CASE REPORT

Rapid Prototyping: Key Tool for Digital Craniofacial Reconstruction

Tanuj Mendiratta[1], Harmanpreet Atwal[2], M Viswambaran[3], Dinesh Kumar[4], Anup Gopi[5]

Abstract

Cranioplasty is performed following a traumatic injury, infection, tumor, or after a previous brain surgery for surgical repair of a defect or deformity. Reconstruction of such large cranial defects with complex geometric shapes (frontal or involving supraorbital ridges) along with soft tissue loss is challenging to reconstruct. Fabrication of polymethylmethacrylate (PMMA) cranial implants by conventional methods of moulage and mold formation may be difficult when the patient has neuromuscular incoordination and when margins of the defect cannot be accurately detected. Three-dimensional anatomic models built by rapid prototyping (RP) can serve as templates for the fabrication of customized cranial prostheses for such cranial defects with high accuracy and precision. This paper aims to present and compare two different techniques of craniofacial reconstruction to restore form and function for large complex cranial defects. In the first case, the cranial implant was fabricated using the conventional method whereas in the second case RP was used to fabricate the prosthesis, which proved to be an accurate, time-efficient, convenient, and easy-to-use alternative with great adaptability to cranial vault defects. The RP technology nowadays plays a pivotal role in digital rehabilitation of large complex craniomaxillofacial defects especially when the patients have compromised neuromuscular coordination, which impedes the clinical step of impression making as the patient cannot maintain an upright posture of the head.

Keywords: Cranial prosthesis, Craniofacial reconstruction, Fused deposition modeling, Rapid prototyping.

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Cranioplasty is performed following a traumatic injury, infection, tumor, or after a previous brain surgery for surgical repair of a defect or deformity. Reconstruction of such large cranial defects with complex geometric shapes (frontal or involving supraorbital ridges) along with soft tissue loss is challenging to reconstruct. Fabrication of polymethylmethacrylate (PMMA) cranial implants by conventional methods of moulage and mold formation may be difficult when the patient has neuromuscular incoordination and when margins of the defect cannot be accurately detected. Three-dimensional anatomic models built by rapid prototyping (RP) can serve as templates for the fabrication of customized cranial prostheses for such cranial defects with high accuracy and precision. This paper aims to present and compare two different techniques of craniofacial reconstruction to restore form and function for large complex cranial defects. In the first case, the cranial implant was fabricated using the conventional method whereas in the second case RP was used to fabricate the prosthesis, which proved to be an accurate, time-efficient, convenient, and easy-to-use alternative with great adaptability to cranial vault defects. The RP technology nowadays plays a pivotal role in digital rehabilitation of large complex craniomaxillofacial defects especially when the patients have compromised neuromuscular coordination, which impedes the clinical step of impression making as the patient cannot maintain an upright posture of the head.

Background

Cranioplasty is repair of acquired defects or congenital deformities of the cranium surgically. It is performed mainly for brain protection, anatomical reconstruction, and cosmetics but evidence has shown that there is also improvement of brain physiology and patient self-esteem.[1] Most of residual cranial defects are due to trauma along with other etiological factors like tumor resections, cerebral decompression craniectomies, pathological conditions like fibro-osseous lesions, bone flap infections, congenital deformities, scleroderma, and intracranial vascular lesions.[2,3] Materials utilized for cranial reconstruction include bone, auto/allografts, distinct biomaterials, and even osteoinductive growth factors.[4] One of the most popular alloplastic materials utilized for cranial reconstruction is PMMA, a conventional transparent thermoplastic first utilized for cranioplasty in the 1940s by Zander, during and after World War II. Polymethylmethacrylate is inexpensive, moldable, adheres to the dura mater without reacting with soft tissues, and has strength comparable to bone with better compression and stress resistance than hydroxyapatite.[4]

Rapid prototyping was introduced in health care by Birx and Lambrecht in 1987, which provided a promising alternative method for surgical planning and simulation compared to the conventional methodology.[5] With the breakthrough in image processing and manufacturing technologies, fabrication of skull templates, custom templates, and even direct prosthesis fabrication for reconstruction of large craniofacial defects restoring both esthetics and function is proving to be one of the best options. This case series highlights

