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Original Article

Analysis of the timing and the usage of drains following cranioplasty on outcomes and the incidence of bone resorption

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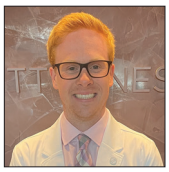

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ABSTRACT

Background: Pediatric cranioplasty is associated with a high rate of complications, including bone resorption (BR) in 20–50% of cases. We aimed to evaluate factors contributing to BR, including the effect of the timing of cranioplasty and the use of post-surgical drains.

Methods: This is a dual institution retrospective review of all patients under 18 years old who underwent a cranioplasty following a decompressive craniectomy (DC) for the treatment of traumatic brain injury between 2011 and 2021. Early cranioplasty was defined as within 30 days after DC and late cranioplasty as >30 days. Patients were grouped by BR and separately by timing to cranioplasty. Groups were compared based on the Glasgow Outcome Scale (GOS) and postoperative drain usage.

Results: A total of 30 patients were included in the study. The mean age was 7.39 (standard deviation = 6.52) and 60% were male. The median time to cranioplasty was 13 days (interquartile range = 10–17). BR was present in 16.7% of cases. A subgaleal drain was utilized in 93.3% and an external ventricular drain (EVD) in 63.3% of patients following cranioplasty. Drain usage was not associated with BR and timing to cranioplasty was not associated with discharge or 6-month GOS.

Conclusion: This study demonstrates that early cranioplasty following DC may have similar outcomes to late cranioplasty. Post-surgical EVDs and subgaleal drains did not increase the incidence of BR, suggesting their importance in the postoperative management of these patients.

Keywords: Bone resorption, Cranioplasty, Decompressive craniectomy, External ventricular drains, Hydrocephalus

INTRODUCTION

Decompressive craniectomy (DC) is a potentially lifesaving procedure that is used to relieve elevated intracranial pressure (ICP) or to evacuate lesions producing symptoms from mass effect following injuries such as severe traumatic brain injury (TBI), stroke, or encephalitis.[4,12,16,17,19-22,25,26] In the pediatric population, several recent studies have demonstrated the safety and efficacy of this procedure, which is likely to lead to an increase in procedure

utilization. As such, there will also be an associated increase in the number of patients with skull defects requiring a subsequent cranioplasty.[10,17,19,23] The most common bone flap utilized in cranioplasty is an autologous bone flap in which the patient's native bone is replaced. This is preferred in children, as the bone flap has the potential to integrate and grow with the continually developing skull.[1,17] Although there are clear benefits of autologous bone flaps, they also come with an increased incidence of bone resorption (BR) in the pediatric population. The incidence of BR has been reported to be as high as 80%, with the mean reported rate in the 20–50% range.[4,10,12,17,20-22] This is significantly higher than in adults, who have bone flap resorption typically reported <10% of the time.[1,21,23,26]

In studies looking at the incidence and risk factors for postoperative complications of cranioplasty, there are conflicting results with a paucity of data determining risk factors and methods of prevention.[21] The effect of cranioplasty timing on complications remains unclear, with one study reporting that earlier cranioplasty decreases the risk of BR, while a majority of studies indicate that timing is not a significant variable with respect to complication rates.[4,10,15,21,22] One previously noted risk factor associated with complications, especially bone flap resorption, is the use of postoperative external ventricular drains (EVDs).[22,26] At this time, there is insufficient evidence to characterize the relationship between the timing of cranioplasty and the use of postoperative drains with the surgical outcomes of cranioplasties. This pilot study explores the relationships between the usage of postoperative EVDs, subgaleal drains, early cranioplasty, and their associations with surgical outcomes and complication rates in the pediatric population.

MATERIALS AND METHODS

Study population

This is a retrospective review of patient data at two medical institutions between the years 2011 and 2021. Patients met inclusion criteria if they were younger than 18 years of age, underwent a DC due to TBI, and underwent a subsequent cranioplasty. Both procedures (DC and cranioplasty) had to be completed at these institutions, as procedures at outside hospitals were excluded. Patients who received a DC for an indication other than TBI were also excluded from the study.

