

CRANIOPLASTY AFTER TREPHINATION USING A NOVEL BIODEGRADABLE BURR HOLE COVER: TECHNICAL CASE REPORT

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OBJECTIVE AND IMPORTANCE: We have developed novel biodegradable polymer implants by using the rapid prototyping technology fused deposition modeling. Early results of a clinical pilot study for cranioplasty are presented.

CLINICAL PRESENTATION: Five patients with the diagnosis of chronic subdural hematoma were included in the study. After trephination and evacuation of the subdural hematoma, burr holes (diameter, 14 mm) were closed using a biodegradable implant made of polycaprolactone. Implants were computer designed with an upper rim diameter of 16 mm and a 14 mm body diameter with a fully interconnected, honeycomb-like architecture of 400 to 600 μm in pore size.

INTERVENTION: Postoperative computed tomographic scans indicated that the plugs were stably anchored in the osseous host environment with no fluid collection detectable. The postoperative course was uneventful, and patients were discharged after 5 days. Follow-up scans after 3, 6, and 12 months showed that the implants were well integrated in the surrounding calvarial bone with new bone filling the porous space.

CONCLUSION: These novel polymer scaffolds made of the slow-degrading material polycaprolactone represent a suitable implant for closure of post-trephination defects.

KEY WORDS: Burr plug, Cranioplasty, Polycaprolactone, Rapid prototyping, Tissue engineering

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A wide variety of bone grafts and bone-substitute materials have been used for cranioplasty. Burr holes often result in small, but undesirable, skin depressions. Bone grafts or substitute materials have been used to fill those defects. Autologous bone is still the gold standard for osseous reconstruction because of its mechanical properties, biocompatibility, and osteoinductive properties. It is, however, associated with donor site morbidity and graft resorption. Tessier (13) has reported the use of split calvarial autologous grafts to bridge craniofacial defects. This technique represents an inexpensive and straightforward approach, but the primary incision needs to be extended to harvest the graft from the surrounding calvarial bone. The bone dust can be collected during the craniotomy procedure and mixed with a hydrogel-like fibrin glue into a paste for filling the defect (8).

Titanium has been used extensively for cranioplasty. Its biocompatibility and mechanical strength combined with its easy handling and ac-

curate fixation justify the relatively high costs (2). Silastic is also used, but its biocompatibility is questionable because of formation of foreign body reaction to its elastomers (14). In recent years, there has been a move toward using osteoinductive biomaterials and implants that allow the ingrowth of bone tissue and so give better integration of the implants. The trend toward using bioresorbable materials, particularly in pediatric craniofacial surgery, has resulted in implants that are eventually replaced by autologous bone (5, 11, 12).

Kobayashi et al. (7) have designed and fabricated various alumina ceramic implants to reconstruct trephination burr holes and to prevent postoperative indentations in the skin. Ceramic implants based on hydroxyapatite are increasingly popular because of their mechanical properties and osteoinductive and integrative characteristics (15).

Our group has designed and fabricated bioresorbable scaffolds for burr hole application in cranioplasty. The design is based on a burr

plug snap-fit mechanism. It is made from polycaprolactone (PCL) polymer, which is biocompatible and degrades slowly, allowing cells to attach, proliferate, and deposit mineralized matrix (16). Several preclinical trials in rabbits (11) and pigs (10) using these implants with differentiated mesenchymal cells have shown that the grafts are well integrated in structural reconstruction of osseous cranial defects. This clinical pilot study reports the initial clinical experience with this novel implant.

PATIENTS AND METHODS

Design and Fabrication of PCL Burr Hole Plugs

The biodegradable polymer is fabricated from medical grade PCL (Osteopore International Pte Ltd., Singapore) using rapid prototyping technology fused deposition modeling (6). The implants are designed so that a larger top case (1 mm thickness) is connected to a central cylinder (3 mm thickness). Orthographic and isometric views of this are shown in *Figure 1, A and B*. The implants have a

