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The virtual morphology and the main movements of the human neck simulations used for car crash studies

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Abstract. The paper presents the studies made on a similar biomechanical system composed by neck, head and thorax bones. The models were defined in a CAD environment which includes Adams algorithm for dynamic simulations. The virtual models and the entire morphology were obtained starting with CT images made on a living human subject. The main movements analyzed were: axial rotation (left-right), lateral bending (left-right) and flexion-extension movement. After simulation was obtained the entire biomechanical behavior based on data tables or diagrams.
That virtual model composed by neck and head can be included in complex system (as a car system) and supposed to several impact simulations (virtual crash tests). Also, our research team built main components of a testing device for dummy car crash neck-head system using anatomical data.

1. Introduction

The objective of this research was to develop a biomechanical model of muscle powered human system consists of head, neck and upper torso, a system that could be used to simulate the impact behavior for automotive crash studies [1,2].

Using computer-aided design (CAD) and dynamic simulation programs was developed a virtual model of the human spine to simulate biomechanical in vitro experiments. That "in vitro" model includes the main muscle groups simulated by springs with dynamic parameters, nonlinear and variable. The development of this biomechanical model of human head-neck system was based on a previous “in vivo” model. The virtual vertebrae of the cervical spine were considered to be composed by rigid bodies in the Adams algorithm dimensional modeling environment included in SolidWorks CAD software.

Were defined interconnection joints, inter-vertebral discs, joints, ligaments, including C0-C1-C2 complex. Neck muscles were considered as the driver elements for the study that includes the main following types of movements (displacements) axial rotation (left-right). The objective of this research was to develop a biomechanical model of muscle powered human system consists of head, neck and upper torso, a system that could be used to simulate the impact behavior for automotive crash studies [1,2].

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2. Biomechanical and morphological aspects of the human neck-head system

The human cervical spine is the upper part of the spine, which supports the head and protects the spinal cord. Axial rotation, lateral bending, extension, and flexion are the four main motions of the head-neck complex [4, 9].


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The human cervical spine consists of seven vertebrae, referred to as C1 through C7. The upper cervical spine consists of occiput (C0), atlas (C1), and axis (C2), and is also called the occipito-atlanto-axial complex (C0-C1-C2). At the base of the skull, the occiput (C0) articulates on the atlas (C1) through the convex occiput condyles (OC). The atlas (C1) is a ring-like structure with anterior and posterior arches where the articular facets and transverse processes are located. The axis (C2) is characterized by an anterior articular surface from the C2 body to articulate with the posterior aspect of the anterior arch of C1 [4, 9].

The C0-C1-C2 complex is the most complicated joint of the skeleton, both anatomically and kinematically. The atlantooccipital (C0-C1) joint lies between the atlas and the occipital condyles of the skull. Between the atlas and the axis, three atlanto-axial (C1-C2) joints occur. Two lateral atlanto-axial joints intervene between the associated facets of the atlas and axis located immediately adjacent to the lateral masses of each vertebra. A median atlantoaxial joint is also present between the dens of the axis and the anterior arch of the atlas. The lower cervical spine is distinct from the upper cervical spine and consists of similar vertebrae from C3 to C7.

Each vertebral body in this region has vertebral arch and three processes (one spinous process and two transverse processes) for muscular and ligamental attachment and articulation. The upper end plate surface is concave from side to side and convex in an anterior-posterior direction, while the lower end plate surface is convex from side to side and concave in an anterior-posterior direction [9].

3. Virtual model and morphology of the neck-head complex

To obtain the virtual components of the human cervical spine were analyzed 351 CT images obtained in different planes (distance between planes is 1 mm)

These images were scaled to a natural scale (1:1) and transfer, one by one, in a parametrical CAD environment where the contours became curves. After that operation the curves were unified in solids using *Loft shape* and the cervical spine were recomposed in a virtual space. In Figure 1 were presented the virtual model of the C1 (Atlas) and the entire virtual cervical spine composed by seven vertebrae.

