Little, J. Paige and Pearcy, Mark J. and Adam, Clayton J. (2007) Are coupled rotations in the lumbar spine largely due to the osseoligamentous anatomy?. In *Proceedings XXIst Congress of the International Society of Biomechanics*(Paper #583), Taipei, Taiwan.

ARE COUPLED ROTATIONS IN THE LUMBAR SPINE A CONSEQUENCE OF THE OSSEOLIGAMENTOUS ANATOMY?

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INTRODUCTION

Previous studies have found that primary rotations in the lumbar spine are accompanied by coupled out-of-plane rotations. However, it is not clear whether this accompanying rotation is due to passive (discs, ligaments and facet joints) or active (muscles) spinal anatomy. The aim of this study was to use a finite element model of the lumbar spine to determine three-dimensional rotations in the loaded spine, due to passive spinal anatomy alone.

METHODS

A three dimensional finite element (FE) model of a human osseoligamentous lumbar spine was developed using the Visible Man CT dataset (The Visible Human Project, U.S. National Library of Medicine) (Figure 1). Vertebral bodies were meshed using eight node hexahedral three-dimensional continuum elements for the internal cancellous bone, overlaid with 4 node shell elements for the cortical shell. Posterior vertebral structures were modeled using quasi-rigid beam elements. Three dimensional continuum elements simulated the annulus fibrosus ground matrix, with tension-only 'rebar' elements embedded at specific orientations to represent the annulus collagen fibres. Hydrostatic fluid elements were overlaid on the inner surface of the annulus to simulate a healthy, hydrostatic nucleus pulposus. A simplified representation for the facet joints was used with 'softened' contact between the articulating surfaces. All ligaments were simulated as tension-only, axial connector elements. Bone and soft tissue material properties were based on prior studies [1]. Physiological motions were simulated by applying a torso compressive force of 500N (comparable to body weight above the lumbar spine), as well as pure rotations simulating the limits of in vivo rotational motion for the lumbar spine (Table 1). Analysis was performed on an SGI Origin 3000 supercomputer using Abaqus/Standard version 6.4.5.

RESULTS AND DISCUSSION

Nucleus pressure ratios in the four discs ranged from 1.42-1.59, close to Nachemson's measured value of 1.5 [2].
Primary rotations in the sagittal, coronal and transverse planes were generally either the same as the average in vivo rotations observed by Pearcy [3] or fell within the first standard deviation of the in vivo data. The three exceptions were for primary flexion and extension at the L3/4 disc (10° and 3°, respectively), and primary left axial rotation at the L4/5 disc (0°). However, in each case these computed rotations fell within the range of data reported by Pearcy. Predicted coupled motions for primary rotation in the sagittal or transverse planes (flexion/extension, axial rotation) were either the same as the average in vivo data or within the first standard deviation. However, primary rotations in the coronal plane (left and right lateral bending) resulted in coupled axial rotations considerably larger than the in vivo data. These coupled rotations generally fell outside both the standard deviation and reported range of in vivo measurements.

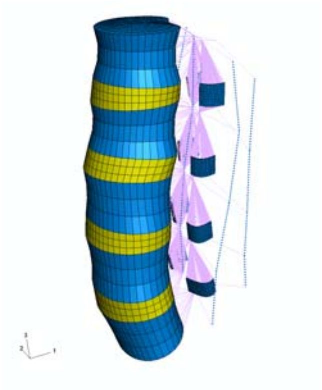

Figure 1: Osseoligamentous Finite Element Model of the Visible Man lumbar spine

CONCLUSIONS

The observed similarity between computed and in vivo nucleus pressures and primary rotations at each spinal level provide confidence in the models' ability to predict the passive mechanics of the osseoligamentous lumbar spine. Coupled rotations due to primary motions in the sagittal and transverse planes appear to be caused by the passive spinal anatomy. However, for lateral bending, data for the computed coupled rotations suggest that the passive anatomy alone does not account for the observed coupled rotation in vivo, and we hypothesize that the muscles play a key role in the coupled response of the spine under this motion.

REFERENCES

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Table 1: Ranges of rotation applied to the lumbar spine finite element model (following Pearcy [3])

Motion	Flexion	Extension	Left lateral bending	Right lateral bending	Left axial rotation	Right axial rotation
Angle of rotation	43°	11°	19°	18°	6°	4°