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Cranioplasty timing and its effect on the functional neurological outcome in traumatic brain injury

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ABSTRACT

The best time to do cranioplasty (CP) and how it will affect the neurological outcome is still in debate. Moreover, being one of the most commonly performed interventions in neurosurgery, its complication rate is among the highest in literature. The aim of this study is to assess the effect of timing of cranioplasty (CP) on the functional neurological outcome and post-operative complications in patients of traumatic brain injury. A retrospective cohort study was conducted in patients who underwent CP between 2018 and 2022. Early and late cranioplasties were defined as surgeries performed within and more than 90 days of decompressive craniectomy, respectively. The Glasgow Outcome Score- Extended (GOSE) and Functional Independence Measure (FIM) were used to assess the neurological outcome. Late CP cohort patients presented with subdural hygroma (SDG), which had a significant correlation. In post-CP complications, SSI, post-CP hydrocephalus and new onset seizures had a significant correlation with late CP ($p < 0.001$). In early CP GOS E score of 6 was seen, whereas a better score of 7 was seen late cohort. In FIM rating, both had maximum number of cases in Minimal Assistance group. The neurological outcome in patients who underwent early versus late CP is almost identical. We drew the conclusion that early CP often resulted in less post-operative morbidity. A lower number of early CP cohort subjects experienced post-CP HCP, seizures, and SSI. In order to reduce postoperative problems in TBI cases receiving DC, we advise an early CP based on the study's findings.

Keywords
bone flap,
Glasgow outcome scale,
FIM scale,
cranial reconstruction,
surgical site infection

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INTRODUCTION

Cranioplasty (CP) after decompressive craniectomy (DC) is necessary not only for cosmetic reason but cranial bone also offers crucial support and maintains normal cerebrospinal fluid (CSF) flow dynamics, and safeguarding crucial structures. Although a common neurosurgical operation, cranioplasty can have serious side effects; rates of total severe problems range from 10.9% to 40.4%. [1, 2] A study done by P Schuss et al stated that complications of CP exceed those of other elective cranial procedures. The overall complication rate after cranioplasty was 16.4% in their study. [3] Chang and associates also published a series with an overall complication rate of 16% following CP. [4]

There are multiple papers which suggest that delaying cranioplasty may lead to more complication and morbidity but literature is scarce regarding the timing of cranioplasty on the overall outcome and functional neurological outcome of the patient. In a study that used transcranial colour doppler to evaluate the effect of CP timing on cerebral blood flow (CBF) velocity in patients who underwent DC, showed better improvements in CBF in the early CP group compared to the late CP group and no difference in complication rate between the two groups. They concluded that optimizing patient selection, treatment course along with early CP has potential benefits for cerebral perfusion.[5]

In numerous articles, there has been contentious discussion about the timing of cranioplasty. Numerous studies suggested that early CP might be advantageous for patients.[6,7] Cranioplasty following DC at an early stage (5-8 weeks after DC) is safe and may result in neurologic improvement, according to Liang and colleagues.[8] Their analysis lacked specific information regarding the frequency of complications following cranioplasty. It is also unknown if the timing of a cranioplasty affects the overall complication rate. Given the high rates of complications connected with the treatment, it is crucial to analyze the neurological outcome in relation to the timing of cranioplasty. The purpose of the present study is to assess the neurological outcome and postoperative complication rates among patients who underwent early versus late cranioplasty with autologous bone flap at a major Level I trauma center.

MATERIALS AND METHODS

Patients' eligibility and study setting

This is a retrospective cohort study, reviewing the neurological outcome and postoperative complications, in cranioplasty patients. Data were collected for all eligible cranioplasties performed between January 2018 and December 2022 at King George's Medical University, Lucknow, Uttar Pradesh, a Level I trauma center serving north western and central state region and receives referrals from all over the state.

All patients who underwent cranioplasty and had preserved bone in the abdominal pocket, during the specified period were included in the study. The exclusion criteria were; patients with congenital cranial defects repaired by cranioplasty, patients who had nonautologous cranioplasty, and patients who had more than 50% of the defect replaced with nonautologous bone.