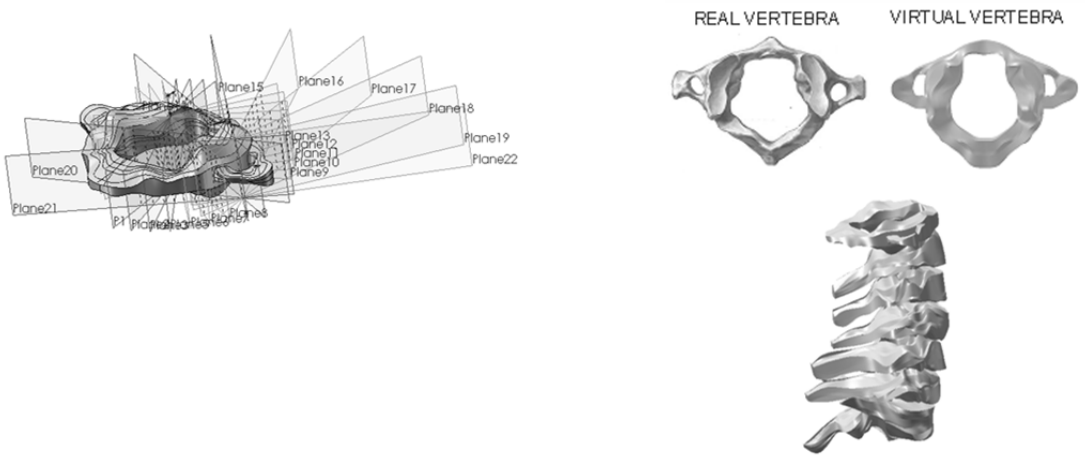


Figure 1 - Virtual morphology of atlas and cervical spine

Using a pre-defined neck, a thorax models and the virtual cervical spine made by seven vertebrae C1-C7 were imported into the assembly environment. In that 3D software module all the bone components were assembled.

4. Simulations of the main movements for the biomechanical system of the human neck-head system

The study on the bio-mechanical have been achieved starting with the next simplifying assumptions:

- Was considered a complete cycle of rotation with the total duration of 1 second;

- In intra-vertebral joints were considered spherical joints (3R) with the Z axis motor with a coupling angle variation;
- Contact between the vertebrae was considered of "impact" with friction;
- Inter-vertebral disc between vertebrae was simulated using four compression springs, except C1-C2 coupling where three springs were used (Figure 2);
- Chest and the shoulder bones were considered fixed;
- Inertial and mass parameters were taken from the literature.

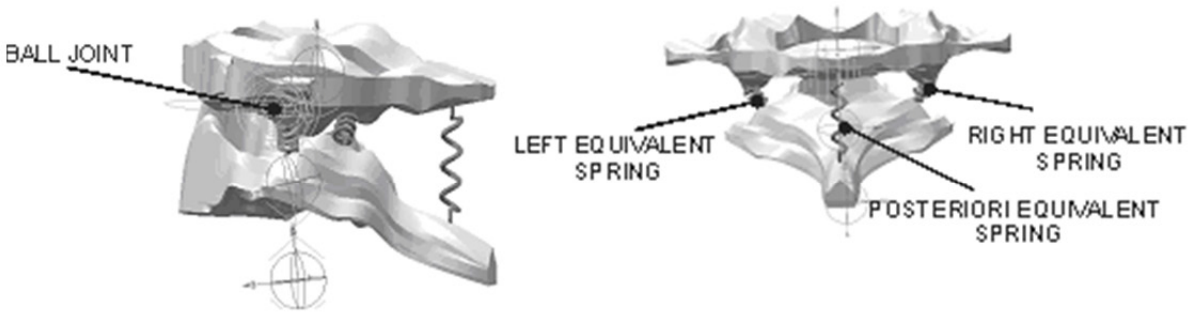


Figure 2 - Biomechanical equivalence for the ligaments of the disc C1-C2 system using three compression springs and ball joint (3R)

In Figure 3 was presented the morphology and the complete biomechanical system for the human neck-head simulation with active elastic elements that simulates the complex cranial-cervical muscle activity.

