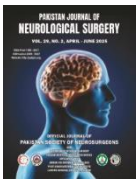

PAKISTAN JOURNAL OF NEUROLOGICAL SURGERY (QUARTERLY) – OFFICIAL JOURNAL OF PAKISTAN SOCIETY OF NEUROSURGEONS

Original Research

Current Concepts in Cranioplasty: Indications, Materials, Surgical Techniques, and Complications

Mumtaz Ali[1], Hanif Ur Rahman[1], Ramzan Hussain[1], Amjid Ali[2], Mansoor[1], Muhammad Aneeq[1] Jabir Shah[1], Yasir Ashraf[2,3]

[1]Department of Neurosurgery, Ali Institute of Neurosciences, Irfan General Hospital, Peshawar – Pakistan
[2]Department of Physiotherapy, Ali Institute of Neurosciences, Irfan General Hospital, Peshawar – Pakistan
[3]Khyber Medical University, Peshawar – Pakistan

ABSTRACT

Objective: This study evaluates the clinical outcomes, materials used, and complications associated with cranioplasty thus providing a comprehensive analysis based on patient's data.

Materials and Methods: This retrospective observational study was conducted at Ali Institute of Neurosciences, Irfan General Hospital, Peshawar from November 2023 to December 2024. A total of 55 patients who underwent cranioplasty were included in the study. The study analyzed patient demographics, indications, material selection, surgical techniques, and postoperative complications.

Results: The most common indication for cranioplasty was post-traumatic defects (63.6%), followed by decompressive craniectomy (25.4%), tumor resection (5.5%), and infection-related bone flap removal (5.5%). The materials used included polyetheretherketone (PEEK) (34.5%), bone cement (30.9%) titanium mesh (18.2%), and acrylic mesh (16.4%). Postoperative infections occurred in 7% of patients and were successfully managed with antibiotics or revision surgery. No cases of implant rejection or resorption were observed.

Conclusion: Cranioplasty plays a crucial role in restoring cranial integrity improving neurological and aesthetic outcomes. Advances in biomaterials particularly PEEK, have enhanced procedural success in our study. While the surgery remains essential for functional and cosmetic rehabilitation optimizing material selection and infection prevention strategies can further improve patient outcomes.

Keywords: Cranioplasty, skull reconstruction, neurosurgery, biomaterials, postoperative complications, PEEK implants, decompressive craniectomy.

Corresponding Author: Mumtaz Ali
Department of Neurosurgery, Ali Institute of Neurosciences, Irfan General Hospital, Peshawar, Pakistan

Date of Submission: 05-01-2025
Date of Revision: 05-05-2025
Date of Acceptance: 01-06-2025
Date of Online Publishing: 30-6-2025

Date of Print: 30-6-2025

DOI: 10.36552/pjns.v29i2.1105

INTRODUCTION

Cranioplasty is a neurosurgical procedure used to reconstruct cranial defects resulting from trauma,

tumor excision, congenital malformations, or decompressive craniectomy.[1-2] These defects may lead to complications like impaired cerebral protection, neurological deficits, and psychological distress due to altered appearance.[3-4] Cranioplasty overcomes these challenges by reconstructing the skull's anatomy thereby restoring both its protective function and aesthetic appearance.[5-6] Historically, cranioplasty has been used since ancient times, with early attempts involving materials like metals and shells.[7-8] The safety and efficacy of the procedure have been improved by centuries of advancements in surgical methods and the introduction of biocompatible materials.[9–10] Cranioplasty not only restores the structural integrity of the skull but also plays a significant role in functional recovery and aesthetic rehabilitation.[11-12] Cranioplasty plays a vital role in improving neurological function, preventing complications such as trephine syndrome, and enhancing the overall quality of life of patients.[13-14] Advancements in biomaterials and surgical techniques over the years have improved the outcomes of cranioplasty and have made it a crucial aspect of reconstructive neurosurgery.[15-16] The necessity for cranioplasty arises from the interplay of functional and cosmetic considerations. While some patients undergo the procedure primarily for aesthetic reasons—such as individuals engaged in professions requiring public interactions (e.g., actors, bankers, teachers, and doctors)—others require cranioplasty to address complications related to cranial defects, including intracranial pressure dysregulation, neurological impairments, and increased vulnerability to brain injury. However, despite its benefits, cranioplasty is associated with certain challenges, including risks of infection, implant rejection, and postoperative complications.