Data acquisition

All data were recorded from the existing electronic chart records including nursing notes, physician notes, operative notes, and imaging studies. The initial type of injury was categorized as closed head injury, skull fracture, and penetrating head injury. Mechanism of injury was categorized as a motor vehicle collision, known accidental, non-accidental trauma (NAT), unknown, and a gunshot wound. Indications for DC were defined as herniation, intractable ICP, midline shift, declining Glasgow Coma Scale/neurologic deterioration, subarachnoid space decompression, subarachnoid space compression, vascular compression, stroke, anoxic brain injury, and hemorrhage. Type of DC was grouped as right/left frontal, right/left parietal, left/right temporal, right/left frontotemporoparietal, bifrontal, bilateral frontotemporal, bilateral parietal, and occipital. Data were subsequently collected for the indications for and type of DC. Other DC data collected were the material utilized for the duraplasty as well as the size of the skull defect following DC. The skull defect size was measured utilizing the AC method that has previously been described.[13,14] Data relevant to the cranioplasty was collected including the timing of the cranioplasty, the type of skull flap replaced, and the operative time. All patients underwent autologous cranioplasty with the bone flaps cryogenically stored in a sterile peel pack at −81°C. The bone flaps were secured with titanium screws and plates. Drain usage was also recorded before and after the cranioplasty. We collected the number of EVDs before cranioplasty from admission, the number of EVDs in place at the time of cranioplasty, the type of drains utilized after cranioplasty, time with EVDs and subgaleal drains after cranioplasty, number of EVDs after cranioplasty, EVD pressure settings, and the mean amount of daily cerebrospinal fluid (CSF) drained.

Patients were retrospectively divided into early and late cranioplasty groups based on operation timing post-DC. Patients who had a cranioplasty in fewer than 30 days after DC were in the early group and patients who had their cranioplasty more than 30 days after DC were in the late group. The decision on timing of cranioplasty was based on imaging results, ICP, softness of craniectomy site, patient neurological and overall progression, and ultimately at the discretion of the operating neurosurgeon. DC surgical site infection was a contraindication to early cranioplasty. Patients were also retrospectively divided into groups based on the presence of BR. The two patient groups were compared using all other variables. BR was determined based on imaging studies [Figure 1], neurosurgical diagnosis, and the need for reoperation. Patients were considered part of the BR group if they required reoperation with a synthetic cranioplasty. All patients underwent follow-up magnetic resonance imaging (MRIs) at the 2-week, 3-months, and then at the 6-month mark and the majority underwent an MRI at the 12-month mark. These images are reviewed for BR and the necessity of further imaging studies is accessed. Furthermore, patients continue to have follow-up appointments during which physical examination is utilized to help detect cases of BR. Imaging from there is done on an as needed basis.

Complications were recorded when there was a need for a follow-up operation. Complications were measured from

