

Reconstruction of Cranial Bone Defects Using Alloplastic Implants Produced from a Stereolithographically-generated Cranial Model

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Abstract

Larger cranial bone defects can cause cranial disfigurement as well as potential mechanical brain trauma. Conventionally pre-fabricated acrylic cranioplasty implants require complicated procedures and result in potential dimensional and contour inaccuracies. The development of stereolithographic techniques for generating acrylic resin skull models allows the pre-fabrication of custom acrylic resin cranial implants with greater clinical predictability.

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Introduction

Cranial bone defects can be a result of trauma, congenital defects, infection¹ or iatrogenically induced by surgery. Even for patients with sufficient hair to cover the affected site, hair styling may not be sufficient to mask off the deficient external cranial contour. It is even more challenging aesthetically if the cranial bone defect is in the frontal or parietal bone region.

Surgical reconstruction of calvarial defects has been recorded by the ancient Incans¹ and Egyptians.² It is known that cranioplasty can alleviate neurological signs resulting from cranial defects.³⁻⁶ Complexity of cranioplasty increases with the size of the defect, especially if the defect is greater than 50 cm².⁷ This is because larger defects usually present more clinical challenges to surgeons.

Although surgical reconstruction of tissue defects with microvascular anastomoses autogenous tissues⁸⁻¹¹ plays an important role in cranial defects reconstruction, operating time is usually long and it involves an additional wound at the donor site. Various techniques using autograft⁸⁻¹⁴ and allograft⁷ have been described in reconstructing cranial bone defects. Alloplastic implants are indicated for cranioplasty when the defect is large and harvesting of a large amount of autogenous tissue graft is difficult.¹⁵ Earlier metallic cranial implants may precipitate headaches and may adversely affect the accu-

racy of electroencephalograms^{16,17} due to high thermal and electrical conductivity.

When alloplastic materials are chosen for cranioplasty, the cranial implant can be made directly on the surgical site (Direct Technique) or pre-fabricated before the surgery using various modelling techniques (Indirect Technique). Titanium,^{18,19} titanium alloy,²⁰ hydroxyapatite cement,²¹ hydroxyapatite ceramic,²² and polymeric fabric²³ are being used in fashioning cranial implants. Polymethylmethacrylate (PMMA) resin is widely used in dentistry and it is the most commonly used material for alloplastic cranioplasty.¹ PMMA has also been used in cranioplasty without much complications.²⁴⁻³¹ PMMA resin is usually available in powder (polymer particle) and liquid (monomer) formula. Upon mixing of the two, polymerization is either initiated by heat or chemical initiators.

Direct Technique

The direct technique usually involves the usage of metallic mesh,³² auto-polymerizing acrylic resin²⁶ or a combination of both.^{17,33} The cranial implant is directly fabricated from the surgical site during the surgery. This technique is suitable for smaller bony defects. However, additional operating time for contouring the implant, exposure of the recipient site to methylmethacrylate monomer and heat generation³⁴ from auto-polymeriz-

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ing acrylic resin during initial stage of curing are the principle disadvantages. Due to the difference in the polymerization method, the auto-polymerizing PMMA resin contains more residual monomer³⁵ and is believed to be the cause of adverse tissue reaction.^{36,37} There are no such concerns in pre-fabricated heat-polymerized acrylic resin cranial implants.

Indirect Technique

When a removed bone flap is available, it can be used for modelling and fabrication of an alloplastic cranial implant.³⁸ When the patient presents without the bone flap, the implant will need to be fashioned by other methods from a cranial model. An accurate cranial model is very important for the ultimate accuracy of the resulting cranial implant. When compared with traditional methods of alloplastic cranioplasty indirect implant fabrication,²⁴ stereolithography generated cranial models³⁹ provide surgeons with highly accurate anatomical information prior to surgery.⁴⁰⁻⁴²

This article describes the background and technique in fabricating PMMA resin cranioplasty implants for larger cranial bony defect reconstruction using a stereolithographically generated acrylic cranial model.

