CASE REPORT

Stereolithography for Posterior Fossa Cranioplasty

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Abstract—Posterior fossa cranioplasty has been suggested for improvement of neurological symptoms following craniectomy. However, there is no particular recommendation in the literature about techniques for prosthesis manufacture and implantation. We report our experience using rapid prototyping technology and stereolithography for pre-surgical implant design and production of cranioplasties.

For thousands of years, cranioplasty has been performed to correct cranial defects. Archeological discoveries of trephined skulls, associated with shaped materials in the correct size and configuration to be used as coverings for cranial defects is strong evidence that cranioplasty has been practiced since the antiquity.¹⁻³⁸ Implantation has been recommended for cosmetic, psychosocial, protective, and more recently, therapeutic purposes. Large cranial defects have been associated with headache, dizziness, discomfort, cognitive and behavioral changes, seizures, and intolerance to vibration.^{1,2,13,39,40} Indications in the literature for cranioplasty have recently been reviewed by Schiffer and Dujovny.^{2,6,41}

Posterior fossa craniectomy is a common procedure for the removal of cerebellopontine angle tumors, cranial nerve neuralgias, vascular lesions of the posterior circulation of the brain, and infectious diseases.⁴²⁻⁵¹ The incidence of postcraniectomy headache for posterior fossa diseases have been reported in the literature.^{46,47} The complex curvature of the occipital bone and uneven anatomical landmarks, particularly when the mastoid process is involved, makes reconstruction difficult. The introduction of stereolithography and computer-aided design/computer aided manufacture (CAD/CAM) to the planning and pre-surgical fabrication of large prosthetic cranial implants solves most of

the previous difficulties encountered in closing large craniotomies. In addition, implants designed and fabricated using these techniques, provide better aesthetic and clinical results.⁵²⁻⁷²

We report our personal experiences with two posterior fossa cases for trigeminal neuralgia and torcular meningioma in which rapid prototyping technology and stereolithography were used to design, and pro-engineering to produce, the final cranial prosthesis.

MATERIALS AND METHODS

Prosthesis Production Technique

Materials and techniques used in pre-surgical design and manufacture of cranial implants has been reported previously.⁵²⁻⁷⁵ Only a brief overview of the methods specific to posterior fossa cranioplasty manufacture is presented. Rapid prototyping is a generic term for several industrial manufacturing processes which create solid, physical objects directly from a computer data file. These industrial techniques were adapted for manufacturing cranial implants in 1995 by the Department of Neurosurgery and researchers in the Biomedical Visualization Laboratory (BVL) at the University of Illinois at Chicago.

Stereolithography

Stereolithography is the technology by which a negative model of the cranial defect is produced in the computer. Patients were scanned on a GE High Speed Advantage scanner (GE Medical Systems Inc., Milwaukee, WI), the CT image data was transferred to DAT (magnetic tape) for back-up, and the tape was loaded into computer workstation. The images are imported to specialized CAD/CAM software (Surgicad Dallas, TX), image processed, and segmented. The resulting image file is converted to an appropriate format for stereolithography. Stereolithography produces a physical model, in a photocurable resin, of the defect which is supplied to a prosthetist.

Reverse Engineering

The stereolithographic mold represents the negative surface of the final cranial prosthesis. The process by which the actual defect is reproduced is called reverse engineering.

Sculpting clay is applied to the stereolithographic model and molded to recreate the inner contours of the skull. A mold of this inner (skull/brain) surface is cast in dental stone of this aggregated piece. The clay is removed and a dental grade wax, capable of holding more refined detail, is used to sculpt the shape of the final implant. Care is taken to maintain appropriate skull contour and thickness, recreating the geometry of the missing bone. The second half of the dental stone mold is poured, the mold halves are separated and the wax removed, leaving a negative space to receive the final implant material.

Pro-Engineering

The technique used to produce the final implant from the reverse engineering model is called pro-engineering.

A methylmethacrylate monomer liquid and polymer powder are mixed to form a soft, pliable mound of material. The resin is carefully packed into the mold to avoid air entrapment and the two halves are clamped tightly together. The resin is slowly cured in a hot water bath. Additional oven curing follows to release residual free monomer trapped in the implant. After trimming and polishing, the finished implant is sent to the operating suite for ethylene oxide gas sterilization.

