Effect of Nucleus Pulposus Size and Location on Internal Stresses in the Intervertebral Disc

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Introduction: Disc degeneration is an important contributor to lower back pain. The relative area of the nucleus pulposus (NP) decreases with degeneration [1, 2]. The NP is located posteriorly to the disc's centroid, which may be an important design criterion for biological repair strategies that aim to replicate the mechanical function of the healthy disc [3]. However, the role of NP size and position, separate from other compositional changes, on disc joint mechanics is not well understood. The objective of this study was to evaluate changes in disc joint mechanics with respect to NP size and centroid location.

Method: A structurally relevant finite element model was developed for a human lumbar disc and validated for compression, rotation, and bending using data in the literature (**Control**: NP:disc ratio = 0.28, NP offset = 5% posteriorly) [4]. The NP was described as an isotropic hyperelastic material, while the annulus fibrosus was described as having nonlinear fibers within an extrafibrillar matrix (isotropic hyperelastic material). Four models were evaluated to assess the effect of relative NP size (**LNP** = larger NP, NP:disc ratio = 0.35; **SNP** = smaller NP, NP:disc ratio = 0.21) and NP centroid location (**ASNP** = anteriorly-shifted NP, NP offset = 0%; **PSNP** = posteriorly shifted NP, NP offset = 10% posteriorly) [2, 3] (Fig.1A). First, a 936 N (0.48 MPa) compressive load was applied. Then, a secondary torsional or bending load was applied (6.5° flexion, 4° extension, 5° lateral bending, and 4° axial rotation, based on [5]). Stress, strain, and pressure distribution were evaluated and compared to the **Control**.

Results: Control: Load-displacement response was within the range of data in the literature for compression, bending, and rotation [6-8]. Increasing NP area increased the disc joint linear-region stiffness in compression (7% increase in **LNP**). The peak pressure at the NP-posterior annulus interface during extension increased by 7% in **PSNP** (Fig. 1B– '*'). Flexion caused peak pressures at the NP-anterior annulus interface, and internal pressures were 10% in the **ASNP** than the control (Fig. 1C–'*').

Discussion: The healthy NP acts like a moving pivot that migrates during bending. Changes in peak pressures during loading, with respect to NP centroid location, suggests that there may be an optimal location for minimizing intradiscal pressures during common physiological activities. These findings suggest that a posterior offset in NP position may optimize stress distributions under flexion and extension. In conclusion, replicating the NP location and size is important for computational models that aim to understand disc function and regenerative medicine strategies that aim to repair damaged or diseased discs.

[1] Roughley, 2006; [2] Adams, 2013; [3] O'Connell, 2007; [4] Yang and O'Connell, 2017; [5] Yamamoto, 1989; [6] Beckstein, 2008; [7] O'Connell, 2011; [8] Meijer, 2010.

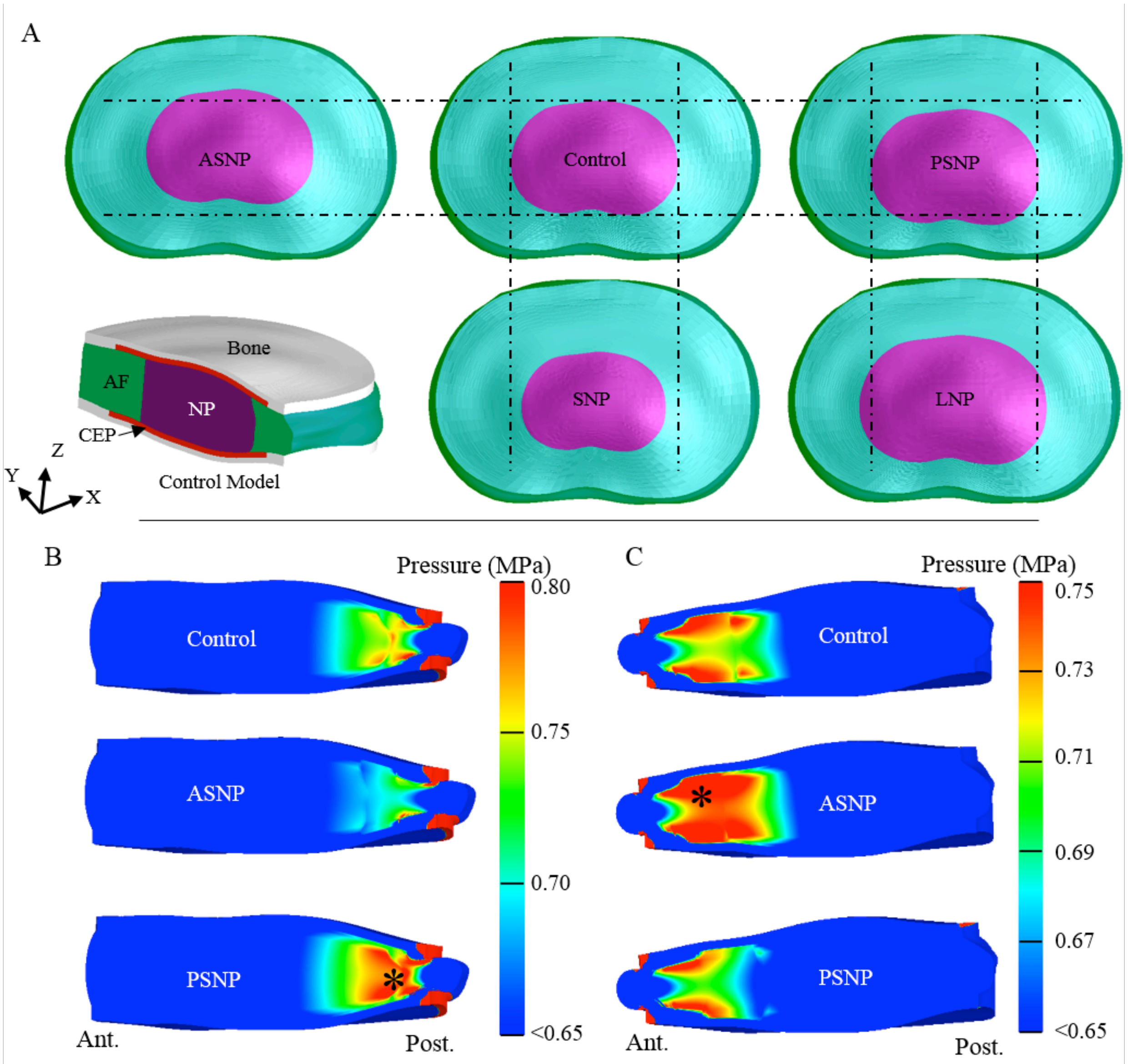

Figure 1. (A) Five models with different nucleus pulposus (NP: purple) conditions based on NP size and location. (B) Pressure distribution in the mid-sagittal plane under compression followed by extension. (C) Pressure distribution in the mid-sagittal plane under compression followed by flexion. Ant. = anterior, Post. = posterior, * represents location of peak pressure.