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RESEARCH

Balancing form and function: A single-center review of autologous vs. synthetic grafts in cranioplasty

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Abstract

Background Cranioplasty is performed to restore cranial integrity following decompressive hemicraniectomy, with both autologous bone grafts (ABGs) and synthetic grafts (SGs) serving as reconstructive options. While previous studies have examined clinical outcomes, there is a lack of robust data comparing aesthetic outcomes and complication rates between ABGs and SGs. This study evaluates these parameters to guide optimal graft selection.

Method A single-center retrospective review was conducted on patients who underwent cranioplasty with either ABGs or SGs between January 2017 and November 2023. Patient demographics, perioperative variables, and postoperative complications were collected. Aesthetic outcomes were assessed using axial CT scans to measure frontal and parietal asymmetry. Statistical analyses included univariate and multivariate comparisons, adjusting for potential confounders such as age, cerebrovascular accident (CVA) history, hypertension (HTN), atrial fibrillation (AFib), ventriculoperitoneal (VP) shunt status, and insurance type.

Results Among 200 patients, 82 (41.0%) received ABGs, and 118 (59.0%) received SGs. Frontal and parietal asymmetry scores did not significantly differ between groups ($p=0.321$, $p=0.348$). Median time to cranioplasty was shorter for ABGs than SGs (106.5 vs. 117 days; $p=0.038$). Postoperative complications were significantly higher in the SG group compared to ABGs (30.5% vs. 9.8%; $p=0.001$), with infections being more frequent in SGs ($p=0.048$). SGs were also associated with a higher rate of revision surgeries.

Conclusions ABGs and SGs provide comparable aesthetic outcomes, but SGs carry a significantly higher risk of complications and revisions. Given its lower complication rates and cost-effectiveness, ABGs should be prioritized when feasible. However, SGs remain a viable option in cases where autologous bone is unavailable or contraindicated. Future studies should focus on long-term follow-up and patient-reported outcomes to further refine cranioplasty decision-making.

Keywords Cranioplasty · Autologous bone graft · Synthetic graft · Aesthetic outcomes · Postoperative complications · Skull reconstruction

Abbreviations

ABG	Autologous bone graft
SG	Synthetic graft
CT	Computed tomography
IRB	Institutional review board
LOS	Length of stay
CVA	Cerebrovascular accident
SDH	Subdural hematoma
TBI	Traumatic brain injury
GSW	Gunshot wound
IPH	Intraparenchymal hemorrhage
SAH	Subarachnoid hemorrhage
STROBE	Strengthening the reporting of observational studies in epidemiology
PMMA	Polymethylmethacrylate
VPS	Ventriculoperitoneal shunt

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Introduction

In cases of stroke or severe traumatic brain injury where a decompressive hemicraniectomy has been performed, patients undergo cranioplasty to restore the integrity of the skull and protect the underlying brain. Beyond its medical advantages, cranioplasties also reinstate facial symmetry pre-trauma, contributing to both functional and aesthetic recovery [14]. Standard practice for cranioplasty reconstruction typically involves autologous bone grafts (ABGs), where the patient's own bone is used for reconstruction [6]. More recent advancements have integrated biosynthetic materials and precision machinery, otherwise known as synthetic grafts (SGs) [11].

Harvested from the patient's skull during the initial craniectomy, ABGs naturally conform to the patient's cranial structure and are often a more cost-effective option [4, 15]. Furthermore, bone cement can be used in combination with the ABG to promote growth and strengthen the defect. However, using ABGs involves certain challenges. To preserve the bone for later use, it is often stored in the abdominal cavity between the craniectomy and cranioplasty. This can lead to complications, including bone resorption, which may cause the ABG to shrink or warp, making it less compatible with the cranial defect [4]. Moreover, there is also an increased risk of infection following craniotomy when introducing the bone into the abdominal pocket [2]. Efforts to mitigate abdominal infection includes the use of cryopreservation extracorporeally, yet it has worse resorption during the window period to cranioplasty [5]. As an alternative, SGs have become an increasingly viable option. SGs may reduce pre-cranioplasty complications by eliminating the risks associated with abdominal storage and bone resorption. While SGs are generally more costly than ABGs, they offer unique benefits that may be preferable based on the patient's clinical circumstances and surgeon preference [4]. Given their various strengths and shortcomings, SGs remain a viable option to achieve personalized cranial restoration [10].

