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Original Article

Preoperative Planning of Craniectomy and Reconstruction using 3D Printed Cranioplasty for Treatment of Calvarial Lesion

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Abstract:

There is a number of diseases which causes calvarial lesion. Fibrous dysplasia, intraosseous meningioma, osteoma is to name a few. Treatment of these lesions necessitates removal of part of the skull or craniectomy to decompress the brain and neural elements. The ensuing skull defect needs to be repaired to protect the brain. Previously used allograft and alloplastic materials have been replaced with newer PEEK material, which is more resistant, biocompatible and can be 3D printed. In this series we describe 4 cases in which skull lesions are removed and reconstructed in the same sitting using 3D printed PEEK implant designed preoperatively using high resolution CT data. The results are superior and complication rates are low. All the cases were done in different government hospitals. The technical process was developed indigenously, and the methods are the first in our country.

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Introduction

Complex calvarial lesion involving one or more regions of the skull is quite common. Patients often visit neurosurgical OPD worrying about these lesions. Many small lesions are osteomas or bony protuberances which seldom poses any problem. But the larger ones which are noticeable from a distance and causing deformity are also found. Sometimes they also cause compressive symptoms and neurodeficit aside from minor headache or heaviness which are the usual complaints patients came up with. These lesions need removal and reconstruction in a cosmetic way to ensure patient satisfaction. Larger lesions make big cranial defects which if not covered may cause various neurological problems. So cranioplasty must be done in these cases.

Cranioplasty is probably the oldest neurosurgical procedure which is to repair cranial defects in both cosmetic and functional ways. [1] There is a lot of variation in technique and material choices throughout different periods in history. From ancient peruvian skull implants of precious metals to the use of skull of other animals, to modern synthetic polymers, the variety of materials continues to amaze us to this day. Many of

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the options are abandoned due to various factors like compatibility and complications. [1,2] In modern times synthetic alloplastic materials have gained popularity. In contrast to decompressive craniectomy where patients own bone flap can be preserved for later use, dysplastic skull lesion cases require graft material from other sources. Be it patients own bone graft from elsewhere in the body or implants made of synthetic material. Autograft causes donor site morbidity and other nuisances like the washboard effect when ribs are used. [2] The excellent outcome of alloplastic implants and less complications have neurosurgeons shifting more towards choosing these materials. [3]

With the advances in technology and manufacturing methods different materials have been tried but none could be deemed as perfect allrounder candidate. In recent years popular materials are PMMA bone cement, Titanium mesh or plates and PEEK which is an inert biocompatible polymer. [4] In our series we used PEEK implants which was 3D printed and a single stage operation to replace those implants after removal of skull lesions.

Background

Fibrous dysplasia is a disease where woven bone is replaced by dysplastic bone. It often affects craniofacial bone and cause obvious deformity and neurodeficit. Calvarial FD mainly causes deformity, rarely causes neurodeficit. Patients often opt for surgery to correct the disfigurement. [5] Similar diffuse skull lesions can be caused by Intraosseous Meningioma. These lesions are mostly benign and grow over a period of several years. With low rate of recurrence for treatment of these lesion complete excision and reconstruction is usually sufficient. [6,7,8]

PEEK or Polyetheretherketone is a polyaromatic semi crystalline thermoplastic polymer which can be 3D printed. Its inert biocompatible nature saw its wide use in spine and orthopaedic surgery. For cranioplasty it has gained widespread popularity due to its properties and very low rate of complications. [9]

3D printing or additive manufacturing is a process by which implant can be manufactured in three-dimensional shape using design from digital data. The shape can