Data collection

Data were retrieved from the archives of the neurosurgery department using two distinct methods; case sheets and the hospital's electronic system from 2018 to 2022. Data included patients' demographics and postoperative complications. The primary indications for performing DC were TBI. Early and late cranioplasties were defined as surgeries performed within and more than 90 days of DC, respectively.

The Glasgow Outcome Score Extended (GOSE) and functional independence measure scores (FIM) were calculated to assess the neurological outcome. The GOSE 8 point scale is scored as follows; (1 = Death), (2 = Persistent vegetative state), (3 = Lower Severe disability), (4 = Upper Severe disability), (5 = Lower Moderate disability), (6 = Upper Moderate disability), (7= lower good recovery) and (8= upper good recovery).[9] Each item on the FIM is scored on a 7-point, Likert scale and the score indicates the amount of assistance required to perform each item (1 = total assistance in all areas, 7 = total independence in all areas).[10] The ratings are based on performance rather than capacity and was acquired by observation, patient interview or telephone interview. A final summed score is created and ranges from 18 – 126, where 18 represents complete dependence/total assistance and 126 represents complete independence.

Statistical analysis

Data were coded before being entered into IBM SPSS (version 23; Armonk, New York, USA: IBM Corporation). Categorical data were presented as frequencies and percentages using descriptive statistics. Age, GOS, FIM, and length of stay are examples of numerical variables for which mean and standard deviation have been determined. To determine the average differences in numerical data between early and late cranioplasty, the independent sample T-test was used. To examine the relationship between categorical data and the date of cranioplasty, the Chi-square test was used. The P-value's statistical significance level was set at 0.05.

RESULTS

A total of 104 cases of autologous cranioplasty were performed in the time period of which 93 were included in the study. 57 (61.3%) of them underwent late cranioplasty and 36 (38.7%) early cranioplasty. 78.50% were male and 21.50% were female. Maximum patient were in the age group of 23-32 years. 27.28% patients in early carnioplasty group were in the age group of 13-22 years, whereas 36.84% of late cranioplasty group were in the age range of 23-32 years (Fig 1).

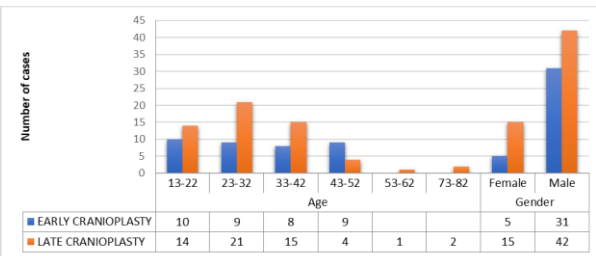

Figure 1. Showing distribution of patients in age groups and gender

The mode of injury in 78.50% was road traffic accident, with 12.90% had history of fall from height and an 8.60% cases had alleged history of physical assault. In the type of injury sustained, 45.20% had mixed type of injury which includes components of both acute SDH and multiple hemorrhagic contusions, 34.40% had acute SDH (Table 1).

62.40% cases had mild head injury, 25.80% were moderate and 11.80% were of severe head injury. This disparity in the presentation GCS might be attributed to the fact that maximum of the severe head injury cases succumb to their injuries in the follow-up period, thus not reporting for cranioplasty. 42 cases underwent right sided decompressive craniectomy, followed closely by left sided decompressive craniectomy (41) and 10.80% cases had bilateral frontal decompressive craniectomy (Table 2).

