A Detailed Finite Element Modelling of the Occipital-Atlanto-Axial joint complex and the Role of Various Ligaments

Kushagra Kumar[1], Harsh Navangul[1], Davidson Jebaseelan[1], Pugazhenthi Subramanian Kalaimani[1,2], Balaji Harinathan[1,2], Aju Bosco[3], Narayan Yoganandan[2]

[1]School of Mechanical Engineering, Vellore Institute of Technology, Chennai India, kushagra.kumar2021c@vitstudent.ac.in; harsh.navangul2021@vitstudent.ac.in, davidson.jd@vit.ac.in , pugazhenthi.sk@vit.ac.in

[2]Medical College of Wisconsin, USA, yoga@mcw.edu , bharinathan@mcw.edu

[3]Madras Medical College, Chennai, India ajubosco@gmail.com

Introduction:

The Occipital-Atlanto-Axial joint complex (C0-C1–C2) is a critical structure in the cervical spine as it houses vital structures with disc-less anatomy and higher range of motion than other cervical motion segments. Understanding its biomechanics is essential for addressing its involvement during various crash scenarios as well as surgical procedures like craniovertebral arthrodesis, corpectomy, spinal fusions and screw fixations in spine.

Objective:

The objective of the study was to develop a detailed finite element model of the C0-C1-C2 complex, incorporating all the ligaments and cartilage. Identifying the involvement of ligaments in this complex for physiological motions will help to understand its biomechanical roles.

Methodology:

The morphometry of the C0-C1-C2 complex with ligaments and cartilages were developed, based on geometrical data from the literature. It focused on key parameters such as spinal canal, and C1 and C2 vertebrae (both anterior and posterior anatomies). The anterior atlanto occipital and posterior atlanto occipital membranes (AAOM, PAOM), and cruciate, transverse, capsular, nuchal, alar and apical ligaments, were included in the model. The complex was fixed at the two ends and physiological loads under flexion, extension and lateral bending were applied at the superior end. ANSA and LS – Dyna software were used for finite element modeling and simulations. The range of motion and maximum principal strains in the ligaments were obtained under all loading modes.

Results:

Under extension loading, the range of motion was 9.8° at the superior (C0-C1) and 12.1° at the inferior (C1-C2) levels. Under flexion loading they were 4.13° and 6.34°. Based on maximum principal strains, the alar ligament was found to play a major role in limiting lateral bending and axial rotation while its effect was minimal during sagittal bending. The nuchal ligament experienced the maximum strain in sagittal bending, followed by the AAOM and PAOM. Similar analyses for lateral bending and axial rotation showed varied strain patterns and C0-C1-C2 cartilage under varying loads. Strain data for other ligaments and other modes will be presented, if the abstract is accepted.

Conclusions:

The developed finite element model simulated the biomechanical behavior of the C0-C2 complex, validated through the range of motion (will be presented) and, also, addressed the sensitivity of ligaments based on strain outputs. The findings emphasize the role of upper cervical ligaments and cartilage in

maintaining spinal stability under different loading modes. The CO-C2 model will be included in our existing C2-T1 spine model for clinical applications such as craniovertebral arthrodesis, fusions and screw fixations in the upper spine. The cervical column model can be used understand the response in other scenarios such as whiplash loading, as upper cervical segments play a role in the S-curve formation and kinematics in this region is attributed suboccipital headaches in clinical studies.