CASE REPORTS

Case 1

WJ is a 58-year-old male with a history of a lump on the left occipital bone and occasional frontal headaches since 1993. MRI showed a torcular menin-

Figure 1. Cranial defect prosthesis and clay negative of Patient 1

gioma infiltrating the bone and skin. A bilateral parieto-occipital craniectomy was performed and a cranial defect was left on the operative site. Minor headaches and pseudo-seizures were present after long-term follow-up. It was decided to perform a protective cranioplasty to cover the cranial defect (Fig. 1). A CAD/CAM of the prosthesis was performed (Fig. 2).

After intubation, the patient was placed under general anesthesia, controlled ventilation, shaved, and draped. The patient was positioned at three-quarters prone. The incision site was infiltrated with 1% Lidocaine and Epinephrine, and the skin incision was made, respecting the previous incision lines. Raney skin clips (Codman, Randolph, MA) were used for hemostasis. The flap was

Figure 2. Post operative brain MRI of Patient 1 showing tumor site and posterior fossa cranioplasty in place.

undermined and dural attachments released, permitting dissection to continue until all margins of the cranial defect were visualized. The surgical site was irrigated with bacitracin. The implant was removed from the bacitracin solution in which it was kept after the ethylene oxide sterilization. Fixation holes were made on the surrounding bone and implant with a Midas high-power drill (Midas Rex, Fort Worth, TX).^{76,77} The implant was fixed in place with screws using four titanium plates. Total immobilization of the prosthesis was attained, which effects restitution of cranial integrity and contour. After careful hemostasis of the periosteum and musculocutaneous flap, the incision was closed in two layers. The subcutaneous/galea was closed with 00 interrupted inverted Polyglycolic acid and the skin, with staples.

Case 2

SD is a 48-year-old female with history of trigeminal neuralgia on the left V2,3 territories. The patient was submitted to two trigeminal microvascular decompressions for the management of the pain. The patient reports an important relief of her symptoms. However, she started complaining of a headache starting close to the cranial defect (Figs. 3 and 4), irradiating to the frontal and temporal regions, worsening with left lateral extension and frontal flexion of the neck, improving partially with rest and minor analgesics. Several pain treatment options were proposed, none giving complete relief of the symptoms. It was decided to perform a CAD/CAM planned cranioplasty based on anecdotal reports of pain improvement after cranioplasty. The

Figure 3. Skull CT scan (bone window) for Patient 2 showing posterior fossa cranial defect

Figure 4. Three-dimensional reconstruction of the skull in Patient 2 showing cranial defect.

prosthesis (Figs. 5A and 5B) was perfectly fixed to the adjacent bone with titanium plates. Surgery was uneventful. Long-term follow-up showed relief of the headache with complete control with minor analgesics upon recurrence.

DISCUSSION

The incidence of postretromastoid craniectomy headache in patients operated on for acoustic neuroma as reported in the literature varies between 9 and 69%. The therapeutic benefits of cranioplasty for relief of headache are controversial.^{43,44,46–48,50,51} Some authors argue that there is no change in the headache pattern in patients undergoing posterior fossa craniectomy and cranioplasty and those without cranioplasty. Some patients report a higher incidence of headaches in the cranioplasty group, as compared to the noncranioplasty group. The intra-operative use of methylmethacrylate for cranioplasty and the sub-optimal local effects of this material for repair of large defects are well established.^{42,73–75} In addition, scars and adhesions, which may be important in the origin and/or maintenance of headaches in this group, are a common result of using intra-operative methylmethacrylate.

Many different techniques and materials have been utilized for cranioplasty in the past twenty years.^{2,73,75} Methylmethacrylate, mersilene, titanium mesh, tantalum mesh, Medpor, hydroxyapatite cement, rib, split bone, and autologous bone have been utilized to reconstruct skull defects intra-operatively.^{13,73,78–84}

Cranioplasty can be performed in two basic ways: intra-operatively as part of the primary surgical proce-

Figure 5. (A) Final cranial prosthesis for Patient 2. (B) Stereolithographic model of cranial defect in Patient 2.

