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Original Research Article

Outcomes of Cranioplasty Using Autologous Bone or Titanium Mesh Following Decompressive Craniectomy: Differences in Complications

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Abstract

Introduction: Decompressive craniectomy (DC) is a life-saving procedure for neurocritical patients with conditions such as severe traumatic brain injury (TBI), ischemic stroke, and subarachnoid hemorrhage. However, it results in cranial defects that necessitate cranioplasty to restore skull integrity, protect brain function, and address cosmetic concerns. The choice of material—autologous bone (AB) or artificial materials like titanium mesh (TM)—remains controversial due to varying complication rates.

Materials and Methods: This comparative cross-sectional study evaluated 23 patients who underwent cranioplasty with AB (n=5) or TM (n=18) between January 2022 and March 2025 at SVP Hospital and NHL Medical College, Ahmedabad. Data on demographics, surgical timing, complications, and outcomes were analyzed. Complications included infections, bone flap resorption (BFR), wound dehiscence, and cosmetic outcomes.

Results: The overall complication rate was 43.47% (AB group: 80%, TM group: 33.33%). BFR occurred exclusively in the AB group (40%), while TM-related complications included surgical site infections, wound dehiscence, and persistent tenderness. Wound dehiscence and multiple bone fragments were significant risk factors for post-cranioplasty infections and BFR, respectively. Cosmetic satisfaction was comparable between groups (82.60% overall), but TM demonstrated shorter operation times, reduced bleeding, and shorter hospital stays.

Conclusion: Cranioplasty using TM showed advantages over AB in terms of lower complication rates, reduced operative time, and improved hospitalization outcomes. However, TM was associated with higher minor complications like wound dehiscence. For patients with larger bone defects, artificial materials may reduce BFR risks. Further prospective randomized trials are needed to validate these findings and optimize cranioplasty outcomes.

Keywords: Autograft, Bone Resorption, Cranioplasty, Hematoma, Infection, Titanium Mesh.

Introduction

In the last 2 decades, Decompressive Craniectomy (DC) played an important role in saving neurocritical patients such as those sustaining severe traumatic brain injury (TBI), ischemic stroke, subarachnoid hemorrhage (SAH), severe intracranial infection and intracranial tumor. As some trials have demonstrated the efficacy of decompressive hemicraniectomy (DC) for severe traumatic brain injury (TBI) in terms of reducing mortality and improving functional outcomes, it has been widely used as salvage treatment for malignant edema of the brain.[1–6] Cranial defects cause not only irreversible damage to the neurological function and cognition of patients but also self-image issues.[4,7] Therefore, cranioplasty has become a common procedure for patients with cranial defects. Cranial reconstruction can not only restore the esthetic contour of the skull to meet the

psychological needs of patients, but also alleviate trephine syndrome, protect brain function, relieve abnormal cerebrospinal fluid circulation, and restore intracranial pressure adaptations[8–11] Several materials, including autologous bone and various artificial materials, have been introduced for CP, but which material is best for CP still remains unclear.[12]

However, many factors such as the timing of surgical intervention, choice of different materials, and area of the calvarial defect can affect the treatment outcomes of cranioplasty and the occurrence of postoperative complications. One of the most debated factors is the choice of cranioplasty material. Biological compatibility should be considered when selecting materials, and there must be sufficient strength, stiffness, and durability that can protect brain function and restore skull shape and hair growth patterns.[13]

In many cases, CP was performed using autologous bone (AB), which was obtained at the time of DC. AB is inexpensive and biocompatible, without any risk of disease transmission and perfectly fits the skull defect. Among materials, autologous bone flaps are usually the first choice at most institutions. Autologous bone also has the potential to grow and fuse with bone at the surgical site and is psychologically acceptable to patients and their relatives. However, complications such as surgical site infection and bone flap resorption (BFR) always remain possible.[12,14]

Cranioplasty is usually performed 2–3 months after craniectomy, so bone preservation should be considered in advance. Autologous bone flaps can be preserved by cryopreservation (placing the bone flap in a special refrigerator according to a pre-planned protocol) or by placing the bone flap in a subcutaneous compartment in the abdominal wall. Various artificial materials (e.g., polymethyl methacrylate, titanium, ceramics, and carbon fiber-reinforced polymers) have been produced to reduce these bioactive complications.[15] Of these artificial materials, titanium mesh is generally considered the material of choice in moderate-sized to large craniectomy defects because it is biologically inert, strong, lightweight, and inexpensive to produce.[16]