[1–3,5]Department of Prosthodontics and Crown and Bridge, Army Dental Centre (Research and Referral), New Delhi, India

[4]Army Dental Center (Research and Referral), New Delhi, India

Corresponding Author: Tanuj Mendiratta, Department of Prosthodontics and Crown and Bridge, Army Dental Centre (Research and Referral), New Delhi, India, Phone: +91 7973870562, e-mail: dr.tanujmendiratta@yahoo.com

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the methodologies for the fabrication of the custom-made PMMA cranial implant by both conventional and RP techniques for the successful management of frontotemporoparietal cranial defect highlighting the advantages of RP over the conventional technique.

Case Description

Case 1

A 59-year-old male was referred to the Department of Prosthodontics for the management of calvarial defect of right side involving the frontotemporoparietal region. On elicitation of medical history, it was found that the patient had sustained malignant ischemic stroke (MCA) and had undergone decompressive craniectomy for the same. After stabilization and postoperative healing, the patient reported for rehabilitation of cranial defect measuring approximately 13 cm × 10 cm in the frontotemporoparietal region. On examination, the bony margins were felt and the enlargement was observed to be painless, soft, nonedematous, and not pedunculated. Considering the nonedematous defect site, uncompromised neuromuscular coordination, and socioeconomic background of the patient, a decision of the conventional method of impression making and fabrication of cranial prosthesis was made for this case.

A multidisciplinary approach was planned for this case, which involved a neurosurgeon and a prosthodontist for surgical and prosthetic phases, respectively. In the prosthetic phase, the rehabilitation of the defect was planned with an alloplastic implant made of medical-grade high-strength PMMA. Patch testing for PMMA was done prior to the prosthesis fabrication to rule out any PMMA allergy.

Impression Making

Markings were made on the inner and outer borders of the cranial defect using an indelible pencil (Fig. 1). A cardboard of the size of the patient head was cut and adapted to the periphery of the calvaria to limit the extent of borders for impression making and preventing the ingress of the material. An irreversible hydrocolloid impression material was then poured onto the defect area carefully to prevent air entrapment. Over which cotton swab was placed on setting impression material, followed by a second pour of lightly mixed Plaster of Paris to provide support to the irreversible hydrocolloid impression material.

The obtained impression was checked for voids or inaccuracies (Fig. 2). It was followed by pouring the impression with type III dental stone to obtain the cast. The inner and outer border lines marked were transferred to the skull model.

Plaster of Paris was used to contour the arbitrary shape of the cranium on the defect site mirror imaging the contralateral side to serve as a guide and form a foundation for the wax pattern fabrication on the skull model (Fig. 3). The wax pattern was fabricated using modeling wax (Fig. 4) and a trial was done followed by dewaxing. The mold was then packed with clear heat-polymerized high-strength medical-grade PMMA (Factor II, USA) as per manufacturer's instructions. A long curing cycle was selected in order to reduce the residual monomer content of the cured prosthesis. The processed prosthesis was trimmed, finished, and polished using pumice and cotton buff. Trial of the finished prosthesis was done on the patient and checked from all the anatomical aspects. Equidistance perforations were indexed over the implant's surface with a round bur (Fig. 5). The perforations aid in preventing the accumulation of fluid beneath the implant after its placement, allow the inward growth of fibrous connective tissue to improve its stabilization, and provide a means to secure the implant. The finished prosthesis was immersed in distilled water for leaching out of any residual monomer.

The prosthesis was sterilized a day prior to the surgical phase in ethylene oxide. Prosthesis was adjusted intraoperatively to have a precise fit of the margins at the defect site (Fig. 6). The screws were tightened into the holes to secure implant into position, and the flap was sutured back into position. The reestablished cranial contour was well appreciated during follow-up visits (Fig. 7).

