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Plenary Lecture

3D MODELING OF THE INTERVERTEBRAL DISC: DIRECT RELATIONSHIP BETWEEN TISSUE COMPOSITION AND MODEL PARAMETERS

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Summary: Age and disease cause significant changes in intervertebral disc composition, resulting in altered mechanical function that may lead to debilitating lower back pain. *In vitro* cadaveric tissue testing has played a crucial role in the understanding spine biomechanics. However, clinical relevance of *in vitro* tests has been limited due to many factors that can introduce artifacts into the data and outcomes.[1] Computational models provide a powerful tool to supplement experimental data, but most models are limited to describing tissue behavior under the loading modality or condition (*e.g.*, healthy or degenerated) used for model calibration. We developed a multi-scale structure-based modeling framework where model parameters are based on sub-tissue level composition, including water and glycosaminoglycan content and collagen fibril stiffness. The model was capable of accurately predicting joint-level mechanics and morphological changes observed with degeneration.

Finite element models were developed using the FEBio computational suite for soft tissue biomechanics. Triphasic material descriptions were used to simulate tissue swelling and account for changes in glycosaminoglycan content with age and degeneration. Models of the annulus fibrosus (AF) and nucleus pulposus (NP) were initially developed to perform model validation on multiple length scales by comparing model predicted mechanics to tissue-level data in the literature. Then, bone-disc-bone models were developed and validated by comparing model-predicted joint-level mechanics to data in the literature. Finally, the validated model was used to study risk of herniation by simulating a wide range of compression with flexion, which has been thought to increase risk of herniation.[2]

16 tissue-level simulations and 13 joint-level simulations were performed for model validation. The model closely matched data in the literature for 26 of 29 cases. Thus, we considered the multi-scale model development framework to be valid for simulating both tissue- and joint-level disc mechanics. Flexion was assessed by moving the center of rotation to better represent changes in rotation based on various physical activities. These simulations showed that torque-based flexion commonly used for *in vitro* experiments hadminimal risk for herniation or disc failure. In contrast, shifting the axis of rotation anteriorly, which is more representative of *in vivo* muscle-based flexion, greatly increased the risk of herniation in locations that are commonly observed clinically. Multi-scale structure-based modeling has the potential to accurately describe and predict disc joint failure that will be important for improving surgical outcomes following fusion or disc replacement.

References

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