This study aims to provide a comprehensive analysis of cranioplasty, including its indications, contraindications, material choices, surgical techniques, and outcomes.

MATERIALS AND METHODS

Study Design and Setting

This retrospective observational study was conducted at Ali Institute of Neurosciences, Irfan General Hospital, Peshawar from November 2023 to December 2024 with ethical approval from the hospital review board and informed consent from patients. A total of 55 patients who underwent cranioplasty for various cranial abnormalities were included in the study. Information about patient demographics, surgical indications, reconstruction materials, surgical procedures, postoperative problems, and overall results were taken from hospital records.

Inclusion Criteria

Our study included all patients who underwent cranioplasty following trauma, decompressive craniectomy, tumor resection surgery, congenital defects, or infections that needed bone flap removal.

Exclusion Criteria

The study excluded all patients who had active infections, uncontrolled hydrocephalus, or significant cerebral edema at the time of surgery.

Preoperative Considerations

Optimal surgical outcomes and reduced complications are achieved when surgeons carefully consider preoperative factors. To determine soft tissue involvement, a patient needs a comprehensive evaluation including CT scans with bone windows and (if needed) MRI to evaluate their complete situation. Moreover, a thorough medical evaluation is also carried out to eliminate contraindications including hemodynamic instability or any systemic infections. Cranioplasty is typically an elective procedure, therefore it should only be carried out

when the patient is medically stable and fully recovered from any previous neurological problems. In cases of infection, a waiting period of 6 to 9 months is generally recommended to ensure complete resolution before undergoing this neurosurgical procedure.

Indications and Contraindications

In various clinical scenarios where cranial abnormalities affect cerebral functionality or the overall health of the patient, cranioplasty should be considered. Some of the common indications of cranioplasty include:

Traumatic Brain Injury (TBI): Severe head trauma may cause fractures in the skull that require surgical intervention. In such scenarios, cranioplasty restores the integrity of the skull. Hence, it shields the brain from external forces.

Decompressive Craniectomy: Cranioplasty is often required to reconstruct the skull after a decompressive craniectomy is performed for conditions such as traumatic brain swelling, stroke, or intracranial hypertension.

Neurosurgical Tumor Resection: Some tumors require aggressive resection involving bone removal therefore a subsequent cranioplasty may be required to reconstruct the skull following a neurosurgical tumor resection.

Congenital Skull Defects: Cranioplasty is necessary for certain patients who have congenital cranial anomalies that impact both cosmesis and brain protection.

Infection-related Bone Removal: Following infection resolution, cranioplasty may be required for severe osteomyelitis, post-operative infections, or complications from previous implants.

Despite its indications, cranioplasty is contraindicated in certain conditions that can lead to surgical failure or complications.

Contraindications Include

Active infection: In case of ongoing systemic or localized infection to prevent implant contamination and failure, cranioplasty should be delayed.

Unresolved intracranial hypertension: Until stability has been achieved, patients with persistently high intracranial pressure shouldn't undergo cranioplasty.

Pediatric patients: In the case of children under 14 synthetic implants are often ineffective due to ongoing cranial growth, leading to implant displacement.

Cranial defects communicating with sinuses: Cranial defects that communicate with the frontal, ethmoidal, or sphenoidal sinuses are at a higher risk of implant failure due to direct exposure to environmental pathogens.

Cranioplasty Materials and Their Evolution

The success of cranioplasty largely depends on the choice of implant material. An ideal cranioplasty material should be lightweight, biologically inert, non-antigenic, durable, moldable, cost-effective, and heat-conductive to prevent thermal effects on the brain. Various materials have been used historically, each with distinct advantages and limitations:

Metals: The earliest cranioplasty materials included metals such as titanium and stainless steel, which offered high strength but carried risks of thermal conductivity and poor cosmetic adaptation.

