Master's Thesis : An in-silico modelling platform for the prediction of Posterior Vault Expansion outcomes

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Spring Assisted Cranioplasty:

An in-silico modelling platform for the prediction of Posterior Vault Expansion outcomes

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Posterior Vault Expansion using springs (PVE) has been adopted at Great Ormond Street Hospital (GOSH) with the aim of normalizing deformed head shapes. These calvarial abnormalities are caused by a birth defect called craniosynostosis. This condition causes the fusion of certain skull sutures before birth and can generate high intracranial pressure when the brain starts developing. The goal of surgical correction is to normalize the head shape by means of metallic distractors (springs) which expand the back portion of the skull and increase the intracranial volume. In case sagittal craniosynostosis correction, it has been shown that surgical outcomes can be predicted numerically using the finite element method (FEM): we hereby tested such method for the prediction of PVE surgical outcomes using information retrievable from Computed Tomography (CT) scans and X-ray images.

Fourteen patients who underwent PVE (age at surgery= 2.0 ± 1.7 years, range [5 months ; 5.5 years]) who received preoperative CT (± 44 days before surgery) and postoperative CT (± 147 days after surgery) were recruited. Seven of these patients were treated using two springs (same model - either S10, S12 or S14), five with four and two with six springs. Information on osteotomies and location of spring attachments were recovered from the postoperative CTs. Springs expansion was simulated over 10 days in Ansys Mechanical 19 R1. Simulated skull shapes were retrieved and compared with postoperative CT images. For each patient, Intracranial Volume (ICV) and Cranial Index (CI) were also computed. Finally, the spring kinematics was updated using X-ray images of a database of 50 patients. The springs dimensions were manually measured for each of them and recorded to update the material properties in order to reflect a different expansion kinematics.

The average postoperative ICV recorded was 1.45 L ± 0.23 L and the simulated model yielded comparable values with an average of 1.39 L ± 0.24 L. The average postoperative CI recovered from CT scans was 87.8 ± 11.1% against 84.4 ± 12.4% for the model. Comparison of the simulated postoperative skull with the postoperative CT skull reconstruction showed very similar extent of expansion. It appeared that the springs involved in a PVE open more slowly than in the case of the sagittal procedure (67% of maximal opening reached after 21 days in opposition to 1 day, respectively).

Finite element modelling seems to be a suitable technique to predict the outcome of PVE with springs. Further developments will expand the model by including crack propagation, which occurs at the skull base in a subset of patients, therefore allowing for further improvement in modeling capability. The final goal of this project is to be able to use this patient specific model (using data

from 3D medical imaging) as a tool for surgical planning for spring assisted posterior vault expansion and improve the current understanding of the effect of surgical correction in patients affected by syndromic craniosynostosis.
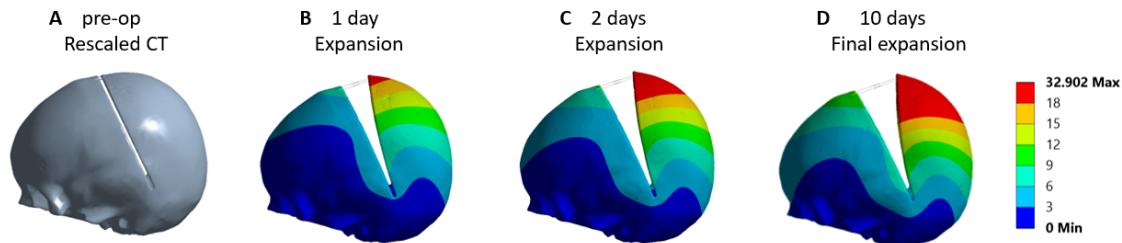

Fig. 1 **a** Pre-operative model with osteotomy and spring conditions, **b,c,d** simulated spring expansion over time for a representative patient.