While studies have explored the overall equivocal postoperative clinical outcomes between ABGs and SGs, few have robustly explored their aesthetic outcomes [3, 8, 9]. Moreover, there is a paucity of research investigating long-term postoperative complications for these two modalities, leaving much to be determined in the true utility of ABGs and SGs. Given the growing interest in neuroplastic surgery and the importance of patient satisfaction, it is essential to consider both the functional and aesthetic outcomes of cranioplasty materials [12]. To address this gap, the present study aims to compare the post-operative aesthetic outcomes and complication rates of ABGs and SGs in cranioplasty. Our goal is to support clinical decision-making by developing a pathway that considers clinical indications and patient preferences, ultimately guiding the selection of the optimal cranioplasty method for achieving successful, individualized outcomes.

Methods

Study design & data collection

This is a single institution retrospective review of patients aged 18 and older who underwent a hemicraniectomy due to stroke or severe traumatic brain injury and subsequent cranioplasty with either ABG or SG from January 2017 through November 2023. The institutional IRB approved the study (STUDY00007277), and patient consent was waived. Exclusion criteria included patients under the age of 18, those who underwent a craniectomies with no subsequent cranioplasties, or those with no postoperative computed tomography (CT) imaging. Electronic medical records were reviewed for patient demographics, clinical characteristics, perioperative details, cranioplasty specifics (implant type, time to cranioplasty, post-operative complications), follow-up time (less than 90-day cutoff excluded), and socioeconomic factors. Synthetic grafts were custom-designed for each patient using preoperative CT imaging and 3D-printing technology, which optimized graft fit and cranial symmetry.

Cranioplasty aesthetics

To account for variability in follow-up and minimize the influence of perioperative inflammation, we evaluated frontal and parietal asymmetry using axial CT scans obtained at least one-month post-cranioplasty. A validated scoring system was used to objectively measure asymmetry without requiring patient input, making it suitable for cases with available postoperative CT scans. Asymmetry was assessed by drawing the midline through the third ventricle and falx cerebri, and calculating the difference between right-to-midline and left-to-midline measurements, designated as frontal and parietal asymmetry scores (Fig. 1) [1].

Statistical analysis

Summary statistics are presented for the overall sample and by patients with either ABG or SG as means, medians, standard deviations, minimums, maximums, and proportions (if categorical). Two-sample t-tests were employed to examine differences in the averages of continuous variables between groups when the normality assumption was met; otherwise, the Wilcoxon rank-sum test was used. Chi-square and Fisher exact tests were used to investigate differences for categorical variables as appropriate. Statistical significance

