Outcomes of Cranioplasty with Synthetic Materials and Autologous Bone Grafts

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OBJECTIVE: **Using current surgical methods, cranioplasty is associated with a high complication rate. We analyzed if there are preexisting medical conditions associated with complications and compared the effect of different implant materials on the degree of complications.**

METHODS: **A retrospective review of the medical records of all patients who underwent cranioplasty for cranial bone defects during the period 2002–2012 was conducted, and 100 consecutive cranioplasty procedures that met eligibility criteria were identified. Patients were analyzed in 4 groups, which were created based on the cranioplasty material: autograft ($n = 20$), bioactive fiber–reinforced composite ($n = 20$), hydroxyapatite ($n = 31$), and other synthetic materials ($n = 29$). Survival estimates were constructed with Kaplan-Meier curves, and the differences between categorical variable levels were determined using a log-rank test. Multiple comparisons were adjusted using a Šidák correction.**

RESULTS: **During a median follow-up time of 14 months (interquartile range 3–39 months), 32 of 100 patients (32.0%) developed at least 1 complication. A minor complication occurred in 13 patients (13.0%), whereas 19 patients (19.0%) developed a major complication, which required reoperation or removal of the implant. In the autograft subgroup, 40.0% of patients required removal of the cranioplasty. The 3-year survival of the autograft subgroup was lower compared with other subgroups of synthetic materials. In hydroxyapatite and bioactive fiber–reinforced composite groups, fewer complications were observed compared with the autograft group.**

CONCLUSIONS: **Based on these results, synthetic materials for cranial bone defect reconstruction exhibit more promising outcomes compared with autograft. There were differences in survival rates among synthetic materials.**

INTRODUCTION

In modern neurosurgical practice, craniectomy is a common procedure that may be needed secondary to a traumatic skull bone fracture, tumor infiltration of the skull bone, a malignant middle cerebral artery infarction, or severe infection. The objective of cranioplasty—reconstruction of a skull bone defect—is to diminish the complications of a craniectomy. These complications include herniation of the cortex through the bone defect, subdural effusion, seizures, and syndrome of the trephined (13, 15). Other objectives are to restore the earlier contour of skull bone and to protect the underlying brain.

Cranioplasty is associated with a high complication rate with present surgical methods (23, 32). A postoperative complication rate of 10%–40% has been reported in large cranioplasty series (2, 6, 17, 35). Frozen autologous bone graft is traditionally used for primary reconstruction because it is readily available. However, more recent reports suggest that problems after cranioplasty with frozen bone may be more common than was thought previously (12, 18). Polymethyl methacrylate (PMMA) is used as bone cement (i.e., polymerized in situ from methyl methacrylate monomer and

Key words
- Autograft
- Bioactive glass
- Bioglass
- Biomaterials
- Craniectomy
- Cranioplasty
- Fiber-reinforced composite
- FRC
- Skull bone defect

Abbreviations and Acronyms
BG: Bioactive glass
FRC: Fiber-reinforced composite
HA: Hydroxyapatite
PE: Polyethylene
PEEK: Polyetheretherketone
PMMA: Polymethyl methacrylate
SSI: Surgical site infection

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polymer powder mixture) and as a bulk polymer implant material. PMMA, when used in bulk polymer form, is considered a reliable and inexpensive implant material (14), which showed better long-term outcomes compared with frozen autograft (22). PMMA, when used as bone cement, causes local toxic reactions, and the material becomes encapsulated by fibrous tissues. Other commercially available materials include hydroxyapatite (HA); titanium; polyethylene (PE); polyetheretherketone (PEEK) (19); and glass fiber–reinforced composite (FRC), which is loaded with particulates of bioactive glass (BG).

Meta-analyses of available data are scarce (9, 28, 29). The optimal timing of cranioplasty and numerous associated risk factors predicting complications are unknown. In the present study, we investigated whether preexisting medical conditions are associated with complications after cranioplasty and compared the degree of complication with different surgical materials. A 10-year consecutive retrospective study was performed to analyze these after cranioplasty.