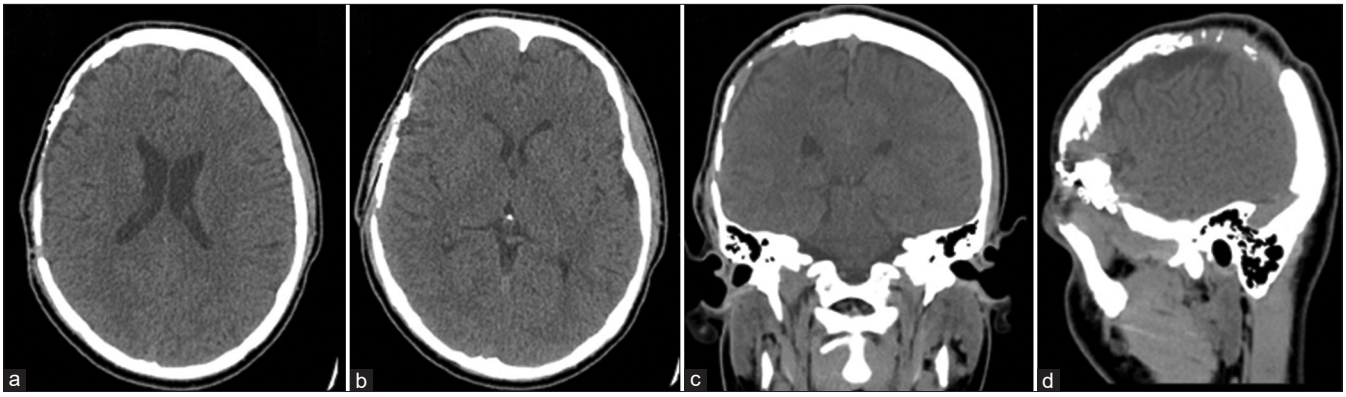

Figure 1: Computed tomography scan depicting bone resorption 1-year following native cranioplasty with a right-sided frontotemporoparietal cranioplasty. (a and b) Axial views of bone resorption. (c) Coronal view demonstrating bone resorption on the right side. (d) Sagittal view demonstrating bone resorption.

the operation to the patient's last follow-up appointment. Any incidence of epidural or subdural hematomas, subdural fluid collection, wound healing disturbance, subgaleal fluid collection, abscess formation, surgical site infection, CSF leak, hydrocephalus requiring a ventriculoperitoneal shunt (VPS), and BR were reported.

All patients had a follow-up period of 6 months. Due to the rural population served by these institutions, longer follow-up periods were not consistently met so to keep the follow-up period equal between all patients, a maximal interval of 6 months was used when measuring functional outcome. Outcomes were measured at discharge, 3-month follow-up, and 6-month follow-up using the previously described Glasgow Outcome Score (GOS). Positive outcomes were defined as s GOS of 4 and 5 indicating moderate, or mild to no disability respectively with preserved patient independence. GOS of 3 was defined as severe disability with loss of independence, 2 as a persistent vegetative state, and GOS of 1 indicated death. Patients were followed for their entire follow-up period for complications.

Statistical analysis

The project is a retrospective and exploratory analysis using descriptive and inferential statistics with an emphasis on hypothesis tests. The project compares the characteristics and outcomes of patients partitioned into two groups. Statistical analyses used two-sided p-values, independent samples, and a significance level of $\alpha = 0.05$. Adjustments to *P*-values to control the family-wise error rate and the false-positive rate have not been made since the study intends to evaluate the plausibility of significant differences and involves large numbers of supporting covariates but only two exposure variables and two primary outcome variables. Confidence intervals for effect sizes and population parameters are not reported since hypothesis testing is the inferential area of focus and limited sample size implies large confidence intervals. Interval level variables are summarized using the mean and standard deviation (SD) while categorical variables are summarized using counts and percentages. Differences in interval level variables are tested using the permutational unequal variance Welch *t*-test based on 1000 permutations. Differences in nominal level and binary variables are tested using Fisher's test. The standardized mean difference is used as the standardized effect size for nominal-level, binary, and interval-level variables. Differences in ordinal level variables are tested using the Mann–Whitney U-test with Cliff's δ as the standardized effect size. To aid in the interpretation of nonsignificant *P*-values, supplementary Figure 1 provides *post hoc* power analyses corresponding to the sample sizes of the project. Data management was performed using Microsoft Excel (Microsoft, Redmond, Washington) and statistical analyses were completed using R version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Demographics

A total of 47 patients who underwent a DC were identified; 30 patients met the final inclusion criteria. At 6-month follow-up, two patients were lost. Of the 30 patients, 18 (60.0%) were male and the mean patient age was 7.39 (SD = 6.53) years. The most common etiology of these patients was motor vehicle collision ($n = 10$, 33.3%), followed by known accidental ($n = 6$, 20.0%), NAT ($n = 8$, 26.7%), and gunshot wound ($n = 6$, 20.0%). There were no mortalities in this patient group. The median time to cranioplasty was 13 days with 80.0% ($n = 24$) of patients undergoing cranioplasty in under 30 days.