Acrylic Polymers: Polymethyl methacrylate (PMMA) was later introduced and initially used in dentistry before being adapted for cranial reconstruction. While easily moldable, PMMA lacked sufficient structural integration.

Bone Cement: Some cranioplasties utilize bone cement, but its inability to form a natural contour

resulted in suboptimal aesthetic outcomes.

Polyetheretherketone (PEEK): The latest advancement in cranioplasty materials is PEEK implants, which provide excellent durability, biocompatibility, and cosmetic outcomes. Unlike traditional materials, PEEK enables better contouring and reduced rejection rates, making it a preferred choice.

Autologous Bone Grafts: In some cases, natural bone from the patient (e.g., fibula, ribs) is harvested and used as an implant, offering superior biocompatibility. Additionally, some surgeons have explored xenografts, where animal-derived bone is adapted for human use.

Operative Procedure

The cranioplasty procedure follows a systematic approach to ensure precision and minimize complications. The steps include:

1. Patient Preparation and Anesthesia: The patient undergoes general anesthesia, and the surgical site is sterilized.
2. *Incision and Exposure:* A careful incision is made over the cranial defect, followed by soft tissue dissection to expose the defect.
3. *Duraplasty:* If dura mater reinforcement is necessary, a duraplasty is performed before implant placement.
4. *Implant Placement:* The selected implant is carefully positioned and secured using plates or screws.
5. *Wound Closure:* The surgical site is meticulously closed in layers to prevent postoperative complications.

RESULTS

Patient Characteristics

As shown in Table 1, A total of 55 patients were included in the study, with a mean age of 35 years (range 18–75). The cohort had a male predominance, with 41 males (75%) and 14 females (25%). The most common comorbidities were hypertension in 15 patients (27%) and diabetes in 10 patients (18%). The mean follow-up period was 6 months.

Indications for Cranioplasty

The primary indications for cranioplasty in this study were post-traumatic cranial defects, observed in 33 patients (60%). This was followed by decompressive craniectomy for malignant cerebral edema in 14 patients (25%), tumor resection in 5 patients (10%), and infection-related bone flap removal in 3 patients (5%).

Materials Used

The selection of cranioplasty materials was based on individual patient needs taking into account factors such as defect size, location, and anatomical complexity. PEEK implants were used in 19 cases (34.5%) for their superior cosmetic and biomechanical properties, particularly in larger defects. Bone cement was selected for 17 cases (30.9%), typically in smaller defects where contouring was less critical. Titanium mesh was used in 10 cases (18.2%) to provide structural support, while acrylic mesh was used in 9 cases (16.4%) for aesthetic purposes.

Postoperative Outcomes and Complications

Postoperative complications occurred in 4 patients (7%), all of whom developed surgical site infections. Two cases were superficial and treated with oral antibiotics, while the remaining two required implant removal and revision surgery due to deeper infections. No cases of implant rejection or resorption were noted during the follow-up period. The remaining 51 patients (93%) experienced uneventful recoveries with satisfactory aesthetic and functional outcomes. At follow-up, 90% of patients reported high satisfaction with both functional and cosmetic outcomes.

DISCUSSION

Cranioplasty is an integral part of neurosurgical practice, providing both functional and cosmetic benefits to patients with cranial defects. Overall, the findings of this study support the existing literature regarding the significance of early intervention, selection of the appropriate material, and complication management. Restoration of skull integrity has been shown to benefit CSF dynamics, cerebral blood flow, and overall neurological function (Piazza & Grady, 2017). Specifically, patients who underwent cranioplasty after decompressive craniectomy showed good neurological improvements and decreased risk of complications such as trephine syndrome.[13] The choice of implant material also significantly influences surgical outcomes. In our study, different materials for cranioplasty were used including PEEK 34.5%, bone cement 30.9%, titanium mesh 18.2%, and acrylic mesh 16.4%. Similar findings have been reported in previous studies, where PEEK implants showed reduced infection rates and improved cranial contouring.[14] Autologous bone grafts exhibit biocompatibility, but they lead to increased bone absorption and infections.[10] One of the major concerns of cranioplasty is postoperative infections. Our study found that infections occurred in 7% of patients, aligning with global reports indicating an infection rate of 5–10%.[4] Patients who undergo delayed cranioplasty after decompressive craniectomy face a higher risk of infections and poorer neurological recovery[5] (Fountain et al, 2021). Therefore, early intervention and strict infection control measures are essential for better patient outcomes. The findings of this study are valuable despite being restricted by a relatively small sample size and single-center data collection. Future studies must include multiple facilities and long-term follow-up of clinical implant stability and satisfactory outcomes of patients. Emerging technologies such as 3D-printed custom implants and bioengineered scaffolds may further revolutionize cranioplasty.[7] Cranioplasty remains a vital reconstructive procedure in neurosurgery with significant functional, neurological, and aesthetic implications. The findings reinforce the importance of optimal material selection, timely surgical intervention, and rigorous infection control in achieving favorable outcomes. With continued advancements in biomaterials and surgical techniques, cranioplasty outcomes will continue to improve and ultimately enhance patients' quality of life.