Patient's information	Sagittal plane	Transverse plane
Patient 3 Time surg. - CT: 29 days Crouzon		
Patient 6 Time surg. - CT: 57 days Crouzon		
Patient 7 Time surg. - CT: 6 days Pfeiffer		
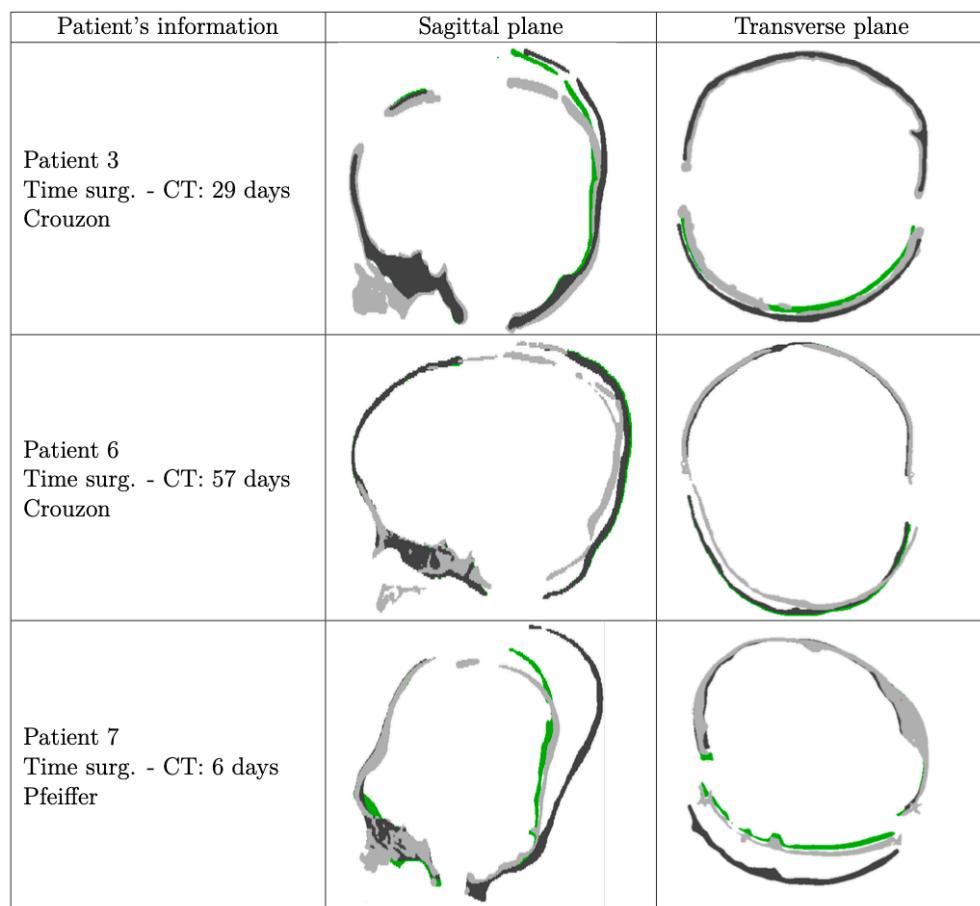
Fig. 1 Illustrations of the comparison between the simulated models (dark grey) and the postoperative CT