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Original Article

Timing of cranioplasty after decompressive craniectomy for trauma

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Abstract

Background: The optimal timing of cranioplasty after decompressive craniectomy for trauma is unknown. The aim of this study was to determine if early cranioplasty after decompressive craniectomy for trauma reduces complications.

Methods: Consecutive cases of patients who underwent autologous cranioplasty after decompressive craniectomy for trauma at a single Level I Trauma Center were studied in a retrospective 10 year data review. Associations of categorical variables were compared using Chi-square test or Fisher's exact test.

Results: A total of 157 patients were divided into early (<12 weeks; 78 patients) and late (≥12 weeks; 79 patients) cranioplasty cohorts. Baseline characteristics were similar between the two cohorts. Cranioplasty operative time was significantly shorter in the early (102 minutes) than the late (125 minutes) cranioplasty cohort ($P = 0.0482$). Overall complication rate in both cohorts was 35%. Infection rates were lower in the early (7.7%) than the late (14%) cranioplasty cohort as was bone graft resorption (15% early, 19% late), hydrocephalus rate (7.7% early, 1.3% late), and postoperative hematoma incidence (3.9% early, 1.3% late). However, these differences were not statistically significant. Patients <18 years of age were at higher risk of bone graft resorption than patients ≥18 years of age (OR 3.32, 95% CI 1.25-8.81; $P = 0.0162$).

Conclusions: After decompressive craniectomy for trauma, early (<12 weeks) cranioplasty does not alter the incidence of complication rates. In patients <18 years of age, early (<12 weeks) cranioplasty increases the risk of bone resorption. Delaying cranioplasty (≥12 weeks) results in longer operative times and may increase costs.

Key Words: Cranioplasty, decompressive craniectomy, trauma

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INTRODUCTION

Decompressive craniectomy to treat elevated intracranial pressure and evacuate mass lesions associated with head injury has been shown to increase survival.[1,2,5,7,9,12-14,20,22] Patients that survive generally require cranioplasty. The incidence of complications after cranioplasty is high, ranging from 12% to 50%.[3,4,6,8,11,15-17] One modifiable factor that may alter the risk of cranioplasty is the timing of cranioplasty after craniectomy. Case series suggest that early cranioplasty is associated with higher rates of infection while delaying cranioplasty may be associated with higher rates of bone resorption.[4,6,16,21,23] We aimed to determine if the timing of cranioplasty after decompressive craniectomy for trauma alters rates of complications.

SUBJECTS AND METHODS

Patient population

We performed a retrospective cohort study of all cases of patients who had undergone cranioplasty after craniectomy for traumaat Oregon Health & Science University (a Level I Trauma Center) between January 2001 and January 2011. The study was approved by the Oregon Health and Science University institutional review board.

Patients were identified by searching Department of Neurological Surgery and billing records using Current Procedural Terminology codes (62140, 62141, 62142, 62143, 62145, 62146, and 62147) to identify all patients who underwent cranioplasty within the study timeframe. Patients who underwent craniectomy for causes other than trauma (e.g. infected bone flaps after tumor surgery, vascular causes of increased intracranial pressure such as stroke or aneurysmal subarachnoid hemorrhage, skull tumors, skull fracture without cerebral edema, and craniosynostosis repair) were excluded.

The following data were collected: Age at cranioplasty, sex, indications for craniectomy, laterality of craniectomy, time between craniectomy and cranioplasty, type of cranioplasty prosthesis (autograft or synthetic), operative time, use of surgical subgaleal drains, length of hospital stay after cranioplasty, and postoperative complications including hematoma, infection, hydrocephalus, or bone resorption.

A hematoma was defined as an epidural or subdural hematoma with clinical signs and symptoms of increased intracranial pressure with or without mid-line shift on postoperative computed tomography (CT) scan. Infection was defined as a surgical-site infection with signs and symptoms of infection (fever, erythema, drainage at the surgical site, elevated white blood cell count) with or without CT imaging characteristics consistent with infection (all patients with infection complications had reoperation with removal of the cranioplasty flap followed by treatment with a several-week course of intravenous antibiotics). All bone flaps were frozen-stored at −40°C to −80°C. Hydrocephalus was defined as clinical signs and symptoms of hydrocephalus (headache, nausea, decreased mental status) with ventriculomegaly on imaging requiring treatment with a cerebrospinal fluid (CSF) shunt. Bone resorption was defined as clinically significant erosion of the bone flap that could be palpated or seen on follow up imaging that was a concern for patient safety and cosmesis. Although follow up time was not consistent among patients, all patients were seen at least one time in follow up within 3 months of cranioplasty.

