A VIRTUAL MODEL OF THE HUMAN CERVICAL SPINE FOR PHYSICS-BASED SIMULATION

Hyung S. Ahn and Denis J. DiAngelo

Department of Biomedical Engineering, The University of Tennessee Health Science Center, Memphis, Tennessee, USA
E-mail: ddiangelo@utmem.edu Web: http://memphis.mecca.org/bme/bttlweb/

INTRODUCTION

With emerging computer technology, there is an effort to integrate computer graphics, diagnostic imaging tools, and computer aided design and engineering analysis programs into biomedical research. The use of computer graphics to model the cervical spine provides the opportunity to create a virtual simulator for kinematics and kinetic testing of the cervical spine. The objective was to develop a graphics - oriented interactive cervical spine model for physics-based dynamic simulation.

METHOD

Modeling of the virtual cervical spine consisted of two main phases: 1) accurately creating the 3-D bony anatomy and 2) defining the interconnecting joints and soft tissue components. In the first phase, the geometry of the skull, cervical vertebrae, and upper torso (clavicles, scapulae, ribs and sternum) were created from female computer tomography (CT) images available through the Visible Human Project® using a medical image processing software (SliceOmatic 4.2, Tomovision) and volumetric surface modeling software (Geomagic Studio 5, Raindrop). To maintain accurate reconstruction of the vertebral geometry, especially at the facet joint regions, a manual-tracing method was used to create each body (C1 to T1). The reconstructed anatomical model is shown in Figure 1. In phase two, the reconstructed Skull-Cervical vertebrae-Upper torso geometry was imported into a physics-based multibody simulation software program (VisualNastran 4D, MSC) that was used to define the interconnecting joints and soft tissue elements. The facet joints were modeled as colliding biconvex surfaces at C1-C2 and a ball on a plane joint between vertebrae C2 through T1 (Figure 2).

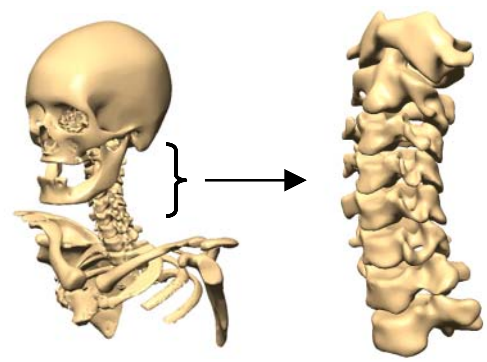


Figure 1: Reconstructed anatomical model without interconnecting structures.

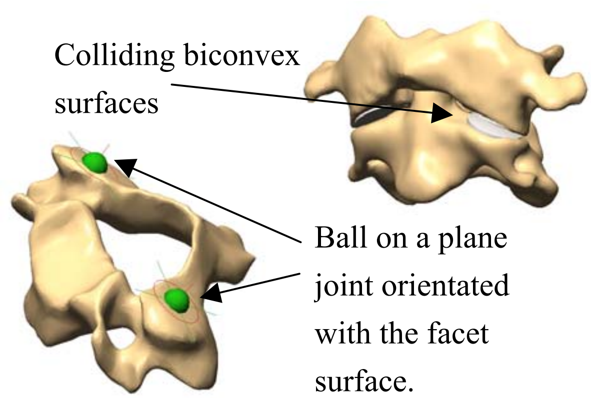
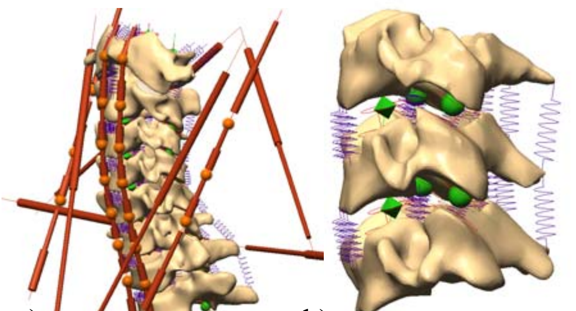


Figure 2: Modeling the Facet Joints.

Muscles were modeled by curving a series of linear actuator (Figure 3a). The actuator elements were controlled by an external application referred to as The Virtual Muscle (Cheng et al, 2000). Intervertebral discs were modeled as nonlinear, viscoelastic elements, with six-degrees of freedom (Figure 3b). Ligaments were modeled as a nonlinear spring-damper element. The material properties of intervertebral discs and ligaments were adopted from the in-vitro experimental data and the literature (Panjabi et al., 2001, Yoganandan et al., 2001).



a) b)

Figure 3: (a) The reconstructed cervical spine with interconnecting structures and (b) exploded view of C3-C4-C5 segments.

RESULTS

A testing protocol replicating the physiologic motion response of the cervical spine (DiAngelo and Foley, 2003) was simulated in the virtual environment using Visual Nastran 4D (Figure 4). The motion response of the virtual spine simulator was comparable to the in vitro test results.

CONCLUDING DISCUSSION

A process for creating an accurate virtual model of human cervical spine was developed and used to simulate the dynamic flexion and extension kinetics.

The model can be used to simulate other biomechanical tests, such as the dynamic motion behavior of spinal arthroplasty or fusion hardware. With muscle control strategies, the model can also enable simulation of in vivo dynamics.

REFERENCES

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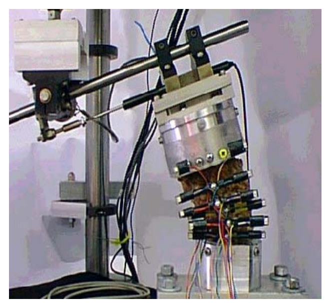
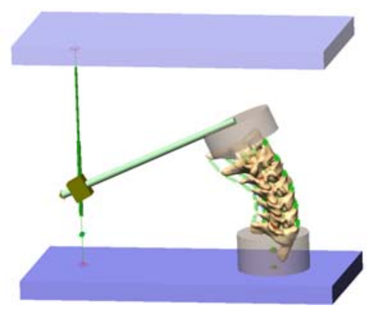


a) In Vitro Testing Arrangement



b) Virtual Simulation Model

Figure 4: Comparison of In Vitro Cervical Spine Model and Virtual Model. a) Extension testing of cervical spine mounted in biomechanical testing system. b) Simulation of the extension dynamics of the virtual cervical spine model.