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Original Research Article

Complications and Risk Factors in Cranioplasty: A Prospective Observational Study at a Tertiary Care Centre

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Abstract:

Background: Cranioplasty is crucial for repairing cranial defects but carries significant risks and complications. This study aimed to identify complications and risk factors associated with cranioplasty at a tertiary care center.

Methods: A prospective observational study was conducted over 12 months with 150 adult patients undergoing cranioplasty. Data on demographics, clinical characteristics, indications, materials used, and postoperative complications were collected. Statistical analyses, including logistic regression, identified significant risk factors.

Results: The mean age was 45.6 years, with 61.33% males. Indications for craniotomy included traumatic brain injury (56.67%), stroke (26.67%), and tumor resection (13.33%). Materials used were autologous bone (40.00%), titanium mesh (36.67%), and custom 3D implants (23.33%). Immediate complications occurred in 30.00% of patients, including infections (12.00%) and hematomas (8.00%). Long-term complications included bone flap resorption (14.67%) and chronic pain (11.33%). Significant risk factors were higher age, BMI, diabetes, hypertension, smoking, autologous bone use, and longer surgery duration. Custom 3D implants were associated with fewer complications.

Conclusion: Cranioplasty poses substantial risks, with age, BMI, co-morbidities, and surgery duration as key risk factors. Custom 3D implants may reduce complication rates. Identifying these factors can improve patient outcomes and guide clinical practices.

Keywords: Cranioplasty, Postoperative Complications, Risk Factors, Autologous Bone Grafts, Titanium Implants.

Introduction

Cranioplasty is a neurosurgical procedure aimed at repairing cranial defects that arise due to various reasons such as trauma, tumor resection, decompressive craniectomy, or congenital abnormalities. The primary purposes of cranioplasty are to provide physical protection to the underlying brain, restore the aesthetic contour of the skull, and potentially improve neurological function by normalizing intracranial pressure dynamics and cerebrospinal fluid circulation. [1]

The practice of cranioplasty dates back to ancient civilizations. Archaeological findings suggest that the Inca civilization performed early forms of cranioplasty using materials such as gold, silver, and gourds. In the 19th and early 20th centuries, autologous bone was often used, though the techniques and materials have since evolved significantly. The introduction of synthetic materials such as methyl methacrylate, titanium, and more recently, patient-specific 3D-printed implants, has revolutionized cranioplasty by improving outcomes and reducing complications. [2] Craniectomy is often performed as a life-saving procedure to alleviate increased intracranial pressure due to conditions such as traumatic brain injury (TBI), malignant cerebral infarction, and intra-cerebral hemorrhage. Other indications include decompression for brain tumors, infections that necessitate the removal of infected bone, and congenital cranial defects. [1,3-4] Cranioplasty is usually considered once the underlying cause for the initial craniectomy has been resolved and the patient is medically stable. The ideal timing is typically between 3 to 6 months post-craniectomy, depending on factors such as the absence of infection, adequate wound healing, and patient's overall neurological status. Preoperative imaging, including CT or MRI, is essential to plan the surgery and assess the suitability of the cranial defect for repair. [1,3]

Autologous bone grafts involve the use of the patient's own bone, usually preserved after the

initial craniectomy. This method has the advantage of biocompatibility and reduced risk of immunogenic response. However, autologous grafts are prone to resorption and infection, which can compromise the integrity of the repair over time. Synthetic Materials (e.g., Titanium, Custom Implants): these materials have become increasingly popular due to their durability and precision. Titanium, being lightweight and strong, is commonly used, especially in patients who are at higher risk of bone resorption or those with large defects. Custom 3D-printed implants made from materials such as polyetheretherketone (PEEK) offer excellent cosmetic outcomes and a perfect fit to the patient's anatomy. However, they are more expensive and may carry a risk of infection and foreign body reaction. [5]

Autologous Bone Grafts: Pros include biocompatibility and cost-effectiveness; cons include a higher risk of resorption and infection.