MATERIALS AND METHODS

Selection Criteria and Study Population

We reviewed electronic medical records from all patients who underwent a skull bone defect (>4 cm^2) reconstruction during a 10-year period at our tertiary care institution, which has Neurosurgical and Head and Neck surgery departments that are responsible for craniofacial reconstructive surgery of people living in Southwest Finland, Satakunta, and Åland Islands areas (combined population of 725,000). A database was generated by querying procedures with the current procedural terminology codes for cranioplasty from June 2002 through December 2012. We excluded patients who had not undergone cranioplasty for previous craniectomy, but rather some other related procedure (i.e., operation for craniosynostosis or a maxillofacial reconstruction). After these exclusion criteria were applied, 84 consecutive patients who underwent 100 cranioplasty procedures were identified to be eligible and were entered into the database.

The medical records were reviewed for the following variables: age, gender, presenting diagnosis, material used for skull bone defect reconstruction, time interval between craniectomy and reconstruction, defect size, and anatomic location. Preexisting conditions considered were the following: diabetes, abuse of intoxicants, immunosuppressive medication, smoking, radiation therapy, infection, and body mass index. The definition of infection included intracranial infection before cranioplasty and infection of the previously implanted material. Follow-up outcome was measured at the following time points: 1 month, 6 months, 12 months, and 36 months. Outcome was defined as normal when no wound healing problems or other complications were observed. We defined complications as major when revision surgery was needed and as minor when conservative treatment was sufficient. The following events after cranioplasty were recorded: superficial incisional surgical site infection (SSI), deep incisional SSI, epidural hematoma, cerebrospinal fluid leak, hydrocephalus, exposure of implant, resorption, implant breakage, implant migration, and cosmetic appearance. The location and the size of each defect were documented from preoperative computed tomography images. The cranial bone defects were classified into 3 groups based on the size of the defect according to the classification by Uygur et al. (34).

Autogenous bone flaps were stored at −80°C under sterile conditions until reimplantation. A swab sample was taken before storage. If bacterial growth was seen, the bone flap was discarded. Intraabdominal placements were not performed at our institution.

Cranioplasty Materials

During the study period, numerous different materials were used for skull bone reconstruction, including autogenous bone, fiber-reinforced composite (FRC) containing particles of BG $S_{53}P_4$ (1), HA bone cement paste, PMMA as a moldable bone cement mass, porous PMMA scaffold coated with BG granules (24), titanium mesh and solid titanium, PEEK, and PE. The autogenous bone flaps were secured with titanium miniplates (Craniofix, Aesculap; B. Braun Melsungen AG, Melsungen, Germany). Alloplasts were fixed in place with titanium screws (Matrix; Synthes, Inc., West Chester, Pennsylvania, USA) or titanium miniplates and occasionally with biodegradable screws. Infection prophylaxis with intravenous antibiotics was given according to department-specific protocols (cefuroxime 3 g preoperatively and 1.5 g 3 times daily for 3 days after cranioplasty).

The 100 cranioplasties were divided into 4 subgroups for subgroup analysis: autograft ($n = 20$), FRC ($n = 20$), HA ($n = 31$), and other synthetic materials ($n = 29$). We merged PMMA, PMMA-BG, PEEK, titanium, and PE into 1 subgroup (other synthetic material) because these alloplasts are less commonly used at our institution.

As in any retrospective study, there was some paucity in the follow-up data. Of 100 patients, 38 (38.0%) had follow-up data at the time point of 3 years. However, if a normal healing pattern was observed at the last follow-up visit, the healing was defined as normal up to the time point of 3 years. This estimate was based on the fact that our institute is responsible for serving the whole population of the area, and if problems had arisen, the patients would have contacted our hospital. The follow-up times of each subgroup are presented in **Tables 1** and **2**.

Statistical Analysis

Patients were analyzed in 4 groups, which were based on the cranioplasty material used. Survival estimates were constructed with Kaplan-Meier curves, and the differences among categorical variable levels were determined using a log-rank test. Multiple comparisons were adjusted using a Šidák correction. Interactions among groups and each continuous independent variable were checked with Cox regression. The confidence level was set at 95%. All analyses were performed using SAS System for Windows, version 9.4 (SAS Institute Inc., Cary, North Carolina, USA), and all figures were drawn using R, version 3.0.2 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Description of Sample

Altogether 100 cranioplasties (84 individual patients) with sufficient complete data were included. Of these 100 cranioplasty procedures, there were 81 primary, 16 secondary, 2 tertiary, and 1 fourth reconstruction during the period 2002–2012. A cranioplasty was performed in 34 female patients (34.0%) and 66 male patients