Reconstruction of the Frontal Sinus and Frontofacial Skeleton With Hydroxyapatite Cement

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Objective: To evaluate the efficacy of a newly developed biomaterial, hydroxyapatite cement, for use in frontal sinus and anterior craniofacial skeletal reconstruction.

Design: A nonrandomized patient cohort that was compared with historical controls of standard treatment with methyl methacrylate implants.

Setting: Craniofacial reconstructive surgery services at 3 referral health care centers. Eligible patients had frontal-cranial defects limited to a maximum size of 25 cm². Patients were randomly selected volunteers with preexistent, acute traumatic or acute surgically induced defects of the frontal sinus and anterior craniofacial skeleton. All patients provided informed consent, and the study was approved by the 3 institutional review boards. Forty patients underwent reconstruction of defects of the anterior craniofacial region, and 38 of these patients were evaluable at 24 months.

Main Outcome Measures: Hydroxyapatite cement was used to reconstruct full-thickness anterior craniofacial skull defects. Standard surgical techniques were used to place all implants. The primary outcome measurement was maintenance of implant volume determined at 24 months by computed tomography and clinical examination. Secondary outcome measures included incidence of complications and infections necessitating implant removal.

Results: Of the 38 evaluable patients, 31 had successful reconstructions at the end of the study, for an overall success of 82% for frontal sinus and frontofacial region reconstruction. Seven patients underwent explantation, 5 for surgical access to the site. Two implants were removed because of infection in the wound, for an overall incidence of approximately 5%. Explant biopsy specimens confirmed implant osseointegration and vascularization.

Conclusions: Hydroxyapatite cement successfully reconstructs full-thickness defects of the frontal sinus and frontofacial region at 24 months. Hydroxyapatite cement appears to be superior to acrylic implants for frontal-cranial reconstruction and by allowing implant osseointegration with improved biocompatibility.

Arch Facial Plast Surg. 2000;2:124-129

The past decade has seen significant advances in the design of osseous implants. This has been a result of improved understanding of skeletal wound healing and a new generation of smart biomaterials. Calcium phosphate biomaterials have been used successfully for bone replacement. A new calcium phosphate cement formulation, hydroxyapatite cement (HAC), forms hydroxyapatite (bone mineral) in situ under physiologic conditions via a setting reaction. The advantage of the cement system and formation in craniofacial reconstruction is the ability to accurately contour and shape complex skull structure. In addition, since bone mineral is formed under physiologic conditions, it enhances the ability for implant osseointegration. Herein, we de-
PATIENTS AND METHODS

From September 1991 through September 1994, patients with skull defects of the anterior craniofacial region were solicited and enrolled in this study. The study was conducted by craniofacial reconstructive surgeons at 3 individual medical centers: Yale–New Haven Hospital, New Haven, Conn; Wilford Hall Medical Center, San Antonio, Tex; and University of Pittsburgh Medical Center, Pittsburgh, Pa. The investigation was performed under investigational device exemption granted by the Food and Drug Administration, and approval was granted by each institution’s investigational review board. Defects were confined to the anterior craniofacial area involving the frontal bone, the frontal sinus complex, the orbital complex, the nasal root, the anterior temporal-zygomatic bone, and the floor of the anterior cranial fossa. The maximum size of individual defects was limited to 5 cm in diameter or 25 cm² surface area dimension. Defects were classified as acute (≤14 days), semi-acute (>14 days and <1 year), and chronic (>1 year).

Patients were excluded for the following reasons: (1) abnormal calcium metabolism, (2) metabolic bone disease, (3) infection within 3 months, (4) immunologic abnormalities, (5) renal disease, (6) pregnancy, (7) therapeutic radiation therapy to the surgical field, (8) cardiovascular disease precluding elective surgery, and (9) age younger than 18 years. Patients underwent preoperative high-resolution computed tomography and blood chemistry studies. Serial examinations were performed in the immediate postoperative period and at 1, 3, 6, 12, and 24 months after surgery. Computed tomography using bone algorithm was used to measure implant volume over time. Implant volumes were compared over time with those of the immediate postoperative scan, and implants were considered unstable if greater than 10% volume loss was measured on any follow-up scan.