Outcomes

Mean GOS at discharge was 3.73 (SD = 0.91) with 26.7% ($n = 8$) of patients having minor to no disability, 23.3% ($n = 7$) having a moderate disability, 46.7% ($n = 14$) of

patients with severe disability, and 3.3% (n = 1) patients in a persistent vegetative state. At 6-month follow-up, the mean GOS was 4.47 (SD = 0.90) with 57.1% (n = 16) of patients having mild to no disability, 21.4% (n = 6) of patients having moderate disability, 17.9% (n = 5) of patients having severe disability, and 3.6% (n = 1) patients in a persistent vegetative state. At 6-month follow-up, 78.6% (n = 22) had favorable outcomes, GOS 4 or 5. The overall complication rate following cranioplasty was 36.0% (n = 11). The most common complications encountered were surgical site infection (16.7%), BR (16.7%), and wound healing disturbance (13.3%). Hydrocephalus occurred in one patient (3.3%) and one patient (3.3%) had a subdural and subgaleal fluid collection. Patients were followed for a mean of 25.2 (SD = 23.81) months following cranioplasty for complications. Patient age, indication for original DC, and timing of DC were not associated with outcome.

Bone resorption

BR occurred in a total of 5 (16.7%) patients. The mean time from discharge to BR was 12 months (SD: 7.3). Age, gender, injury, type of DC, and indication for DC were not associated with BR [Table 1]. BR was significantly correlated to shorter time spent in the pediatric intensive care unit (PICU) and hospital following the cranioplasty operation (P = 0.048 and P = 0.047, respectively). The persistence of resolving hematomas or fluid collections at discharge and 6-month follow-up was also correlated with BR (P = 0.018 and P = 0.014, respectively). The presence of a VPS was not associated with BR (P > 0.999) nor was the presence of an EVD (P = 0.327). BR was not associated with discharge, 3-month or 6-month GOS (P = 0.256, P = 0.578, and P = 0.365, respectively). There was no association between infection or wound healing disturbances and a higher rate of BR (P > 0.999 and P = 0.119). Finally, neither the size of the skull defect nor the material used for the duraplasty were associated with a greater incidence of BR (P = 0.286 and P > 0.999).

Timing of cranioplasty

Of the 30 patients, 24 (80.0%) underwent an early cranioplasty (<30 days) and 6 (20.0%) underwent a late cranioplasty [Table 2]. There was no statistical difference in the demographic data between the two groups. The mean time to cranioplasty in the early group was 11.25 (SD = 3.82) days compared to 86.83 (SD = 44.82) days in the late cranioplasty group. Patients undergoing late cranioplasty had a shorter stay in the hospital and PICU following the cranioplasty operation (P = 0.008 and P = 0.010, respectively). Patients undergoing early cranioplasty more frequently had an EVD in place before the procedure (P = 0.004) and only patients undergoing an early cranioplasty had EVDs after the procedure. There was no difference in the discharge, 3-month, and 6-month GOS scores between the early and late cranioplasty groups (P = 0.182, P = 0.858, and P = 0.876, respectively).

Postsurgical drains

A postoperative drain was used in all patients in the study. A subgaleal drain was utilized in 93.3% (n = 28) of patients following their operation. EVDs were also present in 63.3% (n = 19) of patients. A lumbar drain was used in two patients (6.7%) and a VPS was inserted in two patients (6.7%), one before cranioplasty and one at 3-month follow-up. The use of EVDs and subgaleal drains was not associated with BR or postoperative surgical site infection (P = 0.327 and P > 0.999, respectively). No patients in the late cranioplasty group received an EVD after cranioplasty; EVDs were only present in patients undergoing early cranioplasty.