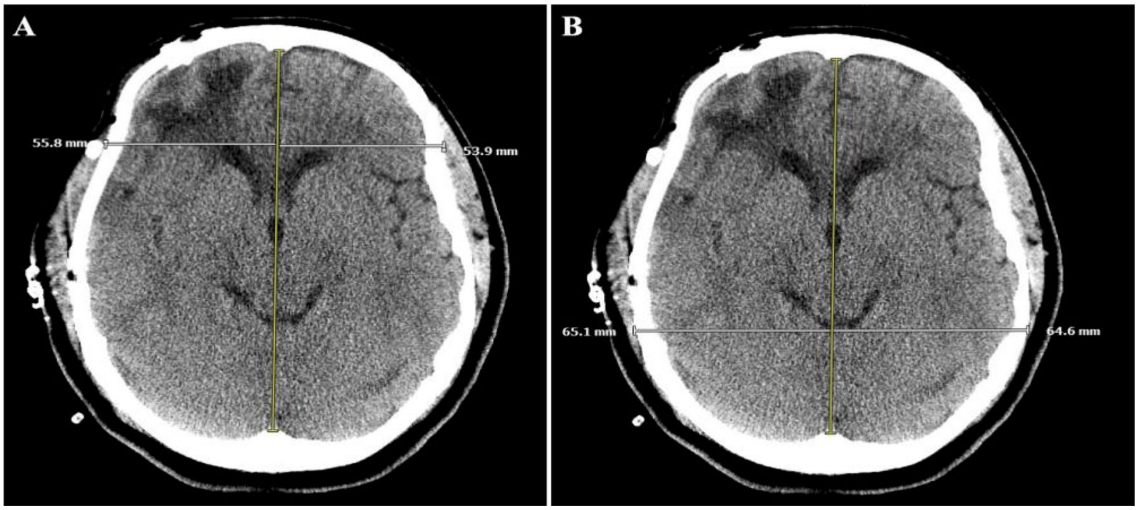

Fig. 1 **A** CT scan image depicting the measurement of frontal asymmetry at the third ventricle level. **B** Measurement of parietal asymmetry at the point of maximum biparietal diameter

was defined as p-values < 0.05. StataMP Software (StataCorp LLC, College Station, Texas) was used to perform all analyses. Multivariate analysis was performed to adjust for potential confounders, including age, cause of injury, history of cerebrovascular accident (CVA), hypertension (HTN), atrial fibrillation (AFib), the presence of a ventriculoperitoneal (VP) shunt, and type of insurance, as these factors were selected for their potential impact on postoperative complications. Results are reported according to the Strengthening the Reporting of Observational Studies in Epidemiology checklist (STROBE) [16].

Results

Patient characteristics

A total of 200 patients who underwent cranioplasties met the inclusion criteria, with 82 (41.0%) undergoing ABGs and 118 (59.0%) undergoing SGs. The cohort was predominantly male ($n = 127$, 63.5%), with a mean age of 49.2 ± 14.8. There was no significant difference in gender distribution between the two cohorts. The ABG cohort was significantly older (49.1 ± 12.2 years) than the SG group (42.4 ± 15.8 years) ($p = 0.001$). There were no significant differences in racial identity between cohorts (Table 1).

There were significantly higher numbers of patients with a history of cerebrovascular accidents (CVA) in the SG group as compared to ABGs (32.2% vs. 6.1%; $p < 0.001$). The ABG group consisted of more patients with a history of hypertension (46.3% vs. 22.9%; $p = 0.001$) and atrial fibrillation (13.4% vs. 4.2%, respectively; $p = 0.019$) (Table 1).

The socioeconomic status, as assessed by median distance to hospital and median income (determined by matching the patient's home zip code with U.S. Census data for median income by zip code), was similar between the groups, with greater travel distances generally associated with lower income (Table 1).

Perioperative variables

Among patients with each condition, 92.0% of those with subdural hematomas, 56.8% with traumatic brain injury, 100.0% with gunshot wounds, and 75.0% with intraparenchymal hemorrhage received SGs ($p < 0.001$). In contrast, patients who underwent cranioplasties following subarachnoid hemorrhages were more likely to receive an ABG (85.7%) ($p < 0.001$). Of note, there were similar numbers of patients undergoing ABGs and SGs for CVA, and intracerebral hemorrhage. In addition, there was no significant difference between cohorts regarding the laterality of the injury ($p = 0.692$) (Table 2).

The median hospital length of stay (LOS) was 5.0 days, with no significant differences between the ABGs and SGs (4.0 vs. 6.0 days, $p = 0.464$). The median follow-up was 227 days, and there was no significant difference between the cohorts (260 vs. 209 days, p = 0.294). The days to cranioplasty significantly differed between the groups, with ABGs waiting a median 106.5 [78] days in comparison to 117 [86] days for SGs ($p = 0.038$) (Table 2).

