Investigation of Facet Articulation During Lateral Bending in the Human Lumbar Spine Using a Model-Based Kinematic Simulation

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INTRODUCTION:

The development of motion-preserving spinal implants necessitates a more complete characterization of physiologic motion of the functional spinal unit (FSU) than is required for the evaluation of fusion devices. Facet joint articulation is particularly poorly understood and has historically been characterized at the expense of joint integrity [1]. To this end, a non-invasive technique, utilizing the fusion of CT reconstructed models and kinematic test data, to investigate facet articulation was developed and applied to a Lateral Bending test.

METHODS:

Image segmentation software (ScanIP, Simpleware UK) was used to generate three-dimensional models of each vertebral body, along with three non-collinear fiducials, in six L1-S1 human lumbar spine segments. These models were imported into the MATLAB environment using a custom-built function. Flexibility tests were then conducted on each specimen using a six degree-of-freedom spine tester (Bose, Smart Test Series, Eden Prairie, MN). The kinematic response of the specimen to loading was recorded via an Optotrak motion capture system. Post-processing of the kinematic data generated time series of rigid body transformations based on reference frames defined by each body's respective fiducials. The facet articulation surfaces were selected based on a distance criterion, and the kinematic transformations for each time frame were applied to each facet surface model. After application of each transformation to the model, the distance of each vertex defining an articulation surface to its nearest neighboring vertex on the surface of the adjacent body was calculated for each time frame. Each facet surface was then colored based on this nearest neighbor distance yielding a Vertex Distance Map (VDM). The contact area was approximated by calculating the number of vertices with corresponding distances below a threshold of 0.75 mm. The Contact Area Ratio (CAR) is expressed as the ratio of this number to the total vertices on the articulation surface.

RESULTS:

Figure 1 shows the VDM for the L3 superior facet superimposed upon the L3 solid model at two time frames. The top and bottom plots represent peak right and peak left lateral bending respectively, and the scale of the color map is in millimeters. Figure 2 shows the CAR (solid line) for the right (top) and left (bottom) L3 superior facets along with the Lateral Bend angle (dashed line) throughout one cycle of the Lateral Bend test.

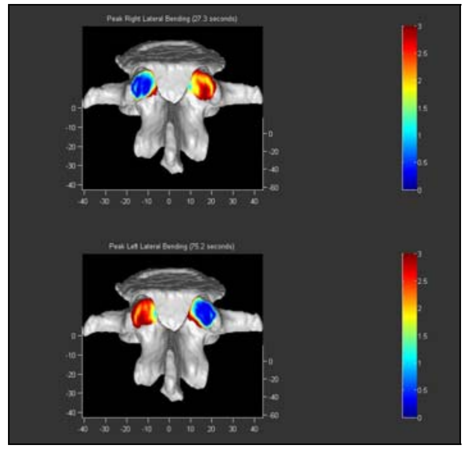

Figure 1: VDM Superimposed on Solid Model

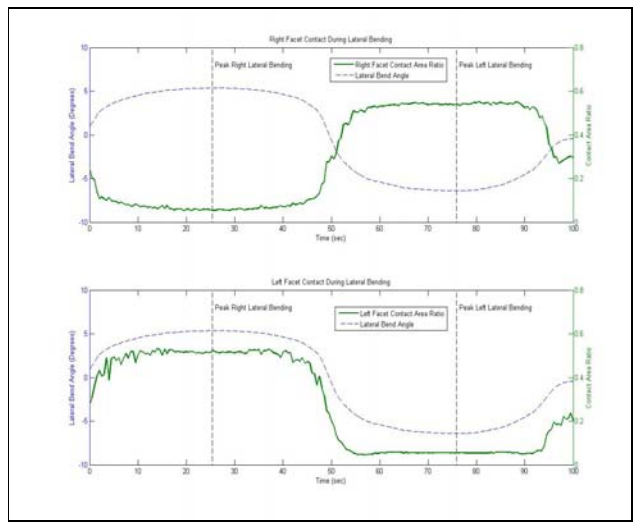

Figure 2: Left and Right Facet Contact Area (Positive angles correspond to Right Lateral Bending while Negative angles correspond to Left Lateral Bending)

DISCUSSION:

Preliminary results show that the VDM gives an intuitive visual interpretation of facet articulation. In addition, articulation can be quantified by estimating the area of contact between two surfaces based on these calculated distances. The data presented clearly shows that during lateral bending the contralateral facets are in contact while the ipsilateral ones are not. Similar results are obtained for all levels of the lumbar spine.

REFERENCES:

[1] Lorenz, M., Patwardhan, A., and Vanderby, R., Jr., 1983, "Load-bearing characteristics of lumbar facets in normal and surgically altered spinal segments," Spine, 8(2), pp. 122-130.