Case 2

A 12-year-old young girl reported to the Department of Prosthodontics for prosthetic rehabilitation of cranial defect on the left side. A detailed history revealed that the patient underwent craniectomy on the left side due to craniopharyngioma, which caused a defect of approximate size 9 cm × 6 cm. Both the treatment options of conventional methodology and RP technology for

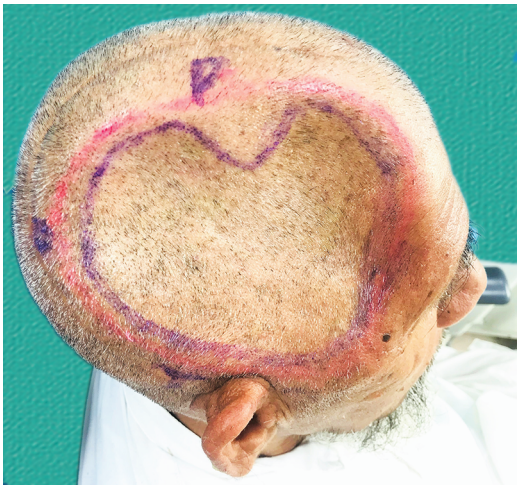


Fig. 1: Markings made at the cranial defect delineating the margins

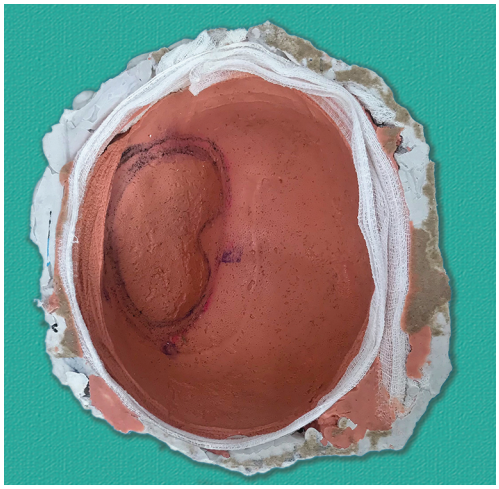