DISCUSSION

After undergoing, DC patients must undergo a cranioplasty in which the skull flap is replaced, thus protecting the brain, restoring cosmesis, and restoring homeostatic CSF hydrodynamics, all of which aid in overall brain recovery.[5,17,24] Although the procedure has been around for centuries, there are many unanswered questions surrounding the procedure due to a lack of data.[1,9,17] For instance, the optimal timing of cranioplasty after DC has yet to be clearly established. There are conflicting reports with some indicating early cranioplasty leads to fewer complications while others state that timing to cranioplasty does not influence complications.[4,10,21,22] Furthermore, BR remains a prominent complication that must be considered. Distinct risk factors have been proposed, but the presence of VPS is the only one consistently reported. In this study, time to cranioplasty did not influence patient outcome. Our patient population suffered from BR less than previously reported which we attribute to our use of postoperative drains.

During cranioplasty, the replaced bone flap may be either autologous, synthetic, or bioprosthetic. Autologous bone flaps are typically the preferred choice, especially in pediatric patients as their skull is still growing and developing.[12,20] Autologous bone flaps undergo better osteointegration compared to synthetic or bioprosthetic material. Furthermore, autologous bone is better equipped to grow with the skull as the patient continues to mature.[24,27] A commonly encountered problem following cranioplasty with autologous bone flaps, however, is bone flap resorption. Bone flap resorption necessitates repeat operations and is associated with significant morbidity.[23] In this study, all patients received an autologous cranioplasty with their original bone flap that was cryogenically stored in a sterile peel pack at −81°C.

Table 1: Comparison of bone resorption.

Variable	Bone resorption (*n*=5)	Non-bone resorption (*n*=25)	SMD	*P* value
Male	2/5 (40.0)	16/25 (64.0)	−0.495	0.364
Age	5.00 (6.53)	7.87 (6.55)	−0.438	0.401
Original insult			1.102	0.594
Closed head injury	2/5 (40.0)	10/25 (40.0)		
Skull fracture	3/5 (60.0)	9/25 (36.0)		
Penetrating head wound	0/5 (0.0)	6/25 (24.0)		
Mechanism of injury			1.069	0.444
Motor vehicle collision	1/5 (20.0)	9/25 (36.0)		
Known accidental	2/5 (40.0)	4/25 (16.0)		
Non accidental trauma	2/5 (40.0)	6/25 (24.0)		
Gun shot wound	0/5 (0.0)	6/25 (24.0)		
Days to cranioplasty	35.60 (36.87)	24.52 (36.43)	0.304	0.650
Cranioplasty operative time in minutes	108.80 (49.54)	143.04 (50.77)	−0.677	0.228
Number of EVDs from admission to cranioplasty	0.60 (0.89)	1.08 (1.00)	−0.487	0.285
Number of EVDs in place at start of cranioplasty	0.40 (0.55)	0.48 (0.51)	−0.155	0.642
Patients with post operative EVD	2/5 (40.0)	17/25 (68.0)	−0.585	0.327
Patients with post operative subgaleal drain	5/5 (100.0)	23/25 (92.0)	0.417	>0.999
Patients with post operative lumbar drain	1/5 (20.0)	1/25 (4.0)	0.508	0.310
Days with EVD post cranioplasty	2.20 (3.19)	4.24 (3.11)	−0.654	0.249
Days with subgaleal drain post cranioplasty	1.60 (0.55)	1.72 (0.74)	−0.168	0.690
Total number of EVDs post cranioplasty	0.40 (0.55)	0.84 (0.62)	−0.721	0.144
Ventriculoperitoneal shunt			0.902	>0.999
Shunt prior to cranioplasty	0/5 (0.0)	1/25 (4.0)		
Shunt after cranioplasty	0/5 (0.0)	1/25 (4.0)		
No shunt	5/5 (100.0)	23/25 (92.0)		
Hospital length of stay after cranioplasty	7.20 (3.42)	13.08 (8.98)	−0.699	0.047
ICU length of stay after cranioplasty	4.40 (1.95)	6.96 (3.76)	−0.719	0.048
			Cliff *δ*	***P* value**
GOS at discharge			0.304	0.256
1	0/5 (0.0)	0/25 (0.0)		
2	0/5 (0.0)	1/25 (4.0)		
3	2/5 (40.0)	12/25 (48.0)		
4	0/5 (0.0)	7/25 (28.0)		
5	3/5 (60.0)	5/25 (20.0)		
GOS at 6-months			0.235	0.365
1	0/5 (0.0)	0/23 (0.0)		
2	0/5 (0.0)	1/23 (4.3)		
3	1/5 (20.0)	4/23 (17.4)		
4	0/5 (0.0)	6/23 (26.1)		
5	4/5 (80.0)	12/23 (52.2)		