Synthetic Materials: Pros include better structural and cosmetic outcomes, lower risk of resorption; cons include higher costs and potential for immunologic complications. Immediate complications, occurring within 30 days post-surgery, include surgical site infections, hematoma formation, cerebrospinal fluid (CSF) leaks, and seizures. Infections are a significant concern, often necessitating antibiotic therapy and sometimes the removal of the implant. Hematomas may require surgical evacuation, while CSF leaks might need lumbar drainage or revision surgery. Long-term complications can emerge months or even years after surgery. These include bone flap resorption, which is more common with autologous grafts, chronic pain, implant loosening or migration, and new-onset neurological deficits. Bone flap resorption can lead to the need for reoperation and the use of synthetic materials. [4-6]

Impact on Patient Outcomes: Complications significantly impact patient outcomes by prolonging hospital stays, increasing healthcare costs, and affecting overall quality of life. Effective management and prevention strategies are crucial to improving patient prognoses and minimizing adverse effects.

Several patient-related factors increase the risk of complications, including advanced age, presence of comorbidities such as diabetes and immunosuppression, poor nutritional status, and history of previous infections or surgeries. Surgery-Related Factors, such as the duration of surgery, the type of cranioplasty material used, and the technical expertise of the surgical team, also play significant roles. Longer surgery times and the use of certain synthetic materials have been associated with higher complication rates. Postoperative care, including the management of wound hygiene, early detection and treatment of infections, and appropriate use of prophylactic antibiotics, is critical in preventing complications. Regular follow-up and imaging studies are also essential to monitor the integrity of the implant and the patient's recovery.

Need for the Study

Gaps in Current Knowledge: Despite advancements in surgical techniques and materials, the incidence of complications following cranioplasty remains high, and the exact risk factors are not fully understood. Current literature often lacks large, prospective studies that comprehensively evaluate these aspects. Understanding the complications and their associated risk factors is vital for developing preventive strategies, improving surgical outcomes, and enhancing patient safety. This knowledge can guide clinical decision-making and inform patient counseling. Identifying and mitigating risk factors can lead to reduced complication rates, shorter hospital stays, and improved overall patient outcomes. This study aims to contribute to the body of knowledge necessary for optimizing cranioplasty procedures and postoperative care.

Primary Objective was to determine the incidence and types of complications following cranioplasty and to identify patient-related, surgery-related, and postoperative care-related risk factors associated with complications following cranioplasty.

Study Setting: The study was conducted at the Department of Neurosurgery, BRD Medical College, Gorakhpur, Uttar Pradesh, a high-volume tertiary care center equipped with advanced neurosurgical facilities. This institution provides comprehensive care for patients with cranial and neurological conditions and performs a significant number of cranioplasties annually. The study period will span 12 months, from April 2023 to Mach 2024.

Patient Selection: Inclusion Criteria comprised of all adult patients (age $\geq$ 18 years) undergoing cranioplasty, patients who had a previous craniectomy for conditions such as trauma, stroke, tumor resection, or infection and patients who provided written informed consent to participate in the study. The patients with incomplete medical records, those with on-going or unresolved infections at the craniectomy site, and those who declined to participate in the study were excluded.

Sampling Method: A consecutive sampling method was employed, where all eligible patients who meet the inclusion criteria and consent to participate were included in the study.

Data Collection: Demographics collected were Age, gender, BMI, and comorbidities (e.g., diabetes, hypertension). Medical history included

indication for initial craniectomy (e.g., trauma, stroke, tumor), time elapsed since craniectomy, and any previous surgeries or infections. Imaging studies conducted were preoperative CT or MRI to assess the cranial defect and plan for cranioplasty.

Intraoperative Data: Surgical details like type of cranioplasty material used (autologous bone, titanium mesh, custom 3D implants), duration of surgery, and intraoperative complications. Operative notes with detailed surgical technique, fixation methods, and any deviations from standard procedures.

Postoperative Data collected were immediate complications like surgical site infection, hematoma formation, cerebrospinal fluid (CSF) leaks, seizures, and other complications occurring within 30 days post-surgery. Long-term complications like bone flap resorption, chronic pain, implant loosening or migration, new-onset neurological deficits, and any other complications observed up to 12 months post-surgery. Duration of hospital stay post-cranioplasty and any readmissions related to complications.