13 cases underwent ventriculo-peritoneal shunt before cranioplasty in the early cranioplasty group, whereas 7 cases in late cranioplasty group underwent CSF diversion before surgery. 3 cases presented with subdural hygroma warranting the need of subduro-peritoneal shunt before surgery in the late cranioplasty cohort. 30.10% cases (n: 28) in total had post operative complication. 36.85% (n: 21) in late cranioplasty cases and 22.20% (n: 8) in early cranioplasty cohort had complications. Hydrocephalus was identified in a total of 9 patients (early, n = 3, 8.30%; late, n = 6, 10.52%. p: <0.001). A total of 11 patients presented with surgical site infection (SSI) postoperatively (early, n = 3; late, n = 8, p: <0.001). Seizures were noted in four patients, and all them underwent late cranioplasty (early, n = 0; late, n = 4, p<0.001) (Table: 3).

Table 1. Timing of cranioplasty and its relation with mode of injury and type of injury.

		Timing of cranioplasty						
		Early cranioplasty		Late cranioplasty		Total		
		Count	Column n %	Count	Column n %	Count	Column n %	P-value
Mode of injury	Ffh	4	11.10%	8	14.00%	12	12.90%	0.051
	Physical assault	0	0.00%	8	14.00%	8	8.60%	
	Rta	32	88.90%	41	71.90%	73	78.50%	
Type of head injury	Acute sdh	12	33.30%	20	35.10%	32	34.40%	0.964
	Contusion	6	16.70%	13	22.80%	19	20.40%	
	Mixed	18	50.00%	24	42.10%	42	45.20%	

Table 2. Correlation between side of decompressive craniectomy and severity of injury.

		Timing of cranioplasty						
		Early cranioplasty		Late cranioplasty		Total		
		N	Column n %	N	Column n %	N	Column n %	P-value
	Bilateral frontal	5	13.90%	5	8.80%	10	10.80%	0.733
	Left	15	41.70%	26	45.60%	41	44.10%	

Side of decompressive craniectomy	Right	16	44.40%	26	45.60%	42	45.20%	
Gcs at presentation	Mild	18	50.00%	40	70.20%	58	62.40%	0.143
	Moderate	12	33.30%	12	21.10%	24	25.80%	
	Severe	6	16.70%	5	8.80%	11	11.80%	

Table 3. Timing of cranioplasty and its correlation with post operative complications.

		Timing of cranioplasty						
		Early cranioplasty		Late cranioplasty		Total		
		Count	Column n %	Count	Column n %	Count	Column n %	P-value
Post op complication	Absent	28	77.80%	36	63.15%	65	69.90%	0.138
	Present	8	22.20%	21	36.85%	28	30.10%	
	Hydrocephalus	3	8.30%	6	10.52%	9	9.67%	P<0.001
	Cardiac complication	1	2.80%	2	3.50%	3	3.20%	
	Pulmonary complication	1	2.80%	1	1.75%	2	2.20%	
	Seizure	0	0.00%	4	7.01%	4	4.30%	P<0.001
	Ssi	3	8.30%	8	14.03%	11	11.82%	P<0.001

Table 4. Timing of cranioplasty with GOS-E and FIM score.

		Timing of cranioplasty						
		Early cranioplasty		Late cranioplasty		Total		
		Count	Column n %	Count	Column n %	Count	Column n %	P-value
Gos e	1	5	13.90%	4	7.00%	9	9.70%	0.288
	2	2	5.60%	0	0.00%	2	2.20%	
	3	4	11.10%	4	7.00%	8	8.60%	
	5	3	8.30%	4	7.00%	7	7.50%	
	6	12	33.30%	17	29.80%	29	31.20%	
	7	9	25.00%	24	42.10%	33	35.50%	
	8	1	2.80%	4	7.00%	5	5.40%	
Fim rating	Complete independence	1	3.20%	3	5.76%	4	4.30%	0.637
	Maximal assistance	5	16.12%	4	7.69%	9	9.70%	
	Minimal assistance	10	27.80%	20	38.46%	30	32.30%	
	Moderate assistance	6	32.25%	11	21.15%	17	18.30%	
	Modified assistance	0	0.00%	1	1.92%	1	1.10%	
	Supervision	8	25.80%	14	26.92%	22	23.70%	
	Total assistance	1	3.20%	0	0.00%	1	1.10%	