Timing of cranioplasty

Patients were divided into two cohorts, early and late, based on the median time to cranioplasty for all patients (median 12 weeks; determined after data collection). The early cohort consisted of patients that underwent cranioplasty within 12 weeks of craniectomy (<12 weeks). The late cohort included all other patients (≥12 weeks). The study included cranioplasty procedures performed by 14 different neurosurgeons within the Department of Neurological Surgery at Oregon Health & Science University. The timing of cranioplasty after craniectomy for trauma was at the discretion of the attending neurosurgeon. While no standardized protocol exists for deciding the appropriate time to perform cranioplasty, factors that are used to make the decision include patient's overall clinical status and a well-healed craniectomy scar as well as patient characteristics such as, distance to the hospital from their living arrangement and the availability of postoperative support once discharged following cranioplasty.

Statistical analysis

Demographic, clinical, and outcome data were compared for these two cohorts. Statistical analysis was performed using Stata (StataCorp LP, College Station, TX). Data were recorded as numbers and proportions. Associations of categorical variables were compared using Chi-square test or Fisher's exact test (when expected numbers were less than 5). Associations between continuous variables were compared using the unpaired 2-tailed Student *t*-test. The associations between the outcomes and effect variables were adjusted for confounders using multivariate logistic regression models. Significance was established at the 95% level.

RESULTS

We identified 157 patients who had undergone cranioplasty after craniectomy for trauma between 2001 and 2010. The mean time to cranioplasty for these patients was 17.4 weeks (range 1-99 weeks). Median time to cranioplasty was 12 weeks. The mean follow up time after cranioplasty for all patients was 24.2 months (range 1-124 months). The mean age for all patients was 29.5 years (range 1 month-83 years) [Table 1].

There were 78 patients in the early cohort (within 12 weeks of craniectomy) and 79 patients in the late cohort. There was no statistically significant difference in age, sex, reason for craniectomy, type of implant (autograft or synthetic), presence of CSF shunt, or use of surgical subgaleal drains between the two cohorts [Table 1]. Operative time for cranioplasty in the late cohort was 23 minutes longer than in the early cohort (102 minutes early, 125 minutes late, $P = 0.0482$). Mean follow up time was longer in the late cranioplasty cohort compared with the early (18.7 months early vs. 29.7 months late) and this difference was statistically significant ($P = 0.0114$).

Comparison of the complication rates between the early and late cohorts revealed no significant difference (34.6% early vs. 35.4% late, $P = 0.9302$). The rates of postoperative hematomas (3.85% early vs. 1.27% late, $P = 0.3111$) and hydrocephalus (7.69% early vs. 1.27% late, $P = 0.0565$) while higher in the early cohort did not reach statistical significance. The rates of infection (7.69% early vs. 13.9% late, $P = 0.2354$) and bone resorption (15.4% early vs. 19.0% late, $P = 0.5863$) were higher in the late cohort but also revealed no statistical significance [Table 2].

Logistic regression analysis was performed using age category (<18 years of age or ≥18 years of age), time to cranioplasty (<12 or ≥12 weeks), sex, type of cranioplasty material (autologous or synthetic), presence of CSF shunt at the time of cranioplasty, or use of subgaleal surgical drains to determine predictors of the two most common complications, infection and bone resorption [Table 3]. There were no significant predictors of infection. An age of <18 years was the only significant predictor of bone resorption (OR 3.32, 95%CI 1.25-8.81, $P = 0.0162$).

Overall complication rates for patients undergoing cranioplasty after craniectomy measured at 6, separate 4 week intervals (<4 weeks, ≥4 to <8 weeks, ≥8 to <12 weeks, ≥12 to <16 weeks, ≥16 to <20 weeks, and ≥20 weeks after craniectomy) are shown in Figure 1. In patients who underwent cranioplasty <4 weeks after craniectomy the complication rate was 23%. Complication rate increases as the time interval between cranioplasty and craniectomy increases to a high of 62% for patients undergoing cranioplasty ≥16 to <20 weeks after craniectomy. However, for those patients undergoing cranioplasty ≥20 weeks after craniectomy, the overall complication rate fell to 22%. A comparison of complication rates reveals no statistical significant, most likely as a result of the small number of patients in each 4 week interval.