These materials are malleable substitutes and require intraoperative molding resulting in increased operation time. Additionally, depending on the surgeon's dexterity, it may result in poor cosmetic outcomes in patients with large defects. Furthermore, as advances in technology and imaging processes have enabled the production of large three-dimensional (3D) custom-made prefabricated plates, 3D customized titanium has been widely used.[17] Titanium is characterized by strength, high biocompatibility, lack of corrosion, biological inertness and satisfactory cosmesis and long-term outcome of patients who underwent CP with titanium mesh is more favorable compared with patients treated with CP using AB [18,19] A randomized controlled trial in Australia showed that patients using Titanium mesh were less likely to undergo a second operation than those using autologous cranioplasty, and another study reported similar results. [5] However, several studies have reported that CP with titanium material is strongly associated with wound or cosmetic complications. The purpose of this study is to compare the complications of cranioplasty using autologous bone graft with titanium mesh implants. It also aims to show which cranioplasty method is effective, has the least complications, and provides the best results. Furthermore, a subgroup analysis to identify risk factors for complications in each group was performed.

Materials and Methods

This is a comparative prospective study conducted between January 2022 and March 2025 in the Department of Neurosurgery, SVP Hospital and Smt. NHL Medical College, Ahmedabad.

Population Group: Patients over 18 years of age who underwent autologous bone/titanium mesh cranioplasty in our hospital were included. A total of 23 patients (5 patients who underwent CP using an autologous bone flap and 18 patients who underwent CP using a titanium mesh) were enrolled. A patient who had multiple bone fragments due to trauma (5), who had a smaller autologous bone than craniotomy size defect (6) and who had infected autologous bone (2) underwent Titanium mesh cranioplasty.

Data Collection Process: Patients who were posted for cranioplasty, previous clinical data on patients' demographic characteristics and possible risk factors—including age, sex, reason for primary operation, operative time for CP and the interval between DC and CP—were collected.

Based on the cause of DC, the patients were divided into two groups: 1) TBI including acute subdural hemorrhage, epidural hemorrhage and traumatic intracranial hemorrhage (T-ICH); and 2) cerebrovascular accidents (CVA) including major infarction, subarachnoid hemorrhage and spontaneous ICH. Patients who were less than 18 years and underwent DC at other hospitals were excluded.

Patients who underwent DC due to infection and brain tumor were also excluded because of the small number of patients. Based on timing, CP was classified into early CP (<90 days after DC) and late CP (≥90 days after DC). Timing of the CP depends on the surgeon's decision according to the patient's condition.

Evaluation of clinical outcomes and complications: Various complications after CP (e.g., postoperative surgical infections, wound dehiscence, and persistent pain after wound healing) were evaluated.

Surgical infection was defined clinically and radiologically by any evidence of infection, including fever, erythema, swelling, and elevated levels of inflammatory markers with evidence of infection on computed tomography (CT) using contrast medium. Mesh extrusion was defined as severe thinning of the soft tissue and skin to show implanted mesh patterns without wound dehiscence. Persistent tenderness at the surgical site was defined as severe pain caused by a gentle touch at the surgical site after the wound had totally healed without any dehiscence. Cosmetic outcome was categorized into three categories: 1) complete satisfaction, satisfied with appearance; 2) partial satisfaction, satisfied with appearance but not ideal (e.g., temporal dimple).

Postoperative hemorrhage was defined as ipsilateral symptomatic hemorrhage on immediately postoperative computed tomography scan after CP warranting reoperation. Wound dehiscence was defined by the rupture or splitting of a previously closed surgical site, resulting in exposure of the implant. Overall complications were defined as all kinds of complications after CP. We performed risk factor analysis both for overall complications in both groups and for specific complications (Surgical site infection in the autologous bone flap group, and surgical site infection, extrusion, wound dehiscence, and persistent tenderness at the surgical site in the titanium mesh group). To summarize, age, sex, operative time for CP, flap size (autologous bone flap size or titanium mesh size), and the interval between DC and CP were analyzed as independent variables and various complications (surgical infection, and other problems) after CP in both groups were analyzed as dependent variables.