SMD: Standardized mean difference, EVD: External ventricular drain, ICU: Intensive care unit, GOS: Glasgow outcome scale, *n*: Number of patients

BR is the most encountered complication following cranioplasty, with rates ranging from 20 to 50% in prior literature.[4,10,12,17,20-22] Rocque *et al*. reported a rate of 21.7% in their multicenter retrospective review and Malcolm *et al*. reported a rate of 20% in their systematic review.[18,22] Piedra *et al*. reported BR in 29.5% of their patients; however, the patients in their study with early cranioplasty had a resorption rate of 14% compared to 49% in their late cranioplasty group.[21] Other studies have reported higher rates of BR including Grant *et al*. and Bowers *et al*. who both reported a rate of 50%.[4,10] Even higher rates have been reported with a 2019 study by Beez *et al*. demonstrating 72.7% of patients experienced BR.[3] Martin *et al*. had an overall rate of 81.8%; however, only 54.4% of the patients required a revision cranioplasty.[20] In this study, we experienced BR at a lower rate than reported in the previous literature of pediatric patients. Of the 30 patients included in this study, 5 (16.7%) patients experienced BR.

Table 2: Comparison of timing of cranioplasty.

Variable	Early (*n*=24)	Late (*n*=6)	SMD	*P* value
Male	14/24 (58.3)	4/6 (66.7)	−0.173	>0.999
Age	6.84 (6.30)	9.61 (7.58)	−0.423	0.422
Original insult			0.347	>0.999
Closed head injury	10/24 (41.7)	2/6 (33.3)		
Skull fracture	9/24 (37.5)	3/6 (50.0)		
Penetrating head wound	5/24 (20.8)	1/6 (16.7)		
Mechanism of injury			0.825	0.323
Motor vehicle collision	6/24 (25.0)	4/6 (66.7)		
Known accidental	6/24 (25.0)	0/6 (0.0)		
Non-accidental trauma	7/24 (29.2)	1/6 (16.7)		
Gun shot wound	5/24 (20.8)	1/6 (16.7)		
Days to cranioplasty	11.25 (3.82)	86.83 (44.82)	−3.925	<0.001
Cranioplasty operative time in minutes	136.96 (55.35)	138.83 (34.87)	−0.036	0.929
Number of EVDs in place at start of cranioplasty	0.58 (0.50)	0.00 (0.00)	1.28	0.004
Patients with post operative EVD	19/24 (79.2)	0/6 (0.0)	2.757	0.001
Patients with post operative subgaleal drain	22/24 (91.7)	6/6 (100.0)	−0.426	>0.999
Patients with post operative lumbar drain	1/24 (4.2)	1/6 (16.7)	−0.418	0.366
Days with EVD post cranioplasty	4.88 (2.77)	0.00 (0.00)	1.944	<0.001
Days with subgaleal drain post cranioplasty	1.75 (0.74)	1.50 (0.55)	0.352	0.323
Total number of EVDs post cranioplasty	0.96 (0.55)	0.00 (0.00)	1.926	<0.001
Complications	9/24 (37.5)	2/6 (33.3)	0.087	>0.999
Bone resorption	3/24 (12.5)	2/6 (33.3)	−0.512	0.254
Infection	5/24 (20.8)	0/6 (0.0)	0.725	0.553
Would healing disturbance	3/24 (12.5)	1/6 (16.7)	−0.118	>0.999
CSF leak	2/24 (8.3)	0/6 (0.0)	0.426	>0.999
Subgaleal fluid collection	1/24 (4.2)	0/6 (0.0)	0.295	>0.999
Subdural fluid collection	1/24 (4.2)	0/6 (0.0)	0.295	>0.999
Hydrocephalus	1/24 (4.2)	0/6 (0.0)	0.295	>0.999
Hospital length of stay after cranioplasty	13.67 (8.73)	5.83 (3.92)	0.97	0.008
ICU length of stay after cranioplasty	7.12 (3.73)	4.17 (1.94)	0.848	0.010
			Ciff's δ	***P* value**
GOS at Discharge			0.333	0.182
1	0/24 (0.0)	0/6 (0.0)		
2	1/24 (4.2)	0/6 (0.0)		
3	9/24 (37.5)	5/6 (83.3)		
4	7/24 (29.2)	0/6 (0.0)		
5	7/24 (29.2)	1/6 (16.7)		
GOS at 6-months			0.038	0.876
1	0/24 (0.0)	0/6 (0.0)		
2	1/22 (4.5)	0/6 (0.0)		
3	4/22 (18.2)	1/6 (16.7)		
4	4/22 (18.2)	2/6 (33.3)		
5	13/22 (59.1)	3/6 (50.0)		