Aesthetic outcomes

Aesthetic outcomes were assessed using CT scans to evaluate frontal and parietal asymmetry (Fig. 1), with scans

Table 1 Patient demographics, comorbidities, socioeconomic factors of patients who underwent cranioplasties with autologous or synthetic flaps

	Total, *N* (%) 200 *Mean (SD)*	Autologous, *N* (%) 82 (41.0) *Mean (SD)*	Synthetic, *N* (%) 118 (59.0) *Mean (SD)*	*p-value*
Age	49.2 (14.8)	49.1 (12.2)	42.4 (15.8)	0.0014
Gender	N (%)	N (%)	N (%)	0.781
Male	127 (63.5)	53 (64.6)	74 (62.7)	
Female	73 (36.5)	29 (35.4)	44 (37.3)	
Race	*N (%)*	*N (%)*	*N (%)*	0.158
White	46 (23.0)	20 (24.4)	26 (22.0)	
Black or African American	106 (53.0)	40 (48.8)	66 (55.9)	
Asian	1 (0.5)	0 (0.0)	1 (0.8)	
American Indian or Alaska. Native	1 (0.5)	1 (1.2)	0 (0.0)	
Hispanic	41 (20.5)	21 (25.6)	20 (16.9)	
Other (Specify)	5 (2.5)	0 (0.0)	5 (4.2)	
Comorbidities	*N (%)*	*N (%)*	*N (%)*	
Drug use	34 (17.0)	14 (17.1)	20 (16.9)	0.982
CVA	43 (21.5)	5 (6.1)	38 (32.2)	< 0.001
Obesity	70 (35.0)	36 (43.9)	34 (28.8)	0.348
Hypertension	65 (32.5)	38 (46.3)	27 (22.9)	0.001
Coronary artery disease	10 (5.0)	7 (8.5)	3 (2.5)	0.056
COPD	1 (0.5)	0 (0.0)	1 (0.8)	0.229
Chronic Kidney Disease	8 (4.0)	4 (4.9)	4 (3.4)	0.597
Hyperlipidemia	24 (12.0)	14 (17.1)	10 (8.5)	0.066
Atrial fibrillation	16 (8.0)	11 (13.4)	5 (4.2)	0.019
Malignancy	10 (5.0)	3 (3.7)	7 (5.9)	0.468
Type II Diabetes Mellitus	33 (16.5)	13 (15.9)	20 (16.9)	0.837
VPS	27 (13.5)	10 (12.2)	17 (14.4)	0.653
Socioeconomic Factors	*Median [IQR]*	*Median [IQR]*	*Median [IQR]*	
Distance to Hospital	13.6 [25]	15.9 [22.1]	11.6 [26.2]	0.098
Median Income	97,613.5 [44,073]	98,637.5 [42,966]	97,417 [43,934]	0.748
Insurance	*N (%)*	*N (%)*	*N (%)*	0.011
Medicaid	45 (22.5)	15 (18.3)	30 (25.4)	
Medicaid HMO	27 (13.5)	4 (4.9)	23 (19.5)	
HMO	31 (15.5)	20 (24.4)	11 (9.3)	
Medicare	36 (18.0)	18 (22.0)	18 (15.3)	
Commercial	1 (0.5)	0 (0)	1 (0.8)	
Private	36 (18.0)	14 (17.1)	22 (18.6)	
Self-Pay	13 (6.5)	7 (8.5)	6 (5.1)	
Work Comp	3 (1.5)	2 (2.4)	1 (0.8)	
Other	7 (3.5)	2 (2.4)	5 (4.2)	

conducted at a median of 2.23 [10.79] months post-cranioplasty. Due to challenges in follow-up, we were unable to collect patient-reported outcomes regarding aesthetic satisfaction. For objective symmetry measurements, perfect symmetry is described as values closer to 0. Using this methodology, there were no significant differences for both frontal asymmetry (2.39 vs. 1.61 mm, $p = 0.321$) and parietal asymmetry (2.39 vs. 2.7 mm, $p = 0.348$) across the two cohorts on univariate analysis. Even when controlling for injury type on multivariate analysis, there were still no significant differences ($p = 0.225$ for frontal and 0.190 for parietal scores, respectively).