A standard surgical technique was used, with subperiosteal dissection and exposure of the defect; this was via a coronal flap exposure unless prior incisions existed (Figure 1). Care was taken to remove any soft tissue at the bone-implant interface in chronic defects. In cases in which paranasal sinus exposure was encountered, all mucosa was carefully removed and the interface was covered with pericranial or fasical graft before implant placement. The HAC powder component was mixed with sterile water until a thick paste consistency was achieved (the solid-liquid ratio was 0.3 cc/g). The implant material was then applied and sculpted to achieve complete volume and contour reconstruction of the defect. The cement was allowed to set in situ for 30 minutes until a firm, solid implant character was achieved; care was taken during this period to remove excess wound fluid by application of suction-and-sponge technique. Defects with diameters greater than 2.5 cm and/or that crossed the frontal convexity had titanium mesh placed at the base of the defect and fixated at the inner calvarial diple; the mesh served as a platform to apply the cement and to dampen dural pulsations that could interfere with the in situ setting phase. Standard closed suction drainage was used to prevent postoperative fluid collection, and perioperative antibiotic therapy was maintained for 5 days.

RESULTS

Forty patients with defects of the frontal sinus and frontofacial region were enrolled in the study. The average age of the patients in the cohort was 43.8 years (range, 19-74 years). Twenty-nine patients (72%) were men, and 11 (28%) were women. Thirty-eight were evaluable at the 24-month end point. Two patients were not evaluable: one was unavailable for follow-up, and the other died of interval disease at 12 months with an intact implant but is excluded from outcome analysis.

Thirty-four (86%) of the defects were surgically induced, with 6 (14%) having a traumatic cause. Stratification of defects into duration revealed that 26 (65%) were acute, 6 (15%) were semi-acute, and 8 (20%) were chronic. The average amount of implant material was 47 g with a range of 15 to 130 g in an extensive defect reconstruction. There were no perioperative mortalities. No patient had any evidence of toxic or allergic reactions. Serial electrolyte evaluation revealed no clinically significant acute or chronic abnormalities. No implants were extruded or became mobile on physical examination.

The overall success for frontal sinus and frontofacial reconstruction as defined by maintaining implant volume at 24 months was 82%; 31 of 38 patients maintained their implants without any volume changes. Seven patients underwent explantation during the evaluation period. Four patients underwent implant explantation for surgical reexploration, and 3 underwent explantation for surgical site infection. Of the patients undergoing explantation during surgical reexploration, 1 had tumor recurrence; the remaining 3 underwent explantation for a recurrent mucous cyst in the frontoethmoid recess. These 3 patients underwent frontal sinus obliteration and reconstruction and had a history of chronic mucoperiosteal inflammation. In these patients, implants were well integrated to the surrounding osseous tissue, but symptomatic cystic mucosal disease became evident in the anterior ethmoid sinus abutting the HAC implant.

Three patients had an implant removed for surgical site infections. One patient had undergone frontal sinus obliteration and presented with clear evidence of purulent infection. On detailed examination at surgery, it became evident that a residual sinus air space that had not been previously exenterated was responsible; we, therefore, classify this to be the result of technical error at the time of the original surgery since the sinus that had been obliterated was stable. This
error is excluded from the explants due to infection analysis because it represents a preventable error. The second patient with a surgical site infection had undergone extensive fronto-orbital reconstruction using HAC and an adipose fat graft to obliterate dead space overlying the implant. The fat graft became infected with Pseudomonas aeruginosa bacteria, and the HAC, which was osseointegrated and vascularized, was subtotally removed as a precaution. The third patient had recurrent frontal sinusitis in a supraorbital recess; the wound was debrided with approximately 50% of the implant remaining. The overall surgical site infection rate is 7.9%; excluding the preventable technical error, surgical site infection leading to explant is 5%.