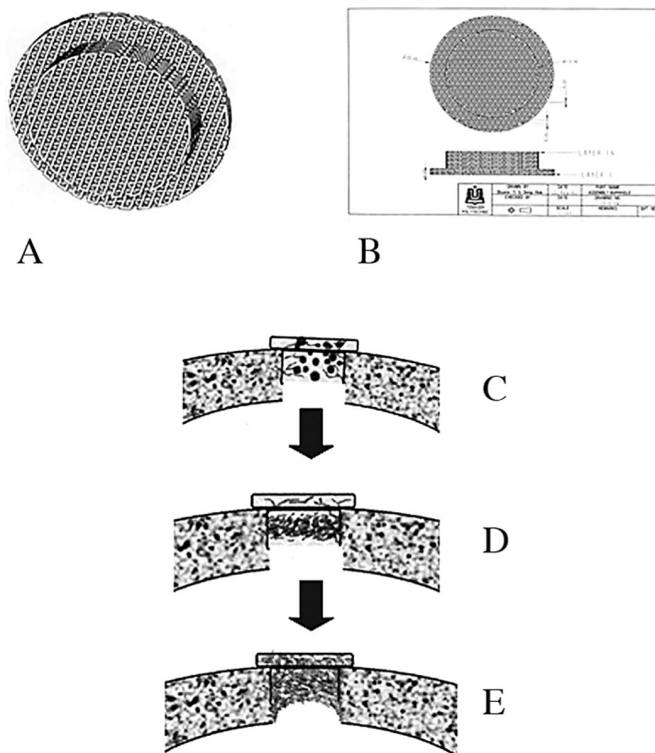


FIGURE 1. Isometric view of burr plug design (A) and schematic drawing showing layer orientation of the PCL filaments (0, 60, 120) (B). Burr plug has completely interconnected pores, an upper rim diameter of 19 mm, and a central cylinder with a diameter of 16 mm. Note space between implant and inner calvarial table (implant thickness, 3 mm). C–E, schematic drawing of parasagittal plane and histological events of burr plug after implantation. Fibrovascular ingrowth comes from the circumference (neighboring calvarium), from the dura underneath, as well as from the overlying soft tissue flap. This is followed by osteoblast migration and differentiation and subsequently the deposition of mineralized matrix in the plane adjacent to trabecular calvarium. Final stage (E) is characterized by complete mineralization of plug, leaving only a dome-shaped impression in inner table area.

completely interconnected porous architecture and a porosity of approximately 60 to 70%. The snap-fit design allows fixing the implant without screws or plates. The larger cap ensures that the burr plug remains in the contoured position of the cranium and is not accidentally pushed too far below the thickness of the cranium. Before implantation, the PCL burr plugs were rinsed three times with changes of phosphate buffered saline and then packed and sterilized with ethylene oxide.

Design of Clinical Trial

The study was reviewed by national and international ethics advisory boards and was approved by the Ethics Committee at the National University Hospital in Singapore in July 2002. Patients eligible for the study were first diagnosed with chronic subdural hematoma that required trephination, drainage, and subsequent cranioplasty. In addition, the patient must not have had any acute or chronic inflammatory diseases, documented allergies, or incompatibility reaction against polymer implant materials.

All patients were informed about the different therapeutic options (leaving the burr hole uncovered or coverage with a conventional titanium implant versus prefabricated biodegradable PCL implant). Five patients (male-female ratio, 4:1), with ages ranging from 22 to 83 years (mean, 41.5 yr), were included in the study. In the first phase, all patients underwent routine trephine craniotomy for chronic hematoma evacuation. Depending on the location of the hematoma, one or two burr holes were created to release the hematoma.

Surgical Procedure

The procedure was performed under general anesthesia. After cleaning and draping the head, the line of incision was drawn with a marker pen. A longitudinal incision was made to the pericranium and a self-spreading tissue retractor inserted. The pericranium was lifted off with a sharp periosteal elevator and a 16 mm burr hole drilled using a manual trephine. Homeostasis was secured. The dura was tented, then incised, and the hematoma evacuated. The area was rinsed using a Foley catheter. Scaffolds coated with autologous blood from the calvarium marrow space were inserted and sealed with 0.5 ml of fibrin glue (Tisseel; Baxter Hyland Immuno, Vienna, Austria). The scalp was closed with 3.0 Vicryl sutures (Ethicon, Sommerville, NJ) and skin with 3.0 Prolene sutures (Ethicon).

Postoperative Follow-up

Clinical Examination

Long-term clinical follow-up evaluations were routinely performed after 3, 6, and 12 months in the outpatient clinic at the National University Hospital. During evaluations, assessments were made regarding postoperative esthetics, patient satisfaction, clinical firmness of the implant, and local or systemic reactions to the implant.

