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A PARAMETRIC FINITE ELEMENT STUDY OF COLLAGEN FIBER ORIENTATION IN LUMBAR INTERVERTEBRAL DISCS

Christine DeDen (Benjamin Ellis, PhD)
Department of Bioengineering

Intervertebral discs within the human lumbar spine are highly susceptible to degradation over time and can result in debilitating lower back pain, making the lumbar spine an area of considerable interest in computational biomechanics. The complex heterogeneous structure of type I collagen fibers within the annulus fibrosus (AF) of lumbar intervertebral discs (IVDs) are important in IVD function, and anatomical dissections reveal that the angle of these fibers with respect to the lateral plane of the IVD can vary significantly and may be dependent on IVD height and width, but no clear consensus exists regarding a universally accepted fiber angle definition. It was hypothesized that collagen fiber angle and disc size influence lumbar spine range of motion (ROM), but to what extent was unknown. To quantify the effects of fiber orientation and IVD geometry, a finite element model specific to a 49-year-old female cadaveric specimen was constructed for the functional spinal units (FSUs) L34 and L45. The model was observed under physiological pure bending moments of flexion, extension, lateral bending, and axial rotation.

This research utilized the finite element method (FEM), which is a numerical technique used for the computational discretization and analysis of complex geometry. FSU L34 and L45 material properties, boundary conditions, and loading scenarios were developed using an open-source FEM software suite called FEBio. Fiber angle definition in the AF of the L34 and L45 IVD was varied parametrically from 25, 45, and 65 degrees, representing the most common fiber angle definitions found in literature. This altered the AF material stiffness so 25 degrees was least stiff and 65 degrees was most stiff. The resulting ROM for flexion, extension, lateral bending, and axial rotation were then compared and IVD height and width measurements of each FSU were recorded to obtain average disc width to height ratios.

The results of this parametric FE study reveal that changes in type I collagen fiber angle in the AF in the L34 and L45 IVDs can have an impact on spinal ROM (Figure 1). It was observed that a smaller fiber angle correlated to a larger spinal rotation for pure bending moments of flexion and lateral bending, but do not have an effect on ROM for extension. This is because flexion and lateral bending ROM is more dependent on the material stiffness of the IVD, while extension is almost entirely dependent on facet contact. Therefore, the IVD geometry and stiffness does not have as big of an impact in extension. IVD stiffness does however impact flexion and lateral bending ROM, such that a smaller fiber angle provided the least resistance in tension, resulting in the largest spinal rotation. This trend was not observed in axial rotation, but fiber angle still altered ROM which suggests that the height and width of IVD geometry had an effect on spinal ROM. Axial rotation therefore depends on both IVD stiffness defined by the fiber angle and IVD geometry. The L34 IVD had a smaller disc height to width ratio than the L45 IVD (Table 1), and in each pure bending moment, L34 ROM is smaller than L45 ROM. This suggests that a smaller disc ratio may result in a smaller spinal rotation because disc stiffness is characterized by both disc material and disc geometry, affecting the L45 IVD more than the L34 IVD.

Quantification of the effects of collagen fiber angle orientation and disc geometry in FSU ROM for a healthy IVD can provide a better understanding of the lumbar spine mechanical behavior and may enhance the ability to replicate the complex musculoskeletal structure of the lumbar spine. This will lead to future advancements in lumbar spine healthcare and better diagnoses and treatment methods for lumbar IVD degradation.