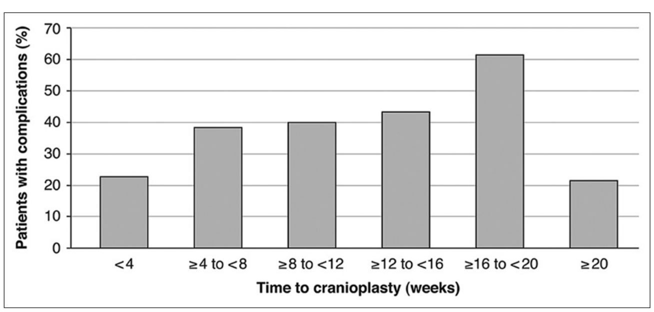

Figure 1: Overall complication rates (%) for patients (n=157) undergoing cranioplasty after craniectomy measured at 4 week intervals (< 4 weeks, ≥4 to <8 weeks, ≥8 to <12 weeks, ≥12 to <16 weeks, ≥16 to <20 weeks, and ≥20 weeks after craniectomy)

DISCUSSION

This retrospective study revealed no statistically significant difference in complications rates between performing cranioplasty early (within 12 weeks) and late (≥12 weeks) in patients undergoing decompressive craniectomy for trauma. The overall complication rate for these trauma patients was 35%, which is similar to previous literature reports.[3,4,6,8,10,11,16,21] This study revealed high rates of postoperative hematoma and hydrocephalus, though not statistically significant with early cranioplasty. Patients in the early cohort may have yet to develop symptomatic

Table 1: Baseline characteristics of early (<12 weeks) and late (≥12 weeks) craniectomy for trauma and cranioplasty cohorts

Characteristic	Early cranioplasty (*n*=78)	Late cranioplasty (*n*=79)	*P* value
Mean age, years (±SD)	27.2 (20.0)	31.9 (17.1)	0.1197
Male patients, *n* (%)	57 (73.0)	57 (72.1)	0.9118
Mean time to cranioplasty, weeks (±SD)	6.76 (3.37)	28.0 (18.4)	
Reason for craniectomy, *n* (%)			
Subdural hematoma	41 (52.6)	37 (46.8)	0.4134
Elevated ICP	24 (30.8)	32 (40.5)	0.1888
Epidural hematoma	7 (9.0)	8 (10.1)	0.6482
Combined SDH/EDH	5 (6.4)	2 (2.5)	0.2498
Skull fracture	1 (1.3)	0 (0)	0.3142
Cranioplasty type, *n* (%)			
Autologous	78 (100)	68 (86.1)	0.3657
Synthetic	0 (0)	11 (13.9)	
Presence of CSF shunt, *n* (%)	6 (7.69)	12 (15.2)	0.1654
Use of subgaleal surgical drain, *n* (%)	44 (56.4)	56 (70.9)	0.2558
Mean operative time, minutes (±SD)	102 (45)	125 (71)	0.0482
Mean follow-up, months (±SD)	18.7 (21.5)	29.7 (31.6)	0.0114

ICP: Intracranial pressure SD: Standard division, SDH: Subdural hemorrhage EDH: Extradural hemorrhage

Table 2: Complications reported in early and late cranioplasty cohorts

Complication (%)	Early cranioplasty (*n*=78)	Late cranioplasty (*n*=79)	*P* value	All patients (*n*=157)
Hematoma	3 (3.85)	1 (1.27)	0.3111	4 (2.55)
Infection	6 (7.69)	11 (13.9)	0.2354	17 (10.8)
Hydrocephalus	6 (7.69)	1 (1.27)	0.0565	7 (4.45)
Bone graft resorption	12 (15.4)	15 (19.0)	0.5863	27 (17.2)
Total	27 (34.6)	28 (35.4)	0.9302	55 (35.0)

Table 3: Logistic regression analysis results for infection and bone resorption (*n*=157)

Variable	Values	Infection (*n*=17, 10.8%)		Resorption (*n*=27, 17.2%)	
		OR (95% CI)	*P* value	OR (95% CI)	*P* value
Age	≥18 years	1.0	0.2672	1.0	0.0162
	18 years	0.40 (0.08, 2.00)		3.32 (1.25, 8.81)	
Time to cranioplasty	<12 weeks	1.0	0.5551	1.0	0.0855
	≥12 weeks	1.41 (0.45, 4.37)		2.25 (0.89, 5.70)	
Sex	Male	1.0	0.6814	1.0	0.2003
	Female	0.77 (0.22, 2.65)		0.48 (0.15, 1.47)	
Type of cranioplasty	Autologous	1.0	0.2518		
	Synthetic	2.51 (0.52, 12.1)		NA	
Presence of VP Shunt	No	1.0	0.3233	1.0	0.6096
	Yes	1.94 (0.52, 7.18)		0.68 (0.15, 3.01)	
Use of surgical drain	Yes	1.0	0.3478	1.0	0.3708
	No	1.94 (0.48, 7.71)		0.64 (0.24, 1.69)	

NA=Not applicable

hydrocephalus because of the time (<12 weeks) between craniectomy and cranioplasty. The higher rates of hydrocephalus in the late cohort (≥12 weeks) might be accounted for by the proportion of patients who already had a ventriculoperitoneal (VP) shunt placed at the time of cranioplasty, suggestive of hydrocephalus treatment.