Problems Encountered in Fabricating a Cranial Model

An accurate three-dimensional model of the cranial defect is essential for cranial implant fabrication. Prior to the availability of the stereolithographic technique, cranial defect models were usually fabricated by making impressions of the patient's shaved scalp using dental impression material after the bony defect was meticulously palpated and carefully outlined using an indelible pencil. The contour of the impression was checked visually and then poured in dental stone. Postero-anterior and lateral cephalometric radiographs were obtained for the same patient. The skull size and defect size were measured from the postero-anterior and lateral cephalometric radiographs. These measurements were then corrected by the percentage magnification in the radiographic process. The thickness of the scalp was then estimated using the difference of the corrected radiographic measurement and the actual measurement of the cranial model. The appropriate thickness of the stone model 'scalp' was then removed from the cranial model and the size and location of the cranial bone defect was also corrected on this modified cranial model. A PMMA resin cranioplasty implant was then fabricated from this corrected cranial model for cranioplasty. However, due to cumulative errors in this procedure, the accuracy of the cranial bone model was limited and the accuracy of the PMMA resin cranial implant fabricated from this method was also unpredictable. Lengthy adjustment on these PMMA resin cranial implants to fit the cranial defect during

reconstructive surgery is not uncommon.

Stereolithographic Technique

Rapid prototyping techniques^{40,43,44} allow the creation of a three-dimensionally accurate anatomic model of the patient's cranial bone defect. The steps in the fabrication of a cranial model using stereography can be summarised as follows:

- (1) CT or MR scanning of the patient,
- (2) Enhancement of edges by image processing,
- (3) Segmentation and extraction of the surface, and
- (4) Acrylic resin cranial model fabrication.⁴⁰

Stereolithography utilises data obtained from CT or MRI scans.^{40-42,45,46} The data are stored in 3-dimensional form and are sliced up into a series of layers. The data are transferred to the stereolithographic apparatus, which then instructs the ultra-violet beam to trace out onto the surface of a pool of acrylic resin monomer. The acrylic resin monomer polymerizes when it is exposed to the ultra-violet light. The depth of the polymerization is controlled by the power of the ultra-violet light source. A slice of pre-determined thickness of the model is made. This polymerized acrylic slice is lowered to become submerged just below the surface of the uncured acrylic resin monomer. Additional layers can be formed onto the preceding layer. This process builds the model from the base upwards. By repeating this process, a complete skull model can be made from the MRI, CT scan^{42,46,47} or other digitised data. Stereolithographically generated PMMA resin models also have superb accuracy^{42,45,46,48} (Fig. 1).

Surgical and Prosthetic Planning

Once the cranial model is obtained, it is used for pre-surgical study of the bony anatomy.⁴⁹ The bony margins can be prepared by the surgeon on the model as it will be done during actual surgery. Gross roughness is removed from the defect margin. The margin of the skull defect is also bevelled so that a slightly diverging margin is obtained. This will allow the cranial implant to onlay onto the skull defect, thus preventing any movement of the implant towards the patient's brain. This modified model is then used for fabricating a custom heat polymerized PMMA resin cranial implant.

A wax sculpture of the skull defect is made directly onto the corrected cranial model. The overall contour of the wax sculpture is copied from the unaffected area and/or adjacent area with normal anatomical contour. The thickness of this wax pattern is verified with the thickness of the adjacent acrylic resin cranial model margin. This wax sculpture is then invested in dental stone and cast in clear heat polymerized PMMA resin material. Multiple 2 mm perforations are then made onto the cranial implant with 1 cm of space in between (Fig. 2). This provides channels for drainage initially



Fig. 1. A life-size computer-generated acrylic cranial defect model. Bony defect involving the right parietal bone and frontal bone. In this case the contour of the unaffected contralateral side is used as a reference for modelling the cranial implant.