Table 1: *Summary of Cranioplasty Study Results.*

Parameter	Percentage (%)	Number of Cases (n)
Gender		
Male	75%	41
Female	25%	14
Indications for Cranioplasty		
Post-Traumatic Defects	60%	33
Decompressive Craniectomy	25%	14
Tumor Resection	10%	5
Infection-Related Bone Removal	5%	3
Cranioplasty Materials Used		
PEEK Implants	34.5%	19
Bone Cement	30.9%	17
Titanium Mesh	18.2%	10
Acrylic Mesh	16.4%	9
Postoperative Complications		
Infection	7%	4
Uneventful Recovery	93%	51

CONCLUSION

Cranioplasty serves as an invaluable procedure that restores the integrity of the skull and also enhances both neurological function and aesthetic appearance. Material selection together with detailed surgical planning directly affects the postoperative success rate. Advances in biomaterials, particularly PEEK have revolutionized cranioplasty outcomes by offering better biocompatibility and durability. While cranioplasty

remains an essential intervention, patient selection, timing, and infection prevention strategies are crucial in optimizing long-term outcomes.

REFERENCES

1. Piazza M, Grady MS. Cranioplasty. Neurosurg Clin N Am. 2017;28(2):257-65. Doi: 10.1016/j.nec.2016.11.008.
2. Broughton E, Pobereskin L, Whitfield PC. Seven years of cranioplasty in a regional neurosurgical centre. Br J Neurosurg. 2014;28(1):34-9. Doi: 10.3109/02688697.2013.815319
3. Rosinski CL, Chaker AN, Zakrzewski J, Geever B, Patel S, Chiu RG, et al. Autologous Bone Cranioplasty: A Retrospective Comparative Analysis of Frozen and Subcutaneous Bone Flap Storage Methods. World Neurosurg. 2019;131:e312-e20. Doi: 10.1016/j.wneu.2019.07.139.
4. Abode-Iyamah KO, Chiang HY, Winslow N, Park B, Zanaty M, Dlouhy BJ, et al. Risk factors for surgical site infections and assessment of vancomycin powder as a preventive measure in patients undergoing first-time cranioplasty. J Neurosurg. 2018;128(4):1241-9. Doi: 10.3171/2016.12.JNS161967.
5. Fountain DM, Henry J, Honeyman S, O'Connor P, Sekhon P, Piper RJ, et al. First Report of a Multicenter Prospective Registry of Cranioplasty in the United Kingdom and Ireland. Neurosurgery. 2021;89(3):518-26. Doi: 10.1093/neuros/nyab220
6. Höhne J, Werzmirzowsky K, Ott C, Hohenberger C, Hassanin BG, Brawanski A, et al. Outcomes of Cranioplasty with Preformed Titanium versus Freehand Molded Polymethylmethacrylate Implants. J Neurol Surg A Cent Eur Neurosurg. 2018;79(3):200-5. Doi: 10.1055/s-0037-1604362
7. Meyer H, Khalid SI, Dorafshar AH, Byrne RW. The Materials Utilized in Cranial Reconstruction: Past, Current, and Future. Plast Surg (Oakv). 2021;29(3):184-96. Doi: 10.1177/2292550320928560.
8. Hsu VM, Tahiri Y, Wilson AJ, Grady MS, Taylor JA. A preliminary report on the use of antibiotic-impregnated methyl methacrylate in salvage cranioplasty. J Craniofac Surg. 2014;25(2):393-6. Doi: 10.1097/SCS.0000000000000655.
9. Millward CP, Doherty JA, Mustafa MA, Humphries TJ, Islim AI, Richardson GE, et al. Cranioplasty with hydroxyapatite or acrylic is associated with a reduced risk of all-cause and infection-associated explantation. Br J Neurosurg. 2022;36(3):385-93. Doi: 10.1080/02688697.2022.2077311