After stratifying the synthetic grafts by cause, there were no significant differences in frontal or parietal symmetry across the causes ($p = 0.665$ for frontal symmetry and $p = 0.958$ for parietal symmetry) on univariate analysis. Similarly, in the multivariate analysis, none of the individual causes were significantly associated with frontal ($p = 0.833$) or parietal ($p = 0.357$) symmetry. (Table 3).

Table 2 Indications for cranioplasty, in-hospital details, follow-up, & aesthetic outcomes

	Total	Autologous	Synthetic	*p-value*
Cause of Injury	*N (%)*	*N (%)*	*N (%)*	0.001
CVA	55 (27.5)	27 (32.9)	28 (23.7)	
SDH	13 (6.5)	1 (1.2)	12 (10.2)	
TBI	61 (30.5)	19 (23.2)	42 (35.6)	
IPH	54 (27.9)	23 (28.0)	31 (26.3)	
SAH	14 (7.0)	12 (14.6)	2 (1.7)	
Infection	2 (1.0)	0 (0.0)	2 (1.7)	
Tumor	1 (0.5)	0 (0.0)	1 (0.8)	
Injury Laterality	*N (%)*	*N (%)*	*N (%)*	0.692
Right	89 (44.5)	36 (40.4)	53 (44.9)	
Left	110 (55)	46 (41.8)	64 (54.2)	
Bilateral	1 (0.5)	0 (0)	1 (0.8)	
Surgical Details	*Median [IQR]*	*Median [IQR]*	*Median [IQR]*	
LOS (days)	26.5 [22]	25 [18]	29 [27]	0.464
Days to Cranioplasty	114 [82]	106.5 [78]	117 [86]	0.038
Follow-Up (days)	227 [225]	260 [225]	209 [213]	0.294
Aesthetic Asymmetry	*Median [IQR] (mm)*	*Median [IQR] (mm)*	*Median [IQR] (mm)*	
Frontal	2.02 [3.34]	2.39 [3.47]	1.61 [3.30]	0.321
Parietal	2.53 [3.16]	2.39 [3.32]	2.7 [3.13]	0.348

Table 3 Aesthetic asymmetry by cranioplasty type and synthetic material showing median [IQR] values for frontal and parietal regions

Aesthetic Asymmetry by Cranioplasty Type				
	Total	Autologous	Synthetic	
N (%)	*200*	*118 (59.0)*	*82 (41.0)*	
	Median [IQR] (mm)	*Median [IQR] (mm)*	*Median [IQR] (mm)*	*p-value*
Frontal Asymmetry	2.02 [3.34]	2.39 [3.47]	1.61 [3.30]	0.321
Parietal Asymmetry	2.53 [3.16]	2.39 [3.32]	2.7 [3.13]	0.348
Aesthetic Asymmetry by Synthetic Implant Type				
	Total	*PEEK*	*Non-PEEK*	
N (%)	118	107 (90.7)	11 (9.3)	
	Median [IQR] (mm)	*Median [IQR] (mm)*	*Median [IQR] (mm)*	*p-value*
Frontal Asymmetry	1.6 [2.91]	1.70 [2.90]	1.57 [3.56]	0.930
Parietal Asymmetry	2.7 [2.90]	2.70 [2.75]	1.08 [4.06]	0.481

Post-cranioplasty complications

Overall, 22.0% of the total cohort experienced complications following their cranioplasty, with SG patients experiencing an overall higher number of complications on both univariate (30.5% vs 9.8%, $p<0.001$) and multivariate analysis ($p<0.001$) (Table 4). This was further emphasized by infection rates as the multivariate analysis showed significantly higher rates in the SG group than ABG group (19.5% vs. 2.4%, $p=0.048$). All other complications were not found to be significant on univariate analysis and include dehiscence ($p=0.460$), hematoma ($p=0.27$), and hydrocephalus ($p=0.725$). For postoperative seizures, there were two noted in patients in the ABG group and none in the SG group.

