ENDOSCOPIC STRIP CRANIECTOMY WITH HELMET THERAPY: A COMPUTATIONAL TOOL FOR PREDICTION OF HEAD RESHAPING

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Introduction

Sagittal craniosynostosis (SC), occurring in 1 in 1,700 births [1], is caused by the premature closure of one or more cranial sutures, and results in abnormal skull development (long and narrow head shape). Endoscopic strip craniectomy followed by helmet therapy (ESCH) is a minimally invasive treatment recently adopted to correct SC. In this procedure, the fused suture is removed, and the skull shape normalized progressively by means of a patient-fitted helmet, designed to allow lateral growth while constricting the sagittal direction.

Methods

Six patients who presented with SC at Connecticut Children's Division of Pediatric Neurosurgery were treated with ESCH (age at surgery: 11 weeks to 9 months) and recruited for this study. Day 1 postop 3D head scan imaging was used to produce the skin 3D models, and the respective skull and intracranial volume (ICV) models by means of surface offsetting (figure 1, right) in Meshmixer® followed by NURBS model creation in Simpleware ScanIP®. Cranial suture location was created on the skull using Solidworks along with the skull base, assumed to lie on the plane passing through nasion and auditori meati. A 15 mm-wide

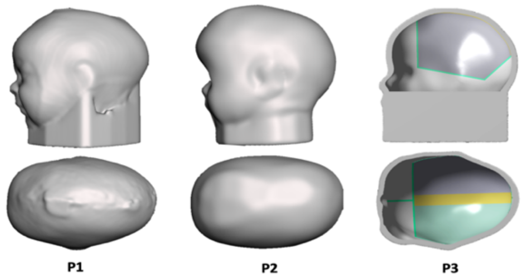

Figure 1. Pre-operative 3D scans of a subset of the population: side view (top row) and top view (bottom row).

osteotomy from cranial bregma to lambda was modelled. Patient-specific helmet models (front and back) were created following postoperative planning as well as operating surgeon indications: areas of free space in each helmet model were left to allow for growth in targeted areas. All parts (skin, skull, ICV, helmet) were assembled, imported into Ansys Workbench and assigned tissue specific mechanical properties retrieved from literature. The model was meshed using linear tetrahedral elements (432.575 ± 86.043 elements).

The simulation was divided into 3 loading steps: 1) and 2) helmet fitting (helmet front and back are separately displaced to fit around the head); 3) head growth, modelled using the thermal expansion model validated by Libby et al. [2]:

$$\Delta V = V_1 \times \alpha \times \Delta T$$

Where α is the coefficient of expansion, ΔT is a temperature difference arbitrarily fixed at 100 °C, V_1 is the initial ICV, and ΔV the ICV increase due to growth. The value of α was fixed at 0.006 1/°C for a 3 month-growth based on trial-and-error testing on one patient. The skull base was fixed in all directions to mimic skull base tethering. In 4 cases, the helmet model was updated (according to the growth) after 3 months of treatment and head growth was simulated for another period of 3-5 months according to the end of treatment date. Validation was carried out by comparing the simulated post-treatment surfaces with post-treatment clinical 3D scans.

Results

The treatment was simulated over 3 months (n=2) or 6 months (n=4). Comparison between the simulated post-treatment head shape and clinical 3D scans showed that 95.9% ± 2.8% of surface data points over the population are included in a [-3; 3] mm range. Figure 2 shows the surface difference pattern at the end of treatment: Accurate shape estimation was obtained over the population.

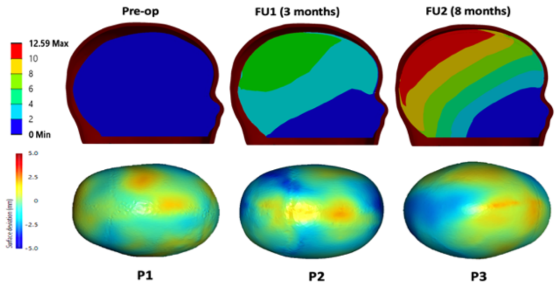

Figure 2. Head growth inside the helmet for representative patient (top row). Surface deviation pattern at the end of treatment for a subset of the population (bottom row).

Discussion

Cranial vault remodeling following ESCH was modeled using a patient-specific 3D geometry where surgical osteotomies as well as helmet model were replicated based on surgeons' indications. The results showed an accurate prediction of the therapy outcomes. Upcoming research will introduce patient-specific skull mechanical properties to further improve the model. This computational tool will help provide guidance and refine the current understanding on the necessary helmet treatment duration.

References

1. Fearon et al., *Plastic and reconstructive surgery*, 133(5):1261–1275, 2012.
2. Libby et al., J. *R. Soc. Interface* 14 : 2017