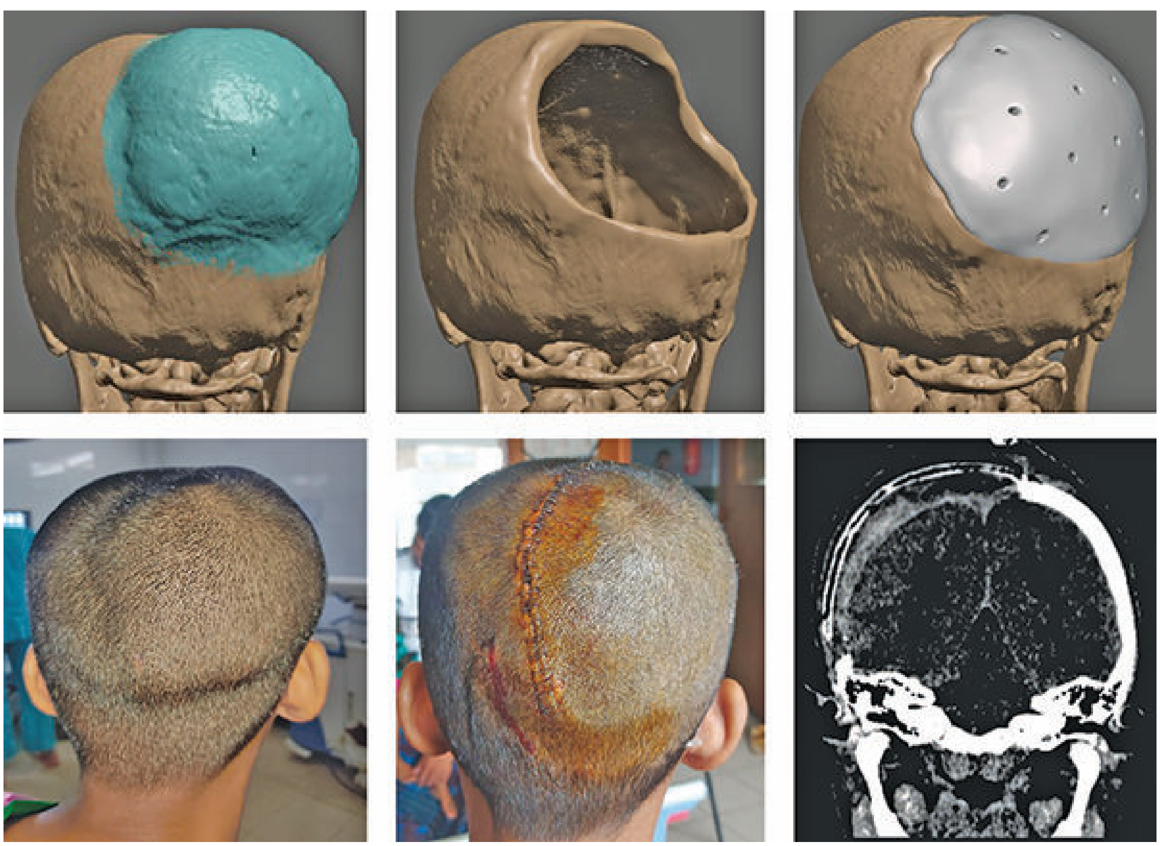

Figure 1: *Large right Parieto-occipital FD; Upper Row: Designing implant in CAD software, Lower row: Preoperative and postoperative picture of patient and postoperative CT scan*

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be designed using 3D CAD software using data from CT scan or other imaging modalities. High resolution 3D printing uses very fine extruder to put materials in fine layers to recreate patients' anatomy authentically which gives superior cosmetic outcome.[10]

Methods

A total of 4 cases are described here. All the patients presented with hard bony swellings in the head. The deformity was obvious and diagnoses was made using CT scan, MRI and other laboratory tests. All the cases were done in tertiary level government hospitals. The plan was to remove the lesion and repair the defect in the same operation. Patient recovery was monitored over next week and followed up for weeks to month. Complications were noted and treated if needed. Comparison with existing literature was done.

Technical details:

For preoperative planning we did high resolution CT scan of head of every patient. Latest multidetector spiral scanners provided upto 0.6mm interval slices resulting in very high detailed 3D model. The scan data was retrieved as DICOM files and transferred to a computer workstation. 3D models were created using volume reconstruction tool (VRT) protocol in CAD software. Initially we used 3D slicer® software, which is an open source, free software supported by NIH.[11] Later, a more refined workflow was devised as we shifted to RadiAnt™ DICOM viewer to obtain high resolution 3D model from the DICOM data. The model was imported in another software Meshmixer™ . A series of tools and algorithm was used to outline the lesion, then a virtual craniotomy is planned. The craniotomy edges were defined and projected onto opposite side using a mirror tool. Thus the implant is designed with perfect edge fitting and contours from patients own anatomy. Further smoothening and sharpening are used to create aesthetically sound and accurate skull flap.

