Residual Strain in the Annulus Fibrosus Decreases with Disc Degeneration

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Introduction: The inner annulus fibrosus (AF) is under large compressive residual strains, while the outer AF experiences tensile residual strains, and therefore, stresses [1]. It is thought that residual stresses act together with internal pressure from the nucleus pulposus to maintain a uniform stress distribution in the radial direction, similar to the behavior observed in arterial walls [2]. Tissue swelling leads to residual stress formation and is largely due to water absorption by glycosaminoglycans (GAG) [3]. The GAG content of the inner AF decreases with degeneration [4]; however, the role GAG content plays on AF residual strains is not clear. Therefore, the objective of this study was to investigate changes in residual strain with disc degeneration.

Method: We developed a structurally relevant finite element model of the AF [5]. The extrafibrillar matrix was described as a triphasic material, where fixed charge density (FCD) represents the GAG content [6]. **Control** model: FCD increased linearly from -300 mmol/L in the inner AF to -100 mmol/L in the outer AF [4]. **Control** model was validated using experimental measurement of residual strains [1]. The **Degenerated** model used a uniform GAG distribution of -100 mmol/L. Fibers orientation gradually changed from ±43° in the inner AF to ±28° in the outer AF, and fiber stiffness decreased from the outer AF to inner AF [7, 8]. Steady-state swelling was simulated by increasing FCD from zero to the specified value, while the surrounding environment was held fixed (0.15M saline). Swelling ratio was calculated as the volume in the deformed condition divided by the volume in the reference configuration. Stress and strain distributions were analyzed to quantify residual stresses and strains from swelling.

Results: **Control**: Residual strain magnitudes and distribution (compression in inner AF and tension in outer AF), and the swelling ratio (1.57) agreed well with experimental observations [1, 9] (Fig. 1A). The swelling ratio in the degenerated AF was 10% lower than the control**.** Residual strain distribution was similar in the degenerate AF, but there was a decrease in residual strain magnitude (Fig. 1B-D).

Discussion: A relatively small change in AF swelling capacity (10%) caused significant changes in residual strains in the outer AF (Fig. 1C). While the frequency of AF tears increases with degeneration [10], the decrease in residual strains may act to protect AF fibers from excessive loading and potential failure. Future work will explore how changes in inner AF swelling affects stress distribution through the AF under mechanical loading, and stress distributions between the nucleus pulposus and AF.

Reference: [1] Michalek 2012; [2] Rachev 2003; [3] Yang 2017; [4] Urban 1979; [5] Peloquin 2014; [6] Lai 1991; [7] Cassidy 1989; [8] Yang 2017; [9] Bezci 2015; [10] Vernon-Roberts 2007.

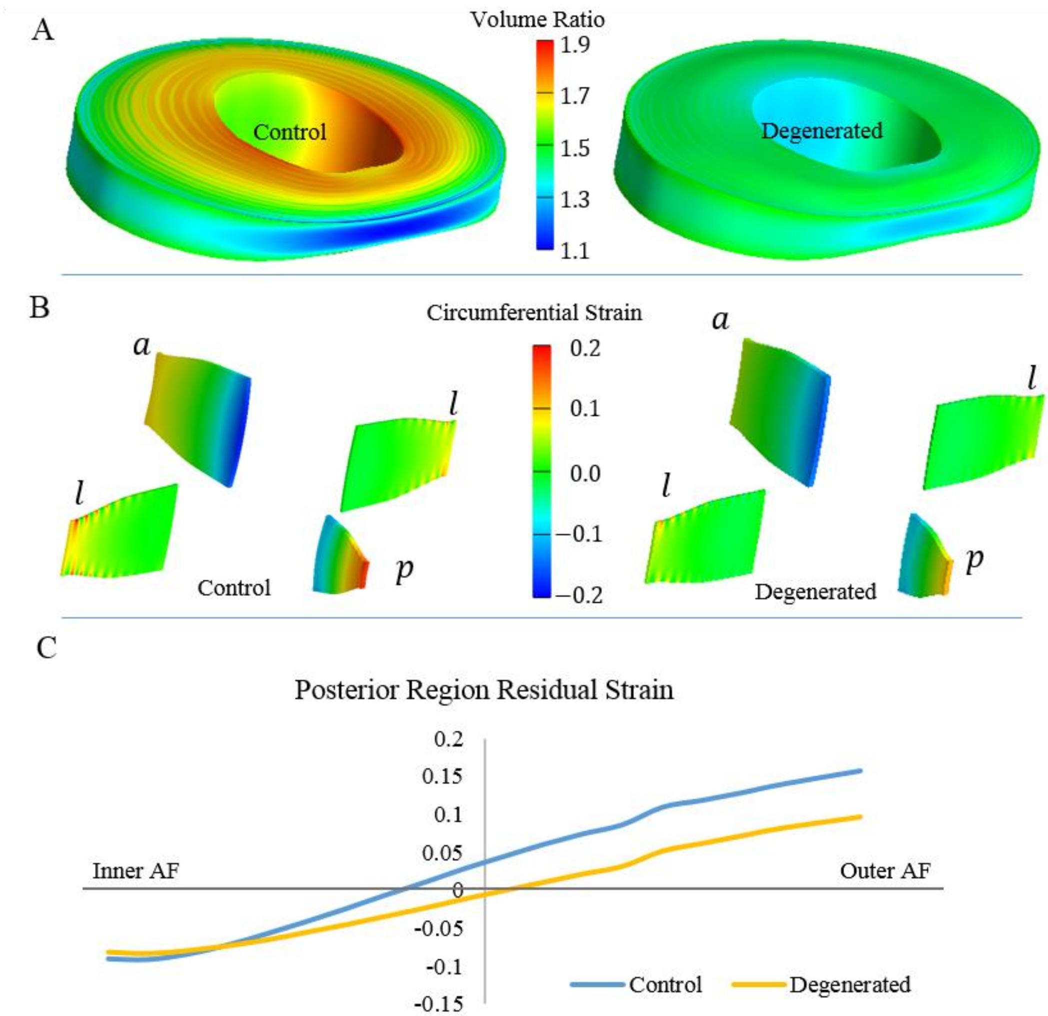

Figure 1. (A) Swelling of control and degenerated model. (B) Strains from the mid-coronal (l-l) and mid-sagittal (a-p) planes. (C) Residual strains from the inner to the outer AF at the mid-disc height of the posterior AF.