SMD: Standardized mean difference, EVD: External ventricular drain, ICU: Intensive care unit, GOS: Glasgow outcome scale, *n*: Number of patients

Postoperative drains, particularly EVDs, lack data surrounding their indication and usage. A previous study conducted by Rocque *et al*. reported that EVD use after cranioplasty was a significant risk factor for BR. However, as the study noted, this may be misleading as the sample size was low and the confidence intervals were wide.[22] Furthermore, data were not included on how many patients received EVDs after cranioplasty. It is possible that most of the patients receiving EVDs had more serious etiologies that created a state in which they were more susceptible to BR. In the same study, EVD use was not implicated in an increased risk of infection.[22] Furthermore, Sobani *et al*. found that having an EVD in place and removed before cranioplasty was associated with higher complication rates.[26] Again, these

patients likely had more severe injuries before cranioplasty requiring the use of EVDs which are likely to be a factor in the increased complication rates. In our patient population, EVDs were utilized in 63.3% (n = 19) of patients, and postoperative subgaleal drains were used in 93.3% (n = 28) of patients. Unlike Sobani *et al*., we found that having an EVD before cranioplasty did not increase the risk of complications specifically BR. The difference in findings between Rocque *et al*. and Sobani *et al*.'s and ours could be due to our utilizing EVDs more frequently and not selecting the most severe patients to receive an EVD.[22,26]

We speculate that in addition to subgaleal drains, EVDs work to decrease the incidence of subgaleal fluid collections. The absence of fluid in this space decreases overall pressure on the bone flap; thus, the bone is more readily vascularized and integrated into the skull. This could allow for a more robust healing process and decreased resorption. We believe that this, in part, may have contributed to our lower rate of resorption. With all but two patients in this study receiving a subgaleal drain, it is difficult to determine the effect the drain usage which had on BR. Furthermore, the incidence of drain use is not well reported in the literature making it difficult to determine the possible influence the drains had on BR.

The importance of timing to cranioplasty on BR and overall outcome within the pediatric population has yet to be elucidated. Several studies have concluded that timing to cranioplasty after DC does not affect BR or other complications in pediatric patients.[4,10,15] This conclusion contrasts with a study conducted by Piedra *et al*. who found that their patients who underwent early cranioplasty had significantly lower BR rates of 14% compared to their patients who underwent late cranioplasty 49%.[21] Thus, there is no clear determination of the effect cranioplasty timing that has on BR. In this study, timing to cranioplasty was not associated with BR; however, this could be due to the relatively small sample size in the late cranioplasty group. This study also found that there was no difference in 6-month outcomes in patients who underwent early versus late cranioplasty. The common standard is late cranioplasty, so the focus was on the outcomes of early cranioplasty. In this study, early cranioplasty had good functional outcomes and our study had a low reported incidence of BR compared to the previous studies. This indicates that early cranioplasty may be a viable option in patients who are clinically stable enough to undergo this procedure. Furthermore, an additional consideration for early cranioplasty may be given for rural patients who present to tertiary care facilities hundreds of miles from their home as this limits the need to return later for a subsequent operation.

