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MECHANICALLY INDUCED STRUCTURAL ADAPTATIONS OF CRANIAL SUTURES

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ABSTRACT

Introduction: Premature occlusions of craniofacial sutures can lead to several medical conditions, including but not limited to craniosynostosis, midfacial hypoplasia, and transverse maxillary deficiency. If left untreated, these conditions can lead to abnormal head shape and facial features, airway obstruction, and intellectual impairment. While it is generally understood that the stress/strain state at suture locations drives bone growth and remodeling, a knowledge gap exists due to the lack of quantitative research directly linking mechanics and the associated biological adaptations. As a result, the prediction of treatment outcome and the optimization of necessary implants and appliances become challenging. Therefore, in this study, the objective was to develop a local finite element (FE) model allowing for highly spatially-resolved observations of stress/strain patterns and subsequent new bone formation for use in correlation with bone growth under normal conditions.

Methods: FE models were created for lambdoid suture-bone complex and full skull using μCT images of rat with 9 μm and 18 μm resolutions, respectively. The linear elastic material properties were retrieved from the literature. The localized boundary conditions at the lambdoid suture under intracranial pressure load were estimated using a simplified skull model. The estimated boundary conditions were then applied to the local lambdoid suture model, and the stress/strain state of the lambdoid suture was determined. New bone formation at sutural edges was measured in rat skull bones by visualizing mineral deposition of a strontium salt that was dosed daily to the rats for 12 weeks as a dynamic bone label, and measured using electron-probe microanalysis (EPMA). This allows for determining the effect of localized mechanical environment on biological adaptations of the lambdoid suture by comparing bone changes with the stress/strain state of the lambdoid suture.

Results and Discussion: Preliminary EPMA identified the location and amount of new mineral deposition surrounding sutural edges, indicating the magnitude of bone growth in response to intracranial pressure and other developmental drivers of intramembranous bone formation (modeling). The comparison between mechanical and biological results showed there are weak to moderate correlations between local stress/strain state of bones and new bone deposition. The maximum principal stress showed a weak correlation ($r=0.26$) with new bone deposition, whereas the minimum principal stress showed moderate correlation ($r = 0.49$). Similarly, the minimum principal strain showed moderate correlation ($r=0.45$) with bone formation. Future work will focus on implementing more representative advanced material models (e.g. viscoelasticity) and increasing sample size to better study correlation.