On univariate analysis, the total number of cranioplasties was significantly increased in the SG cohorts across those undergoing 1 ($n=93$, 78.8%), 2 ($n=24$, 20.3%), or 3 ($n=1$, 0.8%) total cranioplasties ($p=0.001$) (Table 4). On multinomial logistic regression, SGs were significantly associated with an increased likelihood of undergoing a second cranioplasty compared to the first ($p=0.0001$), though the small number of cases for those undergoing a third cranioplasty limited meaningful interpretation.

Table 4 Post-cranioplasty complications

Post-cranioplasty Complications	Total *N (%)*	Autologous *N (%)*	Synthetic *N (%)*	Univariate *P-value*	Multivariate *P-value*
Total	44 (22.0)	8 (9.8)	36 (30.5)	< 0.001	0.019
Infection	25 (12.5)	2 (2.4)	23 (19.5)	0.045	0.048
Dehiscence	16 (8.0)	2 (2.4)	14 (11.9)	0.460	
Hematoma	10 (5.0)	3 (3.7)	7 (5.9)	0.270	
Hydrocephalus	9 (4.5)	2 (2.4)	7 (5.9)	0.725	
Seizure	2 (1.0)	2 (2.4)	0 (0.0)	0.020	N/A*
Revisions	27 (13.5)	2 (2.4)	25 (13.7)	0.001	0.001

*Limited number of observations for robust multivariate analysis

Discussion

This study investigated both the aesthetic outcomes and complications of those undergoing cranioplasties with either ABGs or SGs in an adult population. While prior research has examined short-term complications between these two modalities, there remains a knowledge gap regarding post-operative complications and the durability of aesthetic outcomes over time. Our findings reveal that both ABGs and SGs achieve comparable aesthetic results. However, SGs are associated with higher rates of postoperative complications.

Our results also suggest that the cause of requiring a cranioplasty is a significant factor in whether an ABG or SG is used. The observed differences in whether an autologous or synthetic flap was used for a cranioplasty is closely tied to the underlying cause of injury, as the etiology often dictated whether an autologous or synthetic implant was utilized. For example, in cases of traumatic brain injury (TBI), synthetic implants were significantly more common, likely reflecting the frequent destruction or contamination of autologous flaps in high-energy injuries such as gunshot wounds.

From an aesthetic standpoint, our results demonstrate no significant differences between ABGs and SGs in frontal (2.39 mm vs. 1.61 mm, $p = 0.321$) or parietal asymmetry (2.39 mm vs. 2.7 mm, $p = 0.348$), even after adjusting for injury type. This parity in symmetry outcomes offers clinicians and patients flexibility in choosing a graft material that aligns with individual clinical contexts. Patients, beyond seeking functional restoration, also value the aesthetic reconstruction of cranial symmetry, making this aspect a key consideration in cranioplasty decisions.

Given the absence of significant differences in aesthetic outcomes, it remains crucial to consider hospital burden and other postoperative outcomes in determining optimal graft material selection aimed at improving clinical and patient-driven outcomes. Concerning costs associated with this operation, cranioplasties done with synthetic grafts are considerably more expensive than autologous options, particularly since these implants utilize expensive materials, are custom-designed using preoperative CT imaging, and manufactured via 3D-printing technology [7]. In fact, according to Findlay et al., custom implants account for 89.2% of the total initial cranioplasty hospitalization costs, while autologous grafts represent only 12.2% of the total costs [7]. This cost disparity suggests that ABGs are the more financially viable option, particularly in settings with constrained healthcare resources or limited insurance coverage. However, cost considerations must also account for the cause of injury, associated risks, and postoperative complications. Post-operative complications were significantly higher in the SG cohort compared to the ABG cohort. Infection rates were a major factor in this as they were notably higher in the SG group. For patients receiving ABGs, the large abdominal incisions needed to store the bone often resulted in significant complications, including hematomas and infections leading to our institution transitioning to SGs, which eliminated the need for these large incisions. Despite reducing abdominal complications, SGs introduced new infection risks inherent to synthetic materials, which are challenging to sterilize and prone to infections requiring implant removal and replacement. This pattern mirrors complications seen with other synthetic implants, such as knee replacements, underscoring the broader challenges of using synthetic materials in surgical settings [13]. When a synthetic graft is compromised due to infection, it often necessitates removal and replacement with another synthetic graft, further increasing costs and leading to longer hospital stays, as observed in our population. In contrast, starting with an autologous graft offers a more cost-effective strategy, as infection would then warrant the first use of a synthetic graft rather than a second, mitigating the financial burden associated with repeated synthetic graft replacements.