All explants occurred between 6 and 12 months. Therefore, all implants maintained at 1 year continued to have successful outcomes. Subdividing the cohort into patients with a history of frontal sinus–related defects and a history of significant mucoperiosteal disease, the success at maintaining HAC implants at 2 years is 50% (or 5 of 10 patients) in this subgroup. The incidence of com-
Hydroxyapatite cement has been shown in this study to confirm the findings of previous animal experimentation, ie, osseointegration and osseoconversion of the implant to bone. Figure 2 illustrates the histological features from a core biopsy specimen of a patient explant. The ability to biointegrate is a significant advantage for alloplastic implants and intuitively affords better long-term survival. Hydroxyapatite cement has 2 additional characteristics that are in contrast to ceramic formulations of hydroxyapatite: ease of application and the ability to contour complex 3-dimensional craniofacial structures (such as the orbital rim and walls). Ceramic hydroxyapatite is formed by high-temperature sintering and, therefore, is brittle, making screw fixation to underlying bone difficult. Salyer and Hall, in their study of ceramic hydroxyapatite in craniofacial augmentation, noted clinically apparent implant edges visible through the skin. Hydroxyapatite cement does not have this shortcoming because it is intimately sculpted and adapted to the recipient site during application. Subsequent to our study, Gosain and Burstein et al have reported their clinical experience with HAC for contour augmentation of the craniofacial region. These investigators have reported the ease of application and ability to sculpt the material as critically important and beneficial for contour augmentation.

The use of HAC in frontal sinus obliteration remains unclear from the present experience. With no history of significant sinus mucoperiosteal disease, the success rate is 93% (or 26 of 28 implants); therefore, in patients with frontal defects from trauma or surgically induced defects, HAC is safe and effective. When analyzing those patients with a history of sinus mucoperiosteal disease, 50% are successful (5 of 10 implants). It is, therefore, apparent that this group is at risk for a greater frequency of complications and overall less successful HAC implantation. The outcome of patients in this subgroup may be equivalent between HAC obliteration and adipose obliteration, as popularized by Hardy and Montgomery; however, this is not unequivocally known at this time and thus further study and clinical caution is warranted.

Hydroxyapatite cement is a new calcium phosphate biomaterial with unique properties, making it attractive for frontal sinus and frontofacial augmentation and replacement. The present clinical study validates previous animal experiments and provides evidence of long-term implant safety and efficacy in humans. Hydroxyapatite cement is particularly useful in craniofacial reconstruction because of its ability to biointegrate and provide for easy contouring of complex skeletal architecture.

COMMENT

Frontal sinus and frontofacial skeletal reconstruction remains challenging because of the significant aesthetic and functional consequences of such defects. Defects are commonly encountered as a result of traumatic injury, elective neurologic-transfacial surgical approaches, and correction of congenital deformities. The challenges for wound healing of this skeletal site are volume maintenance and resistance to paranasal sinus infection. Autologous bone remains the standard for comparison of alloplastic techniques. Autografts, when successful, provide for excellent outcomes, but donor site limits and complications, the need for fixation hardware, and difficulties in contouring have continued to spur interest in alloplasts.

Methyl methacrylate has enjoyed considerable popularity as an alloplast for cranial defects. Manson et al in a study of a similar population of anterior frontal cranial defects, found that acrylic, although useful, had a 50% infection rate when in contact with the paranasal sinus mucosa. When infection becomes manifest around an acrylic implant, removal is mandatory since the implant tissue interface is an avascular fibrous capsule. This is in contrast to the findings in the present study, in which the surgical site infection rate was approximately 7.9%.

After accounting for technical errors in 2 patients (failure to totally exenterate the sinus and an infected fat graft used conjointly), HAC appears to provide a significant advantage over acrylic as a cranial replacement when in contact with the paranasal sinuses.

Surgical site infection was approximately 7.9%.

<table>
<thead>
<tr>
<th>Complications</th>
<th>No. (%) of Patients</th>
</tr>
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<tbody>
<tr>
<td>Edema</td>
<td>10 (26)</td>
</tr>
<tr>
<td>Tenderness</td>
<td>6 (16)</td>
</tr>
<tr>
<td>Sinusitis</td>
<td>4 (11)</td>
</tr>
<tr>
<td>Surgical site infection</td>
<td>3 (8)</td>
</tr>
<tr>
<td>Mucous cyst formation</td>
<td>3 (8)</td>
</tr>
<tr>
<td>Headache</td>
<td>3 (8)</td>
</tr>
<tr>
<td>Tissue thinning</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Seroma or hematoma</td>
<td>0</td>
</tr>
</tbody>
</table>

Edema appears as a frequent survey finding; no cases of edema persisted longer than 6 months. Complication evaluation criteria were similar to those for craniofacial surgery done with traditional methods. Noted complications and their frequencies were consistent with historical data reported for this type of surgery.
REFERENCES