10. van de Vijfeijken S, Münker T, Spijker R, Karssemakers LHE, Vandertop WP, Becking AG, et al. Autologous Bone Is Inferior to Alloplastic Cranioplasties: Safety of Autograft and Allograft Materials for Cranioplasties, a Systematic Review. World Neurosurg. 2018;117:443-52 e8. Doi: 10.1016/j.wneu.2018.05.193
11. Still MEH, Samant S, Alvarado A, Neal D, Governale LS, Ching JA. Considerations for Choice of Cranioplasty Material for Pediatric Patients. Pediatr Neurosurg. 2023;58(1):1-7. Doi: 10.1159/000528543.
12. Beuriat PA, Szathmari A, Grassiot B, Di Rocco F, Mottolese C. [Why a hydroxyapatite cranioplasty can be used to repair a cranial bone defect in children: Experience of 19 cases]. Neurochirurgie. 2016;62(5):251-7. Doi: 10.1016/j.neuchi.2016.04.003
13. Wang YC, Wu YC, Chang CW, Chung CL, Lee SS. An algorithmic approach of reconstruction for cranioplasty failure: A case series. Medicine (Baltimore). 2023;102(8):e33011. Doi: 10.1097/MD.0000000000033011
14. Thien A, King NK, Ang BT, Wang E, Ng I. Comparison of polyetheretherketone and titanium cranioplasty after decompressive craniectomy. World Neurosurg. 2015;83(2):176-80. Doi: 10.1016/j.wneu.2014.06.003
15. Rosinski CL, Patel S, Geever B, Chiu RG, Chaker AN, Zakrzewski J, et al. A Retrospective Comparative Analysis of Titanium Mesh and Custom Implants for Cranioplasty. Neurosurgery. 2020;86(1):E15-E22. Doi: 10.1093/neuros/nyz358
16. Pabaney AH, Reinard KA, Asmaro K, Malik GM. Novel technique for cranial reconstruction following retrosigmoid craniectomy using demineralized bone matrix. Clin Neurol Neurosurg. 2015;136:66-70. Doi: 10.1016/j.clineuro.2015.05.034

Additional Information

Disclosures: Authors report no conflict of interest.
Ethical Review Board Approval: For this study Consent was obtained from the hospital ethical committee board.
Funding: N/A.
Data Availability: Data will be made available upon an adequate request by the principal author (shahmumtazali48@gmail.com)
Human Subjects: Consent was obtained by all patients/participants in this study.
Conflict of Interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following:
Financial Relationships: All authors have declared that they have no financial relationships at present or within previous three years with any organizations that might have an interest in the submitted work.
Other Relationships: All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

AUTHORS CONTRIBUTIONS

Sr.#	Author's Full Name	Intellectual Contribution to Paper in Terms of:
1.	Mumtaz Ali, Hanif Ur Rahman & Yasir Ashraf	1. Study design and methodology.
2.	Mumtaz Ali & Yasir Ashraf	2. Paper writing.
3.	Mansoor, Muhammad Aneeq & Jabir Shah	3. Data collection and calculations.
4.	Mumtaz Ali, Yasir Ashraf, Hanif Ur Rahman & Ramzan Hussain	4. Analysis of data and interpretation of results.
5.	Mumtaz Ali, Hanif Ur Rahman, Yasir Ashraf, Mansoor & Jabir Shah	5. Literature review and referencing.
6.	Ramzan Hussain, Amjid Ali & Hanif Ur Rahman	6. Editing and quality insurer.