ture or in the days following the primary procedure after the resolution of the fundamental process that led to its performance. In the former situation, methylmethacrylate, hydroxyapatite cement (HAC), and autologous bone have been broadly utilized. Costantino et al molded HAC for the acute reconstruction of small to moderate sized cranial defects. HAC, in comparison to intra-operative methylmethacrylate, does not produce an exothermic reaction or toxic fumes and infections occur at a lower rate.^{2,73-75} HAC is easily molded to re-establish cranial contour resulting in a good cosmetic appearance.⁷³ When bone defects are larger than 9 cm² or when they involve the mastoid processes, HAC reconstruction is not possible. Moreover, oozing, blood accumulation, or serous material underneath the cranioplasty may lead to infection, reabsorption (in the case of HAC and autologous bone), and ultimately, necessitates a secondary operation to effect closure. For cranioplasty of the posterior fossa in the primary surgery, Samii recommended utilizing the patient's own bone, fixed to the site of the defect with bone plates. He reported a low incidence of complications using this method.⁴⁷

Secondary cranioplasty is performed after resolution of the basic problem that necessitated the need for an implant. Two courses are available for closure of large, geometrically complicated defects: methylmethacrylate applied intra-operatively or a pre-manufactured implant. Stereolithography provides a means of pre-manufacturing the cranial implant avoiding complications generally associated with intra-operative use of methylmethacrylate.

The incorporation of stereolithography into medicine, with its associated laser and computer technologies, and the development of more precise and rapid imaging technologies, permits the manufacture of better-fitting prostheses than ever before. Moreover, when the cranial defects are large, involving difficult and complicated geometry within anatomical structures, intra-operative reconstruction techniques are not as accu-

rate and require lengthy operating time which may lead to reabsorption, return of pre-cranioplasty symptoms, and infection. Stereolithographic pre-manufacture of cranial implants permits a better aesthetic result and substantially decreases the incidence of complications by significantly reducing operating time and hospitalization.

Restoration of the original integrity of the closed cavity of the cranium using a cranial implant is the ultimate goal of all cranioplasty procedures. Stereolithography and polymethylmethacrylate (large defects) and hydroxyapatite cement (small to moderate sized defects) avoid most complications that are cited in the literature and come closest to an "ideal cranioplasty material" for repair of posterior fossa defects. An "ideal implant" has the following characteristics: (1) biodegradable, (2) biocompatible: clinically inert, noncarcinogenic, no foreign body reaction, (3) high impact resistance, (4) ready availability, (5) ease of fabrication into complex shapes, (6) light weight, (7) Poor thermal and electrical conductance, (8) nonexothermic during surgery, (9) nontoxic fumes and/or residues, (10) MRI compatible, (11) capable of being sterilized, and (12) cost effective.

In large cranial defect reconstruction, the more these characteristics are incorporated, the greater the likelihood of success of the surgical procedure. Methylmethacrylate, when used in an implant prepared pre-operatively, has proven to be a good material for posterior fossa corrections. In our institution, it is used in conjunction with stereolithography for the manufacture of all large cranial implants.

One of our patients had a large cranial defect of more than 20 cm² bilaterally in the posterior fossa. The anatomical location, as well as the involvement of both mastoid processes fostered the prefabrication of the implant.

The other case was unilateral and could have been covered intra-operatively utilizing methylmethacrylate.

However, the involvement of the mastoid process on that side necessitated stereolithographic implant manufacturing in order to have a better fit.

Some regions of the skull like the areas of the posterior fossa involving the occipital bone, mastoids, and temporal scama are difficult to reconstruct surgically. The anatomical variation and difficult contours involved with posterior cranial bone defects, and the high morbidity associated with traditional cranioplasty procedures in these sites, requires better methods that produce a perfectly fitting implant. Stereolithography provides a means of pre-manufacturing CAD/CAM generated custom-designed implants of methylmethacrylate, and helped decrease the operative time and hospital costs.

CONCLUSION

Stereolithography has improved the design and fabrication of cranial implants. The search for an ideal implant material incorporating all desired characteristics continues. The results obtained with CAD/CAM generated implants make it possible to improve the quality of life in many patients, protect the brain from further injury, produce a satisfactory aesthetic result, and help alleviate some of the symptoms associated with large cranial defects. A decrease in operative and postoperative recovery times, and a lessening of adverse complications are attributed to these materials and methods. A cost reduction can also be implied, as most of the cost of stereolithography depends on the time used by the milling machine to carve the acrylic. A further development of pro-engineering and rapid prototype technologies will bring the costs to an even lower point, giving a further advantage for the use of stereolithography for cranioplasty implant construction. By producing a perfectly matched implant to cover the defect, the integrity and the original functions of the cranium are restored. Although this report is limited to two cases, it suggests that good results can be attained using stereolithography when applied for the reconstruction of posterior fossa cranial defects.

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