Computed Tomographic Scans

Computed tomographic (CT) scanning was performed on a helical 4-slice scanner (Somatom Volume Zoom Plus 4; Siemens, Erlangen, Germany) A slice thickness of 1 mm and an overlap spacing of 0.5 mm were used with a field view of 206 mm. The images were reconstructed using both soft tissue and bone algorithms.

RESULTS

In all cases, the surgical procedure was performed without complications with a mean operating time of approximately 20 minutes. The user-friendly snap-fit mechanism and the standardized size of the plugs allowed the surgeon to achieve a constant and predictable result in a relatively short operating time. The postoperative course was uneventful, and patients subsequently improved neurologically on the Glasgow coma scale after evacuation of the hematoma (results not presented). No detectable swelling was noticed over the implant, and the patients showed no signs of an acute local or systemic immune reaction, as indicated by a continuous monitoring of the acute phase protein, C-reactive protein (within the norm of: 0.0–1.0 mg/dl in all patients). A total of eight implants were inserted into the five patients (two into three patients and one into two patients). None of the implants had to be removed. The patients were pleased with the cosmetic result of the cranioplasty. In all cases, long-term follow-up after 3, 6, and 12 months indicated an esthetically pleasing scar and a functionally stable cranioplasty as revealed by manual palpation. The following is a representative case.

Patient 1

In this 83-year-old woman who presented with chronic subdural hematoma after a domestic accident, both burr holes were reconstructed with bone marrow-coated PCL implants. CT scans (Fig. 2) indicate the increasing bony consolidation of the implant with almost complete ossification after 1 year. The CT scan sequences indicate that new bone formation starts in the center of the implant adjacent to the marrow space and spreading to the outer and inner

table of the implant. The newly generated bone undergoes remodeling in a trilayered fashion (outer table, marrow space, inner table) similar to the morphological characteristics of the surrounding bony calvarium as shown by the CT scan after 12 months. Bone formation started in the outer aspects of the central cylinder of the implant where the well-vascularized and cell-rich cancellous marrow compartment of the calvarial diploe was in close contact with the honeycomb architecture of the scaffold (Fig. 1, C–E). Subsequently, bone formation filled out the entire cover, leaving only a residual dome-shaped cavity in the region of the inner calvarial table.

DISCUSSION

The unique geometry of craniofacial structures represents a particular challenge for reconstruction. The limitations in solving the remaining, and somewhat difficult, reconstructive surgery problems and its final clinical outcome may be approached from the perspective of the nature of the graft material with which the surgeon works. Current, clinically established therapeutic approaches focus on the implantation of autograft and allografts, metal devices, and ceramic-based implants to assist repair of bone defect sites. However, all these techniques have disadvantages that have been discussed in detail in a number of excellent review articles. These constraints have triggered a need for new therapeutic concepts to design and engineer unparalleled structural and functioning bone grafts. It is within this context that the field of bone engineering has emerged (1, 4). The primary objective of a variety of tissue engineering strategies is to regenerate structural and functional tissue using living cells in combination with a scaffold. The scaffold must have certain characteristics specific for the cranial region. It is desirable that the material should not interfere with subsequent diagnostic imaging techniques, such as CT and magnetic resonance imaging (9).

Most importantly, the graft material must be able to replace a section of calvarial bone. Not only should the implant provide the physical shape of the defect for the purpose of correct anatomic reconstruction, it should ultimately mimic the properties of the bone (9). From the surgical perspective, the implant material should have