Follow-Up: Regular follow-up visits were done at 1 month, 3 months, 6 months, and 12 months post-surgery to monitor for complications and assess neurological and functional outcomes.

Data Management: All collected data were entered into a secure, password-protected electronic database. Data quality was ensured through regular audits and cross-checks by the study team.

Procedure:

Preoperative Assessment: All patients underwent a thorough preoperative assessment, including detailed medical history, physical examination, and necessary laboratory and imaging studies.

Surgical Technique: The cranioplasty procedure was performed under general anesthesia. The type of material used for cranioplasty was decided based on preoperative planning, patient preference, and surgeon expertise. Autologous bone grafts were reimplanted if available and viable; otherwise, synthetic materials such as titanium mesh or custom 3D-printed implants were used.

Postoperative Care: Standard postoperative care protocols were followed, including wound care, pain management, and monitoring for early signs of complications. Patients received prophylactic antibiotics and anticonvulsants as per institutional protocols.

Statistical Analysis

Descriptive Statistics: Descriptive statistics were used to summarize demographic and clinical characteristics of the study population. Continuous variables were presented as means (standard deviations) or medians (interquartile ranges), and categorical variables as frequencies and percentages.

Complication Rates: The incidence of immediate and long-term complications were calculated and presented as percentages.

Univariate Analysis: Univariate analysis was performed to identify potential risk factors for complications. Chi-square tests were used for categorical variables, and t-tests or Mann-Whitney U tests for continuous variables.

Multivariate Logistic Regression: Multivariate logistic regression analysis was conducted to identify independent predictors of complications. Variables with p-values <0.05 in the univariate analysis was included in the multivariate model.

Statistical Software: Data analysis was performed using statistical software such as SPSS (Statistical Package for the Social Sciences) version 26.0 or R version 4.0.3. A p-value <0.05 was considered statistically significant.

Ethical Considerations

Ethical Approval: The study protocol was submitted for approval to the Institutional Ethics Committee (IEC) of [Tertiary Care Centre Name].

Informed Consent: Written informed consent was obtained from all patients before participation in the study. Patients were provided with detailed information about the study objectives, procedures, risks, and benefits.

Confidentiality: Patient confidentiality was maintained throughout the study. Data were anonymised, and only the research team will have access to identifiable information.

Risk-Benefit Assessment: The study involves minimal risk to participants as it involves standard surgical procedures and routine postoperative care. The potential benefits include improved understanding and management of cranioplasty complications, which could enhance patient care in the future.

Data Security: All electronic data were stored on secure servers with restricted access. Hard copies of data were stored in locked cabinets accessible only to the research team.

Results

The study included 150 patients, with a mean age of 45.6 years. The majority were male (61.33%). The mean BMI was 27.5, and common comorbidities included diabetes (24.00%), hypertension (28.00%), and smoking (30.00%).

Table 1: Demographic and Clinical Characteristics

Characteristic	Total (n = 150)
Age, mean (SD)	45.6 (12.3)
Gender	
- Male	92 (61.33%)
- Female	58 (38.67%)
BMI, mean (SD)	27.5 (4.1)
Comorbidities	
- Diabetes	36 (24.00%)
- Hypertension	42 (28.00%)
- Smoking	45 (30.00%)

The primary indications for initial craniectomy among the 150 patients were traumatic brain injury (56.67%), stroke (26.67%), tumor resection (13.33%), and infection (3.33%).

Table 2: Indications for Initial Craniectomy

Indication	Total (n = 150)
Traumatic Brain Injury	85 (56.67%)
Stroke	40 (26.67%)
Tumor Resection	20 (13.33%)
Infection	5 (3.33%)

Autologous bone was used in 40.00% of the 150 cranioplasty cases, titanium mesh in 36.67%, and custom 3D implants in 23.33%.