The choice between ABGs and SGs should be guided by a combination of factors, especially the cause of injury, defect size, comorbid conditions, a patient's body habitus, and socioeconomic factors. When feasible, ABGs should be used due to their low cost and significantly lower post-cranioplasty complications. However, for ABGs placed in the abdominal pocket, the same comorbidities should help guide whether a patient would be at risk of pre-cranioplasty complications. However, this can be avoided if cryopreservation is utilized over an abdominal flap. It should be noted that ABGs are prone to resorption if the time from craniectomy to cranioplasty is prolonged, but this should not be an initial factor in choosing between ABGs and SGs. When ABGs are not viable, SGs remain a valuable option, especially when the patient's medical condition warrants a more stable, customized graft.

Limitations

This study is limited by its retrospective, single-institution design, which introduces potential variability in surgical techniques and perioperative management that may influence both aesthetic outcomes and complication rates. Additionally, the median follow-up of 227 days and aesthetic assessments at 2.23 months do not capture long-term complications such as autologous bone resorption, which can significantly impact cosmetic outcomes and patient satisfaction. Furthermore, our patient population, many of whom have experienced severe neurological injuries, was less likely to follow up long-term, limiting our ability to evaluate late-stage complications. The lack of patient-reported outcome measures (PROMs) also restricted our evaluation of subjective aesthetic concerns, including temporalis wasting, soft tissue atrophy, and scalp scarring, which are not fully captured by objective CT-based symmetry measurements. The absence of standardized aesthetic assessment tools further complicates contextualizing our findings within the existing literature. Future studies should incorporate extended follow-up, validated PROMs, and standardized evaluation methods to provide a more comprehensive assessment of long-term functional and cosmetic outcomes in cranioplasty patients.

Conclusion

This study highlights that both ABGs and SGs yield comparable aesthetic outcomes in cranioplasties but that SGs have significantly more complications associated with them. The cost-effectiveness of ABGs, coupled with their lower complication rates, suggests that they may be a more favorable option. However, in cases where ABGs are not viable or present additional risks, SGs remain a valuable alternative.

Our findings underscore the importance of individualizing graft selection based on factors such as the cause of injury, patient comorbidities, healthcare resources and anticipated recovery trajectory. Future research should focus on extended long-term follow-up and patient-reported aesthetic satisfaction, to provide a more comprehensive understanding of the functional and aesthetic impact of cranioplasty materials on patient outcomes.

Author contribution I.S. contributed to the idea, the data collection, analysis, writing, and edits.

R.G. contributed to the idea, the data collection, analysis, writing, and edits.

E.D. contributed to supervision, writing, and revisions, and guidance as well as editing after initial feedback from Acta Neurochirurgica.

R.P. contributed to supervision and final approval of the paper.

D.F. contributed to supervision, guidance, writing, and initial help with getting IRB approval.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics statement This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

Human ethics and consent to participate This study was approved by the Institutional Review Board, IRB number: 00004771. Due to the retrospective nature of this study, the requirement for obtaining informed consent was waived by the IRB.

Consent to participate Informed consent was not required for this study, as it was a retrospective analysis of existing patient data. The Institutional Review Board granted a waiver of consent.

Conflicts of interest The authors declare no competing interests.