In early cranioplasty cohort GOS E score of 6 (upper moderate severity) was seen in 32.25% cases, whereas a better score of 7 (lower good recovery) was seen in 42.10% cases in late cranioplasty cohort. Overall statistics of both cohort shows a lower good recovery in 35.50% cases. In FIM rating early cranioplasty and late cranioplasty both had maximum number of cases in Minimal Assistance group (early, *n* = 10, 27.80%; late, *n* = 20, 35.10%). This was closely followed by supervision in both groups. (Table 4) The length of stay in early cranioplasty cohort is 9.97 ± 4.61 SD and in late cranioplasty cohort it is 10.67 ± 5.63 SD days. A slight better outcome in FIM score (79.32 ± 21.33) has been noted in late cranioplasty cohort in comparison to the early group (74.94 ± 22.22).

Discussion

The current study looked into how the scheduling of a CP at a Level I trauma center affected the neurological outcome and postoperative complications. There was no statistically significant difference in the overall postoperative complication rates between patients who had early versus late CP (p=0.138). Early versus late subgroup P-values were statistically significant in relation to post operative complications i.e., seizures, post CP hydrocephalus and surgical site infections. Along with that statistical significance has been found in late CP cohort cases who presented with subdural hygroma. The timing of the CP had no effect on the neurological outcome as measured by the FIM and GOSE

Although early CP is defined differently in the literature, it is typically defined as occurring 90 days after DC. As a result, the 90-day cut off criterion was used in the current investigation.[11] Being a trauma center, we also saw a lot of patients with severe TBI, which resulted in malignant cerebral edema. Therefore, it is noteworthy to mention that the FIM and GOSE are expected to slowly improve overtime after decompressive craniectomy (DC). As a result, the FIM and GOS-E were recorded after cranioplasty and not after DC.

30.10% cases (n: 28) in total had post operative complication in our study. 36.85% (n: 21) in late cranioplasty cases and 22.20% cases (n: 9) in early cranioplasty cohort had complications. Cranioplasty, although a routine neurosurgical procedure, can cause significant morbidity; rates of total major complications between 10.9% and 40.4% have been reported in the literature.[1, 12]

In our study 13 cases presented with post DC hydrocephalus and 8 had post cranioplasty ventriculomegaly (early, n = 3, 8.30%; late, n = 5, 10.52%; P <0.001). Hydrocephalus may start to develop secondarily to the disturbance in the dynamics of cerebrospinal fluid. Several studies reported the incidence of hydrocephalus after cranioplasty.[13, 14] Some studies defined hydrocephalus as the need of ventriculoperitoneal shunt insertion. On the contrary, other studies defined hydrocephalus as the finding of dilated ventricles on CT images with or without neurological deficit or poor improvement. The incidence of hydrocephalus reported by these studies were in range 1.4–12.2% which was similar to our findings.[13, 14, 15]

In the late CP cohort 3 patients presented with subdural hygroma (SDG), which had a significant correlation with presenting late following DC for cranioplasty. The generally preferred pathophysiological theory postulates a one-way flap valve mechanism as a result of the traumatic arachnoid membrane rupture that causes cerebrospinal fluid (CSF) entrance in the subdural space.[16, 17] The dura-arachnoid interface, a layer made up of tiny collagen and cellular components kept together loosely by an amorphous substance susceptible to breakdown by physical stress, is thought to be the primary cause of this occurrence.[18] There have, however, been numerous hypotheses put out as to how the SDG came to be. According to the blood brain barrier failure theory, a major contributing cause to the buildup of water in the subdural space and the SDG expansion is the increased permeability of blood capillaries, which raises the osmotic pressure in the subdural space.[18, 19, 20] We postulate that one way flap valve mechanism secondary to arachnoid membrane rupture following traumatic brain injury can result in accumulation of fluid over time. The more duration post DECRA, the more would be the fluid being collected. Along with that post DECRA external cerebral herniation can result in furthering the process of fluid collection and as such we found significant cases of SDG in the late cranioplasty cohort.

