 versus 3.56 ±0.30; p = 0.12), also there was no statistically significant difference in the DRS between early and late groups (8.85 ±2.05 versus 9.5 ±1.93; p = 0.33). Regarding complications of cranioplasty, there was insignificant difference between the two groups.

CONCLUSION: Early cranioplasty can be done safely without higher rates of complications, and it may carry better neurological and functional outcomes than late cranioplasty, however this was not statistically significant.

KEYWORDS: Cranioplasty, Decompressive craniectomy, Functional outcome, Traumatic brain injury.

INTRODUCTION

Decompressive craniectomy (DC) is widely used as a potentially life-saving procedure for treatment of intracranial hypertension and prevention of brain herniation after severe traumatic brain injury and cerebrovascular stroke.[1-3] However, the iatrogenic bone defect after decompressive craniectomy leads to disturbed cerebrospinal fluid (CSF) dynamics with significant effects on the cerebral blood flow and brain metabolism.[2,4,5] Cranioplasty is frequently performed for protection of the brain and cosmetic purposes.[6] Moreover, cranioplasty may also improve neuronal and cognitive function as it may enhance cerebrovascular reserve capacity, cerebral glucose metabolism, postural cerebrospinal fluid circulation and blood flow regulation.[5,7-10] However, rate of complications of cranioplasty after DC ranges from 10% to 40%, including infections, intracranial hemorrhage, reoperations, seizures, extra-axial fluid collection, bone resorption and hydrocephalus.[10-12]

Despite cranioplasty after DC is a common procedure, the proper time for cranioplasty after decompressive craniectomy is a controversial subject.[3,7,8,10,13,14] Delayed cranioplasty usually associated with trephine syndrome and intraoperative severe adhesions with higher risk of parenchymal injury during the surgery.[3,7] However, early cranioplasty has a higher risk of infection, impaired wound healing and postoperative brain swelling.[2,14,15]

Several studies have settled a relationship between time of cranioplasty and functional outcome,[2,3,8,14,15] as

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early restoring of the skull bone after DC improves the hemodynamics of the brain and CSF flow,[4,5] facilitates the rehabilitation, and enhances the physical and cognitive recovery.[3] However, these studies lack the consensus regarding the safety and efficacy of early cranioplasty. Therefore, the need to evaluate the effect of early cranioplasty on the outcome of patients after DC is raised.

This study aims at evaluating the safety and efficacy of early cranioplasty and comparing the functional outcome between early and delayed cranioplasty after DC in severe traumatic brain injury patients.

PATIENTS AND METHODS

Patient population

We performed a retrospective study of patients who underwent cranioplasty after decompressive craniectomy (DC) for severe traumatic brain injury at multiple trauma centers between January 2014 and December 2019. As a routine step in all our institutions, preoperative informed written consent was obtained from all included patients, or from their parents or families if they were incompetent to give a consent. This study was approved by the institutional review board of our institutions.

We excluded patients with age less than 16 years old, patients with initial GCS more than eight at presentation, or those with previous history of neurological problems. Patients who had craniectomy for causes other than trauma (e.g. stroke, aneurysmal subarachnoid hemorrhage), or patients with incomplete data or follow up less than 6 months were also excluded.

Patients' demographics, comorbidities, clinical and radiological data, indication of craniectomy, side of craniectomy, time interval between craniectomy and cranioplasty, cranioplasty material type, operative duration, use of surgical drains, duration of hospital stay after cranioplasty, postoperative complications, and neurological status at the final visit were collected. In this study, GCS was used to evaluate the initial neurological status.[16] Disability rating scale (DRS) and Glasgow outcome score (GOS) were used to evaluate the function outcome of the patients,[17,18] while the Marshall classification score of traumatic brain injury was assessed to classify the radiological findings..[19]

Timing of Cranioplasty

The decision for the appropriate timing of cranioplasty was taken by the treating neurosurgeon, as no standardized protocol exists in the literature. The clinical status of the patient, healing of the craniectomy scar, resolution of brain edema and availability of cranioplasty material either autologous or synthetic can play a role in the appropriate timing of cranioplasty.