DC and CP procedures: We performed DC when patients showed clinical deterioration resulting from refractory increased intracranial pressure despite the best possible medical treatment. All patients underwent standard unilateral frontotemporal-parietal craniectomy. The removed bone flap was separated from the adherent tissue, packed after sterilisation. The choice of material for CP depended on the surgeon's preference and the interval between DC and CP. We used autologous bone or titanium mesh. A patient who had multiple bone fragments, infected bone or small bone than craniectomy size underwent titanium mesh cranioplasty. Before performing CP, the patient's hair was completely removed with an aseptic medical shaver. The scalp was then washed with an aqueous solution, after which povidone-iodine solution was applied several times to the patient's entire head and left to dry. The previous skin incision was re-opened, and the fibrous layer between the artificial dura and galea was dissected and prepared for insertion of the autologous bone or titanium mesh. After the bone flap was washed several times with povidone-iodine and normal saline solution, the flap was re-implanted. Negative drain no. 12 was placed. In the final step, the skin was closed with vicryl subcutaneous sutures and nylon skin sutures.

Statistical Analysis: Frequencies or percentages of variables and means and standard deviations for continuous variables were used to present data**.** Data were presented as the mean and standard deviation for continuous variables and as the frequency or percentage for categorical variables. The analysis was carried out using the independent t-test and the Fisher's exact test. A $p \leq 0.05$ was considered to indicate statistical significance. Confidence interval (CI) was set at 95%.

Results

Between January 2022 and March 2025, 23 patients underwent CP with autologous bone and titanium mesh material at our institution. The CP with AB was conducted on 05 patients; CP with titanium mesh in 18 patients. The mean clinical and radiological follow-up was 28.1±5.1 months (range, 12–45). The patients included 19 males and 04 females. The mean age of patients at the time of CP was 41.5±22.5 years (range, 19–64). The causes of DC were as follows: trauma (11 patients, 47.82%) and CVA (12 patients, 52.17%). The demographic data of 23 patients are summarized in Table 1, and the two groups were well matched at baseline. No statistically significant difference in demographics was observed among the groups.

Table 1: Characteristics of patients of cranioplasty

	AB Group (n=05)	TM Group (n=18)	p-value
Mean age (at the time of cranioplasty)	32±11.34 years	41.5±22.5 years	0.73
Sex ratio (M/F)	4/1	15/3	0.12
Reason for primary operation			
Trauma	03 (4.13)	16 (14.87)	0.13
Cerebrovascular accident	02 (0.87)	02 (3.13)	
Timing of the cranioplasty			
Early surgery (<90)	04 (2.39)	07 (8.61)	0.10
Late surgery (≥90)	01(2.61)	11(9.39)	

Site of DC			
Right	04 (3.48)	12 (12.52)	0.5
Left	01 (1.52)	06 (5.48)	
Mean follow up periods (months)	28.8±9.4	29.1±8.6	0.38

Values are presented as mean±standard deviation or number (%). *All values were generated by one-way ANOVA or chi-square test. AB: autologous bone, TM: titanium mesh, M: male, F: female, IPH: intraparenchymal hemorrhage, DC: decompressive craniectomy.