Fig. 2: Retrieved impression

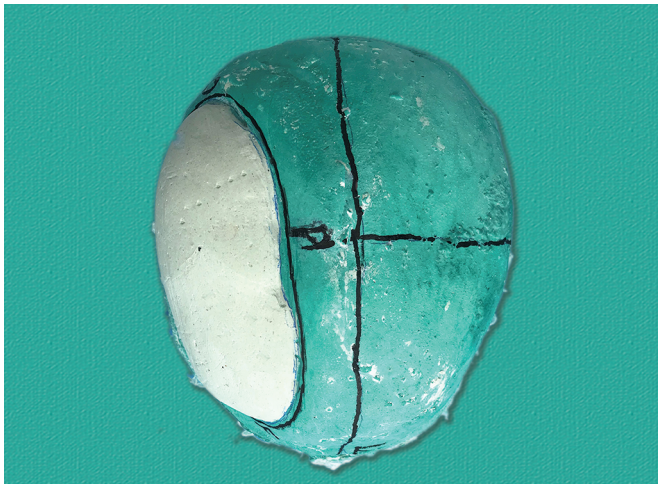


Fig. 3: Skull model with marked margins and POP base for wax pattern adaptation

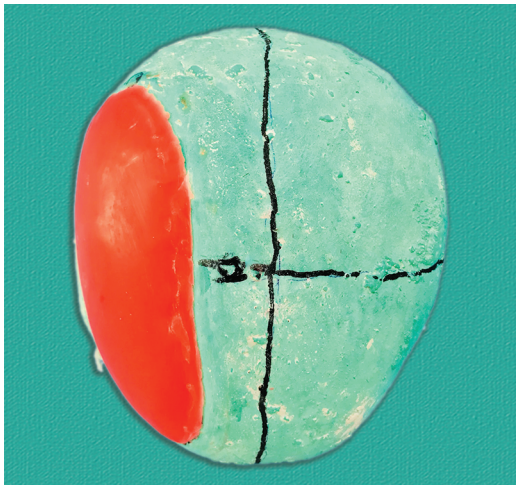


Fig. 4: Wax pattern fabrication on the skull model

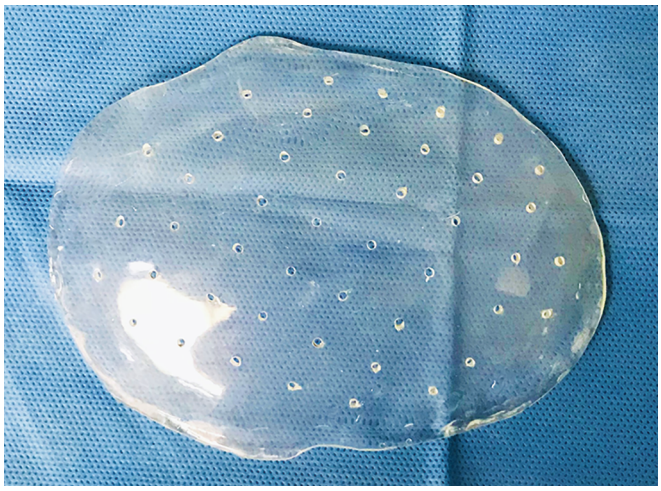


Fig. 5: Finished prosthesis with perforations

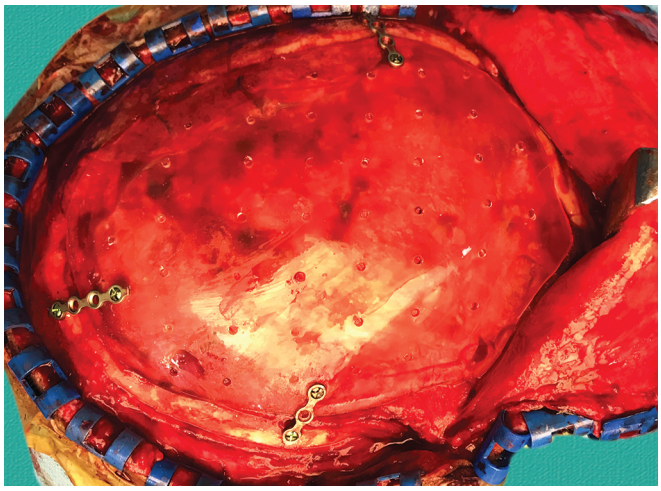


Fig. 6: Prosthesis placed *in situ* intraoperatively

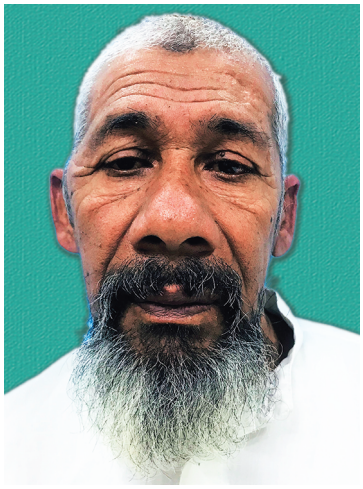


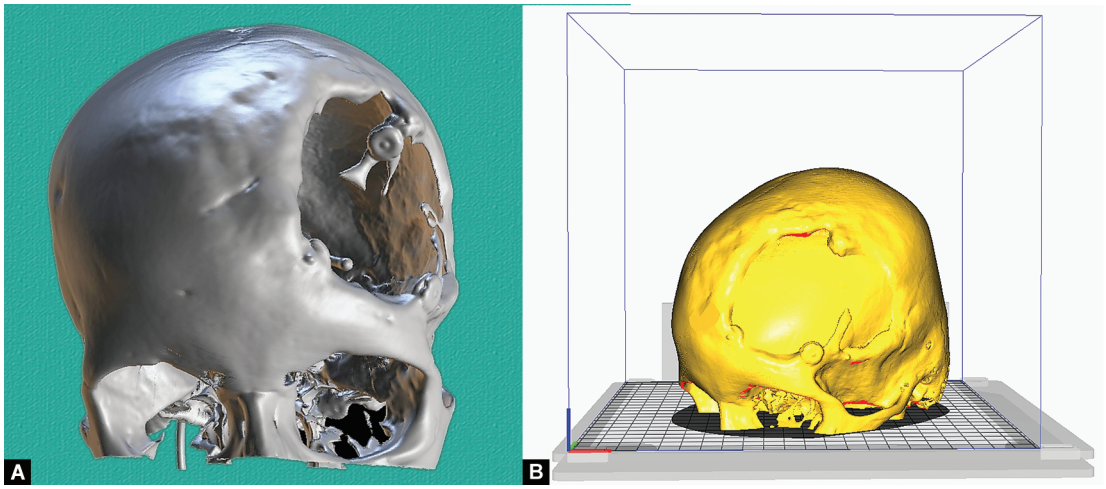
Fig. 7: Postoperative prosthetic rehabilitation