In this study, patients were divided into two groups, according to the time of cranioplasty. The early group included patients that underwent cranioplasty within 2 months after craniectomy, while the late group involved patients who were operated later than 2 months from the initial DC. The cut point for early cranioplasty and late cranioplasty at 2 months was defined based on previously published studies..[20,21]

Cranioplasty

Cranioplasty was performed either during the hospitalization for decompressive craniectomy or in an elective schedule. Computerized tomography (CT) brain with 3-dimensional reconstruction of skull bone was performed in all cases, to check intracranial structures and in some cases for prefabrication of patient specific synthetic implant. Antiplatelet drugs were withdrawn 10 days before surgery.

During cranioplasty, dissection between the myocutaneous flap and the dura-like layer of the brain was performed with exposing the bone margins encasing the craniectomy defect. Autologous bone flap, which was preserved in the subcutaneous layer of abdominal wall during craniectomy, was used when available. If autologous flap was not available, synthetic implants whether polymethylmethacrylate, titanium or polyetheretherketone (PEEK) in a customized three-dimensional mold were used. Tuck-up sutures then fixation of the flap with non-absorbable sutures or titanium osteoplastic miniplates were performed. The temporalis muscle was dissected as a separate layer and fixed at the flap then either subgaleal or epidural drain was inserted. Postoperative CT scan was routinely performed to confirm correct positioning of the flap and to rule out any complications.

Cranioplasty complication

The complications of cranioplasty including postoperative hematoma, postoperative subdural collection, infection, hydrocephalus, post operative CSF leak or bone resorption were assessed and analyzed. Postoperative extra-axial fluid collection was defined as a collection of low-density >1 cm in maximal depth.22,23 Infection was proved when fever, redness or discharge at the surgical site were encountered with or without radiological findings consistent with infection. Hydrocephalus was diagnosed clinically by manifestations of increased intracranial pressure associated with ventriculomegaly on imaging necessitating management with CSF diversion. Bone resorption was defined as significant bony erosion of the bone flap larger than 0.5 cm in its largest diameter and could be clinically palpated, or radiologically seen on follow up images by comparing late CT scan (obtained at least 2 months after cranioplasty) with an early postoperative one (within 24 h).[23]

Statistical analysis

Statistical analysis was carried out utilizing Stata Software 15.1. Descriptive statistical data are summarized as mean ± standard deviation (SD) and/or median or proportions as appropriate. We compared the mean, median or proportion of the exposure factors between patients in both groups using t-test, univariate logistic regression test, chi-square test, Fisher exact test and Kruskal-Wallis equality-of-populations rank test. Whenever appropriate, multivariate regression analysis model was used to eliminate the effects of confounders. The statistical threshold was set at $p < 0.05$.

RESULTS

Patient characteristics

This study included sixty-two patients who had cranioplasty after DC for severe traumatic brain injury between January 2014 and December 2019. There were

44 males and 18 females with mean age of 33.2±15.1 years. Of these patients, 36 patients (58.1%) were operated later than 2 months from the initial DC (late group), while 26 patients (41.9%) underwent cranioplasty within 2 months of craniectomy (early group). **(Table 1)** There was no statistically significant difference as regards age, gender, mean initial GCS at time of DC, type of implant (autograft or synthetic), operative time, or mean follow up time between the two groups. **(Table 1).**

Regarding Marshall classification score of traumatic brain injury, Class V was the most encountered (47.2% late group, 53.8% early group; p = 0.61), followed by Class IV (41.67% late group, 34.61% early group; p = 0.57), and then Class III (11.11% late group, 11.54% early group; p =0.96). **(Table 1).**

Time to cranioplasty and effect of timing on postoperative functional outcome The mean time from DC to cranioplasty in our patients was 76.7±42.2 days, and was statistically significantly lower in the early group (45.3±12 days versus 104.4±33.5 days; p = <0.001) **(Table 1)**. The mean GOS was higher in the early group but without statistical significance (3.85 ±0.35 versus 3.56 ±0.30; p = 0.12). The mean DRS for patients with early cranioplasty was 8.85 ±2.05, while patients who underwent late cranioplasty had a mean DRS of 9.5 ±1.93 which was not also statistically significant (p = 0.33). **(Table 2).**

Complications of cranioplasty

Twelve patients had hydrocephalus post cranioplasty (8 patients (22.2%) in the late group versus 4 patients (15.4%) in the early group; p = 0.5). Postoperative extra-axial fluid collection was identified more commonly in patients who underwent late cranioplasty (6 patients, 16.7%), while it was encountered in 2 patients (7.7%) from the early group, though the difference was not statistically significant (p =0.3). **(Table 3).**