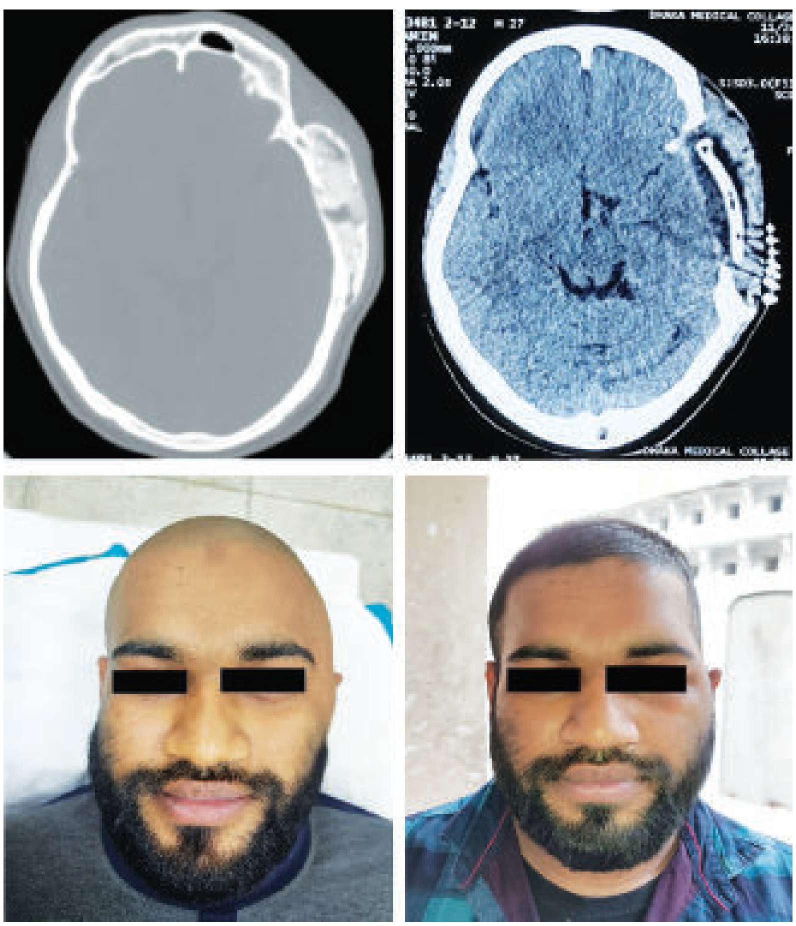

Figure 2. *Operative Exposure, Craniectomy and after implant fixation in a patient with Fronto-orbital FD. CT scan shows excellent cosmetic outcome.*

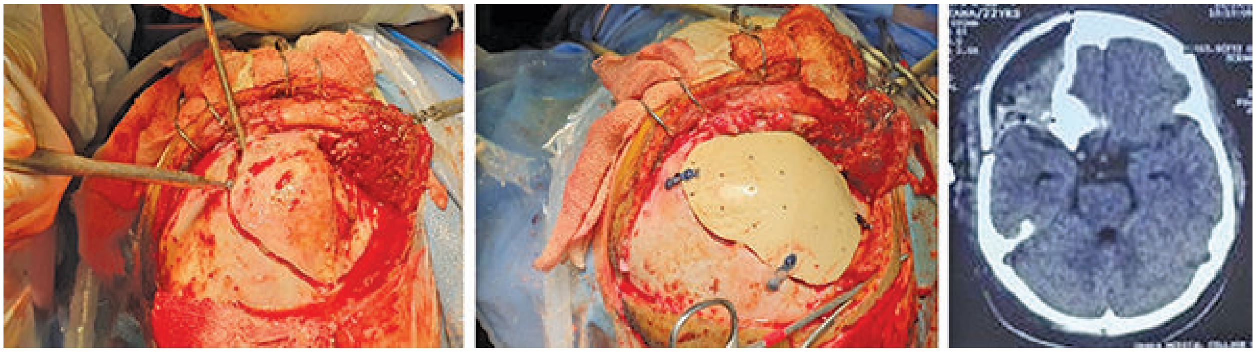

Figure 3. *Left Temporozygomatic FD; Upper Row: Preoperative and postoperative CT, Lower row: Preoperative and postoperative picture of patient.*