prosthesis fabrication were considered. Being a school-going female, the patient was unwilling for hair removal compromising her esthetics. Also considering the poor neuromuscular coordination of the patient, which would impede an upright posture of the head required for conventional impression making, a decision of cranial prosthesis fabrication via RP technology was made.

Skull Template with Base Fabrication

For the fabrication of 3D printed skull template, the patient's DICOM files of CT scan (Fig. 8A) were imported to the Windows-based Mesh software where Standard Tessellation Language (STL) images were created. These STL format images were then modified by fabricating a tentative base (Fig. 8B) at a depth of 3 mm by mirror imaging the contour of the contralateral side. This would aid in easier and faster replication of the contour of the skull on the defect side and would also provide a tentative base for the wax pattern adaptation. These STL images were then transferred to the 3D printer (Ultimaker, Germany) and a 3D anatomy of skull was reconstructed by the fused deposition modeling technique using acrylonitrile and polylactic acid as the printing materials (Fig. 9).

It was followed by wax pattern adaptation on the skull template to a desired shape and contour (Fig. 10A). The conventional procedure was followed as described in the previous case of dewaxing and curing using medical-grade high-strength heat-polymerized PMMA. The retrieved prosthesis was finished and polished and checked for adaptation on the skull template (Fig. 10B).



Figs 8A and B: (A) Preoperative CT scan; (B) STL images with tentative base designed at the defect site

Fig. 9: 3D printed skull template

The surgical phase was performed similarly with a multidisciplinary approach. During the surgical phase, it was observed that the RP fabricated cranial prosthesis required no adjustments intraoperatively and had excellent marginal fit (Fig. 10C), thereby displaying high accuracy and precision along with reduction in the operative time.

Postoperative care instructions were given to the patient, and follow-up appointments were scheduled weekly for 4 weeks to check for any postoperative complications. The patient was advised to maintain the hygiene and to prevent any impact at the surgical site. The postoperative result of the patient displayed excellent esthetics (Fig. 11).

Discussion

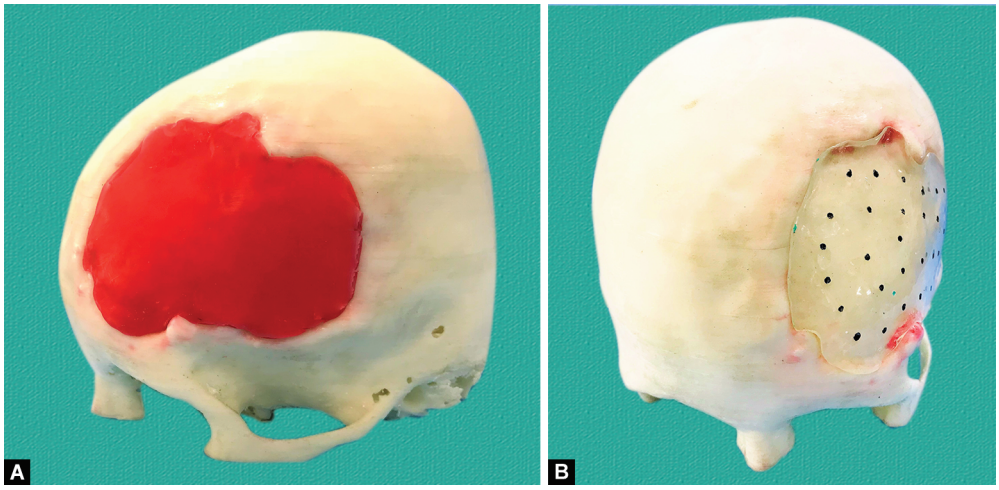
The rehabilitation of cranial defect is important for protection of the brain that is vulnerable to damage at the defect site and to improve the neurological function along with esthetics, which boosts the confidence and appearance of the patient.[5] Both the cases had displayed utmost patient satisfaction along with marked improvement in disfigured esthetics. The conventional method of cranial prosthesis fabrication as illustrated in case one involves extensive clinical and laboratory procedures for which patient's cooperation is also required. But its application is limited in cases where the bony margins of the defect site can't be precisely delineated, patient is uncooperative, has compromised neuromuscular coordination, and is esthetically conscious. However, the field of RP gives promising solution to all these problems and restores large complex defects with few chances of error. It gives results with superior esthetics, high accuracy, with no wastage of material, less operative time, and in both patient- and operator-friendly manner.[6]