scan (light grey) with the optimized kinematics (green).
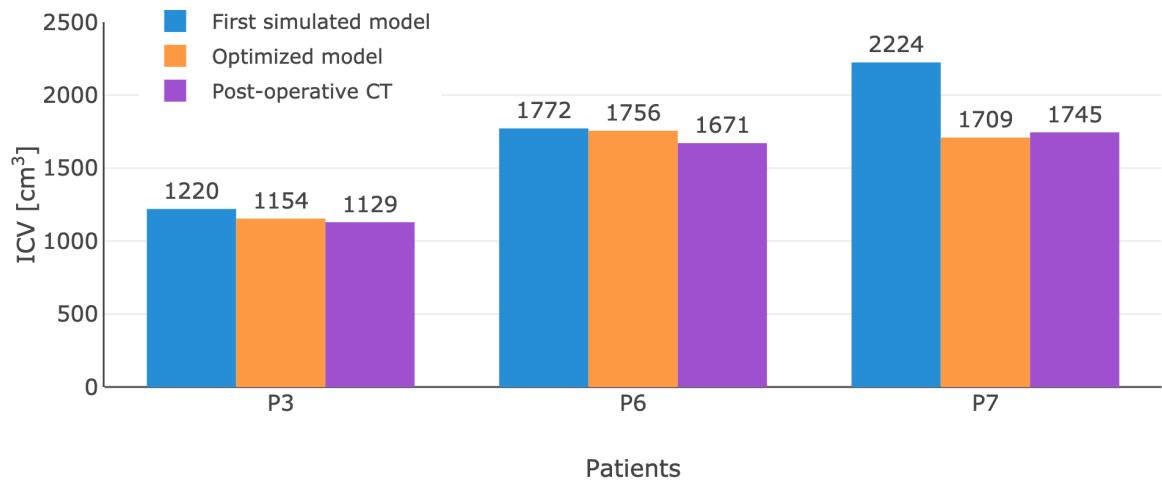
Fig. 2 Bar graph illustrating the comparison between the ICV of the optimized simulated models and post-operative CTs for a subset of patients.
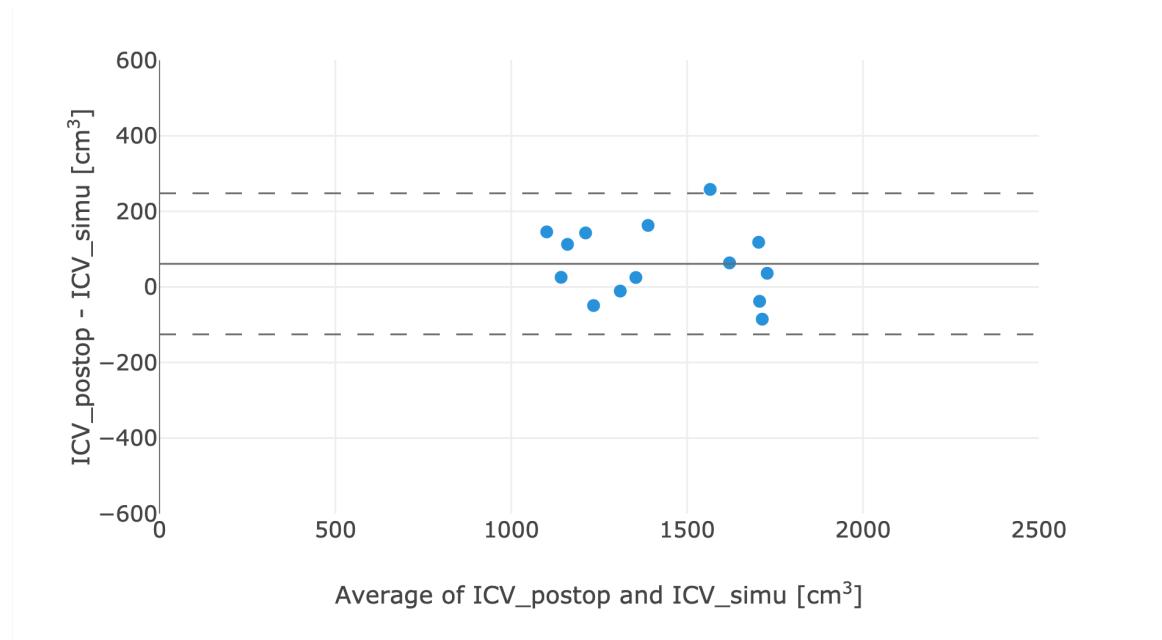

Fig. 3 Bland-Altman plot including the optimized models.