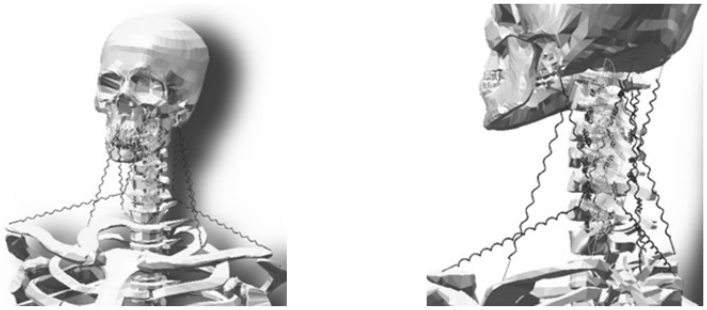


Figure 3 – The morphology [4] and the complete virtual biomechanical system for the human neck-head simulation actuated by virtual muscles.

A first result obtained is the film simulation. Figure 4 presents four important frames of the simulation, using driver and driven elastic elements.



Figure 4 - Four major frames of the simulation movie (left and right axial rotation).

In a similar way, other parameters can be obtained for the other couplings of the human neck (C2-C3, C3-C4, C5-C6, C6-C7). Using the same model, but with other driver elements (other virtual actuated muscles) we obtained simulations for lateral bending and flexion-extension movements (Figure 5), with active elastic elements (similar studies in [4,6,7]).

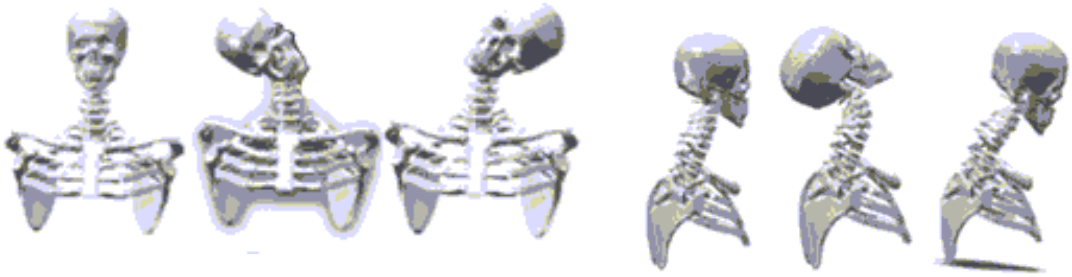


Figure 5 - Three major frames of simulation movie (lateral bending left-right and flexion-extension).

5. Conclusion

The paper presents the usable mode based on SolidWorks software and Adams algorithm for complex systems representations, including bio-mechanics. The presented method is easy and simple, is working step by step and it offers the possibility to understand all the phases of the simulation operation. This software offers the complete access to the usable shape types and to the geometric and mass parameters. The paper shows the advantages of this CAD software, which become a high performance instrument for any complex bio-mechanical system, modeling and analysis (method used in [4,6,7]). That method for modelling and analysis has a lot of advantages as: the easiest way for understanding the elements and the components of the bio-mechanical system; the flexibility given by the parametrical characteristics of the CAD/CAE software for complex shapes; simple and rapidly way to obtain an entire system of results using FEA (Finite Elements Analysis) calculus; using the module for FEA and kinematic simulation the virtual model can give important results as dynamic maps, data tables and graphical representations; a complex bio-mechanical system, like neck-head model, can be easily adapted to the new constrains and new parameters of the virtual crash test [1, 2]. The virtual study of cranio – cervical complex behaviour helped us further in order to determine the effects of the collision: on the vertebrae, intervertebral discs and, last but not least for the cranial area, at the different impact velocities.

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