Overall bone resorption rate was 17% (15% early vs. 19% late, $P = 0.5863$). Surprisingly, few bone resorption after cranioplasty reports can be found in the literature.[11,16] One reason for this discrepancy is likely that most previously published reports do not include children.[3,4,6,8,21,23] In this study, patients <18 years of age were at higher risk of bone resorption than patients ≥18 years of age and required re-operation (OR 3.32, 95%CI 1.25-8.81, $P = 0.0162$), and age was the only significant predictor of bone resorption. Previous studies have shown rates of bone resorption after cranioplasty in children as high as 50%.[11] This increased risk may be attributed to thinner skulls in children, or cranium interval growth before cranioplasty leading to a decrease in bone flap fit. In a prior study of cranioplasty after decompressive craniectomy for all causes, we showed that pediatric patients undergoing cranioplasty >6 weeks after craniectomy had a three time higher incidence of bone resorption requiring re-operation.[19] In the current study there were twice as many patients <18 years of age in the early cohort compared with the late cohort (36.7% early vs. 17.5% late, $P = 0.0064$), therefore bone resorption rate in the late cohort may well be an underestimation.

This study suggests that performing cranioplasty after trauma craniectomy at <12 weeks is as safe as delaying cranioplasty for ≥12 weeks. Complication rate increased in a dose-dependent fashion as the length of time between craniectomy and cranioplasty increased (up to ≥16 to <20 weeks after craniectomy) [Figure 1]. The complication rate in patients undergoing cranioplasty within 4 weeks of cranioplasty was significantly lower than the complication rate in patients undergoing cranioplasty ≥16 to <20 weeks after craniectomy (22.7% vs. 61.%, $P = 0.0328$), respectively. However, if the time interval between craniectomy and cranioplasty was >20 weeks, the complication rate was shown to decline. This same "dose-response" to timing of cranioplasty has been shown in other studies,[10] which rather than indicate an optimal time to perform cranioplasty to reduce the risk of complications, indicates a time when cranioplasty should not be performed as the complication rate can in excess of 50%.

Performing cranioplasty <12 weeks after trauma craniectomy may carry some advantages to delaying cranioplasty for ≥12 weeks. In this study, operative time was significantly shorter in the early cohort (102 minutes early, 125 minutes late, $P = 0.0482$), this could be a result of greater difficult in dissecting the scalp flap and fitting the bone flap. Another possible advantage to performing cranioplasty <12 weeks after trauma craniectomy is the decrease in at risk for additional injury time for patients recovering without a bone flap in place. Rehabilitation therapists may also be overly cautious in recovery efforts while the patient is without a bone flap. Some studies have shown an improved level of consciousness after cranioplasty[15] therefore, cranioplasty performed <12 weeks after trauma craniectomy may hasten recovery.

This study is limited by the risk of bias inherent to retrospective cohort investigations. The study is underpowered (80% power) to show equivalence of complication rates between early and late cohorts, due to the small number of patients evaluated. The factors that lead to timing of cranioplasty for this group of patients were not taken into consideration in the analysis. The cases were obtained from review of 10 years of data at one institution and the procedures were performed by multiple surgeons with varied practices in terms of managing patients after craniectomy, which also subjects the results to a risk of selection bias.

Further, while prior publications have detailed outcomes in larger series of patients,[3,5,7,21] and one could argue that the data we present lacks novelty, we do report that the rates of infection, hydrocephalus, epidural hematoma, or bone resorption are not affected by performing cranioplasty <12 weeks after craniectomy for trauma. While no optimal time to perform cranioplasty was revealed in our study, the time interval of ≥16 to <20 weeks after craniectomy was shown to carry the highest risk of complication. As we have previously shown children are highly susceptible to bone resorption when cranioplasty is delayed for 6 weeks or more after craniectomy.[19] In this trauma study an age of <18 years was the only significant predictor of bone resorption. Further in an article detailing timing of cranioplasty after decompressive craniectomy for ischemic or hemorrhagic stroke, we concluded that complications rates for early cranioplasty (within 10 weeks of craniectomy) are similar to those encountered when cranioplasty is delayed.[18]

CONCLUSION

The rates of infection, hydrocephalus, epidural hematoma, or bone resorption are not affected by performing cranioplasty <12 weeks after craniectomy for trauma. When cranioplasty is delayed operative times are longer, which may increase costs. While no optimal time to perform cranioplasty was revealed in this study, the time interval of ≥16 to <20 weeks after craniectomy was shown to carry the highest risk of complication. As we have previously shown children are highly susceptible to bone resorption when cranioplasty is delayed for 6 weeks or more after craniectomy.[19] In this study an age of <18 years was the only significant predictor of bone resorption. If clinically safe and feasible, cranioplasty during the same hospitalization as craniectomy for trauma can be undertaken without increasing complication risks. However, the optimal timing of cranioplasty after decompressive craniectomy for trauma remains an unknown.

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