References

1. Baldia M, Joseph M, Sharma S et al (2022) Customized cost-effective polymethylmethacrylate cranioplasty: A cosmetic comparison with other low-cost methods of cranioplasty. Acta Neurochir (Wien) 164:655–667. https://doi.org/10.1007/s00701-022-05121-0
2. Baldo S, Tacconi L (2010) Effectiveness and safety of subcutaneous abdominal preservation of autologous bone flap after

decompressive craniectomy: A prospective pilot study. World Neurosurgery 73:552–556. https://doi.org/10.1016/j.wneu.2010.02.018
3. Brommeland T, Rydning PN, Pripp AH, Helseth E (2015) Cranioplasty complications and risk factors associated with bone flap resorption. Scand J Trauma Resusc Emerg Med 23:75. https://doi.org/10.1186/s13049-015-0155-6
4. Dowlati E, Pasko KBD, Molina EA et al (2022) Decompressive hemicraniectomy and cranioplasty using subcutaneously preserved autologous bone flaps versus synthetic implants: perioperative outcomes and cost analysis. J Neurosurg 137:1831–1838. https://doi.org/10.3171/2022.3.JNS212637
5. Ernst G, Qeadan F, Carlson AP (2018) Subcutaneous bone flap storage after emergency craniectomy: Cost-effectiveness and rate of resorption. J Neurosurg 129:1604–1610. https://doi.org/10.3171/2017.6.JNS17943
6. Fan M, Wang Q, Sun P et al (2018) Cryopreservation of autologous cranial bone flaps for cranioplasty: A large sample retrospective study. World Neurosurg 109:e853–e859. https://doi.org/10.1016/j.wneu.2017.10.112
7. Findlay M, Bauer SZ, Gautam D et al (2024) Cost differences between autologous and nonautologous cranioplasty implants: A propensity score–matched value driven outcomes analysis. World Neurosurg: X 22:100358. https://doi.org/10.1016/j.wnsx.2024.100358
8. Goedemans T, Verbaan D, Van Der Veer O et al (2020) Complications in cranioplasty after decompressive craniectomy: Timing of the intervention. J Neurol 267:1312–1320. https://doi.org/10.1007/s00415-020-09695-6
9. Gooch MR, Gin GE, Kenning TJ, German JW (2009) Complications of cranioplasty following decompressive craniectomy: Analysis of 62 cases. FOC 26:E9. https://doi.org/10.3171/2009.3.FOCUS0962
10. Harris DA, Fong AJ, Buchanan EP et al (2014) History of synthetic materials in alloplastic cranioplasty. Neurosurg Focus 36:E20. https://doi.org/10.3171/2014.2.FOCUS13560
11. He L (2024) Biomaterials for regenerative cranioplasty: Current state of clinical application and future challenges. JFB 15. https://doi.org/10.3390/jfb15040084
12. Huq S, Khalafallah AM, Brem H et al (2020) Introducing medical students to the burgeoning field of neuroplastic surgery. J Craniofac Surg 31:891–892. https://doi.org/10.1097/SCS.0000000000006351
13. Rodriguez-Merchan EC, Delgado-Martinez AD (2022) Risk factors for periprosthetic joint infection after primary total knee arthroplasty. J Clin Med 11:6128. https://doi.org/10.3390/jcm11206128
14. Shahid AH, Mohanty M, Singla N et al (2018) The effect of cranioplasty following decompressive craniectomy on cerebral blood perfusion, neurological, and cognitive outcome. J Neurosurg 128:229–235. https://doi.org/10.3171/2016.10.JNS16678
15. Sundseth J, Sundseth A, Berg-Johnsen J et al (2014) Cranioplasty with autologous cryopreserved bone after decompressive craniectomy. Complications and risk factors for developing surgical site infection. Acta Neurochir 156:805–811. https://doi.org/10.1007/s00701-013-1992-6
16. Vandenbroucke JP (2007) Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): Explanation and elaboration. Ann Intern Med 147:W. https://doi.org/10.7326/0003-4819-147-8-200710160-00010-w1