In silico prediction of intracranial pressure during infant skull growth

Abhijeet Singh[1], Akshay Ganeshkumar[2], Deepak Kumar Gupta[2], Kaushik Mukherjee[1], Sudipto Mukherjee[1]
[1] Department of Mechanical Engineering, Indian Institute of Technology (IIT) Delhi, Delhi, India
[2] All India Institute of Medical Sciences (AIIMS) Delhi, Delhi, India

Email: jeetubit96@gmail.com

Summary

Most of the established frameworks, capturing skull growth, fail to estimate intracranial pressure during early child growth. This study proposes a finite element-based computational framework to predict intracranial pressure in skull during early child growth. This methodology could later be used to understand the increased intracranial pressure in children with craniosynostosis.

Introduction

The infant skull expands rapidly from birth to the first year of age [1]. Recent finite element (FE) studies predicted infant skull growth by giving thermal expansion to the brain [2, 3]. But the maximum predicted contact pressure in these studies exceeds the limit of normal intracranial pressure (ICP), i.e., 2 kPa [4]. To the best of our knowledge, no FE study predicted contact pressure between the skull and intracranial volume (ICV) in the normal range of ICP. Therefore, the aim of the study was to establish a computational framework that can be used to understand the biomechanics of neurocranium growth while predicting realistic intracranial pressure.

Methods

The infant skull of the 3-year-old Total Human Model for Safety (THUMS) model was used to predict the normal child skull growth [5]. The model was iteratively scaled down to achieve an ICV of the child's skull at birth, i.e., 492 ml [6]. A 2.5 mm thick cerebrospinal fluid (CSF) was created between the skull and brain [7]. The final developed model had four components: skull, sutures, CSF, and brain (Figure 1).

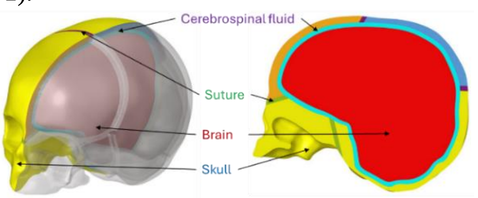

Figure 1: Finite element model consisting of skull, sutures, CSF, and brain (displaying sagittal view).

The brain-CSF contact surface was modeled as frictional with a 0.1 coefficient of friction. The bonded interface behavior was enforced between the rest of the contact surfaces. All the components were modeled as linear, elastic, and isotropic materials [2, 3]. The three nodes on the bottom part of the facial bones were fixed to prevent rigid displacement. Two different methodologies were employed while implementing thermal expansion analogy to capture neurocranium growth. In methodology I, thermal expansion was only given to the brain (Scenario I) while in methodology II, thermal expansion was given to the skull, sutures, CSF, and brain (Scenario II). The temperature difference was set at 1K for both scenarios. The thermal expansion coefficient under Scenario II was iteratively varied to match the final ICV (i.e., 538 ml) obtained from Scenario I. This approach was followed to compare the skull growth and normal ICP obtained from both scenarios. The increase in ICV was 46 ml for both scenarios. The thermal expansion coefficients under Scenario I and Scenario II were 0.1/K and 0.03/K, respectively.

Results and Discussion

The maximum contact pressures between the brain and CSF near the calvaria were approximately 1.7 MPa (Figure 2A) and 0.58 kPa (Figure 2B), under Scenario I and Scenario II, respectively.

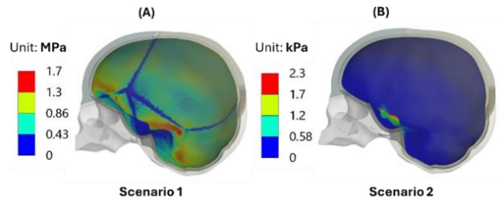

Figure 2: Pressure map across brain surface under (A) Scenario I and (B) Scenario II.

The contact pressure between the brain and CSF surface near the calvaria (i.e., 0.58 kPa) obtained from Scenario II was found to be within the maximum limit of normal ICP, i.e., 2 kPa [4]. The displacement map suggested that facial growth was greater than calvarial growth under Scenario II as compared to that of Scenario I. The brain volume was higher under Scenario I (i.e., 462 ml) than Scenario II (i.e., 452 ml) despite the same intracranial volume after simulated neurocranial growth. Higher brain volume in Scenario I was the result of prescribing thermal expansion only to brain. Additionally, it also resulted in overprediction of intracranial pressure. Therefore, methodology II, wherein, the growth of entire skull was simulated via thermal expansion seems to be a better alternative to study skull growth in children.

Conclusions

This study showed that the thermal expansion analogy-based FE framework could realistically predict intracranial pressure during neurocranium growth.

References

[1] Liang, C. et al. (2023). *Sci. Rep.*, **13**: 1-14.
[2] Cross, C. et al. (2021). *Front. Cell Dev. Biol.*, **9**: 1-11.
[3] Cross, C. et al. (2022). *Front. Bioeng. Biotechnol.*, **10**.
[4] Czosnyka, M. et al. (2004). *J. Neurol. Neurosurg. Psychiatry.*, **75**: 813-821.
[5] Iwamoto, M. et al. (2015). *Traffic Inj. Prev.*, **16**: S36-S48.
[6] Ren, J. Y. et al. (2022). *Front. Neurosci.*, **16**.
[7] Lam, W. W. M. et al. (2001). *Pediatr. Neurol.*, **25**: 380-384.