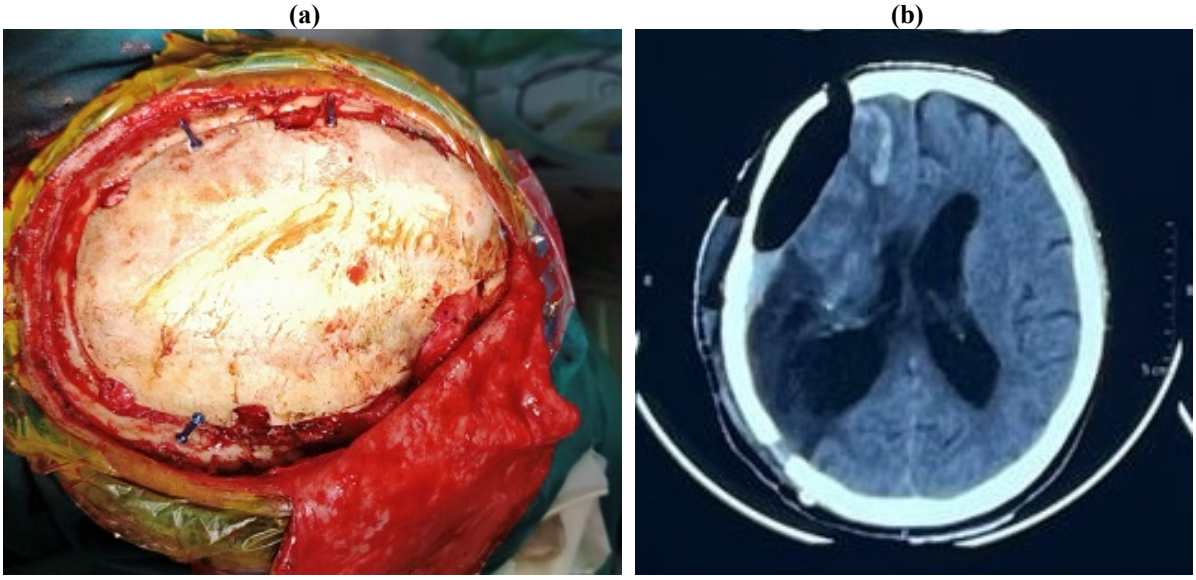

Figure 1: Autologous Bone cranioplasty (AB) (a): intraoperative image, (b): CT image

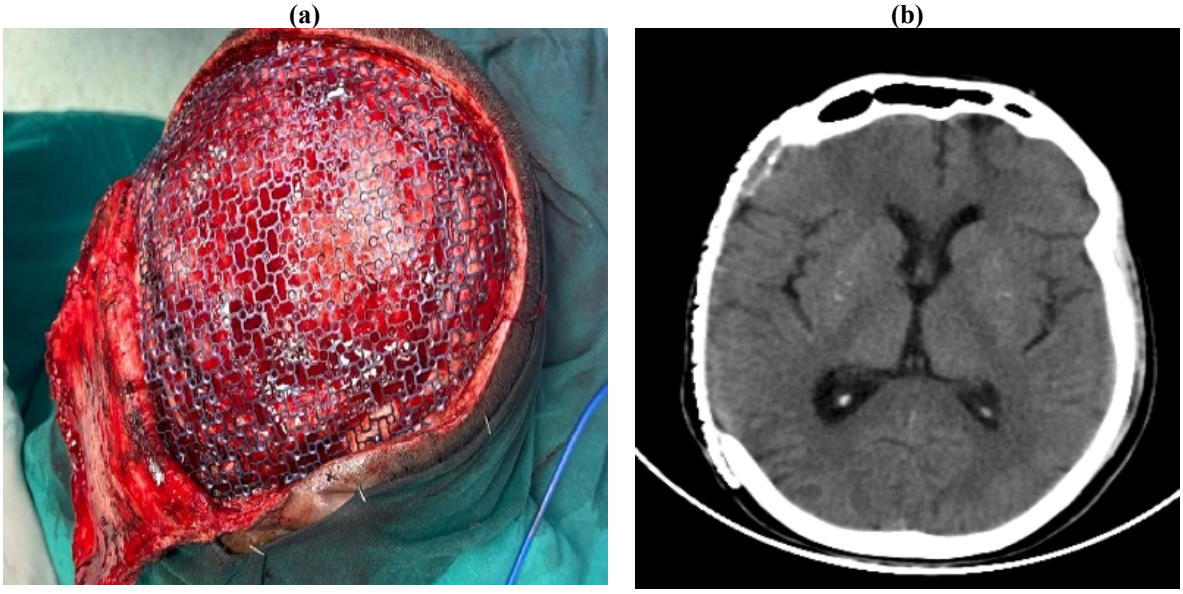

Figure 2: Titanium Mesh cranioplasty (TM) (a): intraoperative image, (b): CT image

Comparison of cosmetic outcomes, operation time, bleeding loss and hospital stay. The cosmetic outcomes in the AB group including 04 patients were completely satisfactory and 01 were partially satisfactory. The corresponding cosmetic outcomes in the TM group were 15 were completely satisfactory and 03 were partially satisfactory. No significant differences were observed between two groups ($\chi 2$ -test: AB vs. TM, p=0.75). Duration of hospitalization and intra-operative parameters were also evaluated. The TM group demonstrated the shortest in-hospital stay compared with the other AB groups (one-way ANOVA with post-hoc analysis, p=0.00). Regarding the intraoperative parameters, patients in the AB group experienced the shorter operation time among the TM groups (one-way ANOVA with post-hoc analysis, p=0.00). Clinical outcomes are summarized in Table 2.

