Multiscale Modeling of Facet Capsule Mechanobiology: Integrating Modeling and Experimental Techniques

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The ligamentous capsule that surrounds the facet joint between adjacent vertebrae in the spine has been implicated in pain from spinal trauma and degeneration, especially due to neck injury and in degenerative low-back pain. But, the specific mechanisms of its injury, pain production and the relation between tissue-level events and cellular responses remain poorly described. This project focuses on understanding the link between the tissue and cellular scales, using a combination of theoretical and experimental techniques. Aspects of the overall project include integrating mechanical tissue tests with structural characterization to define the capsule's response with structural multiscale modeling approaches to construct appropriate and accurate models of spinal facet joint capsules. Further studies expand that work to understanding how the local mechanical environment of the capsule can activate and modulate the response of neurons embedding in the collagen of the capsule. In particular, execution of those initiatives falls in to several broad efforts:

- Tissue-Scale Mechanical Characterization studies, including biaxial mechanical and in situ tests on cadaveric human facet capsules. The facet capsule tissue has been shown to be nonlinear, anisotropic, and mildly viscoelastic.
- Structural Characterization, via polarized light and polarization-sensitive optical coherence tomography.
- Structural Multiscale Computational Modeling, using the structure determined optically to construct a two-scale model of the capsule under load. At present, the a hyperelastic, two component model has been developed, with the fibers of the capsule represented by a discrete network at the microscopic scale and the non-fibrous material represented by a continuous (Neo-Hookean) solid.
- Simulated Injury in a Collagen Gel Model, in which neurons are cultured in a collagen gel that is stretched to strains corresponding to those sufficient to induce pain or physiologic loading in vivo, based on prior work in animal models. The larger gel strains correspond to greater neuronal expression and release of pERK, whose activation has been shown to be a key intracellular signaling mechanism in neurons and pain.
- Development of Cell-in-Tissue and End-Organ-in-Tissue Simulations, in which the multiscale model is used to represent regions of tissue and a cell or receptor embedded within the tissue.