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Polymethylmethacrylate cranioplasty using low-cost customized 3D printed moulds for cranial defects – a single centre experience: technical note

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Abstract

We report our experience with 3D customized cranioplasties for large cranial defects. They were made by casting bone cement in custom made moulds at the time of surgery. Between October 2015 and January 2018, 29 patients underwent the procedure; 25 underwent elective cranioplasties for large cranial defects and four were bone tumour resection and reconstruction cases. The majority of patients (96.5%) reported a satisfactory aesthetic outcome. The method proved to be effective and affordable.

KEYWORDS
cranioplasty; trauma; outcome; meningioma

Introduction

Reconstruction of large cranial defects is a challenging procedure with important cosmetic and functional outcomes. Such defects are secondary to decompressive craniectomies for brain oedema, trauma, infections, and tumours.[1] When autologous bone reconstruction is not viable, synthetic materials are used, among which polymethymetacrilate (PMMA) is well attested. PMMA can be shaped manually but for large defects the cosmetic results may be poor and operations longer compared to using custom engineered implants.[2] Customized PMMA cranioplasty using 3D printed CT-guided molds have recently been shown to be as effective, yet less costly than other prefabricated implants (e.g. titanium, hydroxyapatite, polyetheretherketone).[2] The aim of the present study was to report our experience with the customized PMMA cranioplasty procedures.

Patients and methods

Retrospective review of patients who underwent a 3D PMMA cranioplasty at our Department from October 2015, when the method was first introduced, to January 2018. These data were retrieved: a) patient age; b) patient gender; c) initial diagnosis; d) interval between craniectomy and cranioplasty; e) site of defect; f) size of defect; g) postoperative patient reported aesthetic outcome using a four-point Likert scale (0 = strongly not satisfied to 3 = very satisfied); h) duration of surgery; and i) complications.

Cases were elective cranioplasty patients for reconstruction of large cranial defects, or patients with tumours in which large bony defects were anticipated. All patients underwent a preoperative high-resolution (1.25mm slices) computed tomography (CT) scan. The CT data of the patients were sent electronically to a printing company and were used to generate 3D models of the defects using free open-source 3D Slicer software (www.slicer.org). The virtual models were then used to produce moulds that were negatives of a 3mm thick lamina of the outer surface of the skull. Skull defects were reconstructed as mirror images of the contralateral side and moulds were produced from MED 610 material. The material is a rigid, transparent biocompatible photopolymer used for medical and dental models. Images were processed using Solidworks® software (Solidworks Corp., Concord, MA, USA) and the moulds printed using a commercially available outsourced Objet30 OrthoDesk (Stratasys, Ltd., Eden Prairie, MN) 3D printer. The moulds were delivered to our Department a day before the surgery and sterilized in the central sterile services department. Intraoperatively, the mould was wetted with saline, PMMA (Codman cranioplastic kit®, USA), was mixed and evenly spread in the mould cavity, and the mould tightened with screws to obtain a 3 mm thick implant. Edges of the cooled implant were trimmed using a high speed drill as necessary. Finally, the implants were fixed in place using microscrews and microplates. All procedures were performed under general anaesthesia.

Categorical data were summarized as absolute (relative) frequencies and continuous data as mean±SD. The study was granted approval for publication by the Institutional Review Board of the Zagreb University Clinical Hospital Centre.

Results

Custom made cranioplasties were performed on 29 patients, of whom 25 underwent elective cranioplasties for large cranial defects and four were bone tumour resection and reconstruction cases. In the latter group, tumour resection margins were translated to the surgical site using a 3D template in three patients and using neuronavigation in one patient (illustrative case is summarized in Figure 1). Average age of patients was 43±18 years and female to male ratio was approximately 1:3. Trauma was the predominant initial pathology and the frontal-temporal-parietal region was the most common location. Defects of the left side were more common than the right or bilateral.

Average size of defects was 107.6±52.9 cm^2. In the elective cranioplasty group, the average time from initial craniotomy to cranioplasty was 22.6±21.9 months, operation time 2.0±0.7 hours, and length of hospital stay 4.1±0.9 days. Four patients (13.8%) developed cranioplasty-related complications: two patients had to be re-operated because of screw loosening and migration; one patient developed subdural hygroma and was surgically treated one month later; one patient operated for a giant intraosseous frontal meningioma developed pseudomeningocoelae which required three revision surgeries. One patient was dissatisfied with the aesthetic outcome, and two patients were relatively satisfied. Patient data are summarized in Table 1.

Discussion

The growing accessibility of the 3D printing technology has led to its wide use in clinical practice, including cranioplasty procedures. Since customized cranioplasty was introduced at our Department in 2015, 29 patients have had the procedure and the majority reported a satisfactory cosmetic outcome, while the duration of surgery was shorter for all cases compared to the traditional hand modelling method.

One patient reported a unisatisfactory aesthetic outcome, which was due to temporal fossa hollowing. This complication is well known and various methods have been developed to augment the defect.[3] HDPE implants might be a feasible augmentation method for our patients and our aim is to use them to complement the customized cranioplasties. Also, we noticed that the clinical results improved significantly after the first few cases. This is due to learning by both the surgeons as well as the technicians planning the 3D mould. Delicate nuances, such as excessive or poorly defined edges, can significantly impact aesthetic outcome.

Apart from its effectiveness, this method is not as expensive as other prefabricated customized implants: the approximate cost for the entire process is about 900 USD. In Croatia, the costs of the procedure are covered by the universal health care system; therefore, from the patient perspective the new method is superior in all aspects to the traditional one. Since in our country these procedures are performed only at our Department and some of the neighbouring countries do not perform them at all, we hope this report will urge other colleagues in the country and region to implement the method into their everyday practice.

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Disclosure statement

The authors report no conflict of interest.

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Table 1 Summary of patient data

age (years)		43±18
gender	female	7 (24.1)
	male	22 (75.9)
initial cause	trauma	12 (41.4)
	intracranial empyema	6 (20.7)
	cranial tumour	4 (13.8)
	subdural haematoma	3 (10.3)
	intracerebral haemorrhage	2 (6.9)
	epidural haematoma	1 (3.4)
	infarction	1 (3.4)
location of defect	FTP	15 (51.7)
	F	6 (20.7)
	FT	3 (10.3)
	FTPO	2 (6.9)
	TP	2 (6.9)
	FP	1 (3.5)
site of defect	left	13 (44.8)
	right	11 (37.9)
	bilateral	5 (17.2)
size of defect (cm^2)		107.6±52.9
craniectomy-cranioplasty time interval (months)*		22.6±21.9
operation time (hours)*		2.0±0.7
complications		4 (13.8)
length of hospital stay (days)	cranioplasty only	4.1±0.9
	tumour removal+cranioplasty	26±16.1
aesthetic outcome*	0 (strongly dissatisfied)	0 (0)
	1 (not satisfied)	1 (4)
	2 (satisfied)	2 (8)
	3 (very satisfied)	22 (88)

numbers are absolute (relative) frequencies or means±SD; F – frontal; T – temporal; P – parietal; O – occipital; *cranioplasty only cases