Table 2: Outcomes of the patients who underwent primary cranioplasty according to the materials

	AB Group (n=05)	TM Group (n=18)	p-value
Time interval from DC to CP (days)	80.7±58.6	87±53.7	0.84
Cosmetic outcome			
Completely satisfaction	04 (4.13)	15 (14.87)	0.8
Partial satisfaction	01 (0.87)	03 (3.13)	
Postoperative overall complications			
Infection	01	03	0.00*
Bone flap resorption	02	00	
Wound dehiscence	00	02	
Implant displacement	00	00	
Postoperative hemorrhage	01	01	
Mean operation time (minutes)	188.3±53.0	201.2±55.5	0.00*
Average hospital stay (day)	16.7±7.8	15.1±5.8	0.01*

Values are presented as mean±standard deviation or number (%). *All values were generated by one-way ANOVA or chi-square test. AB: autologous bone, TM: titanium mesh, M: male, F: female, IPH: intraparenchymal hemorrhage, DC: decompressive craniectomy, * statistically significant

Complications: During the follow-up periods, overall postoperative complications occurred in 10 (43.47%) of 23 patients (04 patients [17.39%] in AB group, 06 patients [26.08%] in TM group). Complications are summarized in Table 2.

Factors affecting post-CP infection: A total of four cases (17.39%) of post CP-infections were observed among the 23 patients. They include one post CP-infections in the AB group (4.34%), three post CP-infections in the TM group (13.04%).

One infected implant was removed (Figure 3). Patient groups without post-CP infection were compared with those who were diagnosed with post-CP infection (Table 3).

Table 3: Univariate analysis comparing the no-infection and the infection groups after cranioplasty

Clinical parameter	No infection (n=19)	Infection (n=4)	p-value
Age (years)			
≥60 years	04 (5.78)	03 (1.22)	0.33
<60 years	15 (13.22)	1 (2.78)	
Sex			
Male	16 (15.7)	03 (3.3)	0.65
Female	03 (3.3)	01 (0.7)	
Timing of the cranioplasty			
Early surgery (<90 days)	09 (9.09)	2 (1.91)	0.92
Late surgery (≥90 days)	10 (9.91)	2 (2.09)	
Location of craniectomy			
Right	14 (13.22)	02 (2.78)	0.34
Left	05 (5.78)	02 (1.22)	
Cause of craniectomy			
Trauma	18 (15.7)	01 (3.3)	0.0008*
Vascular accident	01 (3.3)	03 (0.7)	
Implants			
Autologous bone	03 (4.13)	02 (0.87)	0.13
Titanium Mesh	16 (14.87)	02 (3.13)	
Postoperative wound dehiscence			
No	03 (4.13)	02 (0.87)	0.13
Yes	16 (14.87)	02 (3.13)	
Operation time (minutes)	184.6±48.3	241.7±55.6	0.07

Values are presented as mean±standard deviation or number (%). *All values were generated by one-way ANOVA or chi-square test. AB : autologous bone, TM : titanium mesh, M : male, F : female, IPH : intraparenchymal hemorrhage, DC : decompressive craniectomy