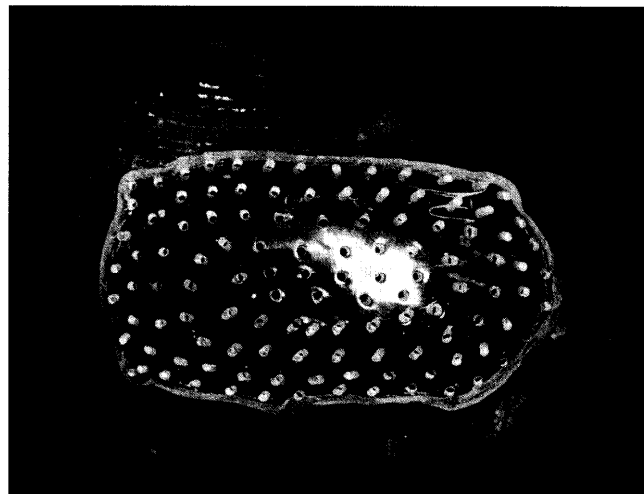


Fig. 2. Polymethylmethacrylate resin cranial implant fabricated from the acrylic resin cranial model (Fig. 1). The shape of the implant is determined by the contour of the adjacent bone bed as well as the contralateral cranial contour. Note multiple perforations on the implant.



Fig. 3. Cranioplasty implant secured to the bone bed. Note the proper marginal adaptation between the implant and the cranial bone.

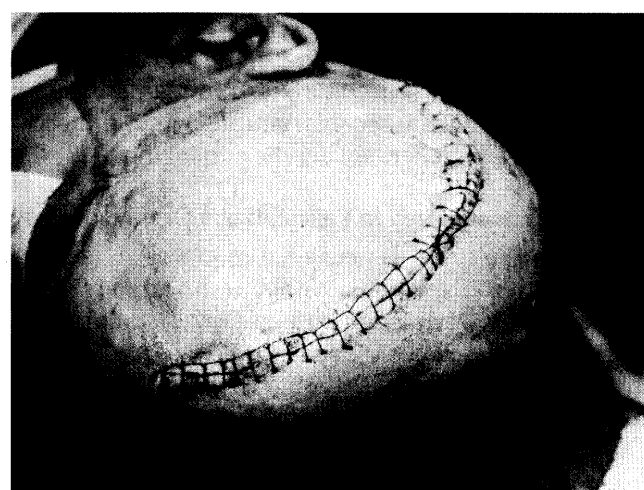


Fig. 4. Immediate postoperative view. Contour of the cranial bone is restored.

after surgery as well as room for fibrous tissue to grow through and form a fibrous encapsulation of the alloplastic implant upon healing. The PMMA cranial implant is then polished, packaged, and sterilised in ethylene oxide at low temperature for 48 hours, followed by 24 hours of aeration⁴¹ and is then ready for use.

During surgery, a flap is raised and the cranial bone defect is exposed. Gross bony marginal roughness is removed according to previous model surgery to facilitate insertion of the cranial implant. The cranial implant is then placed onto the defect and is checked for a proper fit. Adjustment to the implant can be done at this stage with an air rotor handpiece if excessive material is found. After the fit of the implant is confirmed, it can be secured to the cranial defect by wiring into the adjacent cranial bone (Fig. 3) and the flap is closed in the usual manner (Fig. 4).

Discussion

It is well accepted that autogenous bone should be the material of choice for bony reconstructions. Harvesting a sufficient amount of bone for a larger bony defect requires a donor site from a distant part of the body. The disadvantage of such a procedure is the involvement of an additional surgical wound and an increase in operating time. Cranioplasty using alloplastic materials has been well documented. Alloplastic cranioplasty is preferred in larger cranial defects⁴¹ and is applicable regardless of the size of the defect. Preoperative shaping of alloplastic cranial implants can be accomplished before the surgery. This also helps to reduce the operation time.

The accuracy of indirect cranial implants is dependent on the accuracy of the bony defect model. Traditionally, the fabrication of cranial implants using models obtained from shaved scalp impressions relies heavily on

the clinical experience of the operator. With the stereolithography technique and other rapid modelling technologies, accurate three-dimensional models can be made to aid in the planning and the fabrication of appropriate implants.

Conclusion

Alloplastic cranioplasty is a viable alternative for reconstructing craniofacial bony defects. The accuracy of this procedure can be greatly enhanced by MRI and CT scans, stereolithographically generated models and proper surgical planning. With the use of 3-D rapid prototyping model systems, the surgical and prosthetic team can fully explore the patient's anatomy prior to actual surgery. Minimal adjustments of the cranial implant during surgery will be necessary.

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