A total of 11 patients presented with surgical site infection (SSI) postoperatively (Early, n = 3, 8.30%; Late, n = 8, 14.03%, p<0.001). The SSI rate in our study is 8.60% which is significantly low than that in literature.[21] The rate of infection in early versus late cranioplasty was statistically insignificant, according to a comprehensive review by Yadla et al.[22] Many published research also support the correlation of DC for TBI and greater post-CP infection rates.[6, 23] The initial contamination of the skull by traumatic discontinuities in the skin, as well as the presence of numerous scars from trauma and surgery impair the vascularization of the surgical flap and delay the healing of the wound after CP. The bigger skull abnormalities that developed after DC after TBI and their connection to a delayed integration of the reimplanted bone flap may also be at play in this situation. Lastly, the possible involvement of the air cavities of the skull, involved by fractures or by the decompressive flap, may also increase the infection rate of the reimplanted bone after CP. [24, 25, 26] But in our study, we hypothesize that the longer we wait after DC, the greater the likelihood of increased adhesion between the various layers of the scalp and the underlying duramater and its augmented portion. As a result, it must undergo substantial dissection during the process, requiring significant tissue handling over a prolonged period of time. Due to the flap's constant contact against the borders of the craniectomy site, there is a risk that there may be microischemic alterations in addition to the increase in intraoperative duration. Higher intraoperative duration, higher adhesions between the layers and the potential for ischemia alterations in the flap around the borders of the craniectomy site may all contribute to an increase in the post-CP infection rate in the late cranioplasty.

Diffuse cerebral edema and ischemia cause toxic mediators and excitatory cellular components to be released, which cause the onset of early seizures. As an extradural procedure, cranioplasty requires handling of brain tissue during the extradural plane dissection, which could result in cerebral edema. The dissection will lessen localized cerebral blood flow due to the severance between the scalp and dura mater, which may cause relative ischemia in the underlying cortex. In order to enable the improved shape of the bone flap after cranioplasty, brain tissue is additionally altered. These modifications may cause seizure activity in already seizure suceptible brain tissue and is the principal hypothesis behind post-cranioplasty seizures.[27, 28 29] Seizures are a significant, well-documented side effect of cranioplasty. In our study, there were 4.30% occurrences of post-cranioplasty new-onset seizures.

All the cases were in the late cranioplasty cohort, thus providing a significant correlation between new onset seizures with late cranioplasty. According to a systemic analysis by Malcom JG et al, the incidence of new-onset seizures after cranioplasty is 5-6%.[30] In their study 37% of early seizures following cranioplasty occurred within the first 24 hours, 16% occurred during the first week, and 47% occurred after that. In a study published in 2018, Yeap et al. looked into the prevalence of post-cranioplasty seizures among patients who received the procedure at their facility. 89 patients (26.5%) out of 336 patients with no prior history of seizures developed new-onset seizures. Similar studies have stated development of post CP seizures but the incidence of seizures in both groups (early vs. late) were statistically insignificant.[30, 31, 32]

Bitemporal and convexity cranioplasties were linked to seizures in a research by Zanaty et al., however the link was not statistically significant.[33] Increased seizure risk has been linked to surgery after cranioplasty for hematoma evacuation, but it has also been reported to be minor.[33, 34] In our investigation, all four patients of newly developing seizures underwent convexity cranioplasties, with hematoma evacuation performed in all. Timing of cranioplasty has been shown to be significant predictor for developing new onset seizure. As with our study, wherein we found significant correlation between late cranioplasty and occurrence of post CP, other studies also showed increased risk of seizure in patients who underwent late cranioplasty. [35, 36] Some studies also showed the benefits of early cranioplasty in minimizing the risk of seizure. [35, 36, 37]