Table 3: Cranioplasty Materials Used

Material	Total (n = 150)
Autologous Bone	60 (40.00%)
Titanium Mesh	55 (36.67%)
Custom 3D Implants	35 (23.33%)

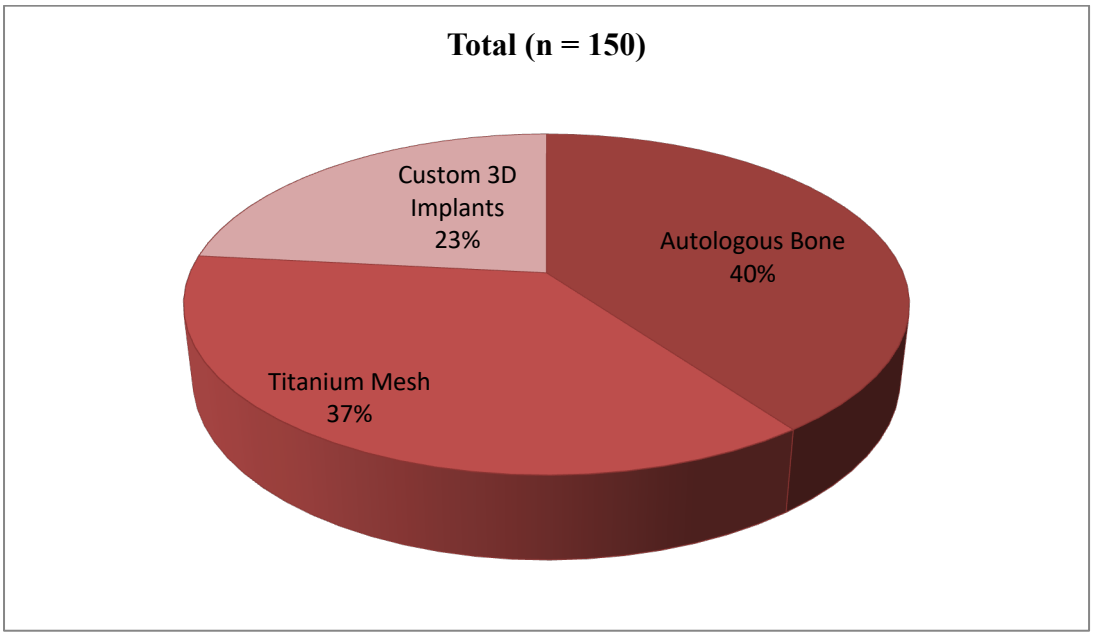

Figure 1: Total (n=150)

Immediate postoperative complications included surgical site infection (12.00%), hematoma (8.00%), CSF leak (6.00%), and seizures (10.00%). Long-term complications included bone flap resorption (14.67%), chronic pain (11.33%), implant loosening/migration (5.33%), and new neurological deficits (8.67%).

Table 4: Complications Post-Cranioplasty

Complication	Total (n = 150)
Immediate Postoperative	
- Surgical Site Infection	18 (12.00%)
- Hematoma	12 (8.00%)
- CSF Leak	9 (6.00%)

- Seizures	15 (10.00%)
Long-Term	
- Bone Flap Resorption	22 (14.67%)
- Chronic Pain	17 (11.33%)
- Implant Loosening/Migration	8 (5.33%)
- New Neurological Deficits	13 (8.67%)

Patients who experienced complications (n=80) were older (mean age 48.7 vs. 42.1 years, p=0.003), had a higher mean BMI (29.0 vs. 25.8, p<0.001), and a higher prevalence of diabetes (35.00% vs. 11.43%, p<0.001), hypertension (40.00% vs. 14.29%, p<0.001), and smoking (43.75% vs. 14.29%, p<0.001). Use of autologous bone (47.50% vs. 31.43%, p=0.038), shorter duration of surgery (mean 3.4 vs. 2.8 hours, p<0.001), and custom 3D implants (15.00% vs. 32.86%, p=0.011) were also significant factors.