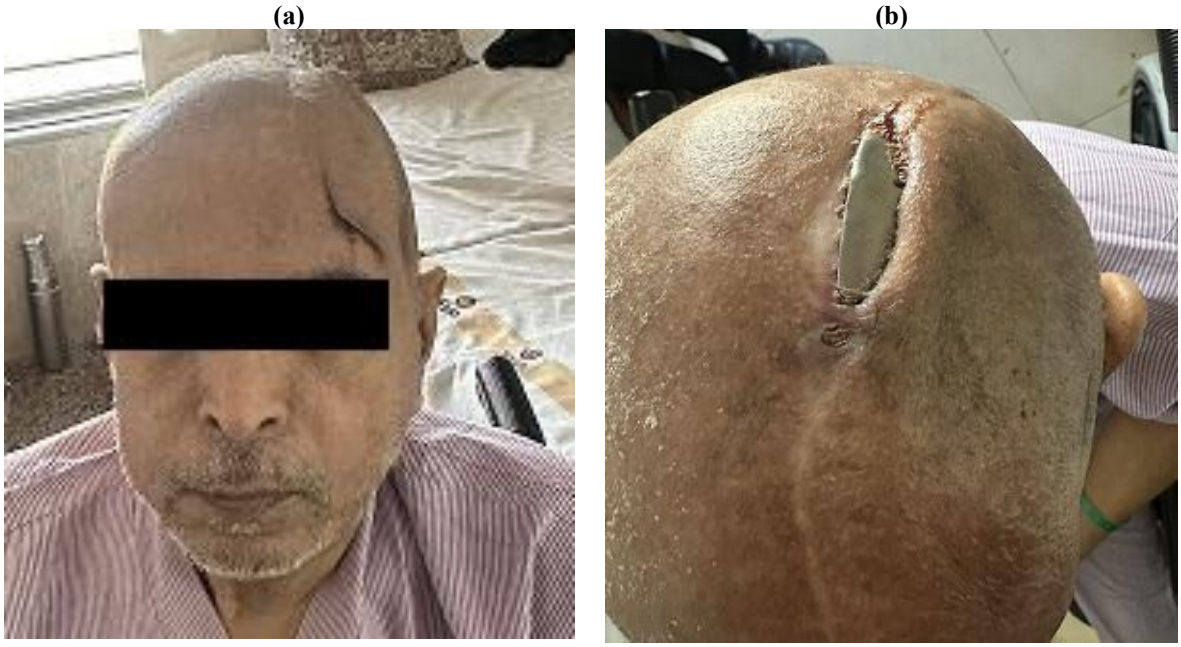

Figure 3: Exposed Mesh in operated case of Titanium mesh cranioplasty a; first site over frontal region, b; second site over parietal region

Wound dehiscence was a significant risk factor only for post-CP infection. The type of implants and timing of the surgery were not associated with a higher infection rate after CP. The cause of DC trended toward statistical significance.

Discussion

Cranial defects are a common cause of neurocognitive decline and are caused by a variety of mechanisms, such as craniocerebral pressure fluctuations, decreased cerebral blood flow, and changes in cerebrospinal fluid dynamics and brain metabolism. In addition, symptoms of epilepsy, brain atrophy, and brain subsidence caused by skull defects seriously affect the physiological and psychological health of patients. Therefore, cranioplasty, as a secondary operation for the treatment of skull defects, not only reconstructs the physical protection of brain tissue but also restores the contour of the skull, which is helpful for patients to maintain their societal and family functions.[15]

However, with continuous improvements in cranioplasty techniques and technology, the surgical effect on patients with skull defects mainly depends on the repair materials. Various complications after CP were found, and regardless of which material was used, the rate of complications was relatively high.[18] In patients treated with CP using an autologous bone flap, the rate of complications after CP was 80% (04/05), almost half of which consisted of BFR. The rate of complications in the titanium mesh group was also high, reaching 33.33%. However, a greater variety of complications was observed in patients who underwent CP with an autologous bone flap. Titanium mesh plates have been introduced as an alternative material for autologous bone flap, with advantages including a low risk of tissue reaction and biological inertness, especially in patients with large bone defects.[17] However, in this study, the risk of minor complications— including mainly cosmetic problems, such as extrusion, dehiscence, and exposure of the titanium mesh—was relatively high, reaching 55%. There are some limitations of this study. The small sample size with a relatively short-term follow-up period and missing values due to loss to follow-up are important limitations in drawing generalizable conclusions. Further-more, our study had a cross sectional design and enrolled patients at a single center. Hence, selection bias was not avoided.