Myocardial infarction was seen in 3.2% cases in our study, which were managed in consultation with cardiology. In a study done by Lester Lee et al 0.82% cases developed a non-ST elevated myocardial infarction (NSTEMI), immediately post-operatively.[38] A systematic review by De Cola *et al*. showed that motor improvement occurs in the early cranioplasty group, coupled with improved other parameters, such as cognition.[39] In another study by Archavlis *et al*., showed improved neurological function, including motor power if cranioplasty is performed within 7 weeks, compared to later than 7 weeks.[40] The speculate mechanism of why motor improvement occurs is mainly due to post cranioplasty physical therapy, precluding the timing difference of cranioplasty on motor improvement.[39, 40]

In our study we had a slight difference in the overall GOSE and functional independence measure in both the cohort. In early cranioplasty cohort GOS E score of 6 (upper moderate severity) was seen in 33.30% cases; whereas a better score of 7 (lower good recovery) was seen in 42.10% cases in late cranioplasty cohort. This may be attributed to the fact the patients in late cranioplasty cohort had longer duration of time to recover from the primary insult. In FIM rating early cranioplasty and late cranioplasty both had maximum number of cases in Minimal Assistance group (early, n = 10, 27.80%; late, n = 20, 35.10%). A slight better outcome in FIM score (79.32 ± 21.33) has been noted in late cranioplasty cohort in comparison to the early group (74.94 ± 22.22). Di Stefano et al. demonstrated a greater degree of recovery after CP at 6 months, however Honeybul et al. (2016) found that CP performed between 3 and 6 months results in a greater degree of cognitive recovery.[41, 42] This improved outcome in cases of late CP is a result of the physiological cerebrospinal fluid circulation being restored, which in turn allows for an effective restoration of blood circulation and, as a result, of the large-scale neural networks important for cognition (Corallo et al., 2017). [43] The follow-up assessment was completed in Honeybul et al. (2016) after 3 days of CP, but Corallo et al. (2017) and Di Stefano et al. (2016) completed it after 1 month, indicating the significant discrepancy that could influence the results. This observation from the studies are crucial in our study as well, which might explain the better FIM and GOS-E score in the late CP cases. Similiarly, in many studies the greatest improvements were evident many months after cranioplasty and most of the clinical improvement due to cranioplasty is secondary to prolonged effects on brain physiology, rather than immediate changes. [41, 42, 43, 44]

In the early cranioplasty cohort, the length of stay was 9.97 ± 4.61 SD days, whereas in the late cranioplasty cohort, it was 10.67 ± 5.63 SD days. A Aloraidi et al, in their study also stated an increase length of stay in the group of patients who had late cranioplasty.[44] The longer length of stay in the late CP group can be due to the fact that they required more time to recover from postoperative complications, particularly SSI and seizures, which both required close monitoring and rapid therapy to stop the patient's further deterioration.

Conclusion

There are a few limitations that need to be considered before interpreting the results of the present experiment. The study's retrospective methodology makes it vulnerable to selection and information bias, which is its first flaw. Second, fewer people took part in the study because none of the patients who received non autologous cranioplasty were included. Despite these drawbacks, the current investigation demonstrated the significance of comparing the neurological outcome and post surgical complications. The neurological outcome in patients who underwent early versus late cranioplasty is almost identical with a slight better outcome in late CP cohort which can be attributed to longer recovery period since DC.

Early and late cranioplasty had statistically significant variations in the rates of all postoperative complications. We draw the conclusion that early cranioplasty often resulted in less post-operative morbidity. A lower number of early CP cohort subjects experienced post-CP HCP, seizures, and SSI. Early CP cases also typically have shorter hospital stays, which puts less strain on the hospital's resources. In order to reduce postoperative problems in TBI cases receiving DC, we advise an early treatment for CP based on the study's findings. Overall, the neurological result was not significantly affected by the time of the cranioplasty. Owing to the mentioned limitations in the study we recommend a multicenter, prospective studies investigating the neuropsychological outcome pre/postoperatively in relation to cranioplasty timing.

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Abbreviations

cranioplasty (CP)
decompressive craniectomy (DC)
subdural hygroma (SDG)
traumatic brain injury (TBI)
standard deviation (SD

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