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ENHANCING ACCURACY OF A FE MODEL OF THE FEMALE CERVICAL SPINE: COMPARATIVE ANALYSIS BETWEEN MODELLING TECHNIQUES

Afonso J. C. Silva[1], Ricardo Alves de Sousa[1], Fábio Fernandes[1]

[1] TEMA - Centre for Mechanical Technology and Automation, Department of Mechanical Engineering, Campus Universitário de Santiago, University of Aveiro, 3810-193 Aveiro, Portugal

afonso.carvalho.silva@ua.pt; rsousa@ua.pt; fabiofernandes@ua.pt

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1 INTRODUCTION

Finite Element Models (FEMs) of the neck serve as valuable tools for biomechanical analysis of cervical kinematics. Given that the cervical spine is a complex structure and one of the most frequently injured sites among all spinal injuries [1], precise modelling and definition of its components are crucial for developing a bio-realistic model. Furthermore, one of the most prevalent cervical injuries is whiplash. It may result in many clinical manifestations classified as whiplash-associated disorders (WAD). The risk of sustaining WAD is significantly influenced by sex, as females are at a higher risk of developing symptoms [2]. This phenomenon can be attributed to several factors, including differences in body proportions, neck anatomy, and muscle strength [3], to name a few. These findings emphasize the importance of considering sex differences in assessing and diagnosing neck injuries. Thus, the objective of this study was to develop a new FEM of the female cervical spine that will more accurately represent the group most affected by such injuries while also comparing different components and modeling techniques in FEMs of the cervical spine, enhancing our understanding of its intricate dynamics.

2 METHODS

The proposed alterations for this study include the addition of annulus fibrosus (AF) fibers, treating the vertebrae as rigid bodies, and employing a novel methodology for modeling the nucleus pulposus. These were applied on a previously developed model and were systematically compared amongst themselves. The initial model was created from the CT scans of a 49-year-old female subject by using a hybrid methodology of combining medical images and parametric studies. Four components were modelled: the vertebrae, the intervertebral discs (IVD), the facet joints and the ligaments.

Furthermore, considering that the initial model did not have the AF fibers on the IVDs, it was imperative to enhance its accuracy by incorporating these crucial anatomical features. Consequently, the AF fibers were integrated into the model, and their influence on the kinematics of the cervical spine was assessed. Thus, these were modelled using tension-only truss elements, aiming to simulate their biomechanical behavior accurately within the model.

Moreover, seeing that the vertebrae are relatively stiff structures that resist deformation under physiological loads, and that the small deformations they endure under extreme loads can typically be neglected, these can be modelled analytically as rigid components. This model simplification will increase the efficiency of the analysis. As such, additional simulations were performed, considering all bony components to be rigid.

Finally, considering that the nucleus pulposus is primarily composed of water (70-90%) [4] and exhibits behavior akin to an incompressible liquid [5], it can be effectively modelled as such through various numerical methods. This study introduces the proposition of modelling this component as a "fluid cavity".

3 INITIAL FINDINGS

The model was divided into functional spinal units (FSUs), each composed of pairs of adjacent vertebrae. The FSUs were subjected to six pure moments of 1Nm working in flexion, extension, axial rotation, and lateral bending. In each scenario, the range of motion (ROM) was monitored. The accuracy of the initial model was validated by comparing output predictions with data from previously published studies, including in vitro studies [6] and other models. Furthermore, in each scenario of the proposed updates, the results were compared with those from the original model. Most of the results obtained fell within the standard deviation of the corresponding test averages.

4 DISCUSSION

Despite the absence of fibers in the initial model, it still was validated. However, as anticipated, the AF fibers played a significant role in restricting the movement of the cervical spine, most notably in axial rotation. As such, this study highlights the importance of these components in cervical models and models encompassing the entire spinal column since their inclusion yielded superior results with more bio-realistic outcomes.

Moreover, some stiffness was observed when treating the vertebrae as rigid bodies. However, this did not significantly impact the model's performance, resulting in an average time reduction of approximately 80%. Considering that most cervical spine injuries occur at the level of soft tissue structures rather than the vertebrae themselves, modelling them as rigid bodies does not significantly affect the clinical relevance of the model. In certain situations, however, when studying the effects of bone injuries, it may be necessary to model the vertebrae as deformable structures to accurately capture the cervical spine's mechanical behavior.

Incorporating a fluid-like behavior in the nucleus pulposus introduces a novel technique capable of enhancing precision in representing IVD. If validated, this approach will provide opportunities to analyze the mechanisms of disc herniation and its impact on spine kinematics.

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REFERENCES

[1] C. Zanza *et al.*, "Cervical spine injury: clinical and medico-legal overview," *Radiol med*, vol. 128, no. 1, pp. 103–112, Jan. 2023, doi: 10.1007/s11547-022-01578-2.

[2] L. JAKOBSSON, H. NORIN, and M. Y. SVENSSON, "Parameters Influencing AIS 1 Neck Injury Outcome in Frontal Impacts," *Traffic Injury Prevention*, vol. 5, no. 2, pp. 156–163, Jun. 2004, doi: 10.1080/15389580490435989.

[3] B. D. Stemper and B. D. Corner, "Whiplash-Associated Disorders: Occupant Kinematics and Neck Morphology," *Journal of Orthopaedic & Sports Physical Therapy*, vol. 46, no. 10, pp. 834–844, Oct. 2016, doi: 10.2519/jospt.2016.6846.

[4] H. M. Raheem, B. Bay, and S. Rochefort, "Viscoelastic properties of a novel hydrogel/foam composites for nucleus pulposus replacement," *SN Appl. Sci.*, vol. 1, no. 8, p. 809, Jul. 2019, doi: 10.1007/s42452-019-0855-z.

[5] D. U. Erbulut, I. Zafarparandeh, I. Lazoglu, and A. F. Ozer, "Application of an asymmetric finite element model of the C2-T1 cervical spine for evaluating the role of soft tissues in stability," *Medical Engineering & Physics*, vol. 36, no. 7, pp. 915–921, Jul. 2014, doi: 10.1016/j.medengphy.2014.02.020.

[6] M. M. Panjabi *et al.*, "Mechanical Properties of the Human Cervical Spine as Shown by Three-Dimensional Load–Displacement Curves:," *Spine*, vol. 26, no. 24, pp. 2692–2700, Dec. 2001, doi: 10.1097/00007632-200112150-00012.