Effects Of Center Of Rotation Shift In Sagittal Plane On Load Sharing Characteristics Of The Lumbar Spine

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Introduction: The kinematics of the spine is defined with the range of motion (ROM) and center of rotation (COR), whereas kinetics of the spine expressed as facet pressures, disc stresses, and ligament forces. Normal motion of the spine stems from the tender balance between kinetics and kinematics of the spine. It has been shown that any structural changes in the spinal unit such as disc degeneration or any kind of column instability can cause a shift in the COR. Moreover, poorly designed or suboptimally placed motion preservation devices can cause a significant change of COR from the intact location. However there is little information in the literature about the consequences of an acute shift of COR on kinetics and kinematics of the lumbar spine. Therefore, in this study, we investigated the changes in the load sharing characteristics in the lumbar spine with respect to changes in imposed COR points by using a finite element (FE) model.
Methods: A three-dimensional FE model of the L4-L5 unit was constructed from the computed tomography (CT) images (Fig. 1). The L4 and L5 vertebrae were consisted of trabecular and cortical bones, and posterior bony elements. On the other hand, the intervertebral disc was modeled as to include nucleus pulposus, annulus fibers and ground substance, and cartilaginous endplates. Facet joints were simulated by defining a frictionless contact between facet cartilage layers. Ligaments were defined with non-linear force-deflection curves.
Pure rotations around pre-determined CORs were simulated by applying 7.5 Nm bending moments in sagittal plane. The loads were applied through rigid beam elements one end concentrated in a single node, which was the designated COR, and the other end attached to the superior endplate of the L4 vertebra. The node, on which the loads were applied, was constrained in all of the translational directions to obtain a fixed COR scenario.
For pre-determined COR locations, 5 points were selected on the intersection of sagittal and axial planes, and a 6th point (6F, 6E) were selected at one disc height below the point 4 for flexion and 3 for extension, to investigate the case of vertical shift in the COR (Fig. 2A). The points 3 and 4 were identified as the locations with the highest ROM obtained, which indicated a close approximation of the natural CORs of the segment in flexion and extension. For the ease of comparison, all results at each COR point were normalized to that of the points 3 and 4 in extension and flexion, respectively.
Results: In flexion, minimum and maximum ROM values were obtained at points 1 and 4, respectively. In extension, the ROM values were minimum at the point 1 and maximum at point 3 . Change in ROM due to vertical shift was higher in flexion (%5) than in extension (%2).
There were no facet forces generated during flexion except point 6F. In extension, average facet force was maximum at point 3, whereas the vertical shift in COR decreased the average facet force at point 6E . In flexion, maximum annulus stress had a steady trend initially and reached a maximum around the point 5, which was similar to point 6F . Similarly, in extension, maximum annulus stress had an increasing trend around the points 1-4 and 6E .
In flexion, all ligament loads increased through the initial anterior COR locations and then decreased toward the posterior COR locations (Fig. 3A). The SSL was not activated when the COR was at the points 1 and 2, but reached a maximum at the point 4. The ALL was barely activated during flexion in all COR points except for the point 1. When the COR was moved to the point 6F in flexion, all ligament loads increased again. In extension, only the ALL and CL experienced loading while the other ligaments remained passive (Fig. 3B). The ALL showed continuously increasing load when the COR moved from the point 1 through 4, then decreased at the point 5. The CL had a maximum when the COR was at the point 3. During the rotation about the point 6E in extension, loads of ALL and CL decreased or increased, respectively, compared to those obtained at the point 3.
Discussion: This comparative analysis showed that the load sharing characteristics of the spine was strongly correlated with the location of the COR and that the location of the COR was a result of the tendency of the vertebra to move in the path of least cumulative resistance.
The change in the COR location varied the path of the motion and thus the stress distribution within the disc, the stretch of each ligament and pressure on the facets. Hence, at any COR location, the rotation of the vertebra caused a new composition of load distribution of among the elements of the segment. The change in the ROM at each COR point observed in the current results can be explained by this variation in the load sharing characteristics.
Significance: The reduction in the ROM due to the change in the COR was strikingly high and indicated that suboptimally designed and/or placed motion preservation devices can theoretically prevent motion. It is also important to note that some

ligaments as well as the disc and the facets experienced increased stress at the shifted CORs compared to the relatively natural COR. Prolonged exposure to increased stress can deteriorate the integrity of these structures and accelerate degeneration process.

Based on the findings of this study, utmost care should be taken in motion preservation device operations to accommodate the intact location of COR.

Acknowledgments: NA

References:

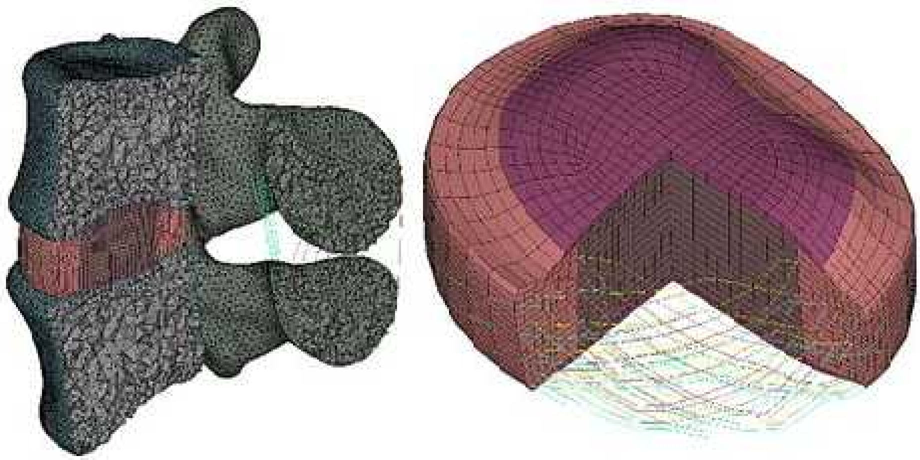

Figure 1. A section view of the L4-5 finite element model (**left**) and intervertebral disc with annulus fibers exposed (**right**).

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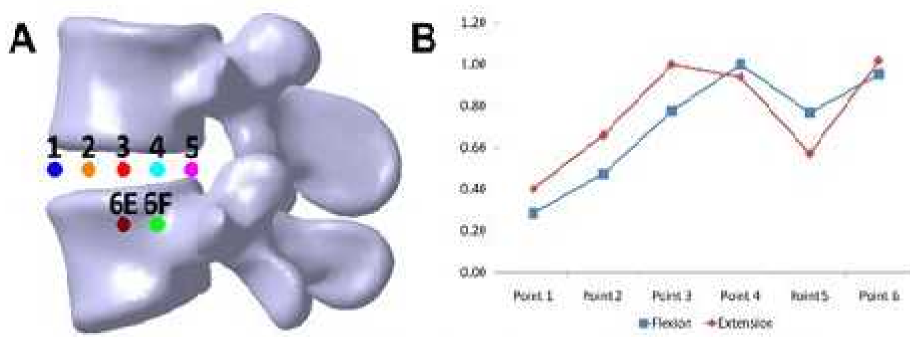

Figure 2. (**A**) Designated COR points in sagittal plane. (**B**) ROM with respect to imposed COR(s) as normalized to those at points 3 or 4 in flexion and extension and left axial rotation.