Cosmetic outcomes and parameters: Regardless of the implanted material, the majority of the patients (82.60%) were satisfied with the cosmetic results. AB or TM is user-friendly and perfectly matches the skull defect. Nevertheless, no significant differences in cosmetic outcomes were observed between the two groups. Unsatisfactory cosmetic outcome is mostly attributed to temporal hollowing resulting in atrophy of frontal and temporalis muscle following initial DC rather than implant material. Additionally, other factors of cosmetic outcome unrelated to implant material include hair length, location of the defect and skin thickness. In the present study, cosmetic outcome was not associated with the implant materials and synthetic materials represent an attractive alternative option comparable to AB. The TM group showed shorter operation time and less bleeding loss than the group. Theoretically, the parameters should be similar in AB and TM groups, due to these implants needed for the intraoperative molding process. It is

assumed that the additional operation time and bleeding are caused by differences in timing of surgery between the two groups. In the present study, the number of patients undergoing early CP in the CT group was higher than in the AB group. The longer the time interval separating DC from CP, the greater is the time needed for dissection of scalp from the dura. Moreover, in case of multiple skull fractures in AB group, the additional operation time corresponds to the time needed for skull fixation with the screw. The additional bleeding loss in the AB group is probably related to the timing of surgery and the longer operation time.

Factors affecting post-CP infection: Considering the overall infection rate in cranial procedures varying between 1% and 2%, the overall infection rate of CP (ten cases, 43.47%) in this study demonstrated a high infection rate, consistent with other reports.[14] A recent meta-analysis reported lack of significant difference in infection rate between AB and titanium materials.[19] There was a trend toward lower post-operative complication rates following PEEK cranioplasty versus autologous grafts, and lower implant failure rates with PEEK versus titanium mesh implants.[20] In this study, the TM group showed a higher post-CP infection rate than the AB group. We speculated that TM contains a porous structure, which may induce bacterial proliferation. The timing of CP appears to be an important factor underlying the post-CP infection and is still disputed.[21,22] In this study, our results showed that the timing of CP had no effect on the incidence of post-CP infection (early CP, 18.18% vs late CP, 16.66%; p=0.92). Although we did not statistically confirm that early CP had a lower infection rate than late CP, we were inclined to perform early CP if subsidence of brain edema was confirmed.

Early CP facilitates dissection of the tissue planes easily with reduced intraoperative bleeding and operation time. For patients, they can be rehabilitated earlier and allow an improvement of neurological functions. In our study, only wound dehiscence was significantly associated with post-CP infections, consistent with studies reported by Riordan and colleagues. CP patients undergo at least two or more surgical procedures at the same site, resulting in friable soft tissue, skin retraction, thinning and reduction in scalp tensile force. Therefore, wound healing may be delayed, leading to skin colonization, which increases the risk of post-CP infections.[13,23] However, due to the small number of patients (n=23) and a cross sectional study may not be precise in documenting the degree of wound dehiscence. Therefore, it is difficult to conclude whether the degree of wound dehiscence affects the post-CP infection. Conversely, implant infection during the operation may be a cause of wound dehiscence. Sundseth et al.[13] Recommend tissue augmentation or tissue expansion of the scalp before CP in pediatric patients to minimize the chance of wound breakdown. Although this study is small, tissue augmentation before CP is a good preoperative procedure to reduce the incidence of wound dehiscence in specific patients.

Conclusion

A relatively high complication rate was observed after CP for surgical bone defects after DC for vascular accident. In comparison with AB, TM group shows benefits in terms of post-CP complication rate, intraoperative blood loss, operation time and in-hospital stay. Different complications occurred depending on the material that was used. Another artificial material may be a better option in patients with a larger surgical bone defect. Furthermore, in order to reduce the rate of complications after CP with a titanium mesh plate, other artificial materials—especially without a mesh print—should be recommended. Among the parameters, wound dehiscence and multiple bone fragments were associated with post-CP infection and BFR, respectively. In order to substantiate these findings, a prospective randomized controlled trial will be required.

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Study Limitations: This study has several limitations. First, it includes data from a single tertiary care institution. second include the cross sectional format and nonrandomized patient groups. The other limitation relates to known or unknown bias such as different surgical indications and surgical techniques and/or lateralization of the trauma patients in this area.

Abbreviation: DC: Decompressive Craniectomy, CP: Cranioplasty, TBI: Traumatic Brain Injury, AB: Autologous Bone, TM: Titanium Mesh

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