Five patients (8.1%) developed postoperative CSF leak; 3 in the late group (8.3%) versus 2 in the early group (7.7%) (p = 0.9) and 7 patients (11.3%) had postoperative infection; 4 in the late group (11.1%) versus 3 in the early group (11.5%) (p =0.96). Bone resorption in those who had cranioplasty with autologous graft was noted in only 4 patients (6.5%), with statistically insignificant difference between late (3 patients, 8.3%) or early groups (1 patient, 3.8%) (p = 0.48). **(Table 3).**

Table 1: Characteristics of 62 patients who had cranioplasty after decompressive craniectomy (DC) for severe traumatic brain injury

	Total 62 (100%)	Late 36 (58.1%)	Early 26 (41.9%)	p value
Age: (mean ± SD)	33.2±15.1	32.8±15.4	33.6±15.1	0.84
Gender: No (%)				
Male	44 (70.97%)	26 (72.22%)	18 (69.23%)	0.80
Female	18 (29.03%)	10 (27.78%)	8 (30.77%)	
Initial GCS at time of DC (mean ± SD)	6.71 ±0.301	6.56 ±0.42	6.92 ±0.41	0.12
Marshall Classification score				
Class III: No (%)	7 (11.29%)	4 (11.11%)	3 (11.54%)	0.96
Class IV: No (%)	24 (38.71%)	15 (41.67%)	9 (34.61%)	0.57
Class V: No (%)	31 (50%)	17 (47.22%)	14 (53.85%)	0.61
Time interval from DC to cranioplasty in days (mean ± SD)	76.7±42.2	104.4±33.5	45.3±12	<0.001*
Operative time in minutes (mean±SD)	155.6±35.9	153.9±33.2	158.1±37.5	0.65
Cranioplasty graft				
Autologous: No (%)	45 (72.58%)	25 (69.44%)	20 (76.92%)	0.51
Synthetic: No (%)	17 (27.42%)	11 (30.56%)	6 (23.08%)	
Follow up in days (mean ± SD)	341.5±296.5	326.7±278	361.8±324.8	0.64

SD: Standard deviation, GCS: Glasgow coma scale, DC: Decompressive craniectomy.

Table 2: Postoperative Glasgow outcome score (GOS) and Disability rating scale (DRS) of early and late cranioplasty groups

	Total 62(100%)	Late (>2m) 36(58.1%)	Early (≤ 2m) 26(41.9%)	P value
Glasgow outcome score (GOS): (mean ± SD)	3.68 ±0.23	3.56 ±0.30	3.85 ±0.35	0.12
Disability Rating Scale (DRS) (mean ± SD)	9.23 ±1.41	9.5 ±1.93	8.85 ±2.05	0.33

GOS: Glasgow Outcome Score, DRS:Disability Rating Scale, SD: standard deviation.

Table 3: Postoperative complications of early and late cranioplasty groups

	Total 62 (100%)	Late (>2m) 36 (58.1%)	Early (≤ 2m) 26 (41.9%)	P value
Hydrocephalus: No (%)	12(19.4%)	8(22.2%)	4(15.4%)	0.5
Postoperative extra-axial fluid collection: No (%)	8(12.9%)	6(16.7%)	2(7.7%)	0.3
Postoperative CSF leak: No (%)	5(8.1%)	3(8.3%)	2(7.7%)	0.9
Postoperative infection: No (%)	7(11.3%)	4(11.1%)	3(11.5%)	0.96
Bone resorption: No (%)	4(6.5%)	3(8.3%)	1(3.8%)	0.48

CSF: Cerebrospinal fluid.

DISCUSSION

In severe traumatic brain injury, DC for intractable intracranial pressure (ICP) elevation has been shown to increase survival, and patient who survive, need later to undergo cranioplasty.[24-27] Cranioplasty is mainly carried out for cosmetic reasons, but it also improves cerebral blood flow and metabolism leading to improving the neurological and cognitive functions.[28-31] Songara et al. concluded that there was improvement in CT perfusion parameters after either early or late cranioplasty on both operated and contralateral sides, and this was correlated favorably with the improvement in neuro-cognitive outcome.[30]

The determination of the proper timing of cranioplasty after DC is still a matter of debate. As early cranioplasty was analyzed in several studies with shorter operative time, hospital stay and better functional outcomes.[7,14,15,32,33] However, early cranioplasty has also been reported with higher complication rates as impaired wound healing, epidural or subdural hematoma, infection, and hydrocephalus.[21,34] We therefore carried out a retrospective analysis of 62 patients with severe head injury who underwent cranioplasty after DC to evaluate effect of timing on the performance outcomes and postoperative complications.