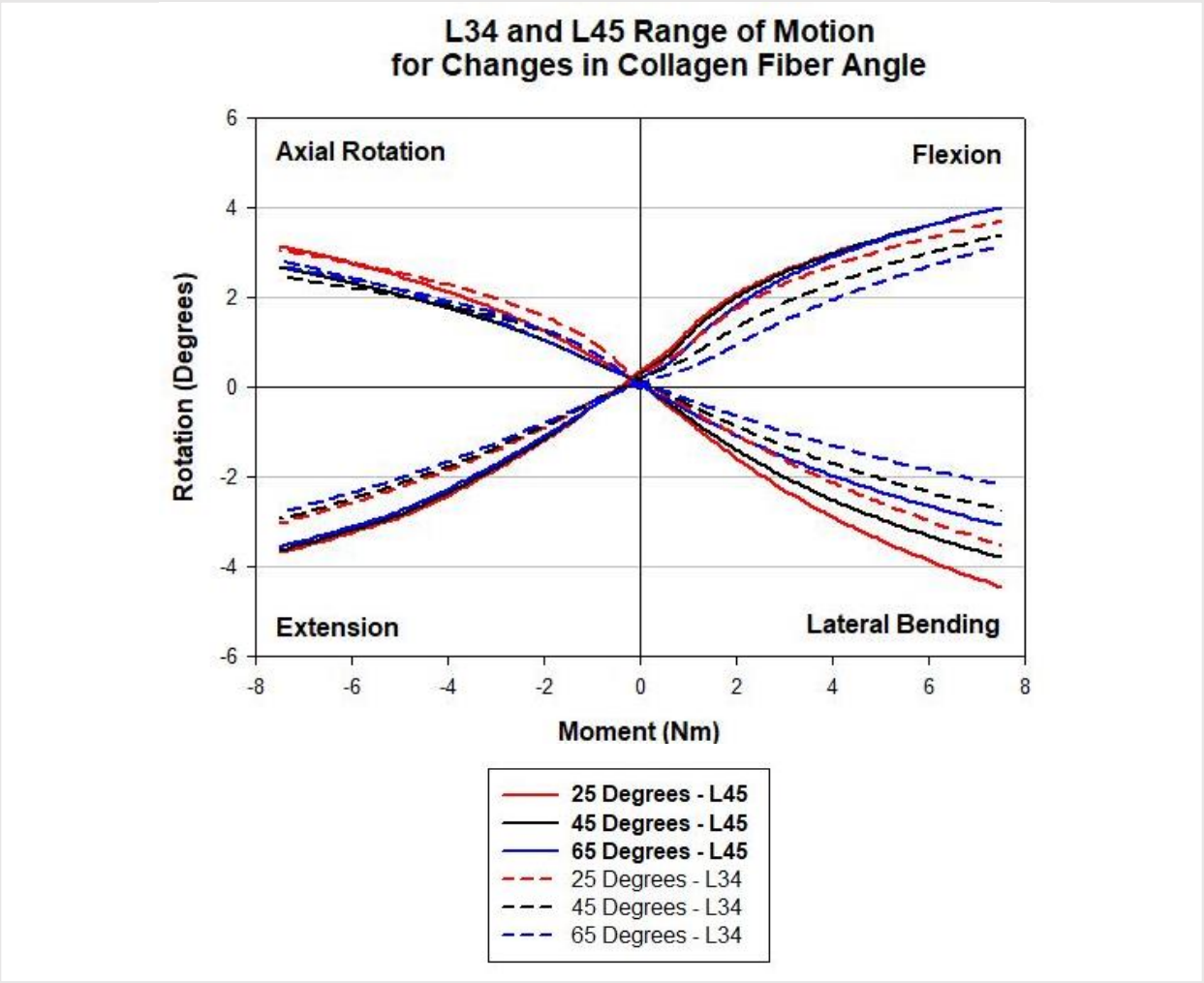

Figure 1. ROM results of FSU L34 and L45 for flexion, extension, lateral bending, and axial rotation when fiber angle was varied parametrically from 25, 45, and 65 degrees with respect to the lateral plane of the IVD.

Lumbar Intervertebral Disc Measurements		
FSU	**L34**	**L45**
Average Disc Height (mm)	6.013	11.619
Average Disc Width (mm)	38.375	36.912
Average Disc / Average Disc Width (mm)	0.157	0.315

Table 1. IVD geometry measurements of L34 and L45.