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Patient-specific 3D-printed Helmet for Post-craniectomy Defect – A Case Report

Sherby Suet-Ying Pang
University of Hong Kong
Evan Fang (evanjfang@gmail.com)
University of Hong Kong Faculty of Engineering https://orcid.org/0000-0003-0034-0753
Kam Wai Chen
Queen Mary Hospital
Matthew Leung
University of Hong Kong
Velda Ling-Yu Chow
University of Hong Kong
Christian Fang
University of Hong Kong

Case report

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Abstract

Background: Patients who undergo decompressive craniectomy (DC) are often fitted with a protective helmet that protects the craniectomy site from injury during rehabilitation. However, conventional "one-size-fits-all" helmets may not be feasible for certain craniectomy defects. We describe the production and use of a custom 3D-printed helmet for a DC patient where a conventional helmet was not feasible due to the craniectomy defect configuration.

Case presentation: A 65-year-old male with ethmoid sinonasal carcinoma underwent cranionasal resection and DC with free vastus lateralis flap reconstruction to treat cerebrospinal fluid leakage. He required an external helmet to protect the craniectomy site, however, the rim of a conventional helmet compressed the craniectomy site, and the straps compressed the vascular pedicle of the muscle flap. Computed topography (CT) scans of the patient's cranium were imported into 3D modelling software and used to fabricate a patient-specific, strapless helmet using fused deposition modelling (FDM). The final helmet fit the patient perfectly and circumvented the compression issues, while also providing better cosmesis than the conventional helmet. Four months postoperatively, the helmet remains intact and in use.

Conclusions: 3D printing can be used to produce low-volume, patient-specific external devices for rehabilitation where standardized adjuncts not optimal. Once initial start-up costs and training are overcome, these devices can be produced by surgeons themselves to meet a wide range of clinical needs.

Background

Decompressive craniectomy (DC) is a neurosurgical procedure used to treat life-threatening elevations in intracranial pressure caused by cerebral edema. Removal of the cranial segment leaves the craniectomy site unprotected during the recovery period. Patients are left at risk for severe brain injury in the event of a traumatic impact to the craniectomy site, with death having been reported as a result [1, 2]. Protective helmets are commonly prescribed to patients who have undergone DC to prevent injury to the craniectomy site during the postoperative period. Conventional helmets are fixed to the head with straps that cross over the chin to prevent slipping and rotation. However, the "one-size-fits-all" design is not always feasible. The use of patient-specific 3D-printed helmets has been reported in the literature for the purpose of improving cosmesis and patient satisfaction [3], but their applicability extends beyond aesthetics. Here, we describe the production and use of a custom 3D-printed helmet for a DC patient where use of a conventional helmet was not feasible.

Case Presentation

A 65-year-old Asian male presented to our centre with a history of lung cancer with brain metastasis. He was treated with radiotherapy in 2002, after which he developed sinonasal carcinoma. He underwent cranionasal resection and craniectomy in February 2020 by an ear, nose and throat surgeon and neurosurgeon following neoadjuvant chemoradiation. Recovery was complicated by cerebrospinal fluid (CSF) leakage from the nose. An attempt was made to repair the defect with temporalis fascia and lumbar drainage of the CSF, however, the leakage persisted. A second repair attempt was made in June 2020 using a fascial graft and a free vastus lateralis muscle flap. Because the superficial temporal vessels had been sacrificed in the previous surgery, the pedicle vessels had to be grafted and anastomosed to vessels in the neck. A 21 cm radial artery graft and a long saphenous vein graft were harvested and anastomosed in end-to-end fashion using interrupted nylon suture. The pedicle artery was anastomosed to the radial artery graft, then to the right facial artery. The pedicle vein was anastomosed to the long saphenous vein graft, then to the internal jugular vein. The pedicle vessel ran through a subcutaneous tunnel along the patient's right temple and preauricular area. The frontal bone was not returned after craniectomy in order to avoid strangulating the muscle flap. The patient recovered uneventfully afterwards.

The resultant frontal skull defect from the supraorbital rim to the vertex measured 64 mm vertically and 95 mm across (Fig. 1). An external helmet was necessary to prevent injury to this region of the brain during rehabilitation. However, our conventional ready-made helmets were deemed unsuitable for two reasons: First, the anterior edge of the conventional helmet landed 1 cm above the eyebrow line and would have violated the craniectomy defect (Fig. 2); second, the conventional helmet was fixed by straps across the temple and submental regions bilaterally, which would have compressed the vein grafts and neck vessel anastomoses. To circumvent these issues, a perfectly fitting, strapless 3D-printed helmet was designed.

Computed tomography (CT) scans of the head were obtained in Digital Imaging and Communications in Medicine (DICOM) format with 1 mm slice thickness and a 512 × 512 region of interest (ROI) resolution, corresponding to a voxel size of 0.410 × 0.410 × 1 mm. The images were imported into Mimics v21 software (Materialise NV, Leuven, Belgium) and segmented using the low-noise soft tissue convolution kernel and Hounsfield unit thresholding (Fig. 3). A two-layered soft tissue and bony 3D model was created in Standard Triangle Language (STL) format and refined using Meshmixer v3.5 software (Autodesk, San Rafael, CA, USA) and 3-matic v13 software (Materialise). Mesh reduction (decimation), smoothing, and defect filling techniques were applied to the 3D head model to reduce its triangular complexity. A smoothed layer with a 2 mm offset from the skin surface was created to accommodate the patient's hair (Fig. 4). The model was further smoothed at the craniectomy site to prevent impingement by the helmet and abrasion at the edge of the site.