Through different studies, a variety of scores were used to evaluate post cranioplasty neurological and functional outcomes, but no study proved the use of a particular tool. We used in our study GOS and DRS to evaluate the functional outcome of our patients and were recorded post cranioplasty in subsequent follow up visits. We revealed slightly better neurological outcomes regarding GOS and DRS in those who had cranioplasty early (within 2 months) than late (> 2 months), but without statistical significance, which may be related to the small population number in our study and larger cohorts are needed. Malcolm et al., in their systematic review of the literature and meta-analysis confirmed better neurological outcomes with cranioplasty, and early cranioplasty may lead to even more improvements.[35] Also, Kim et al, found that cognitive functions, especially locomotion, self-care, orientation, and language functions, improved in patients who underwent early cranioplasty more than in patients with late cranioplasty.[14] Chibbaro et al. also observed a clear improvement of neurological and cognitive functions after early cranioplasty and proposed that it may shorten the operative time, prevent rehospitalization and decrease cost of treatment.[25]

The risk of post cranioplasty complications ranges from

10% to 40%, which includes infections, intracranial hemorrhage, extra-axial fluid collection, hydrocephalus, seizures and bone resorptions.[10-12,,23,36] In the current study infections, extra-axial fluid collection and hydrocephalus were the most common postoperative complications. Despite previous studies reported that early cranioplasty have been associated with higher complication rates as epidural or subdural hematoma, impaired wound healing, hydrocephalus and infection,[21,34] this retrospective study showed no statistically significant difference regarding complication rates between early and late cranioplasty in patients who underwent DC for severe head injury. Xu et al. and Malcolm et al. showed also comparable complication rates between early and late cranioplasty after DC.[34,35] Similarly, Aloraidi et al. reported in their study insignificant differences in the rates of complications after early and late cranioplasty.[37]

Hydrocephalus had been reported post cranioplasty in several studies and occurs due to disturbances in the CSF dynamics.[30,35] In our study the risk of occurrence of postoperative hydrocephalus requiring CSF diversion procedure did not differ significantly between early and late groups. Bjornson et al. showed insignificant increased risk of hydrocephalus with early cranioplasty.[38] On the other hand, some studies reported higher incidence of hydrocephalus in those who underwent early cranioplasty in comparison to late cranioplasty.[32-34] However, these studies did not report data on the presence of pre-cranioplasty hydrocephalus, which may have been more prevalent among early cranioplasty patients.

In our study, there was insignificant difference regarding infection rates after cranioplasty between early and late groups, in concurring with previous studies that analyzed the risk of postoperative infection[7,32,33,34,39]

Overall bone resorption rate in our study was low as 6.5%, with no statistically significant difference between early and late cohorts and this may be attributed to our exclusion of patients with age less than 16 years old. Piedra et al reported in their study that patients of age <18 years were at higher risk of bone resorption than patients of age ≥18 years and required re operation, and that the age was the only significant predictor of bone resorption.32 Also, previous studies have revealed rates of bone resorption in children after cranioplasty as high as 50%.40 This increased risk in children may be due to thin skull bones, or interval cranium growth before cranioplasty causing a decrease in bone flap fit.

Study limitations

The limitations of this study are those inherent to retrospective nature and small patients' population. Also, our cases were collected from multiple centers with variable practice of different surgeons, which also may be a source of bias. So larger prospective studies evaluating long-term outcomes will be needed to establish the real effect and proper timing of cranioplasty.

CONCLUSION

Early cranioplasty can be done safely without higher rates of complications, also it may carry better neurological and functional outcomes than patients who had late cranioplasty, however this was not statistically significant. Larger prospective studies are needed to investigate the proper timing and its relation to functional and cognitive outcomes.

List of abbreviations

CSF: Cerebrospinal fluid.
CT: Computerized tomography.
DC: Decompressive craniectomy.
DRS: Disability rating scale.
GCS: Glasgow coma scale.
GOS: Glasgow outcome score.
ICP: Intracranial pressure.
PEEK: Polyetheretherketone.
SD: Standard deviation.

Disclosure

The authors report no conflict of interest in the materials or methods used in this study or the findings specified in this paper.

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