REAL-TIME MONITORING OF STRESSES AND DISPLACEMENTS IN CERVICAL NUCLEI PULPOSI DURING CERVICAL SPINE MANIPULATION: A FINITE ELEMENT MODEL ANALYSIS

Li-Ping Wu, MD,[a] Yuan-Qiao Huang, MM,[b] Das Manas, MD,[c] Yong-yuan Chen, MM,[a] Ji-hong Fan, MD,[d] and Hua-gui Mo, BS[e]

ABSTRACT

Objective: The objective of this study was to research the distribution of stresses and displacements in cervical nuclei pulposi during simulated cervical spine manipulation (CSM).

Methods: A 3-dimensional finite element model of $C_{3/4}$~$C_{6/7}$ was established. The detailed mechanical parameters of CSM were analyzed and simulated. During the process, the changes in stresses and displacements of cervical nuclei pulposi within the model were displayed simultaneously and dynamically.

Results: Cervical spine manipulation with right rotation was targeted at the C_4 spinous process of the model. During traction, levels of stresses and displacements of the nuclei pulposi exhibited an initial decrease followed by an increase. The major stresses and displacements affected the $C_{3/4}$ nucleus pulposus during rotation in CSM, when its morphology gradually changed from circular to elliptical. The highest stress (48.53 kPa) occurred at its right superior edge, on rotating 40° to the right. It protruded toward the right superior, creating a gap in its left inferior aspect. The highest displacement, also at 40° right, occurred at its left superior edge and measured 0.7966 mm. Dimensions of stresses and displacements reduced quickly on rapid return to neutral position.

Conclusion: The morphology of the $C_{3/4}$ nucleus pulposus changed during CSM with right rotation, and it created a gap in its left inferior aspect. Biomechanically, it is more safe and rational to rotate toward the healthy side than the prolapsed side of the intervertebral disk during CSM. Upon ensuring due safety, the closer the application force is to the diseased intervertebral disk, the better is the effect of CSM. (J Manipulative Physiol Ther 2014;37:561-568)

Key Indexing Terms: *Cervical Vertebrae; Manipulation; Spinal; Nucleus Pulposus; Finite Element Analysis; Stress; Displacement*

With an increase in rates of cervical spinal diseases in recent years,[1] increasing populations worldwide tend to receive cervical spinal manipulation (CSM) therapy with assured efficacy.[2–4] According to the British and Scottish Chiropractic Associations, about 2.25 million people adopt CSM therapy on an annual basis.[5] Chiropractors delivered close to 135 million neck manipulations over a 10-year period between 1988 and 1997 in Canada,[6] and approximately 18 to 38 million Americans sought CSM therapy in about a year.[7]

[a] Associate Professor, Department of Orthopedics, Jiangmen Central Hospital of Guangdong Province China (Affiliated Jiangmen Hospital of Sun Yat-Sen University), Jiangmen, Guangdong, PR China.

[b] Professor, Department of Orthopedics, Jiangmen Central Hospital of Guangdong Province China (Affiliated Jiangmen Hospital of Sun Yat-Sen University), Jiangmen, Guangdong, PR China.

[c] Associate Professor, Department of Anatomy, Sanford School of Medicine, University of South Dakota, Vermillion, SD.

[d] Associate Researcher, Department of Anatomy, School of Basic Medical Sciences, Southern Medical University, Guangzhou, PR China.

[e] Physician-in-charge, Department of Orthopedics, Jiangmen Central Hospital of Guangdong Province China (Affiliated Jiangmen Hospital of Sun Yat-Sen University), Jiangmen, Guangdong, PR China.

Submit requests for reprints to: Wu Li-ping, MD Associate Professor, Department of Orthopedics, Jiangmen Central Hospital of Guangdong Province China (Affiliated Jiangmen Hospital of Sun Yat-Sen University), No. 23, Haibang St, Pengjiang District, 529031 Jiangmen City, Guangdong Province, PR China. (e-mail: *12303383@qq.com*).

Paper submitted March 18, 2014; in revised form April 30, 2014; accepted May 13, 2014.

0161-4754

http://dx.doi.org/10.1016/j.jmpt.2014.05.007

In order to increase its efficacy and reduce its adverse effects in an increasing population worldwide, a safe and rational operative approach to CSM is of paramount importance. Generally speaking, CSM typically combines stretching and rotation.[4] The direction of rotation, however, barely receives any attention during CSM. Because most cervical intervertebral (IV) disks in patients receiving CSM have already prolapsed to either side, rotations can be directed in 3 different ways; toward the healthy side, toward the affected or the prolapsed side, or both. To the best of our knowledge, there has not been any research to determine the safer or the more rational direction.