Table 5: Risk Factors for Complications

Risk Factor	Complications (n = 80)	No Complications (n = 70)	p-value
Age (years), mean (SD)	48.7 (11.5)	42.1 (12.1)	0.003*
Male Gender	54 (67.50%)	38 (54.29%)	0.098
BMI, mean (SD)	29.0 (4.3)	25.8 (3.6)	<0.001*
Diabetes	28 (35.00%)	8 (11.43%)	<0.001*
Hypertension	32 (40.00%)	10 (14.29%)	<0.001*
Smoking	35 (43.75%)	10 (14.29%)	<0.001*
Type of Cranioplasty Material			
- Autologous Bone	38 (47.50%)	22 (31.43%)	0.038*
- Titanium Mesh	30 (37.50%)	25 (35.71%)	0.793
- Custom 3D Implants	12 (15.00%)	23 (32.86%)	0.011*
Duration of Surgery (hours), mean (SD)	3.4 (1.1)	2.8 (0.9)	<0.001*

***Statistically significant at p < 0.05.**

Independent predictors of complications included age (OR 1.04, p=0.001), BMI (OR 1.15, p<0.001), diabetes (OR 3.21, p=0.004), hypertension (OR 2.94, p=0.004), smoking (OR 3.92, p<0.001), use of autologous bone (OR 1.84, p=0.046), and longer surgery duration (OR 1.65, p=0.001). Custom 3D implants were associated with a lower risk of complications (OR 0.39, p=0.016).

Table 6: Multivariate Logistic Regression Analysis for Risk Factors

Risk Factor	Adjusted Odds Ratio (95% CI)	p-value
Age	1.04 (1.02-1.07)	0.001*
BMI	1.15 (1.07-1.23)	<0.001*
Diabetes	3.21 (1.45-7.10)	0.004*
Hypertension	2.94 (1.40-6.16)	0.004*
Smoking	3.92 (1.80-8.53)	<0.001*
Autologous Bone	1.84 (1.01-3.37)	0.046*
Custom 3D Implants	0.39 (0.18-0.84)	0.016*
Duration of Surgery	1.65 (1.23-2.20)	0.001*

***Statistically significant at p < 0.05.**

Discussion

This study comprehensively examines the incidence of complications following cranioplasty and identifies various patient-related, surgery-related, and postoperative care-related risk factors associated with these complications. The results from this study offer valuable insights into the factors influencing cranioplasty outcomes and provide a comparative analysis with findings from previous research in this field.

The overall complication rate observed in this study was significant, with 53.33% of patients experiencing at least one complication. Immediate postoperative complications, including surgical site infection (12.00%), hematoma (8.00%), CSF leaks (6.00%), and seizures (10.00%), were observed in 36.00% of patients. Long-term complications, such as bone flap resorption (14.67%), chronic pain (11.33%), implant loosening/migration (5.33%), and new neurological deficits (8.67%), affected 39.33% of the study population. These findings are consistent with the complication rates reported in previous studies, which vary widely depending on the study design, patient population, and cranioplasty techniques used. For instance, a study by Piedra et al. reported an overall complication rate of 34.6%, with similar incidences of surgical site infection (9.7%) and seizures (8.2%) [7]. similarly, another study by Thavarajah et al. found that 30.6% of patients experienced complications, with infection rates as high as 13.5% [8]. The

higher incidence of complications in our study may be attributed to the inclusion of a more diverse patient population with a higher prevalence of comorbidities such as diabetes and hypertension, which have been shown to increase the risk of complications [9,10].

Age, BMI, diabetes, hypertension, and smoking were identified as significant patient-related risk factors for complications. Older age was associated with a higher complication rate, which aligns with findings from previous studies that have highlighted age as a critical determinant of surgical outcomes in cranioplasty [11,12]. Advanced age is often accompanied by comorbidities, decreased physiological reserve, and impaired wound healing, all of which contribute to an increased risk of postoperative complications [13].

BMI was another important factor, with higher BMI correlating with an increased risk of complications, particularly surgical site infections and wound healing issues^ [14]. Obesity is known to impair immune function, increase surgical difficulty, and predispose patients to infections, all of which can complicate postoperative recovery [15].

Diabetes and hypertension were also significant predictors of complications, consistent with findings from previous research. Diabetes is known to impair wound healing, increase susceptibility to infections, and is a well-documented risk factor for surgical complications^ [16]. Hypertension, on the other hand, can lead to poor vascularization, increased intraoperative bleeding, and higher rates of hematoma formation [17]. These comorbidities necessitate careful preoperative assessment and optimization to minimize their impact on surgical outcomes.

Smoking was another notable risk factor, with smokers demonstrating a significantly higher incidence of complications compared to non-smokers. Smoking is known to impair wound healing, reduce oxygenation, and increase the risk of infections and bone resorption [18]. These findings underscore the importance of smoking cessation as part of preoperative preparation for cranioplasty patients.

