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A COMPUTATIONAL MODEL OF THE CERVICAL SPINE: APLICATION TO ANTERIOR CERVICAL FUSION ANALYSIS

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Computational models of the cervical spine have several applications not only in understanding the role of different anatomical structures and their biomechanical behaviour but also to provide additional knowledge on disease conditions and surgical interventions. One of the standard surgical procedures for disc degenerative disease is anterior cervical fusion. Since it restrains the motion in the correspondent functional unit, it will affect the range of motion (ROM) and stress at that level as well as on the adjacent functional units. The evolution of the computer capabilities and Finite Element software has stimulated the development of more complex computational models to study the spine biomechanics, including not only the vertebrae but also soft tissues such as ligaments. However, it should be noted that the material properties assumed for these structures have a strong influence in the biomechanical response of the computational models.

The objective of this work is to develop a finite element model of the cervical spine which accurately reproduces the behaviour of the spine in order to analyse non-physiological situations, particularly surgical procedures such as cervical fusion. A complete finite element model of the cervical spine from C2 to T1 was build where the ligaments were assumed to be either linear elastic or nonlinear, with different combinations of cross sectional areas and elastic properties based on available literature. ROM is then computed for the movements of flexion, extension, lateral bending and axial rotation. For the first step, the influence of the material properties of the ligaments on the computed ROM was studied. Then a set of medical devices used in the anterior cervical fusion was developed and inserted in the model in order to simulate the several different scenarios of this procedure.

Results show a decrease on the ROM values with the insertion of the ligaments as expected. Changes are more pronounced for flexion (70%) and less significant for extension (12%) which is consistent with the different influence of the major ligaments on each basic movements of the spine reported by the literature. The validation of the model is done by comparing the obtained results with previous studies. Through the minimization of the differences between the computed ROM and those from in vitro studies it is possible to select the most suitable combination of ligaments' properties for the reproduction of the biomechanical behaviour of the cervical spine. The properties selected were based in the calibrated model of Kallemeyn et al. [1] with the cross sectional areas from Zhang et al. [2, 3].

Afterward, an analysis of the ROM changes after the insertion of the medical devices is made, comparing the different simulated scenarios with the initial state (without surgical intervention) and among them (Fig.1).

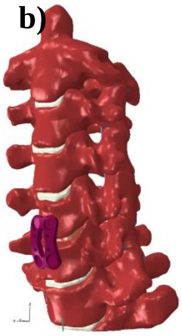
a)

c)

Flexion	ROM (degrees)		Relative Difference (%)
	physiologic model	anterior plate model	
C2-C3	4.429	4.435	**0.13**
C3-C4	4.572	4.572	**0.00**
C4-C5	5.563	5.581	**0.31**
C5-C6	4.188	0.206	**-95.08**
C6-C7	4.715	4.784	**1.46**

Lateral Bending	ROM (degrees)		Relative Difference (%)
	physiologic model	anterior plate model	
C2-C3	2.779	2.773	**-0.21**
C3-C4	3.231	3.146	**-2.66**
C4-C5	2.587	2.452	**-5.20**
C5-C6	1.791	0.139	**-92.23**
C6-C7	2.214	2.265	**2.28**

b)



Extension	ROM (degrees)		Relative Difference (%)
	physiologic model	anterior plate model	
C2-C3	3.541	3.541	**0.00**
C3-C4	3.289	3.277	**-0.35**
C4-C5	2.372	2.636	**11.11**
C5-C6	2.401	0.229	**-90.45**
C6-C7	4.318	5.388	**24.77**

Axial Rotation	ROM (degrees)		Relative Difference (%)
	physiologic model	anterior plate model	
C2-C3	6.016	6.022	**0.10**
C3-C4	4.830	4.819	**-0.24**
C4-C5	6.492	6.521	**0.45**
C5-C6	3.553	0.145	**-95.92**
C6-C7	1.519	1.588	**4.53**

Figure1. a) C2-T1 Finite Element model for the physiologic case; b) C2-T1 Finite Element model for one of the post-surgical scenarios: anterior cervical plate, cage and graft; c) Table with the ROM results for all the functional units in both models and the correspondent relative difference between them.

As a first conclusion, the study shows that the insertion of ligaments in the finite element model influences differently the basic movements according to the importance of the ligaments action in each of them. The use of different combinations of ligament properties (elastic properties and cross sectional areas) influence significantly the ROM obtained by the finite element model. With respect to the comparison between the pre and post-surgical situation, the work shows the restriction of movement in the fusion functional unit and the changes in adjacent segments when fusion is considered (fig. 1). The ROM changes in the adjacent level are particularly evident for the lateral bending movement, which may be a consequence of the insertion of the anterior cervical plate. These results highlight the relevance of computational models for pre-clinical tests of spinal devices used in different surgical scenarios.

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