DC and cranioplasty are known to alter CSF hydrodynamics within the brain, resulting in higher rates of hydrocephalus.[2,6-8] With the skull flap removed, atmospheric pressure on the brain affects the normal flow of CSF. During cardiac systole, the brain expands outward until it is halted by the cranium which causes expansion inward. This compresses the ventricles and causes the flow of CSF.[11] With increased elastance secondary to a missing skull flap, the brain is not forced to expand inward to the same degree, and therefore, hydrocephalus can develop. Replacement of the skull flap normalizes the pressure and compliance thus restoring adequate CSF flow. This was demonstrated by Dujovny *et al*. when they used cine phase-contrast MRI to describe CSF and vascular changes following cranioplasty in a singular patient, the results of which demonstrated increased venous outflow, significant changes in CSF oscillatory flow, and a two-fold increase in CSF pulsatile velocity following replacement of the bone flap.[7] This is further demonstrated in a study by Carballo-Cuello *et al*., in which a shorter time to cranioplasty was significantly associated with decreased rates of hydrocephalus.[6] Early cranioplasty can limit the risk of hydrocephalus and help restore normal CSF flux, thus reversing and preventing hydrocephalus secondary to bone flap removal. In our study, 80.0% (n = 24) of patients underwent early cranioplasty. There were three patients with hydrocephalus before cranioplasty. Two of the cases were treated with EVDs, with hydrocephalus resolution following cranioplasty. The third patient received a VPS before cranioplasty and kept the VPS following the operation. Paired with the usage of drains, we believe that our early cranioplasty was important in the prevention of hydrocephalus in a population suspected of high levels. As demonstrated, early cranioplasty resolved the hydrocephalus before it required a shunt. The patient who was in the late cranioplasty group did require a shunt before undergoing cranioplasty and still required it following the procedure. We did not have any patients develop hydrocephalus after cranioplasty during their hospital stay. One patient (3.3%) developed hydrocephalus 3 months after discharge. This patient had a VPS inserted and did well afterward with no ongoing sequelae. Early cranioplasty may help prevent cases of shunt-dependent hydrocephalus, however, could increase the risk of it later.

Limitations

A limitation of this study is the retrospective nature resulting in a lack of randomization which can include bias. Due to the retrospective nature, there was not a consistent set time point for every patient who received follow-up imaging. Due to the numerous covariates and limited sample size, we were unable to utilize multivariable regression analysis to determine the independent predictors of BR. We have dichotomized time to cranioplasty, a continuous variable, into a binary variable. For larger studies, it may be preferable to measure the association of time with cranioplasty and BR using methods such as logistic regression. *P*-values have not been adjusted for multiplicity and should not be used to infer definitive effects. In

addition, the methodologic constraints and small sample size (n = 30) limit the study's generalizability. Type II errors cannot be completely ruled out due to the pilot scale of the samples included in the study. However, this study has a comparable number of patients with the previous published literature and provides a comprehensive assessment of pediatric patients undergoing early and late DC at our institution.[3,8-10,15,20] Furthermore, due to the low study number, we were able to collect substantial data for each patient. This allowed ample descriptive characteristics to be included in the study. Our study was also the first to focus attention on drains and their effect on outcomes and may provide the framework for future larger cohort studies at our institution. Finally, four surgeons were operating in this patient population and final decision-making came down to surgeon preference. A prospective study would provide the necessary randomization and capture data that are not available in chart reviews and should be considered for the future.

CONCLUSION

In this present study, the timing of cranioplasty did not influence outcome or BR indicating that early cranioplasty is a suitable option when patients are clinically stable. BR was not increased by our use of drains or early cranioplasty. This study was one of the larger studies looking at cranioplasties in pediatric patients and has the lowest reported incidence of BR.

Data availability statement

All data generated or analyzed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Declaration of patient consent

The Institutional Review Board (IRB) permission obtained for the study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The author(s) confirms that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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