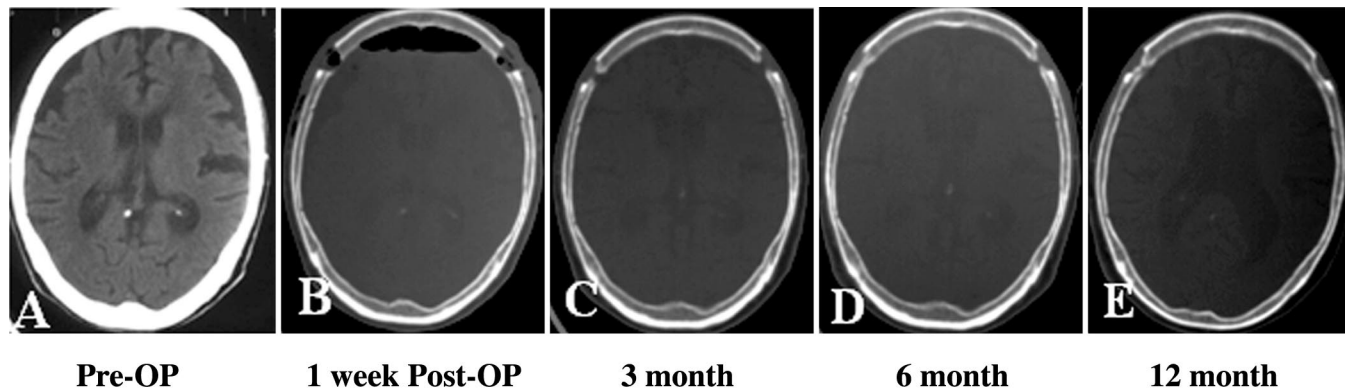


FIGURE 2. A, preoperative CT scan of bilateral subdural hematoma of an 83-year-old patient. B, subsequent CT scan after release of hematoma and reconstruction with two burr plugs (blood coated and fibrin sealed). CT

scans after 3 months (C), 6 months (D), and 12 months (E). Note the increasing bone formation over time leading to a new calvarial diploe (2 cortical layers separated by a cancellous middle layer) in PCL burr hole.

good handling properties and be easily fixed to the skull. Our interdisciplinary group has studied and developed the parameters to process PCL and several polymer-based composites (PCL/hydroxyapatite, PCL/tricalcium phosphate, etc.) by fused deposition modeling. These first generation scaffolds (PCL) were studied for more than 5 years both in vitro and in vivo before the clinical trial was started (11). The PCL scaffold is characterized by a slow-degrading synthetic polymer framework and provides a biomimetic milieu for the initial blood clot phase of wound healing. The entrapped blood clot acts as a cell delivery vehicle. The completely interconnected architecture of the PCL scaffold allows for rapid and homogeneous vascularization. This design not only assists in early and proper integration of the implant into the native host bone but also allows for adequate delivery of nutrients to the invading precursor cells. The effect of good tissue integration was confirmed by postoperative CT scans of the patients' cranium showing ingrowth of surrounding bone into the PCL scaffold. Mineralization was observed after 3 months with multiple mineralized foci seen throughout the scaffold. Conceptually, if bone formation were to completely fill out the implant-covered defect at a stage when the material was still present in abundance, the later polymer degradation products would have destructive effects on the newly formed bone (3). Thus, ideally, the graft material should be one that allows for an early and functionally stable integration into the native host bone as well as a balance between bone formation and slow material degradation.

CONCLUSIONS

Although our clinical experience comprises only a short-term evaluation (up to 12 months), we conclude that PCL scaffolds are well tolerated by patients and show the following characteristics: 1) they have excellent biocompatibility, 2) PCL is a suitable material within a bony environment, acting as a bone guiding template, 3) PCL's strength and fracture-resistant properties enable the implant to be firmly anchored in the surrounding calvarium, leading to stable reconstruction; and 4) the mushroom button design of the burr plug provides user-friendly handling and predictable clinical results. We will continue with long-term follow-up to evaluate the material degradation and how bone remodeling takes place within the implant.

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COMMENTS

The authors report on a novel burr hole cover that was used to fill eight burr holes in five patients. The burr hole plugs made of polycaprolactone are biodegradable and osteoconductive. While the series published demonstrates satisfactory results, it is too small to define the rate of complications and the rate of cosmetically significant reabsorption. Where this technique fits into our armamentarium used to repair cranial defects is uncertain, but the possibility of filling a bony defect with the patient's own bone is attractive.

Allan H. Friedman

Durham, North Carolina

The authors report a biodegradable burr hole cover to improve the cosmetic result after surgery. They have demonstrated that this self-fitting biodegradable cover made from polycaprolactone will allow new bone formation within the matrix formed by the material.

There are many techniques for improving the minor cosmetic defect from a burr hole and this type of biodegradable cover will likely become a feasible option. The ultimate cost of the product will be a factor in the clinical decision.

William F. Chandler

Ann Arbor, Michigan

The authors have presented an interesting way of filling the burr holes after performing craniotomy. I usually use a titanium disc to do this. If the biodegradable polymer comes in various sizes and shapes, it would be equivalent to using a titanium disc. I do not see any special advantages, or disadvantages of this new technique, as compared to the titanium discs.

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