Although many theories and assumptions have been set up to explain the mechanisms underlying the techniques of spinal manipulation, there still is not a clear and fully understood one.[4,8,9] There was an earlier assumption that lumbar spinal manipulation (SM) could restore a herniated disk to its normal position, which now has been ruled out.[10] Another theory,[11] with some support,[12,13] assumes that compression of the nerve root is relieved by a small displacement between it and the prolapsed IV disk during lumbar SM. Is there a similar phenomenon with CSM? Because a herniated IV disk mainly involves prolapse of the nucleus pulposus, how is its morphology affected during CSM? How does it displace during CSM? As of yet, we had very little information about these.

In recent years, finite element (FE) analysis, as a useful method, has been applied to research the mechanisms of SM. A little amount of research has been conducted using this technique to analyze the stress and displacement of a lumbar spinal segment during lumbar SM.[14,15] A literature reports the biomechanical changes of the cervical IV disk and fiber stress with the application of axial distraction.[16] Literatures about manipulation, however, show that none had explored the changes in stresses and displacements of cervical nuclei pulposi during CSM, using FE analysis. The objective of the current computational FE study, therefore, was to investigate the characteristic changes in stresses and displacements of cervical nuclei pulposi during simulated CSM. Also, the current report is a more in-depth follow-up on the initial data that were reported earlier.[17]

Methods

The 3-Dimensional FE Model of $C_{3/4}$~$C_{6/7}$ Segments

A 3-dimensional (3-D) FE model of $C_{3/4}$~$C_{6/7}$ segments was developed from the computed tomographic and magnetic resonance imaging scans of a 36-year-old Chinese man. Prior anteroposterior and lateral radiographs were obtained to exclude cervical spine malformation, variation, degeneration, trauma, or any other factor that could influence the results of the experiment. Ethical approval for this study was obtained from the Human Research Ethics Committee, Southern Medical University, PR China. The 3-D cervical image was reconstructed using Mimics software 10.01 (Materialize Company, Leuven, Belgium) from the computed tomographic and magnetic resonance scan images. Next, the reconstructed image was imported to Geomagic Studio 10.0 software (Raindrop Company, Marble Hill, MO) for division and reconditioning. It was then imported to MSC.Patran software (MSC Software Corporation, Santa Ana, CA) to develop FE mesh. Finally, the 3-D FE model of $C_{3/4}$~$C_{6/7}$ segments was set up. The model components contained 31 633 nodes and 149 788 unit elements, which included cortical bone, cancellous bone, end plates, annulus fibrosus, nucleus pulposus, and posterior facets. The materials used for various components in this model were closely matched with the available published data.[18–20] To validate this FE model, the predicted kinematics data, in terms of range of motion under different static loading configurations, were analyzed and compared with the in vitro experimental data.[21–23] The analysis to simulate CSM was performed using commercially available FE software (MSC.Marc; MSC Software Corporation).

The Simulation and Loading of CSM

Although there are many techniques of CSM in the clinical setting, cervical traction combined with rotatory manipulation is considered to be highly effective and is widely used, especially in China.[24] We therefore used it in our research. The detailed steps of this technique were adopted from previous literature.[4,24] The direction of rotation to simulate CSM was set to right. All of the quantized mechanical parameters in the computer program to simulate CSM were adopted from preliminary studies.[4,24–28]

First, downward vertical forces of 100 N were loaded to the cervical spine specimen to simulate gravitational force exerted on it by the head. Next, upward vertical forces of 200 N were applied to it simulating traction of CSM. After this, a thrust of 4.727 ± 1.037 kg was exerted on the C_4 spinous process by the operator's thumb.[29] The sagittal diameters of the spinal canal and the C_4 disk in the average normal Chinese population are 13.29 mm[30] and 17.3 mm,[25] respectively. The length of the C_4 spinous process was determined to be 15 mm in our research. The length, therefore, between the center of C_4 disk and the C_4 spinous process was calculated to be 3.6 cm. The moment of force affecting the C_4 spinous process during CSM could hence be deduced as 1.7 Nm. The direction of thrust on C_4 spinous process by the operator's thumb was 30° left anterior. Next, the C_4 vertebra of the model was made to rotate 25° to the right. It was then made to rotate a further 15° to the right, followed by a rapid return to the neutral position. The interval between rotating the final 15° and returning to the neutral position was 0.11 seconds.[31] This was a complete simulation of CSM.