Rapid prototyping has revolutionized the treatment planning in medical and dental field and its applications to maxillofacial reconstruction include restoration of acquired maxillofacial deformities and defects, correction of dentomaxillofacial deformities, and fabrication of maxillofacial prostheses. According to material and forming methods, RP technologies can be classified into more than 10 types. The most commonly used in dentistry are stereolithography (SLA), selective laser sintering (SLS), fused deposition modeling (FDM), laminated object modeling (LOM), and 3D jet printing (3DP).[7] With the advent of RP technology, the range of possible patient-customized implant is expanding.[8] The complex 3D models can be created by additive process of building an object in layers defined by a computer model that has been virtually sliced allowing for fabricating complex shapes with fine details and undercuts.[9] The science of RP technology still has more scope to expand its application by improving its speed of production, accuracy, strength, and finish of the printed products and also increasing the variety of materials available for prototype construction along with cost-effectiveness.

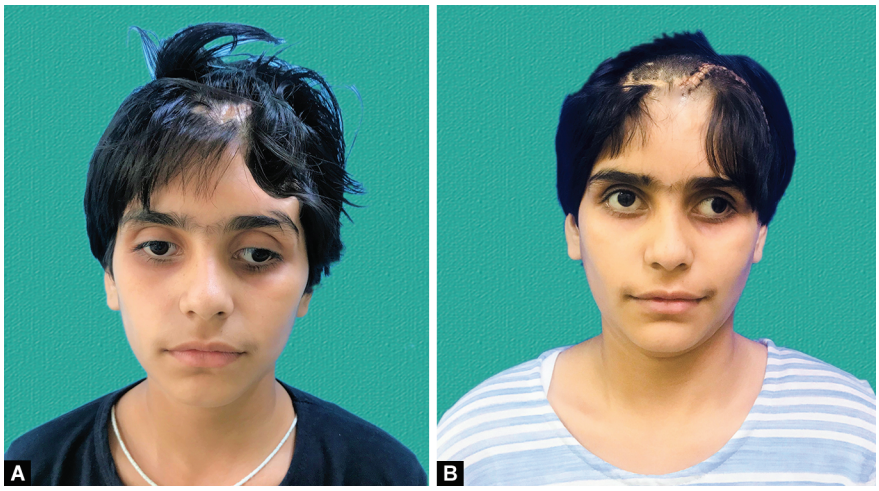
Thus, rapid prototyping is a fast-growing manufacturing technology that is now being widely used for prosthetic rehabilitation of compromised patients with cranial defects. Digitalization of technology along with superior biocompatible materials yields prostheses with excellent form and function. As it is rightly said, we do not use technology, we live technology.

Declaration of Patient Consent

The authors certify that they have obtained all appropriate patient consent forms for the images and clinical data illustrated.



Figs 10A and B: (A) Wax pattern fabrication; (B) Finished cranial plate evaluated for marginal fit. (C) Prosthesis placed *in situ* intraoperatively



Figs 11A and B: (A) Preoperative; (B) Postoperative

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