The 3D head model was printed for helmet design and liner fabrication (Fig. 5a). The helmet was designed to rest on the supraorbital bar and wrap around the vertex and occipital area to avoid compressing the craniectomy defect. A 6 mm layer of Plastazote® foam was fitted to the model and shaped such that the pressure-sensitive areas were avoided (Fig. 5b). A window was created over the right temple and facial area in order to avoid compression of the free vastus lateralis muscle flap pedicle. The foam-fitted head model was scanned using a Spectra 3D scanner (Vorum, Vancouver, Canada). The scanned model was imported to Canfit computer-aided design (CAD) software (Vorum), which was used to define the borders of the helmet and produce a 6 mm-thick prototype helmet model (Figs. 6 and 7).

The helmet model was then 3D printed using medically designated (ISO 10993 and USP Class VI biocompatibility certified) acrylonitrile butadiene styrene (ABS-M30i, Stratasys, MI, USA) by an industrial-grade fused deposition modelling (FDM) printer (Fortus 450mc, Stratasys). The model was printed with a layer thickness of 0.178 mm with a sparse infill density set at 18% to decrease weight and improve patient comfort. The helmet was lined with the foam insert and tested for fitting on the 3D head model (Fig. 8).

Upon wearing, the helmet was confirmed to fit properly, without the need for straps to secure it to the patient's head (Fig. 9). The patient had a prolonged stay in a rehabilitation hospital for physiotherapy. Four months postoperatively, he has undergone three months of daily physiotherapy, including focused lower limb strength training in the form of cycling and kicking exercises. He can now walk with fair stability using a rollator and the assistance of another person. His Glasgow Coma Scale (GCS) score is E4V2M6 and he remains dependent on others for self-care and activities of daily living. The helmet has proven sufficiently durable and remains wholly intact and in use at the time of writing.

Discussion

With recent technological advances in rapid prototyping, 3D printing provides a low-cost, quick, and tailor-made solution to various clinical problems. It has been applied extensively in plastic and reconstructive, head and neck, and neurosurgical operations [4, 5]. 3D printing is particularly useful in preoperative surgical planning, production of intraoperative cutting guides and models, communicative and educational models, and production of prosthetics and orthotics.

In the past, external protective helmets for DC patients have been manufactured in a one-size-fits-all manner with adjustable straps. However, with certain craniectomy defects, these helmets may be unusable. In our case, a conventional helmet would have risked compressing the brain and pedicle vessels. With the 3D-printed helmet, we were able to able to circumvent these problems while avoiding the need for straps due to the helmet's patient-specific fitting. It also enhanced patient comfort due to the better fit and lighter weight as compared to conventional helmets. Aside from functional benefit, the 3D-printed helmet also provided better cosmesis than the conventional helmet. A similar application was reported to improve cosmesis and psychosocial wellbeing in a patient who underwent a bifrontal craniectomy [3].

Several aspects of our design and fabrication process may preclude its popularization. First, the initial learning curve for 3D modelling software use took several months for our surgical team to overcome. Second, the initial investment for specialized software and 3D printers remains substantial, although these devices are becoming more commonplace. Third, the durability of the material for use as an external device has not been extensively validated by prosthetics and orthotics studies. Finally, the helmet offset and foam thickness measurements were based on experience and remain to be optimized and validated scientifically. Nonetheless, with training and initial setup costs overcome, the material cost of our helmet was 58 euros, design time was approximately 3 hours, and machine time was 11 hours (Fig. 10). Only one model was produced, and the production cycle was completed in under one week by a surgeon.

To conclude, our case demonstrates that 3D printing of low-volume, patient-specific external devices has applications in rehabilitation. When initial start-up costs and training are overcome, 3D printing is a diverse technology can be implemented by surgeons themselves to manage a wide range of challenging clinical scenarios.

Abbreviations

3D	3-dimensional
CSF	Cerebrospinal fluid
CT	Computed tomography
DC	Decompressive craniectomy
DICOM	Digital imaging and communications in medicine
GCS	Glasgow Coma Scale
ROI	Region of interest
STL	Standard triangle language
FDM	Fused deposition modelling

Declarations

Ethics approval: Ethics approval was not required for this article as it is a report on current practice.

Consent for publication: Consent for publication was given in writing by the patient’s relatives.

Availability of data and materials: Data sharing is not applicable to this article as no datasets were generated or analysed.

Competing interests: The authors declare that they have no competing interests.

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Author’s contributions: KWC designed the helmet. CF coordinated helmet printing. EF assisted with manuscript writing and submission. SSYP was a major contributor in writing the manuscript. VLYC was the chief surgeon of the operation. All authors read and approved the final manuscript.

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