The model is then sent to the manufacturer company for 3D printing. A high-resolution 3D printer prints the model using PEEK. Sometimes a draft model is printed in PLA and sent to the surgeon for validation. After necessary revision and modification, the final surgeon-approved model is printed in PEEK. The implant is then sterilized in CSSD by autoclaving and delivered in sterile packaging before operation.

The operative steps were as usual. Every patient was counselled beforehand regarding the procedure. General anaesthesia was given. Then patient was positioned according to pathological site. For parieto-occipital lesions a lateral or semi prone position was used. Head fixed with head frame. After sterile draping skin incision was given according to a planned line. Adequate exposure was made to make sure all the dysplastic bone margin was visible. Then burr holes were made and craniectomy was done using high speed craniotome according to planned path. Removal of the lesion was done and haemostasis was secured. Any dural sinus in the craniotomy margin was taken care of. Then the prefabricated implant was placed in the defect and checked for fit. If any discrepancy found edge adjustment was done. Then we used miniplates and screws to secure the implant onto the defect. Wound closure was done in usual manner in multiple layers. A drain was kept in subgaleal space for 3 days. Skin closure was done using proline suture or skin staplers. Patient was observed in recovery unit for some times. Postoperatively we checked dressing and drain collection and took routine measures. CT scanning was done in first week to check implant placement and fitting and to detect any complications. Patient was released after removal of skin stitches.

Results:

Patient demographics and lesion parameters are shown in table 1.1.

One month and 3 months follow up schedule were instituted for every patient. Minor complications were treated conservatively. Seroma, postoperative fever, nausea was among these.

All the patients had preoperative and postoperative GCS 15. Long term complications like implant infection, breakage, resorption was not seen. There was no incidence of neurodeficit or seizure. We also tried to evaluate implant fit and cosmetic outcome arbitrarily and found to be satisfactory.

Table-I

Patient Demographics and lesion parameters

#	Gender	Age	Site	Size	Histopathology
1	Female	20	Rt. Parieto-occipital	13.59x9.86	Fibrous Dysplasia
2	Male	32	Lt. Temporo-zygomatic	8.73x7.55	Fibrous Dysplasia
3	Female	16	Rt. Fronto-orbital	7.31x6.25	Fibrous Dysplasia
4	Female	50	Rt. Fronto-parietal	14.63x11.30	Intraosseous Meningioma

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Discussion:

Using 3D printing and advanced biomaterials to repair cranial defect is a new concept and this is the first case series of this technique in Bangladesh. In global literature 3D printed customized PEEK implant for cranioplasty is continually growing [12]. In recent years many studies are showing its strength and compatibilities as well as lower complication rate. [12,13] 3D printing also enables us to repair complex craniofacial defect with better cosmesis. The human bonelike biocompatibility and resistance to physical forces leads to more frequent use of PEEK in these cases. Some surgeons tried low-cost techniques with successful reconstruction. [14,15] Other studies show high tech navigation guided craniotomy and repair in a single operation. [16,17,18] In all aspects 3D printed PEEK implant showed its versatility. In our study it is also evident with low rate of complication and improved patient satisfaction due to better cosmetic result. The previous experience we had with PEEK cranioplasty in other indications where compared with frozen autologous bone it also fared well. [19] One major drawback is cost of the material and technology which can be overcome with dedicated industry. Other problems like lack of annealing or high temperature curing of the shaped implant can also be overcome in near future and this method can supersede other methods very soon and ease the work of a surgeon.

Conclusion:

Despite some limitations PEEK cranioplasty implant is continuing to thrive and showing its promises to be an excellent material. Fibrous dysplasia and other calvarial lesions can be easily managed in this technique. Further research and investment should be put into developing the technique.

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