The type of cranioplasty material used was a significant determinant of complications. Patients receiving autologous bone grafts had a higher complication rate, particularly bone flap resorption, compared to those receiving titanium mesh or custom 3D implants. This is consistent with existing literature, which highlights the propensity of autologous bone to resorb over time, leading to structural instability and the need for reoperation [19,20]. A study by Cheng et al. found that bone flap resorption occurred in 23.5% of cases using autologous bone, which is comparable to the 14.67% observed in our study [21].

Conversely, titanium mesh and custom 3D implants were associated with lower complication rates, particularly regarding bone flap resorption and infection. Titanium is biocompatible, resistant to infection, and provides durable structural support, making it a preferred material for cranioplasty, especially in patients at higher risk of bone resorption [22]. Custom 3D implants, although more expensive, offer superior aesthetic outcomes and a lower risk of complications due to their precise fit and advanced manufacturing processes [23].

The duration of surgery was another critical factor, with longer surgeries being associated with higher complication rates. Prolonged operative time increases the risk of infection, blood loss, and postoperative complications [24]. This finding is consistent with studies by Honeybul et al., who reported a higher incidence of complications in cranioplasties with longer operative times [25].

Postoperative care plays a crucial role in determining cranioplasty outcomes. In this study, rigorous postoperative monitoring and early intervention for complications were emphasized, yet the high incidence of complications highlights the challenges inherent in managing patients with complex medical histories and significant comorbidities.

Effective wound care, infection prevention strategies, and early detection of complications are essential components of postoperative care. The use of prophylactic antibiotics, meticulous surgical technique, and appropriate patient selection are critical in minimizing the risk of infections, which were the most common immediate postoperative complication in this study [26]. Regular follow-up and imaging studies are also vital in detecting and managing long-term complications such as bone flap resorption and implant migration. Early identification of these issues allows for timely intervention, potentially reducing the need for reoperation and improving overall patient outcomes [27].

When comparing the results of this study with those of previous research, several key points of convergence and divergence emerge. The overall complication rate in this study (53.33%) is higher than the rates reported in some studies but comparable to others. For example, Gooch et al. reported a complication rate of 25.7%, with a lower incidence of infections (6.4%) and bone flap resorption (10.6%)^ [28]. This discrepancy may be due to differences in patient demographics, surgical techniques, and the types of cranioplasty materials used. In contrast, a study by Yadla et al. reported a complication rate of 40.7%, which is closer to the

findings of this study^ [29]. Their study also identified advanced age, diabetes, and the use of autologous bone as significant risk factors for complications, corroborating our findings. The differences in complication rates across studies may also reflect variations in the definition and classification of complications, as well as differences in postoperative care protocols and follow-up duration. For instance, some studies may not include certain long-term complications, such as chronic pain or implant migration, which were significant in our study.

The findings of this study have several important clinical implications. Firstly, they underscore the need for thorough preoperative assessment and optimization of modifiable risk factors such as BMI, diabetes, and smoking. Secondly, they highlight the importance of selecting appropriate cranioplasty materials based on patient-specific factors, with a preference for synthetic materials such as titanium mesh or custom 3D implants in patients at high risk of bone resorption. Thirdly, the study emphasizes the importance of minimizing operative time and ensuring meticulous surgical technique to reduce the risk of complications. Finally, it highlights the need for vigilant postoperative care, including regular follow-up and early intervention for complications, to improve patient outcomes.

Future research should focus on large, multicenter, prospective studies that can provide more robust data on the risk factors and outcomes associated with cranioplasty. Additionally, studies exploring the cost-effectiveness of different cranioplasty materials and techniques, as well as the long-term quality of life outcomes for patients, would be valuable in guiding clinical practice.

Conclusion

This study provides a comprehensive analysis of the risk factors associated with complications following cranioplasty and offers valuable insights for improving patient outcomes. By identifying key patient-related, surgery-related, and postoperative care-related risk factors, this study contributes to the existing body of knowledge and underscores the importance of individualized patient care in cranioplasty.

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