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Research paper

Effect of orientation and targeted extracellular matrix degradation on the shear mechanical properties of the annulus fibrosus

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ABSTRACT

The intervertebral disc experiences combinations of compression, torsion, and bending that subject the disc substructures, particularly the annulus fibrosus (AF), to multidirectional loads and deformations. Combined tensile and shear loading is a particularly important loading paradigm, as compressive loads place the AF in circumferential hoop tension, and spine torsion or bending induces AF shear. Yet the anisotropy of AF mechanical properties in shear, as well as important structure-function mechanisms governing this response, are not well-understood. The objective of this study, therefore, was to investigate the effects of tissue orientation and enzymatic degradation of glycosaminoglycan (GAG) and elastin on AF shear mechanical properties. Significant anisotropy was found: the circumferential shear modulus, $G_{\theta z}$, was an order of magnitude greater than the radial shear modulus, $G_{r\theta}$. In the circumferential direction, prestrain significantly increased the shear modulus, suggesting an important role for collagen fiber stretch in shear properties for this orientation. While not significant and highly variable, ChABC treatment to remove GAG increased the circumferential shear modulus compared to PBS control ($p = 0.15$). Together with the established literature for tensile loading of fiber-reinforced GAG-rich tissues, the trends for changes in shear modulus with ChABC treatment reflect complex, structure-function relationships between GAG and collagen that potentially occur over several hierarchical scales. Elastase digestion did not significantly affect shear modulus with respect to PBS control; further contributing to the notion that circumferential shear modulus is dominated by collagen fiber stretch. The results of this study highlight the complexity of the structure-function relationships that govern the mechanical response of the AF in radial and circumferential shear, and provide new and more accurate data for the validation of material models and tissue-engineered disc replacements.

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